



Marine and Tropical Sciences Research Facility

Spatial and temporal patterns of indicators of reef health on the Great Barrier Reef



Steven Delean and Glenn De'ath



Australian Government
Department of the Environment,
Water, Heritage and the Arts



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Acronyms used in this report

2D	Two-dimensional
AIMS	Australian Institute of Marine Science
COTS	Crown-of-thorns starfish
GAM	Generalised additive models
GAMM	Generalised additive mixed models
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GLMM	Generalised linear mixed models
LTMP	Long Term Monitoring Program (of AIMS)
MTSRF	Marine and Tropical Sciences Research Facility
MSE	Median Standard error
NRM	Natural Resource Management
PCA	Principal Components Analysis
PE	Prediction error
PhD	Doctor of Philosophy
QDPI&F	Queensland Department of Primary Industries and Fisheries
RAP	Representative Areas Program (of GBRMPA)
RRRC	Reef and Rainforest Research Centre Limited
SE	Standard error
WQ	Water quality

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Executive Summary

Spatial patterns and temporal change of the reef biota of the Great Barrier Reef (GBR) are examined, and potential indicators of reef ecosystem health are presented and discussed. These indicators form a hierarchy and range through indicators based on taxonomic and functional groups to composite indicators of relative reef ecosystem health, one based on the benthos and the other based on fish abundance and diversity.

Spatial patterns and temporal change of these indicators are modelled and presented through maps, trend plots and tabulations. The spatial analyses are based on: (a) relative distance across and along the GBR; and (b) six marine regions adjacent to coastal Natural Resource Management (NRM) regions. By basing the spatial analyses on NRM regions, the health indicators can provide valuable input to regionally-based coastal management programs.

These analyses show similar spatial patterns of relative reef ecosystem health across both individual and composite indicators, with reefs in the central inner-shelf regions being in relatively poor health (Figure A).

The patterns of relative health were also related to measures of water quality based on water clarity and concentrations of chlorophyll, and for some indicators, poorer health coincided with low levels of water quality (low clarity and high chlorophyll).

The analyses of temporal indicators show consistent declines in relative benthic health of the inner and mid-shelf regions of the GBR over the last decade, but improvements in the relative health of fish communities, in particular on the outer shelf.

Analyses of indicators of relative reef health on the Great Barrier Reef

The analyses in this report are based on data collected under the Australian Institute of Marine Science (AIMS) Long Term Monitoring Program (LTMP) including: (1) video transects of benthos and visual transects of fishes sampled on LTMP 'core' reefs and reefs sampled to monitor the impact of the Great Barrier Reef Marine Park Authority's (GBRMPA) Representative Areas Program (RAP); and (2) visual census of coral cover and crown-of-thorns starfish (COTS) density sampled using 'manta tow'. Water quality measures were based on data collected by the AIMS water quality monitoring program and QDPI&F surveys.

1. Three reef ecosystem health indicators were selected for benthos and for fishes. The choice of the six indicators was based on ecological knowledge, exploratory data analysis and data availability. The multivariate structure among all potential indicators examined suggested the chosen six to be representative of 'a healthy reef' (in so far as the data of this study permits); i.e. we assumed a healthy reef to have high diversity and abundance of fish and corals, and low levels of crown-of-thorns starfish and macroalgae. The six indicators were modelled spatially using relative distance across and along the GBR as spatial predictors, and the resulting maps showed strong concurrence within the benthos and fish groups. A composite index was developed for benthos and for fishes and these were also modelled spatially and mapped. Uncertainty levels of spatial patterns and relative health were also estimated and displayed.
2. In addition to the six selected indicators, summary analyses of all the potential indicators examined are presented through maps, trend plots and tabulations in the second and third sections of this report. Despite the limited use of some of these variables as

general indicators, these results provide useful information about their current spatial distributions and temporal trends.

3. Risk maps based on plausible values that determine 'high', 'moderate' and 'low' relative health risk were generated and interpreted, with high risk corresponding to poor health and low risk corresponding to good health. Regions of relative risk were mapped for all health indicators using the '10-30-60 rule'. Based on predicted values of the indicators for 2,870 gazetted reefs of the GBR, reefs with values less than the 10th percentile were labeled as 'high risk' (i.e. of poor health), the 10th-30th percentiles are 'moderate risk', and higher than the 40th percentile of the observed data are declared 'low risk' (i.e. of good health). Within the maps, the colours red, orange and green indicate high, moderate and low risk regions respectively. For ease of display, regions rather than reefs are colored, however it should be remembered that the risk levels pertain to the reefs. **It should also be emphasised that these measures of health and risk are relative, not absolute (e.g. areas categorised as 'poor' are relatively less healthy than 'good' areas given the specific health index used, but may not be 'unhealthy' in absolute terms).** Relative reef health differs in important ways from some concepts of 'ecosystem health' in the wider ecological literature. Relative measures are however useful for spatial and temporal comparison, and with additional work may lead to the recommendation of absolute levels as has been the case with water quality parameters.
4. The reefs at greatest relative risk for both benthos and fishes are located in the inner central third of the GBR, with a greater cross-shelf extent for benthos (Figure A). In terms of the NRM regions, this corresponds to the inshore areas from the Wet Tropics and Burdekin to the upper Mackay-Whitsunday. Higher estimated relative risk for fishes in the southern inner GBR (Figure A) was estimated with high uncertainty (Figure B) because of the lack of data from that region, and should be interpreted with caution. The reliability (i.e. precision) of estimates from spatial models was lower in data poor regions of the GBR.
5. Temporal changes of selected benthos and fish parameters were modelled for each of the NRM regions broken down by inner-, mid- and outer-shelf reefs. Long-term averages and linear trends for the reefs of the fifteen NRM by inner-mid-outer regions were estimated and tabulated.
6. Selected biotic indicators of reef ecosystem health were related to measures of water quality and relative distance along and across the shelf. Water quality measures were highly correlated with relative distance across the GBR. Since it was not possible to discriminate between the effects of these variables, predictions based on water quality and relative distance along were compared to those based on the relative distance across and along. Overall, water clarity and chlorophyll (to a lesser degree) were useful predictors of reef health, and the higher relative risk regions for benthos and fishes largely coincide with regions of poor water quality.

In summary, this report contains extensive analyses of long-term benthos and fish survey data covering 190 reefs across fifteen years. Indicators of relative reef health have been developed and shown to be coherent in their inter-relationships. These indicators show consistent spatial patterns for benthos and fishes, with the central inner third of the GBR in relatively poor health. They also show consistent temporal declines in benthos in that same region over the past decade, and increasing health of fishes on the outer shelf.

This report also shows the association between poor water quality and poor relative reef health, a result consistent with previous research. By providing analyses on the basis of NRM regions, the results of this study can provide input to regional management plans, in particular with regard to the current Reef Rescue Plan (GBRMPA).

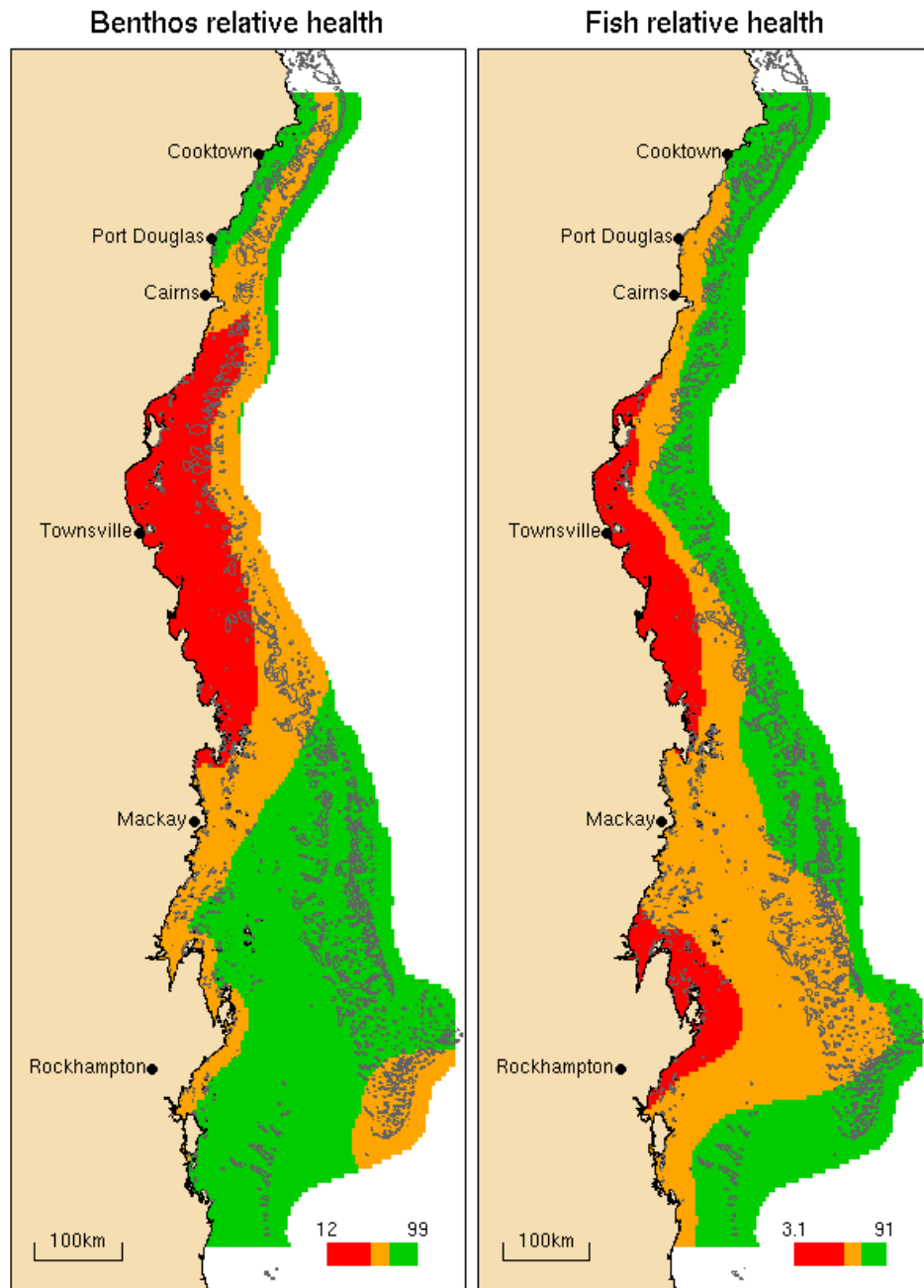


Figure A: Spatial patterns of relative ecosystem health based on benthic (*left*) and fish (*right*) composite reef health indices across the Great Barrier Reef, averaged over 2005-2007. The red, orange and green colours indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

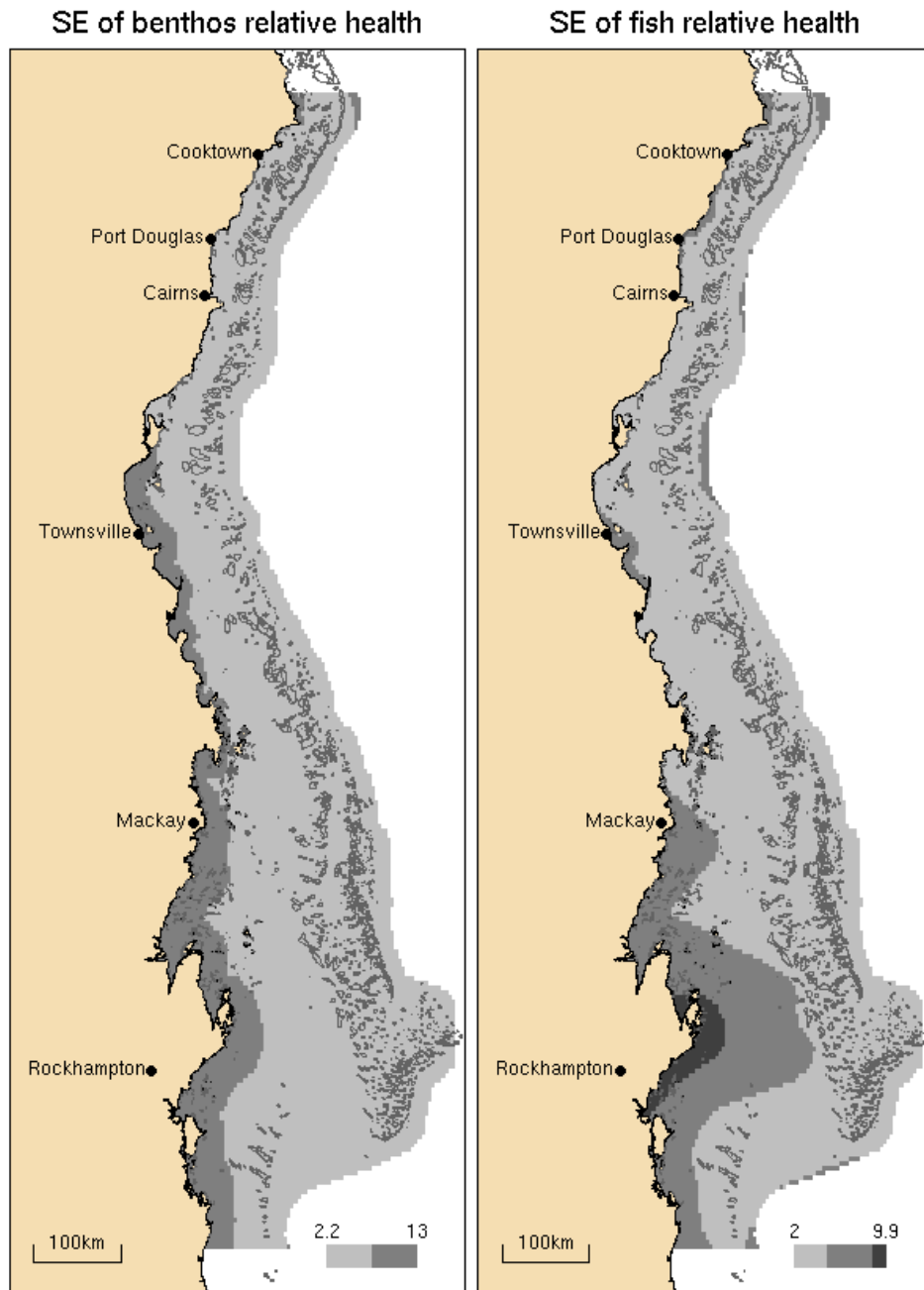


Figure B: Standard errors (SE) for spatial patterns of relative ecosystem health based on benthic (*left*) and fish (*right*) composite reef health indices across the Great Barrier Reef, averaged over 2005-2007. The grayscale indicates decreasing precision from light grey to dark grey formed by the 60th and 90th percentile breaks of the SEs respectively. For the benthic index, light grey regions had SEs less than 1.5 times the Median SE (MSE); grey regions had SEs less than 2.6 times the MSE. For the fish index, light grey regions had SEs less than 1.2 times the MSE; grey regions had SEs less than 2.2 times the MSE; and dark grey regions had SEs greater than 2.2 times the MSE.

1. Objectives and methods

Introduction

This work comprises three components. First, analyses are presented identifying a subset of important reef ecosystem health indicator variables on the Great Barrier Reef (GBR). Composite indices of reef benthos health and reef fish community health are calculated from these indicator variables. Analyses show consistent spatial patterns of relative reef ecosystem health for both individual biotic indicators and composite indices. Regional differences associated with Natural Resource Management (NRM) zones (Figure 1.1) and temporal trends in composite indices are presented and discussed.

Second, summaries are presented of the spatial patterns of variation in all potential reef ecosystem health indicator variables that were examined. Spatial patterns of each indicator variable are predicted for all GBR reefs and these predictions are provided for use in the Reef Atlas project (see <http://reefatlas.org.au/>).

Third, temporal trends are provided in all potential reef ecosystem health indicator variables, broken down by NRM marine regions and by distance across the continental shelf. Plots are displayed on equal y-scales to show average regional differences and the pattern and magnitude of temporal changes.

Objectives

This project aims to provide:

1. Spatial and temporal summaries of selected indicators of ecosystem health and thresholds of concern identified from prior knowledge or extreme values from the observed range for the selected indicators; and
2. Integrated summaries of relative coral reef ecosystem health for NRM regions using data from the Australian Institute of Marine Science (AIMS) Long Term Monitoring Program (LTMP).

The specific indicator variables of ecosystem health modelled at the reef level were:

- a) Benthic cover – hard coral, soft coral, and algae;
- b) Benthic genera cover – *Acropora*, *Goniopora*, *Montipora*, *Pocillopora*, *Porites*;
- c) Algae cover – macroalgae, coralline algae, turf algae;
- d) Fish trophic group abundance – herbivores, planktivores, predators, benthic feeders, benthic/plankton feeders;
- e) Fish diversity – total abundance, richness, Shannon diversity, Simpson diversity; and
- f) Manta tow measures – hard coral (for comparison with intensive survey data), crown-of-thorns starfish (COTS) density, and COTS outbreak status.

Spatial models are constructed from current average values of these indicator variables. Maps of spatial patterns and relative reef health are presented. Temporal trends are estimated within three cross-shelf areas for the marine regions adjacent to six NRM zones. Spatial means and linear trends are presented. Two composite indices are calculated, and spatial patterns and temporal trends in these indices are analysed and discussed. Relationships between key indicator variables and environmental water quality variables are also presented.

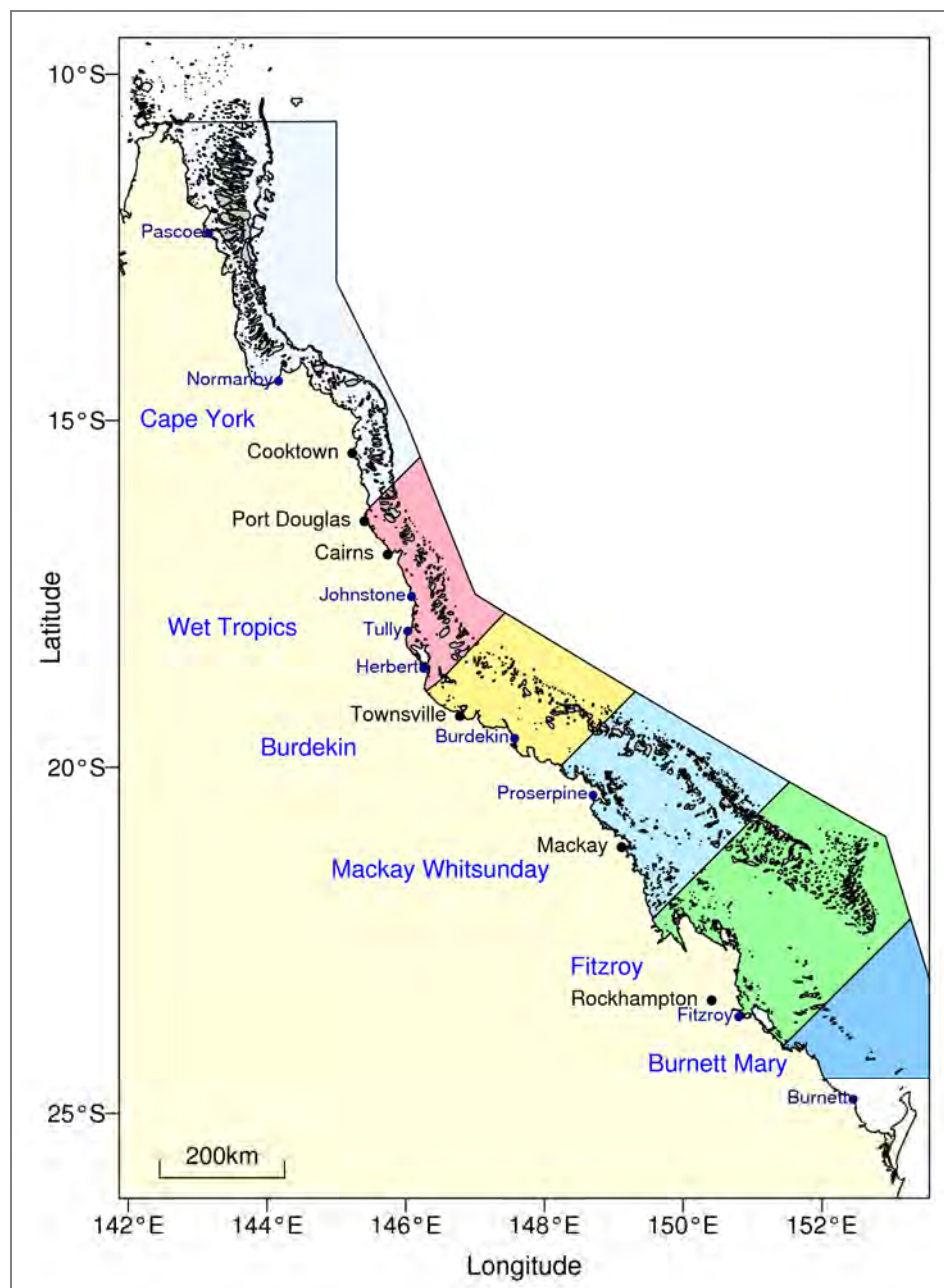


Figure 1.1: Delineation of the six marine regions adjacent to the NRM regions with GBR boundaries. These regions cover the whole World Heritage Area. Major towns and the locations of coastal outflow of major rivers are also shown.

2. Methods

Manta tow survey data

This project used data from 238 reefs surveyed using the manta tow technique as part of the AIMS COTS surveys and the LTMP (Figure 2.1). Data from the survey years corresponding to the LTMP surveys were used (1993-2007). Manta tow survey reefs are targeted for survey on an annual or triennial basis as part of the LTMP (Sweatman *et al.* 2005).

The manta tow is a rapid assessment technique that provides information over large reef areas. The sampling unit is the complete reef perimeter (or a large proportion thereof). A trained snorkeller with a 'manta board' is towed behind a tender around the perimeter of each survey reef close to the reef crest. The observer surveys a swathe ten metres wide out from the reef crest. The perimeter is divided into a series of 'tows' – the boat stops every two minutes (~ 200m) and the observer records the mean coral cover (i.e. scored into categories of cover) and the number of COTS observed for each tow. This process continues until the entire reef perimeter is surveyed (Miller 2003). The towpath is standardised by following a course marked on an aerial photograph of each reef so that approximately the same zones are surveyed each time, and between-observer comparisons are carried out to minimise differences among observers and between years. Mean coral cover is calculated for each reef at each survey taking the mid-point of the coral cover category for each tow and then averaging over all tows for that reef.

Intensive survey transect data

Transects on forty-eight reefs were surveyed annually between 1993 and 2007 in six latitudinal sectors of the GBR as part of the LTMP conducted by AIMS. Intensive SCUBA surveys of benthic and fish assemblages were conducted at these reefs. Reefs were surveyed in three cross-shelf zones within each of the six latitudinal sectors, though no inner- and mid-shelf reefs were available in the southernmost sectors (Figure 2.1). Three or more reefs were generally sampled within each of these shelves by sector combinations. Five permanently-marked fifty-metre transects located between the six-metre and nine-metre depth contours within each of three sites on the northeast quadrant of each reef were surveyed (Sweatman *et al.* 2005). Sampling the same quadrant of each reef enabled comparisons of a common habitat among sectors and among reefs within sectors.

In 2006, an additional forty-six reefs were sampled using the LTMP sampling protocols as part of a program to monitor the effectiveness of the Great Barrier Reef Marine Park Authority (GBRMPA) Representative Areas Program (RAP). These reefs were located in mid- and outer-shelf areas of the central and southern GBR sectors adjacent to the Wet Tropics, Burdekin, Mackay-Whitsunday, Fitzroy and Burnett Mary NRM zones (Figure 2.1).

Fish assemblage data

Reef fish communities were surveyed annually between 1993 and 2007 on forty-eight reefs in six latitudinal sectors of the GBR as part of the LTMP. In 2006, reef fish communities were surveyed on an additional forty-six RAP reefs. Abundance counts of up to 210 species of reef fishes from ten families (*Acanthuridae*, *Chaetodontidae*, *Labridae*, *Lethrinidae*, *Lutjanidae*, *Pomacentridae*, *Scaridae*, *Serranidae*, *Siganidae* and *Zanclidae*) were recorded by visual census on each transect. Two transect widths were used: (1) five-metre belts for large mobile reef fishes; and (2) one-metre belts for the small, site-attached pomacentrid fishes (Halford and Thompson 1996). Counts were summed over all fifteen transects on each site to estimate abundances per reef for each survey year.

Fish species counts were combined to give univariate summary measures of total abundance, richness and diversity. These summary measures of community composition only therefore represent summaries for the subset of targeted species. Shannon and Gini-simpson measures of diversity were presented on the scale of the effective numbers of species (Jost 2006). Fish species were also grouped according to trophic feeding categories (i.e. functional groups) based on both field observations and existing literature. Five broad groupings were used to classify: herbivores, benthic feeders, benthic/plankton feeders, planktivores and predators.

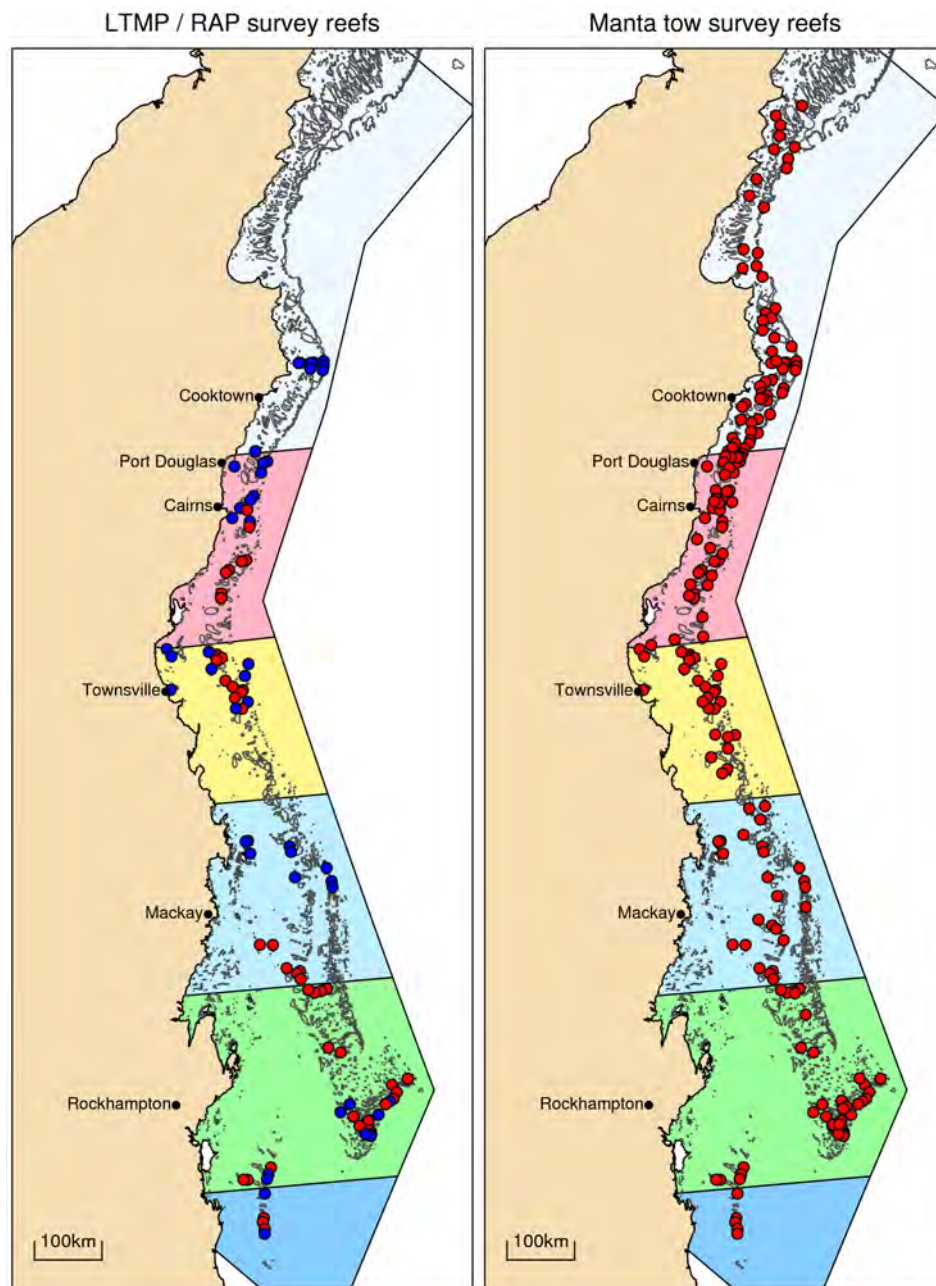


Figure 2.1: Locations of survey reefs on the GBR. Intensively surveyed reefs under the LTMP (blue circles) and RAP (red circles) sampling programs are shown in the left panel; rapid assessment manta tow reefs (red circles) are shown in the right panel. The six marine regions adjacent to the NRM regions with GBR boundaries are also shown. Major towns and the GBR reef matrix are also shown for reference.

Benthic cover data

Benthic data were recorded using underwater video (Abdo *et al.* 2004) on the same transects as for the fish visual census. Surveys were conducted annually from 1993 to 2007 on the forty-eight reefs (Figure 2.1). The video recorded a thirty centimetre wide strip along the edge of a measuring tape layed out along each transect. Percent cover of corals was estimated using a point sampling technique from 200 points on the video footage of each transect (i.e. images were captured from forty regularly-spaced frames and five systematically-distributed points were overlayed on each image and the benthic organism under each point was recorded). Hard and soft corals and algae were identified to the highest taxonomic resolution possible (i.e. genus level for hard corals, and family or genus for soft corals). The life form of benthic biota was also recorded. Estimated percent hard coral cover was based on an average of three sites at each reef. The benthic surveys were conducted in accordance with standard operating procedures developed at AIMS for the LTMP (Abdo *et al.* 2004).

3. Data sets

Several data sets were used for this report:

1. LTMP data collected from 'core' (i.e. intensively-sampled) reefs from 1993-2007. These data comprised benthic cover estimated from video transects and fish abundance estimated from visual surveys.
2. LTMP data collected from 'manta tow' reefs from 1993-2007. These data comprised hard coral cover and COTS density estimated from manta tows.
3. Lagoon water quality (WQ) data (i.e. chlorophyll) collected by AIMS (Miles Furnas and co-workers) from 1976-2006, and long-term chlorophyll monitoring data collected by GBRMPA and AIMS over the period 1992-2006. The actual data used in this report were derived from spatial predictions from models estimated in De'ath and Fabricius (2007).
4. Water clarity data based on secchi disks sourced from QDPI&F seagrass monitoring data (Rob Coles), and other AIMS data (Katharina Fabricius and Miles Furnas). Again, the actual data used in this report were derived from spatial predictions from models estimated in De'ath and Fabricius (2007).

Spatial models of the indicator variables used combined data from LTMP 'core' reefs and RAP reefs, averaged over the last two survey years (i.e. RAP reefs were only sampled at that time). Temporal patterns of change in the indicator variables was modelled only using LTMP 'core' reefs (except for analyses of COTS density and hard coral cover that used data sampled from manta tow reefs), within spatial 'units' categorised by shelf position for each NRM region.

4. Statistical modelling

Multivariate analyses of reef biota

Multivariate relationships between reef ecosystem health indicator variables were modelled using Principal Components Analysis (PCA). Biplots were used to graphically display the correlation structure among the variables. Reefs were shown as points and the variables as vectors on the biplots. All variables were standardised to the same scale using z-scores prior to analysis. Measures of fish abundance and cover of macroalgae were log transformed prior to scaling.

Spatial patterns of reef biota

Spatial maps were produced to show differences in reef fish and benthos across the GBR. These maps were generated from the values predicted from statistical models, which fitted smooth, two-dimensional (2D) surfaces over the area of the GBR. Specifically, generalised additive models (Wood 2006) were used to analyse the spatial variation across and along the continental shelf over the entire GBR. These models incorporate smoothers to estimate the relationships between the response and predictor variables, and as such can account for nonlinearity. Spline smoothers, which are interpolating methods for fitting smooth curves to data, were used. The smooth 2D spatial surfaces were estimated with thin plate splines (Wood 2003), which estimate a smooth function of multiple variables. The smoothness of the fit (i.e. how straight or wobbly the relationship) was determined by fitting a series of models with a fixed range of degrees of freedom, and selecting the smoothness that minimised the prediction error (PE). The PE of a model is defined as the sum of squared prediction errors (observed – predicted values) divided by the sum of squared observations about the overall mean. An upper maximum degree of freedom of 25% of the sample size was used to prevent overfitting that may result from spatial autocorrelation in the data.

As stated above, generalised additive models were used. These models are ‘generalised’ in the sense that they allow for residual variation to be non-normally distributed, and for predictions of the response variable to be constrained within a specified range (e.g. fish counts cannot be negative). For the models used in this report, link and variance functions were selected according to the type of response variables used for each analysis. Response variables measuring the proportion of cover of the benthos were modelled with a logit link and binomial variance function. Fish abundance variables were modelled with a log link and Poisson variance function, and all other variables were modelled with a constant link and normal variance function.

The spatial predictors in the models were based on the relative distance across and along the GBR, as in De'ath and Fabricius (2007). Relative distance across and along the GBR takes advantage of the natural boundaries of the GBR that affect many of the bio-physical processes of the GBR, and provides a simple interpretation for models that do not include interactions between across and along.

Predicted spatial patterns of reef biota were categorised into levels of high, moderate and low relative health. The spatial models were used to predict values for all reefs on the GBR ($n = 2870$). These values were categorised by the quantiles of the predicted distribution to include the proportion of sampled reefs with the lowest ten percent of reef health values, and the lowest forty percent of reef health values. Spatial maps showing the relative reef health were then produced.

The reliability (i.e. precision) of estimates from spatial models was lower in data poor regions of the GBR. Estimates of the uncertainty of spatial predictions were therefore provided.

Standard errors for the predicted values from the spatial models were calculated for all reefs on the GBR ($n = 2870$). These values were categorised by the quantiles of the predicted distribution to include the proportion of sampled reefs with the highest ten percent of standard error values, and the highest forty percent of standard error values. These breakpoints were standardised by the median observed standard error to provide a measure of the magnitude of the standard errors in each category. These values are provided in the figure legends for standard error maps. The spatial limitations of the LTMP sampling, particularly the low numbers of inshore reefs, should be taken into consideration when interpreting spatial predictions.

Temporal trends of reef biota

Graphs were produced to show changes in reef fish and benthos over time for discrete regions of the GBR. These trends over time were estimated from statistical models that included smooth functions (i.e. splines) to identify nonlinear changes, if present. These temporal trends were modelled using generalised linear mixed models (GLMM) (Breslow and Clayton 1993, Bates and Saikat 2004). The smoothness of temporal trends (i.e. how straight or wobbly the trend) was estimated under generalised cross-validation (Wood 2004). Among reef variation was included as a random effect.

Analyses were conducted for the inner, mid and outer shelf areas of the marine regions adjacent to the six NRM regions. Estimated trends were plotted for each variable on an equal y-scale to highlight regional differences and the magnitude of effect sizes. Confidence intervals were plotted to provide a measure of the precision of the estimate of the temporal trend. The GBR-wide mean was also plotted for each variable to facilitate inter-regional comparisons.

Relationships between biota and water quality on the GBR

Graphs were produced to show differences in reef ecosystem health indicators with varying values of water quality, cross-shelf distance and latitude. Once again smoothing functions (i.e. splines) were used to show nonlinear patterns. Generalised additive models were used to examine additive relationships between each of six reef ecosystem health indicator variables and spatial across and along shelf distances and two water quality variables. The water quality variables used were the Secchi depth (m), a measure of water clarity, and chlorophyll ($\mu\text{g L}^{-1}$) (De'ath and Fabricius 2007). All four predictor variables were not included in a single model because of the very high correlation between the across shelf distance and water clarity (i.e. Secchi depth). Therefore, two models were fitted to each response variable: (1) the additive effects of along shelf distance, Secchi depth and chlorophyll; and (2) the additive effects of across and along shelf distance. The relative fits of the two models were compared using the adjusted r^2 .

Statistical software

All analyses were done using the R statistical software system (R Development Core Team 2007).

5. Indicators of reef ecosystem health on the Great Barrier Reef

Multivariate relationships between reef health indicators

Multivariate relationships between potential indicators of reef ecosystem health were examined to identify underlying patterns. The indicator variables were recorded from reefs surveyed under the LTMP 'core', RAP and manta tow monitoring programs between 2005 and 2007, and therefore represent 'current status'. Multiple years were used to maximise the spatial coverage of the analyses (i.e. to include as many reefs from the different survey programs as possible). Values from individual reefs visited more than once during this period were averaged over time. All variables were standardised to z-scores (i.e. mean zero and unit variance) prior to analysis to allow equal weight comparisons. Fish abundances and macroalgae cover were log transformed prior to standardisation to reduce the influence of extreme values. Important variables were identified that summarised these relationships based on their relative contribution to the overall multivariate structure and prior ecological knowledge.

There were strong multivariate relationships among the variables and the first two principal components explained 44% of the total variance (Figure 5.1). Strong correlations were identified between hard coral cover recorded from video transects and from manta tow on LTMP core reefs, and these variables were also correlated with *Acropora* cover and the abundance of benthic feeding fishes. These variables were negatively correlated with the proportion of reefs affected by COTS, and the benthic cover of macroalgae and turf algae. Non-*Acropora* hard coral genera had lower contributions to the overall pattern and generally had low benthic cover. Strong correlations were also identified between the total abundance of fishes and the abundances of the fish trophic groups 'planktivores', 'benthic/plankton feeders' and 'predators'. These variables were negatively correlated with herbivorous fish abundance, and two fish diversity measures (i.e. Shannon and Simpson diversity), and to a lesser extent fish richness.

On the basis of the above results the variable set was reduced to six variables. The three benthic variables included were hard coral cover (i.e. a combined measure from manta and LTMP surveys), macroalgae cover, and COTS status (i.e. whether there was an outbreak or recovery from COTS or not). The three fish variables included were the total abundance of fishes, fish richness, and fish diversity (i.e. Shannon diversity). The first two principal components explained sixty percent of the variance among these variables and the strong correlations identified above were maintained (Figure 5.1).

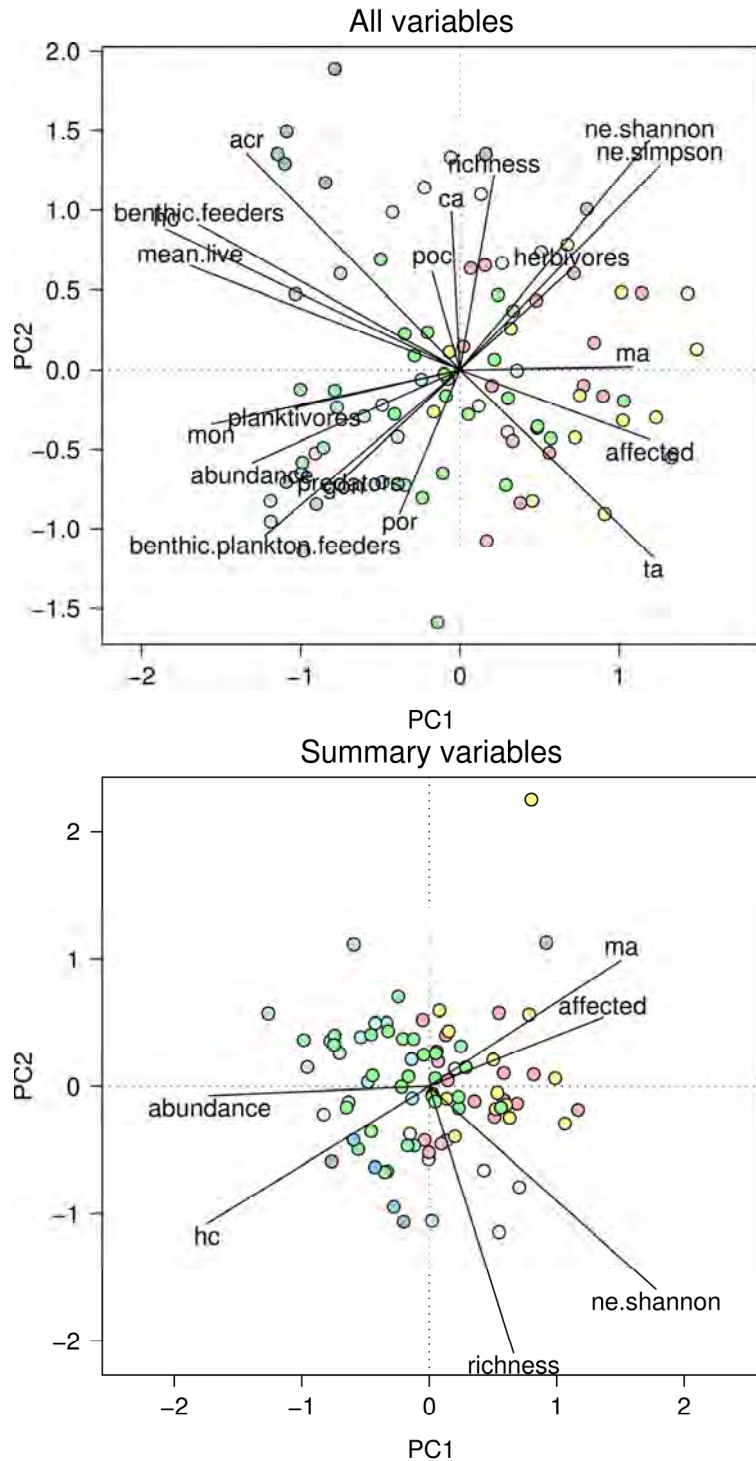


Figure 5.1: Principal components biplot showing the multivariate relationships among all ecosystem health variables examined (*top*), and among a subset of important indicators (*bottom*) identified based on the multivariate structure and prior ecological knowledge. Symbols represent reefs coloured by NRM region: Cape York (blue); Wet Tropics (pink); Burdekin (yellow); Mackay Whitsunday (light blue); Fitzroy (green); Burnett Mary (sky blue). Vectors represent variables: *hc* = Hard coral; *mean.live* = Manta hard coral; *ma* = Macroalgae; *affected* = Affected by COTS; *abundance* and *richness* of fishes; *ne.shannon* = Shannon diversity.

Spatial patterns of selected reef ecosystem health indicators

Spatial patterns over the GBR shelf were modelled using generalised additive models as smooth functions of the relative distances across and along the shelf. Spatial patterns explained 43% of the variations in hard coral cover and showed a 2.7-fold increase with latitude from the central to southern GBR. The pattern was characterised by areas of high cover in the far north of the Cape York NRM region and in the southern Burnett Mary NRM region, and low cover in the central GBR Wet Tropics and Burdekin NRM regions (Figure 5.2). The reliability of hard coral cover patterns was high, with the exception of the data-poor regions of the inner southern GBR and the outer northernmost areas (Figure 5.3). In contrast, macroalgae cover was highest in the inshore areas of the Wet Tropics and Burdekin NRM regions, and low throughout other regions. Macroalgae declined 3.8-fold across the shelf and increased ten-fold in the central section relative to the north and south. The pattern explained 77% of the variation in macroalgae cover. The reliability of macroalgae estimates was lowest adjacent to the areas of highest cover (Figure 5.3) due to the sharp decline between high and low cover areas which cannot be reliably estimated without overfitting models to the data. The proportion of reefs affected by COTS (i.e. either outbreaking or recovering) increased four-fold in the central GBR Wet Tropics and Burdekin NRM regions relative to the northern and southern regions, but was also high in the Burnett Mary region, and the pattern explained forty percent of the variation (Figure 5.2). The reliability of these estimates was generally uniform, but was lowest adjacent to the upper Mackay Whitsunday NRM region (Figure 5.3).

Total fish abundance increased by nine percent in the mid shelf relative to inner and outer shelf areas, and was five percent lower in the north relative to the Burdekin and Mackay Whitsunday NRM regions (Figure 5.4), and this pattern explained 59% of the variation. Fish richness and diversity followed somewhat similar patterns and increased three-fold across the shelf on average and increased 1.5-fold from the Fitzroy region in the south to the northern Wet Tropics and Cape York regions (Figure 5.4). Spatial patterns explained eighty percent of the variation in richness and sixty percent of the variation in diversity. The reliability of estimates of fish abundance, richness and diversity were generally high (Figure 5.5), with the exception of the data poor region of the inner southern GBR.

Spatial patterns in each indicator variable were translated into measures of relative health using quantiles of the distributions of each variable. High values of hard coral cover, fish abundance, fish richness and fish diversity, and low values of macroalgae and COTS effects were considered to represent relatively healthy reef ecosystems, whilst low values of the former and high values of the latter represent relatively unhealthy systems. This model does not distinguish the effects of biophysical gradients from anthropogenic effects which are the focus of measures of ecosystem health in the wider ecological literature. Quantiles classifying the ten percent of values at the 'unhealthy' end of the spectrum, and the sixty percent of values at the 'healthy' end for each variable were used to classify areas according to their relative health. Thus, red shows poor relative health areas, orange shows moderate relative health areas, and green good relative health areas. The consistently evident pattern from these figures is the poor relative health status of inshore and mid-shelf reefs in the Wet Tropics and Burdekin NRM zones of the central GBR. Standard errors for spatial patterns of relative reef health were displayed separately to show the reliability of estimates using a greyscale indicating decreasing precision from light to dark.

Results are summarised in Appendix 1.

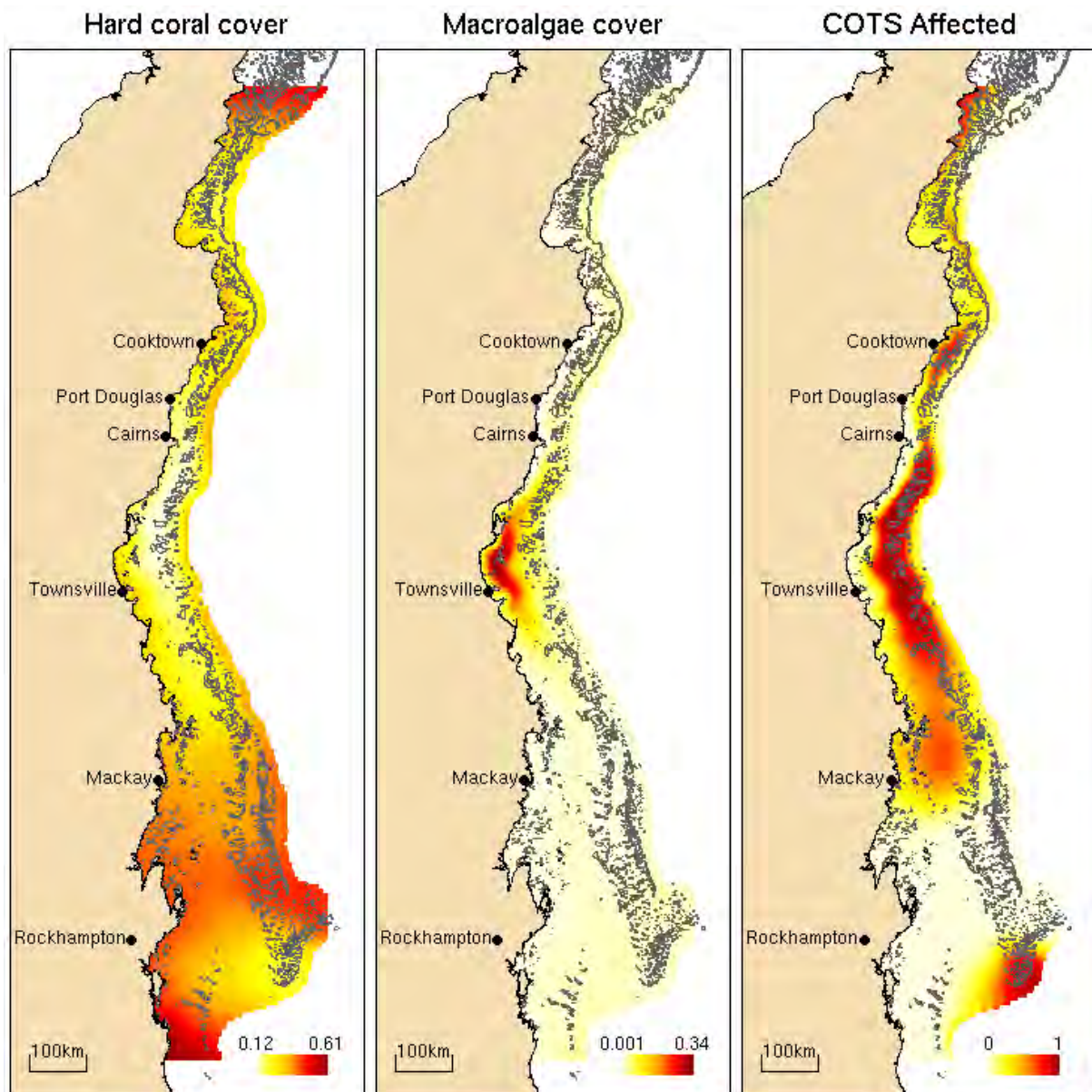


Figure 5.2: Spatial patterns of benthic reef health indicator variables hard coral cover (*left*), macroalgae cover (*centre*) and the proportion of reefs affected by COTS (*right*) across the GBR averaged over 2005-2007.

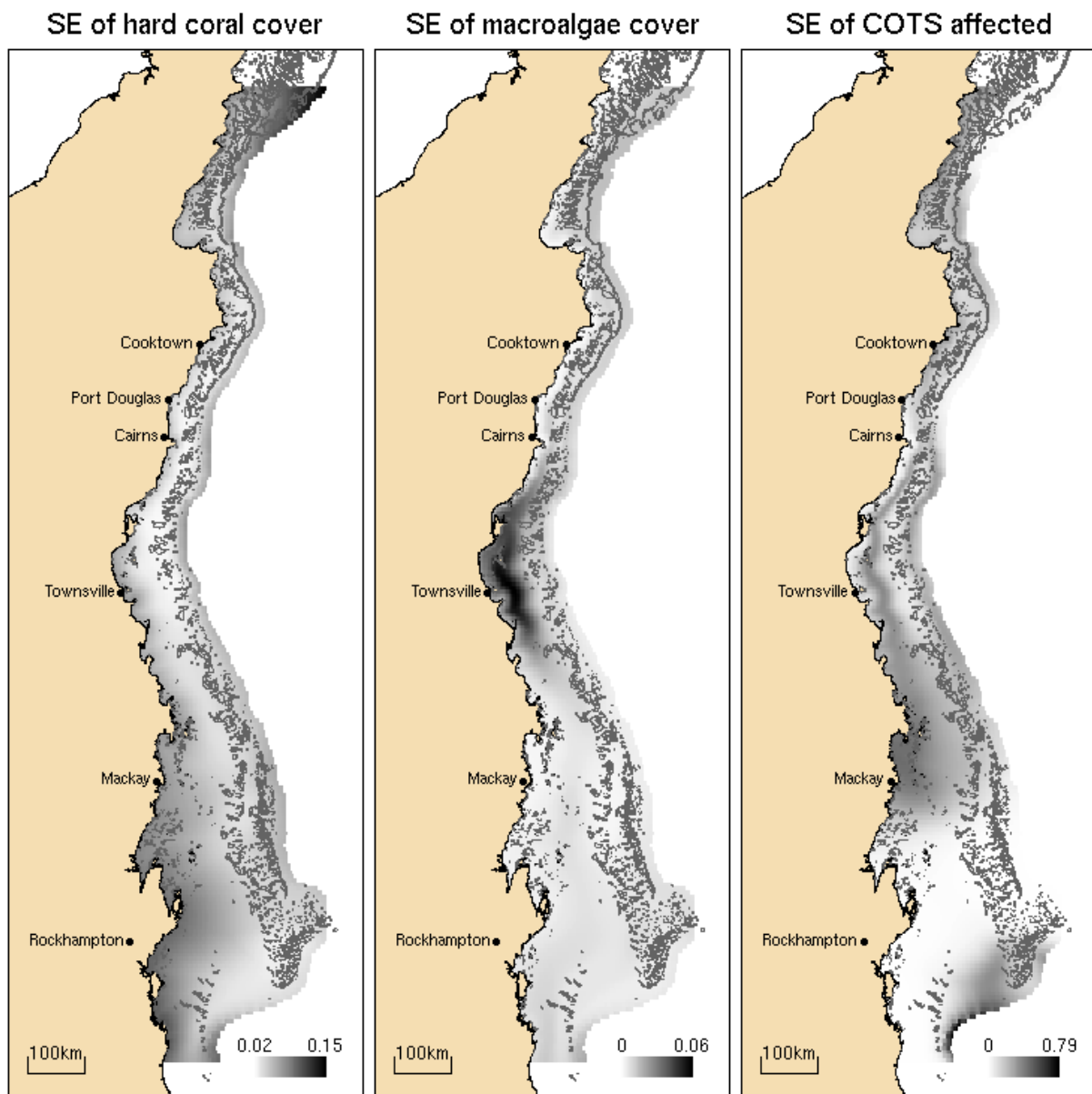


Figure 5.3: Standard errors for spatial patterns of benthic reef health indicator variables hard coral cover (*left*), macroalgae cover (*centre*) and the proportion of reefs affected by COTS (*right*) across the GBR averaged over 2005-2007. The greyscale indicates decreasing precision from light to dark.

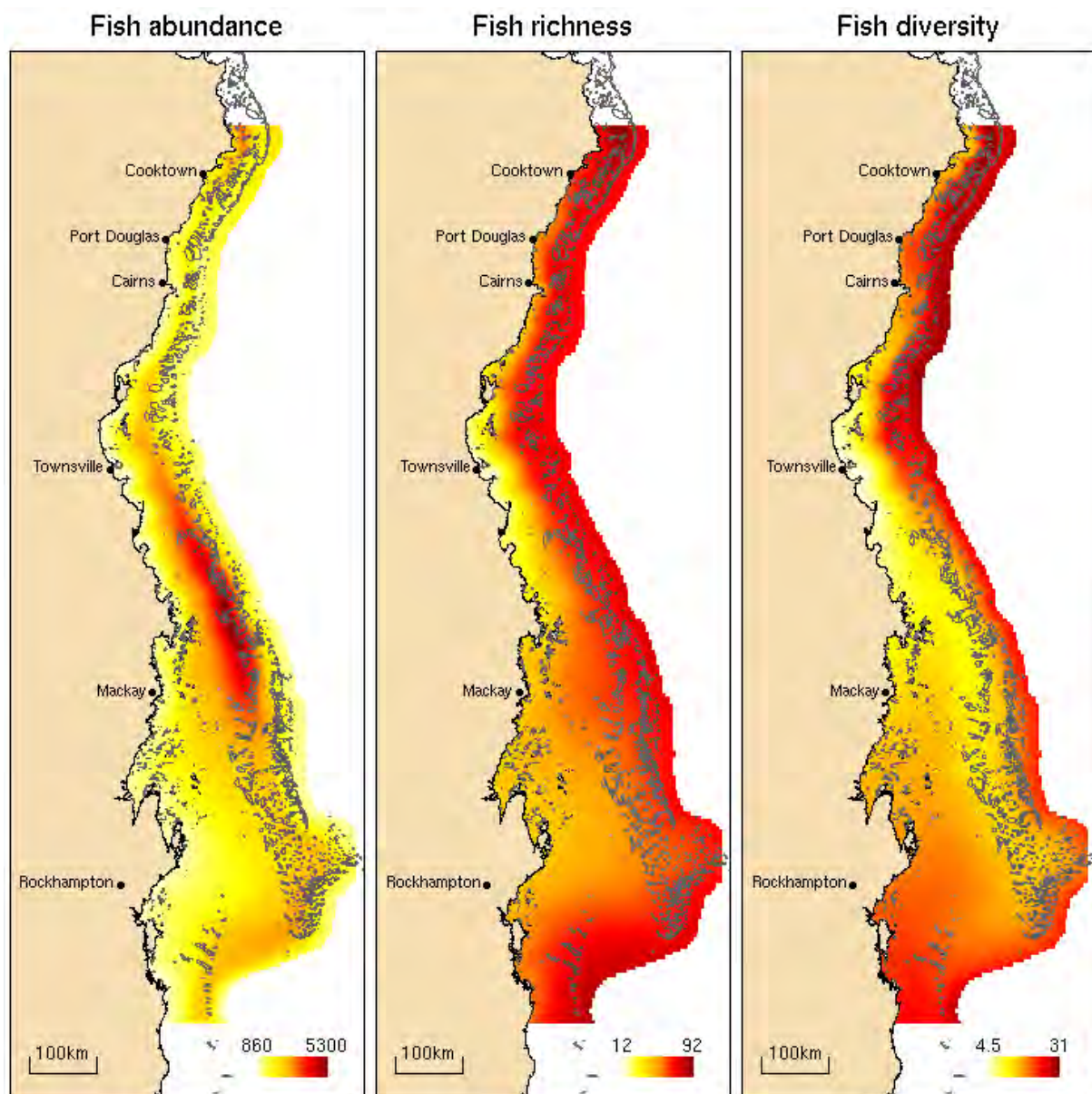


Figure 5.4: Spatial patterns of fish reef health indicator variables fish abundance (*left*), fish richness (*centre*) and fish diversity (*right*) across the GBR averaged over 2005-2007.

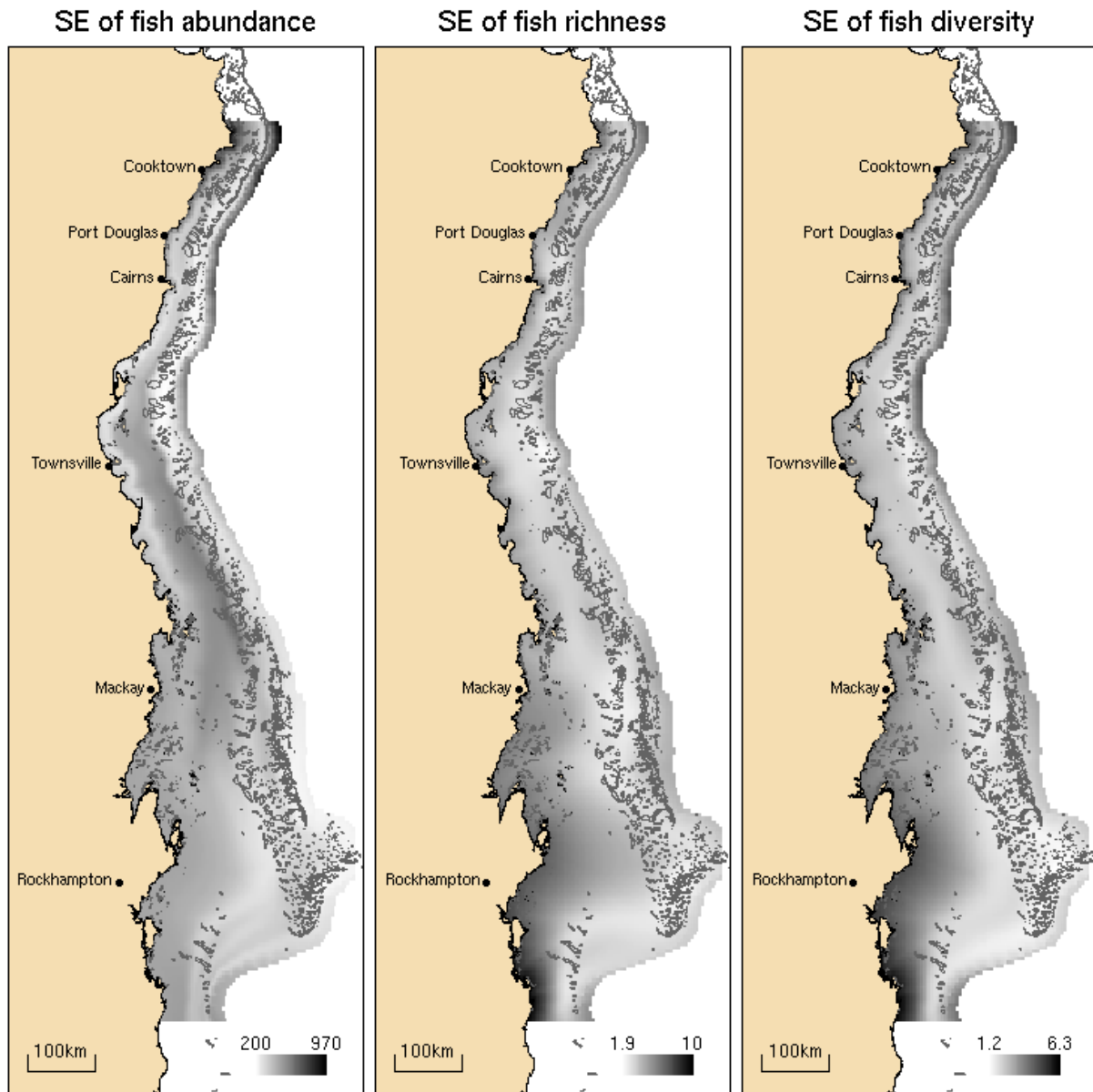


Figure 5.5: Standard errors for spatial patterns of fish reef health indicator variables fish abundance (*left*), fish richness (*centre*) and fish diversity (*right*) across the GBR averaged over 2005-2007. The greyscale indicates decreasing precision from light to dark.

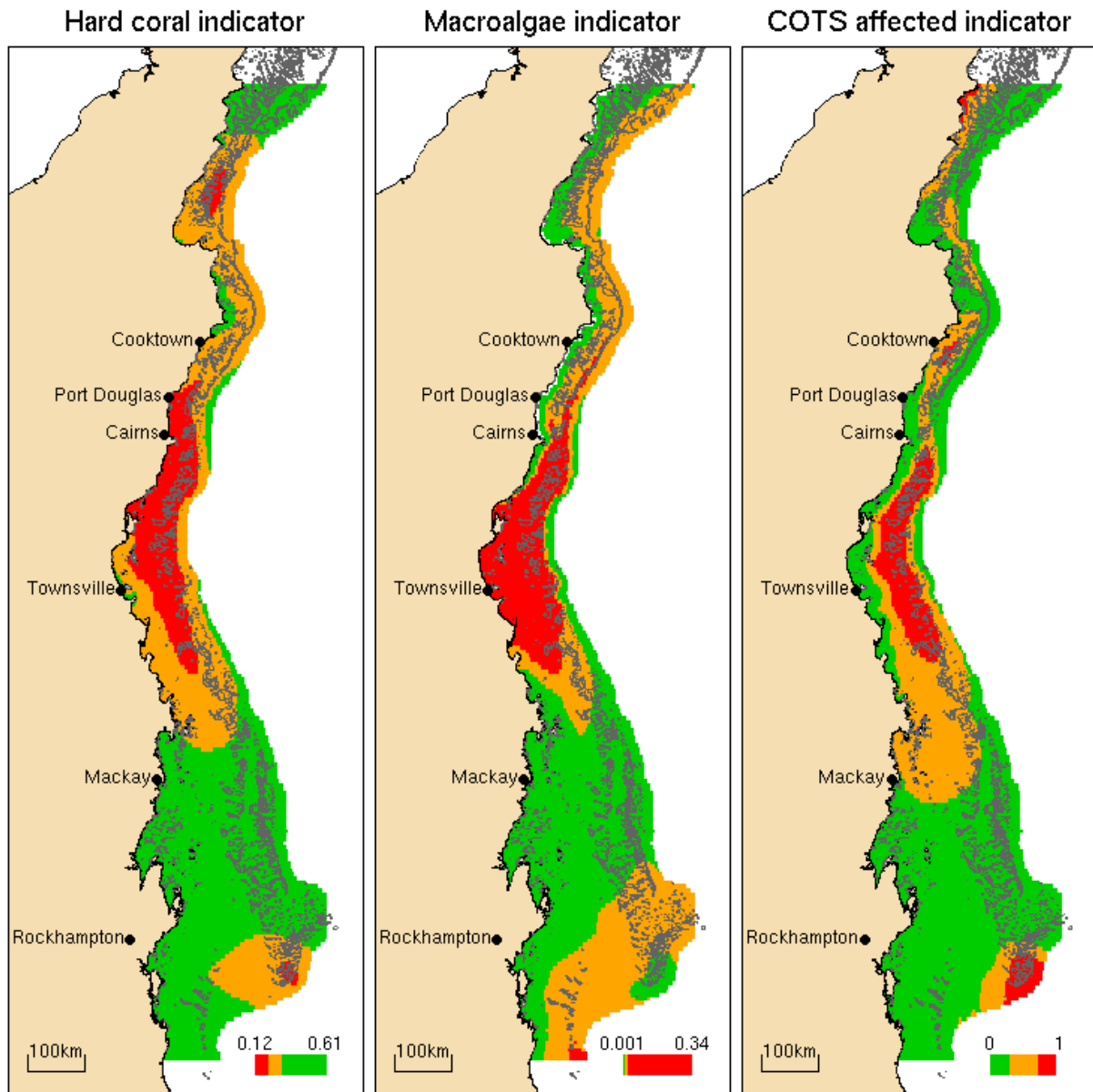


Figure 5.6: Spatial patterns of relative ecosystem health based on hard coral cover (*left*), macroalgae cover (*centre*) and the proportion of reefs affected by COTS (*right*) across the GBR averaged over 2005-2007. The red, orange and green indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

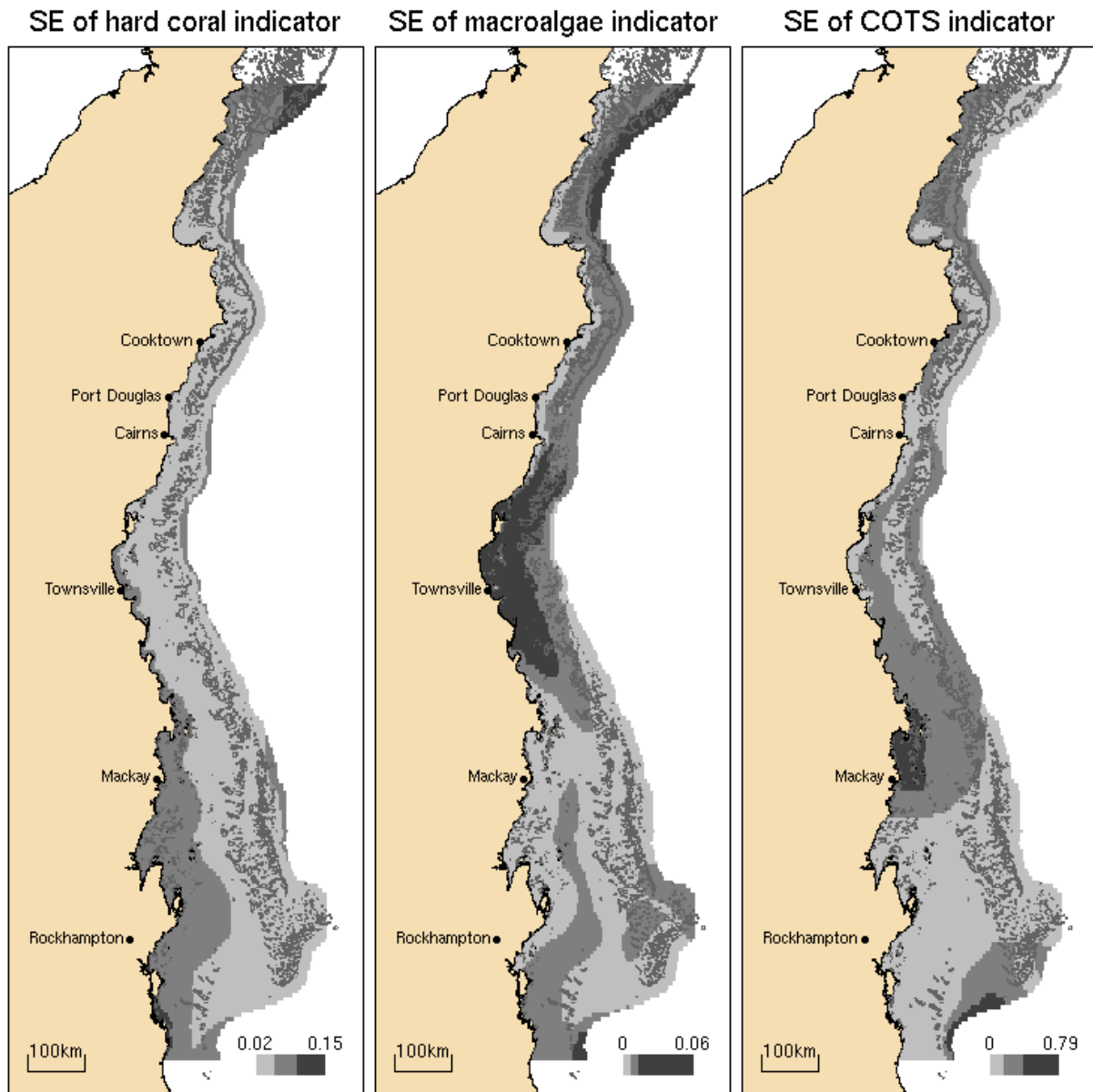


Figure 5.7: Standard errors (SE) for spatial patterns of relative ecosystem health based on hard coral cover (*left*), macroalgae cover (*centre*) and the proportion of reefs affected by COTS (*right*) across the GBR averaged over 2005-2007. The greyscale indicates decreasing precision from light grey to dark grey formed by the 60th and 90th percentile breaks of the standard errors respectively. For the hard coral indicator, light grey regions had SE less than 1.2 times the Median SE (MSE), grey regions had SE less than 2.0 times the MSE, and dark grey regions had greater than 2.0 times the MSE. For the macroalgae indicator, light grey regions had SE less than 1.0 times the MSE, grey regions had SE less than 2.1 times the MSE, and dark grey regions had SE greater than 2.1 times the MSE. For the COTS affected indicator, light grey regions had SE less than 1.4 times the MSE, grey regions had SE less than 3.2 times the MSE, and dark grey regions had SE greater than 3.2 times the MSE

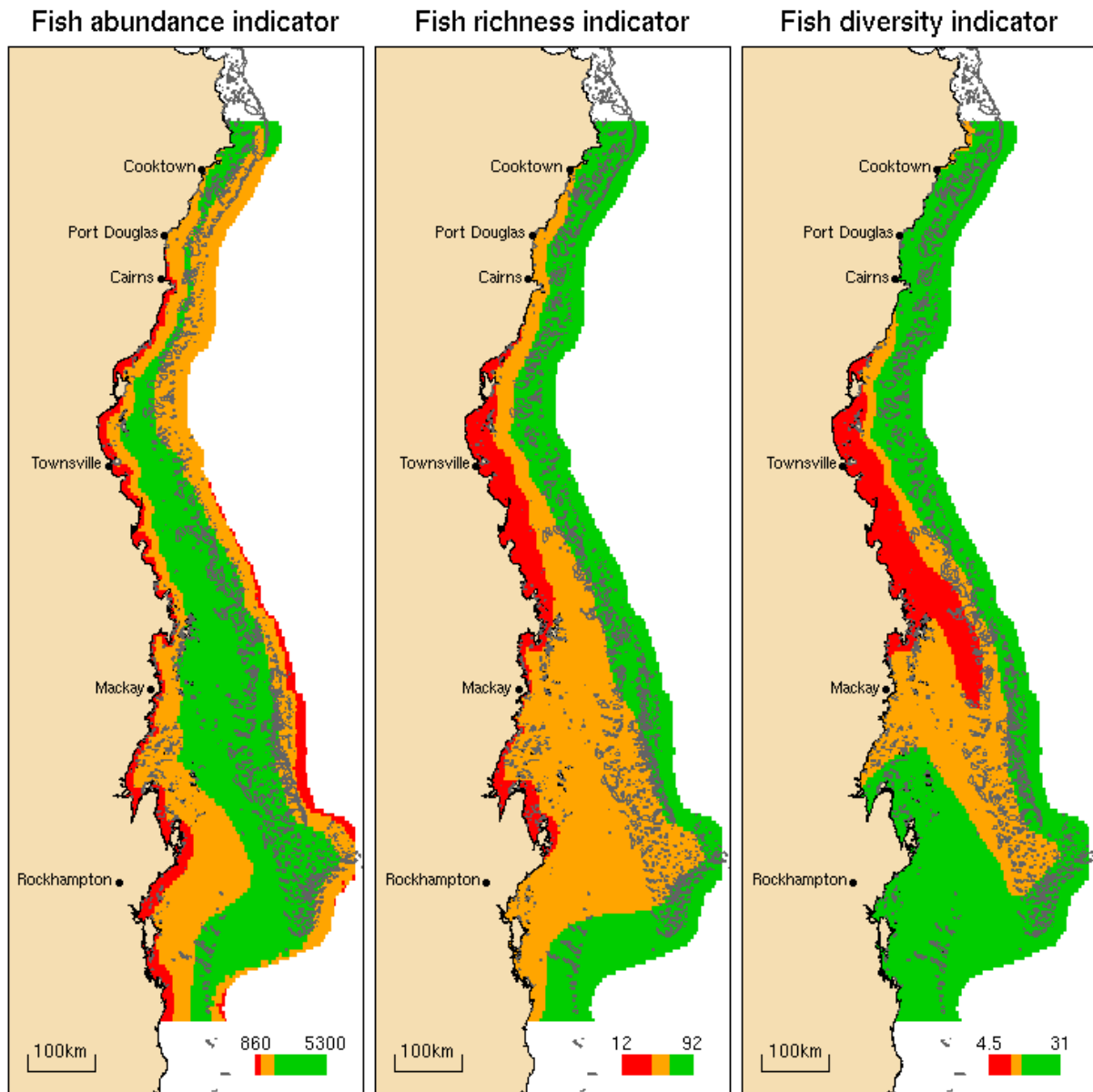


Figure 5.8: Spatial patterns of relative ecosystem health based on fish abundance (*left*), fish richness (*centre*) and fish diversity (*right*) across the GBR averaged over 2005-2007. The red, orange and green indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

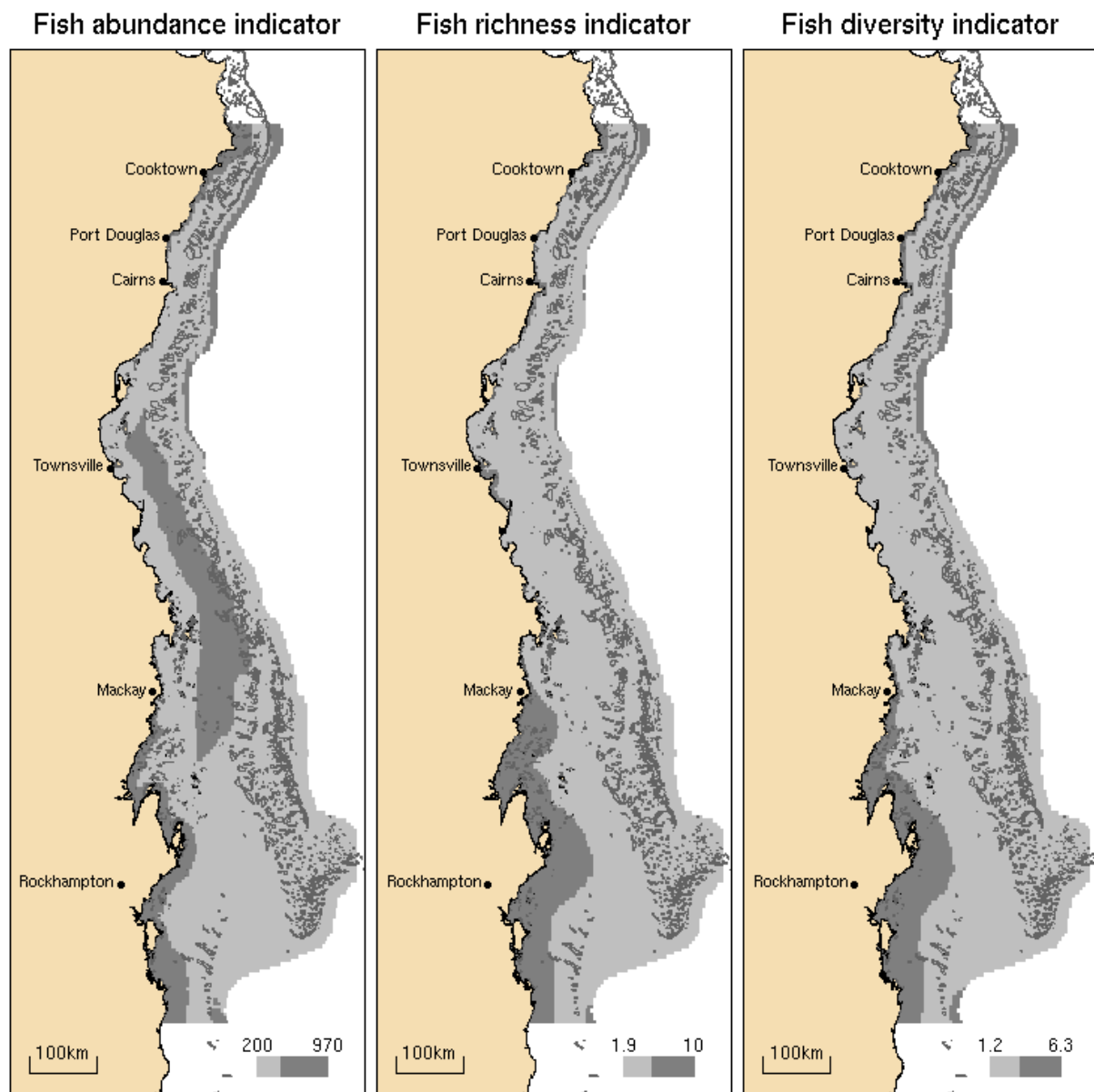


Figure 5.9: Standard errors (SE) for spatial patterns of relative ecosystem health based on fish abundance (*left*), fish richness (*centre*) and fish diversity (*right*) across the GBR averaged over 2005–2007. The greyscale indicates decreasing precision from light grey to dark grey formed by the 60th and 90th percentile breaks of the standard errors respectively. For the fish abundance indicator, light grey regions had SE less than 1.2 times the Median SE (MSE), grey regions had SE less than 5.3 times the MSE, and dark grey regions had greater than 5.3 times the MSE. For the fish richness indicator, light grey regions had SE less than 1.3 times the MSE, grey regions had SE less than 3.1 times the MSE, and dark grey regions had SE greater than 3.1 times the MSE. For the fish diversity indicator, light grey regions had SE less than 1.4 times the MSE, grey regions had SE less than 2.7 times the MSE, and dark grey regions had SE greater than 2.7 times the MSE

Spatial patterns of composite indices of reef ecosystem health

Composite indices of relative reef health were constructed for the benthos and the fish using the sets of indicator variables described above. These indices were calculated as the sum of the set of z-score standardised variables (i.e. with the appropriate sign changes such that summing did not cancel the contribution of some variables). Fish abundance and macroalgae cover were log transformed prior to standardisation. Thus, negative values of the composite indices represent poor relative health and positive values represent good relative health.

There was no significant across-shelf pattern in the benthic reef health index; however there was a 3.6-fold decline in reef health in the Wet Tropics and Burdekin NRM regions relative to regions to the north and south. This pattern explained 39% of the variation in the index. There was a 7.3-fold increase in the fish index of reef health from inshore to the mid and outer shelf regions. Additionally, the index was 2.8-fold lower in Fitzroy and Mackay Whitsunday NRM regions relative to the northern Cape York region. These patterns explained sixty percent of the total variation (Figure 5.10). The reliability of estimates was generally high, except for some inshore areas, particularly the inner southern region (Figure 5.11).

These spatial patterns in reef health indices similarly highlight the poor health status of the inshore Wet Tropics and Burdekin reefs relative to the outer shelf reefs and the generally healthier southern GBR reefs (Figure 5.12). Again, the reliability of estimates was generally high, except for some inshore areas, particularly the inner southern region (Figure 5.13).

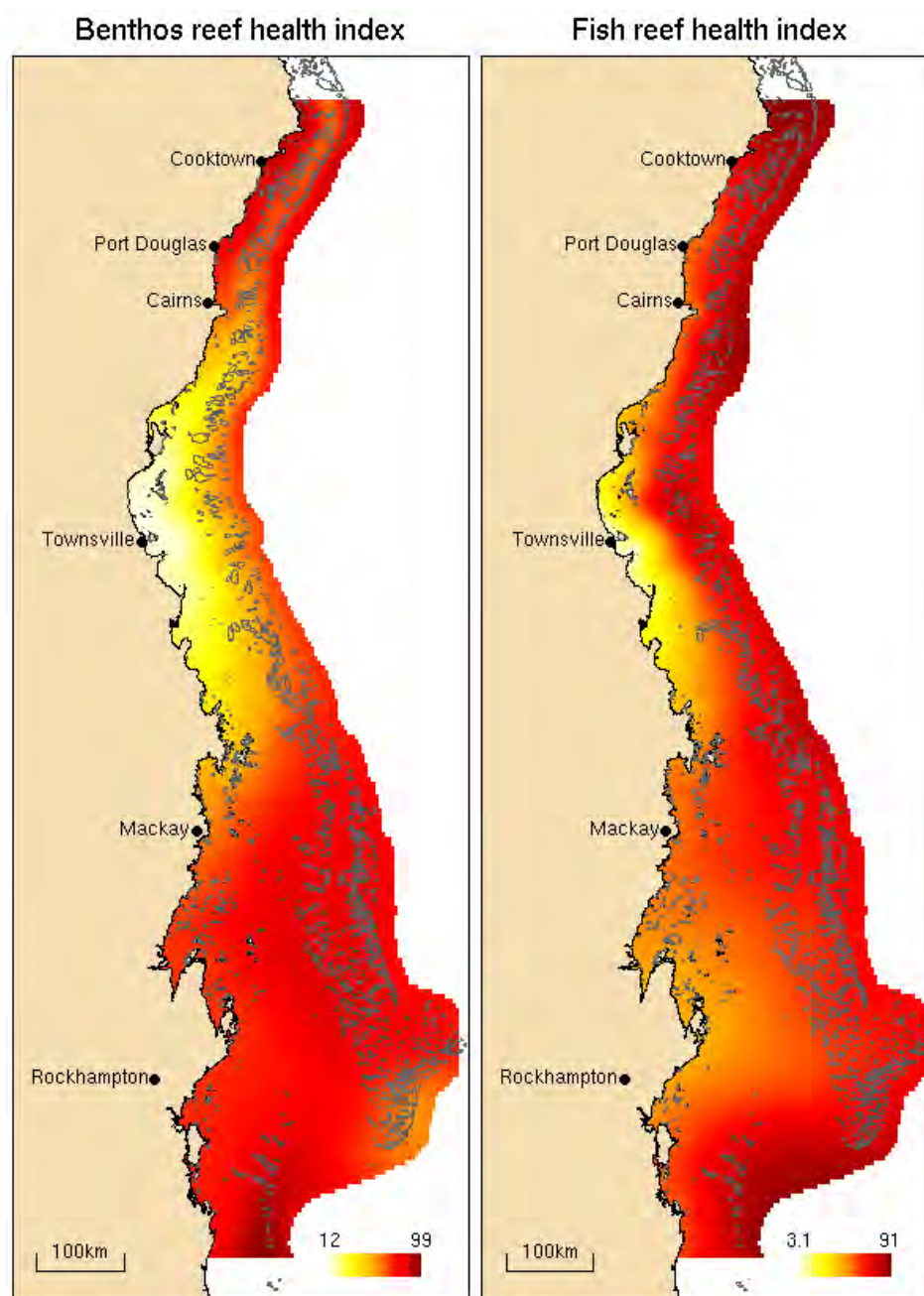


Figure 5.10: Spatial patterns of benthic (*left*) and fish (*right*) composite reef health indices across the GBR averaged over 2005-2007.

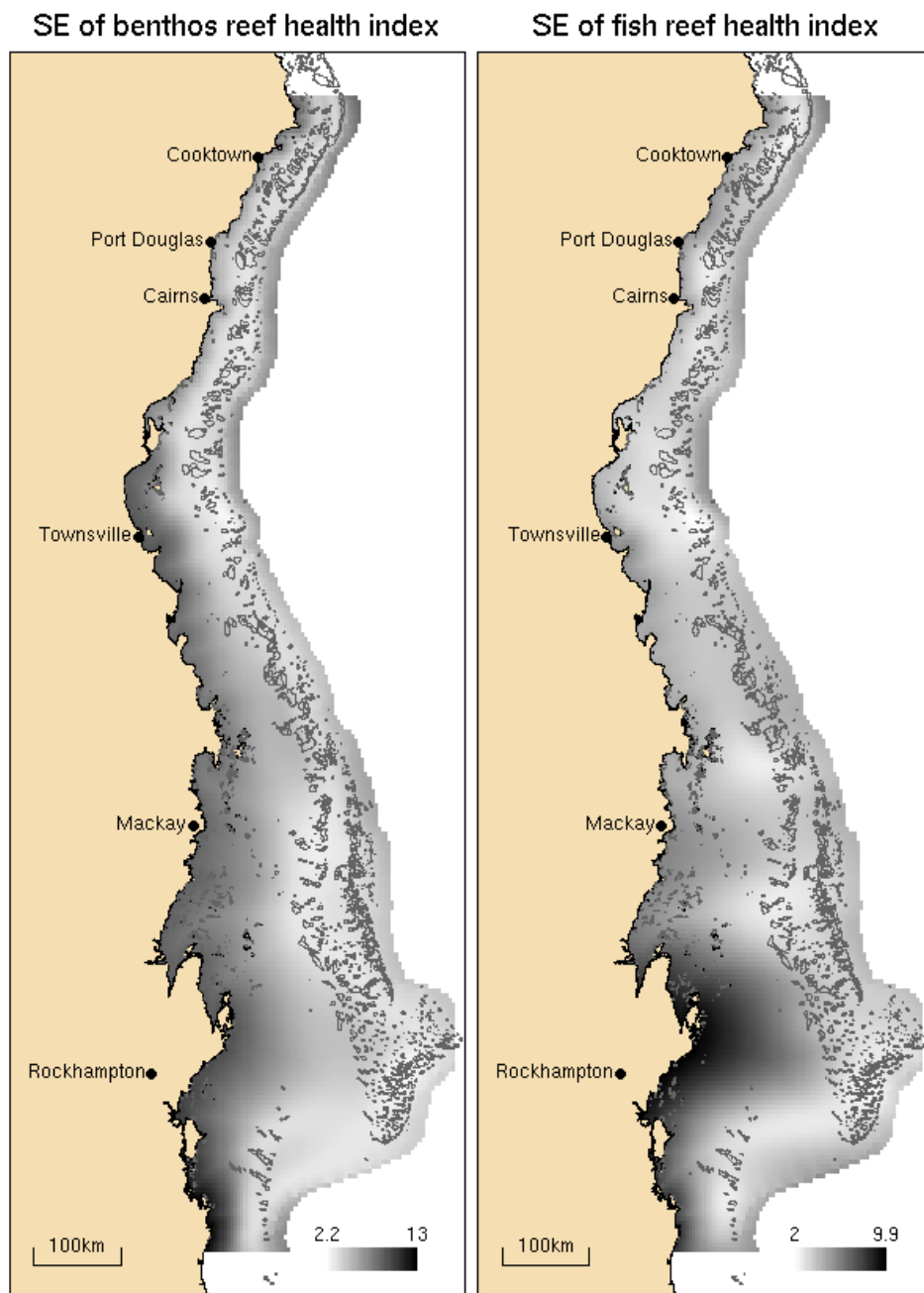


Figure 5.11: Standard errors for spatial patterns of benthic (*left*) and fish (*right*) composite reef health indices across the GBR averaged over 2005-2007. The grayscale indicates decreasing precision from light to dark.

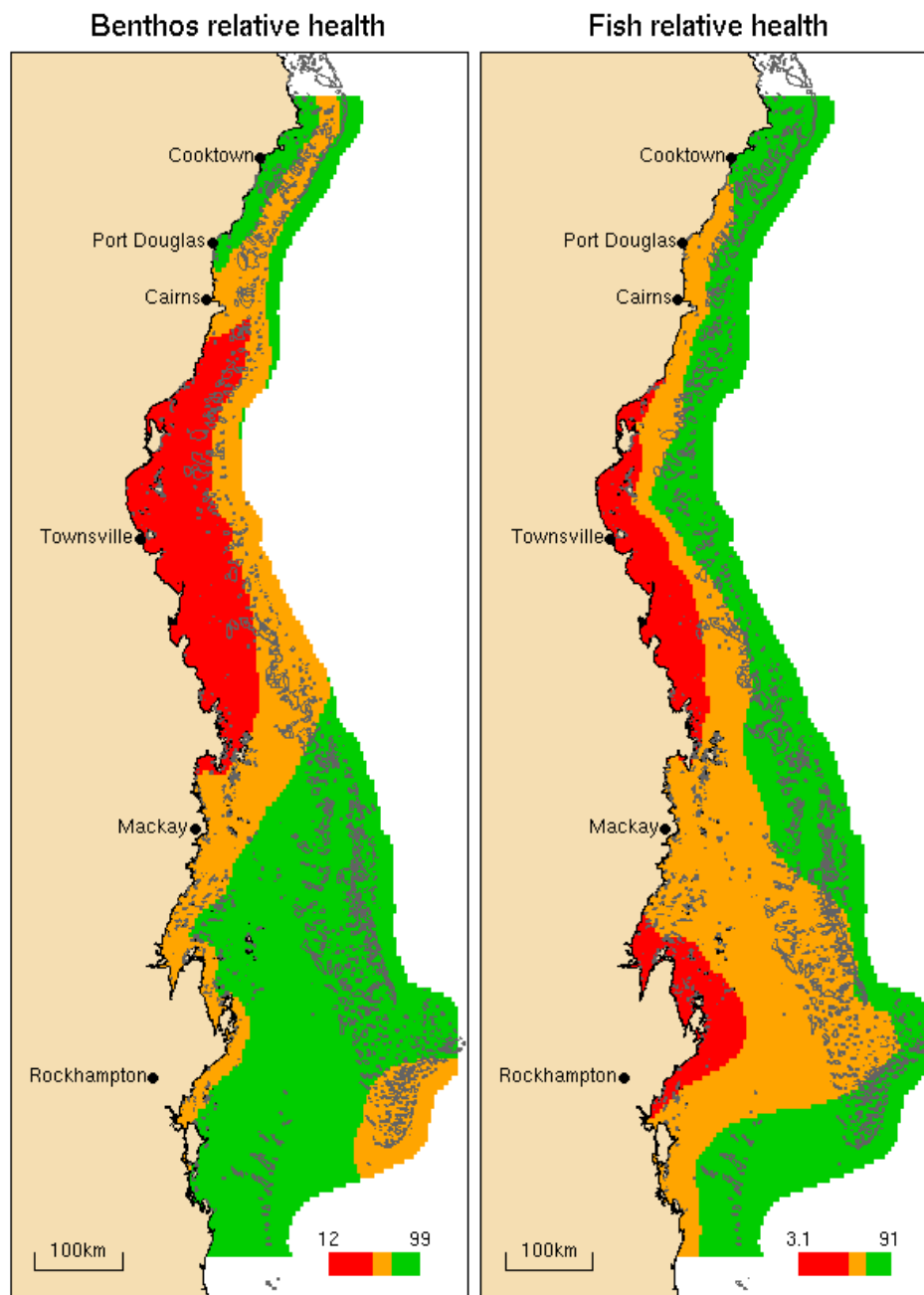


Figure 5.12: Spatial patterns of relative ecosystem health based on benthic (*left*) and fish (*right*) composite reef health indices across the GBR averaged over 2005-2007. The red, orange and green indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

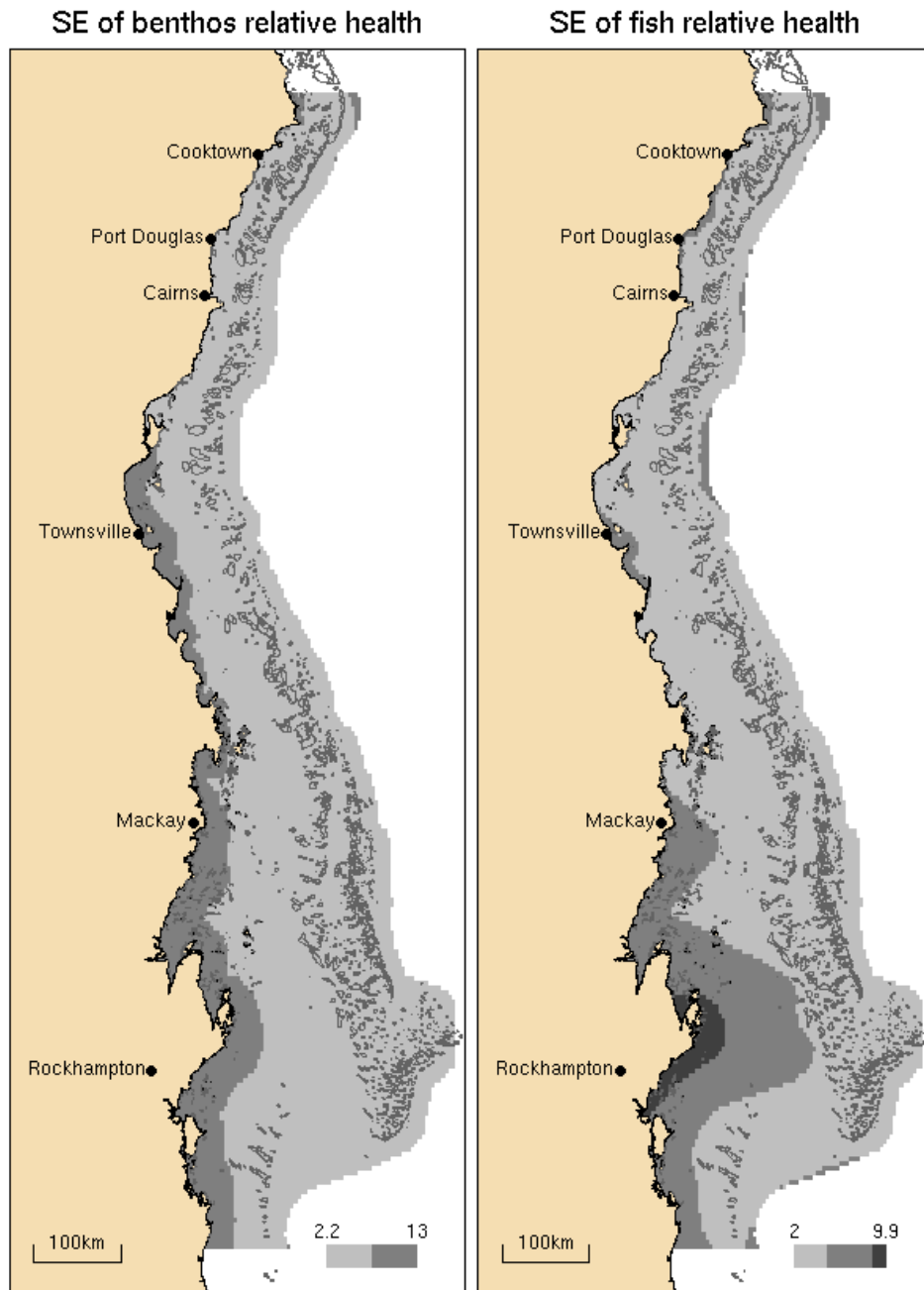


Figure 5.13: Standard errors (SE) for spatial patterns of relative ecosystem health based on benthic (*left*) and fish (*right*) composite reef health indices across the GBR averaged over 2005-2007. The greyscale indicates decreasing precision from light grey to dark grey formed by the 60th and 90th percentile breaks of the standard errors respectively. For the benthic index, light grey regions had SE less than 1.5 times the median SE (MSE); grey regions had SE less than 2.6 times the MSE. For the fish index, light grey regions had SE less than 1.2 times the MSE; grey regions had SE less than 2.2 times the MSE and dark grey regions had SE greater than 2.2 times the MSE.

Temporal trends of composite indices of reef ecosystem health

Temporal trends in the composite indices of reef health were modelled using generalised additive mixed models fitted to each region separately. Smooth functions were used to account for nonlinearity in the temporal trends.

Benthic reef health was below the GBR average in the Burdekin inner and mid-shelf, and the Cape York and Wet Tropics mid-shelf regions, and above average in the Cape York and Mackay Whitsunday inner shelf, and the outer shelf of the Cape York, Mackay Whitsunday, Fitzroy and Burnett Mary regions (Figure 5.14; Table 5.1). Fish reef health was below average in the Burdekin and Mackay Whitsunday inner shelf regions, and above average in the Cape York, Wet Tropics and Burdekin mid-shelf, and the outer shelf of the Cape York and Burdekin regions (Figure 5.15; Table 5.1).

Table 5.1: Mean annual values and 95% confidence intervals of the (a) benthic, and (b) fish reef health indices predicted across the six NRM regions and three cross-shelf positions in the GBR. Indices are scaled to range 0-100; Benthic index mean = 41.8; Fish index mean = 69.4. Green highlights above average health, red highlights below average health. The highest and lowest two values are marked with an asterisk. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Benthic index								
GBR Mean	46.5	36.9, 56.1	32.5	27.3, 37.8	49.2	43.4, 55.1	42.0	37.6, 46.3
Cape York	51.4	42.8, 60.1	23.9*	21.9, 26.0	47.3	45.3, 49.2	37.9	29.3, 46.4
Wet Tropics	37.1	19.8, 54.4	30.6	20.6, 40.6	41.1	25.0, 57.2	36.2	27.7, 44.7
Burdekin	26.3	21.4, 31.2	24.1*	19.7, 28.5	37.7	25.0, 50.4	30.3	23.1, 37.6
Mackay-Whitsunday	58.9*	51.8, 66.0	40.4	22.3, 58.4	52.9	46.5, 59.3	50.7	42.3, 59.1
Fitzroy			40.8	32.9, 48.7	53.4	42.5, 64.2	46.4	38.7, 54.0
Burnett-Mary					67.6*	63.7, 71.4	67.6	63.7, 71.4
	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) Fish index								
GBR Mean	56.0	45.0, 67.1	74.2	70.9, 77.6	71.3	67.3, 75.4	68.6	64.7, 72.5
Cape York	67.0	42.9, 91.1	82.3*	74.6, 90.0	82.9*	80.8, 85.0	77.9	69.3, 86.6
Wet Tropics	66.4	53.8, 79.0	75.0	73.7, 76.2	71.5	66.8, 76.1	71.0	66.1, 75.8
Burdekin	34.3	14.5, 54.1	78.1	75.9, 80.3	75.1	70.9, 79.3	62.5	47.8, 77.3
Mackay-Whitsunday	56.4*	53.9, 58.9	68.9	64.7, 73.1	69.9	58.1, 81.7	65.1	59.3, 70.8
Fitzroy			68.2	64.0, 72.3	67.3	63.7, 70.9	67.8	65.0, 70.5
Burnett-Mary					58.3*	52.4, 64.3	58.3	52.4, 64.3

Additionally, there was significant average decline in benthic reef health over time across the entire shelf in the Burdekin region, and in the Wet Tropics inner shelf and Fitzroy mid-shelf regions (Figure 5.8; Table 5.2). Benthic reef health only increased on average in the Cape York and Burnett Mary outer shelf regions associated with recovery after storm damage in the early 1990s without further disturbances (though there has been significant loss in coral cover in the Cape York outer shelf in recent years (Figure 5.8). Increases in fish health over time were evident in the Mackay Whitsunday inner shelf, Cape York mid-shelf and Wet Tropics, Fitzroy and Burnett Mary outer shelf regions (Figure 5.9; Table 5.2).

Table 5.2: Mean percent linear change values and 95% confidence intervals of the (a) benthic, and (b) fish reef health indices predicted across the six NRM regions and three cross-shelf positions in the GBR. Green highlights above average health, red highlights below average health. The highest and lowest two values within regions are marked with an asterisk. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
(a) Benthic index	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	-0.66	-1.52, 0.21	-1.09	-1.48, -0.70	1.10	0.68, 1.53	-0.13	-0.42, 0.16
Cape York	0.60	-1.16, 2.35	-0.53	-1.31, 0.24	2.35*	1.48, 3.23	0.73	0.10, 1.35
Wet Tropics	-1.78	-3.27, -0.28	-0.34	-0.95, 0.28	0.06	-0.47, 0.60	-0.62	-1.12, -0.11
Burdekin	-4.74*	-7.81, -1.67	-2.52*	-3.32, -1.71	-1.08	-1.95, -0.21	-1.97	-2.56, -1.38
Mackay-Whitsunday	-0.41	-1.88, 1.06	-0.19	-1.26, 0.88	0.30	-0.17, 0.77	-0.07	-0.64, 0.49
Fitzroy			-1.67	-2.51, -0.83	0.19	-0.83, 1.20	-0.91	-1.57, -0.25
Burnett-Mary					5.00*	4.04, 5.97	5.00	4.04, 5.97

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
(b) Fish index	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	0.16	-0.11, 0.44	0.11	-0.05, 0.26	0.79	0.58, 1.00	0.38	0.26, 0.50
Cape York	0.32	-0.12, 0.76	0.44	0.06, 0.82	0.04	-0.32, 0.40	0.28	0.06, 0.50
Wet Tropics	-0.20	-0.72, 0.31	0.21	-0.13, 0.54	0.48	0.00, 0.95	0.16	-0.09, 0.41
Burdekin	-0.06	-0.80, 0.68	0.16	-0.13, 0.45	0.05	-0.39, 0.49	0.07	-0.20, 0.33
Mackay-Whitsunday	0.56	-0.01, 1.12	0.18	-0.33, 0.70	0.26	-0.20, 0.71	0.34	0.05, 0.63
Fitzroy			-0.28	-0.53, -0.02	1.29*	0.85, 1.73	0.39	0.12, 0.67
Burnett-Mary					2.97*	2.50, 3.43	2.97	2.50, 3.43

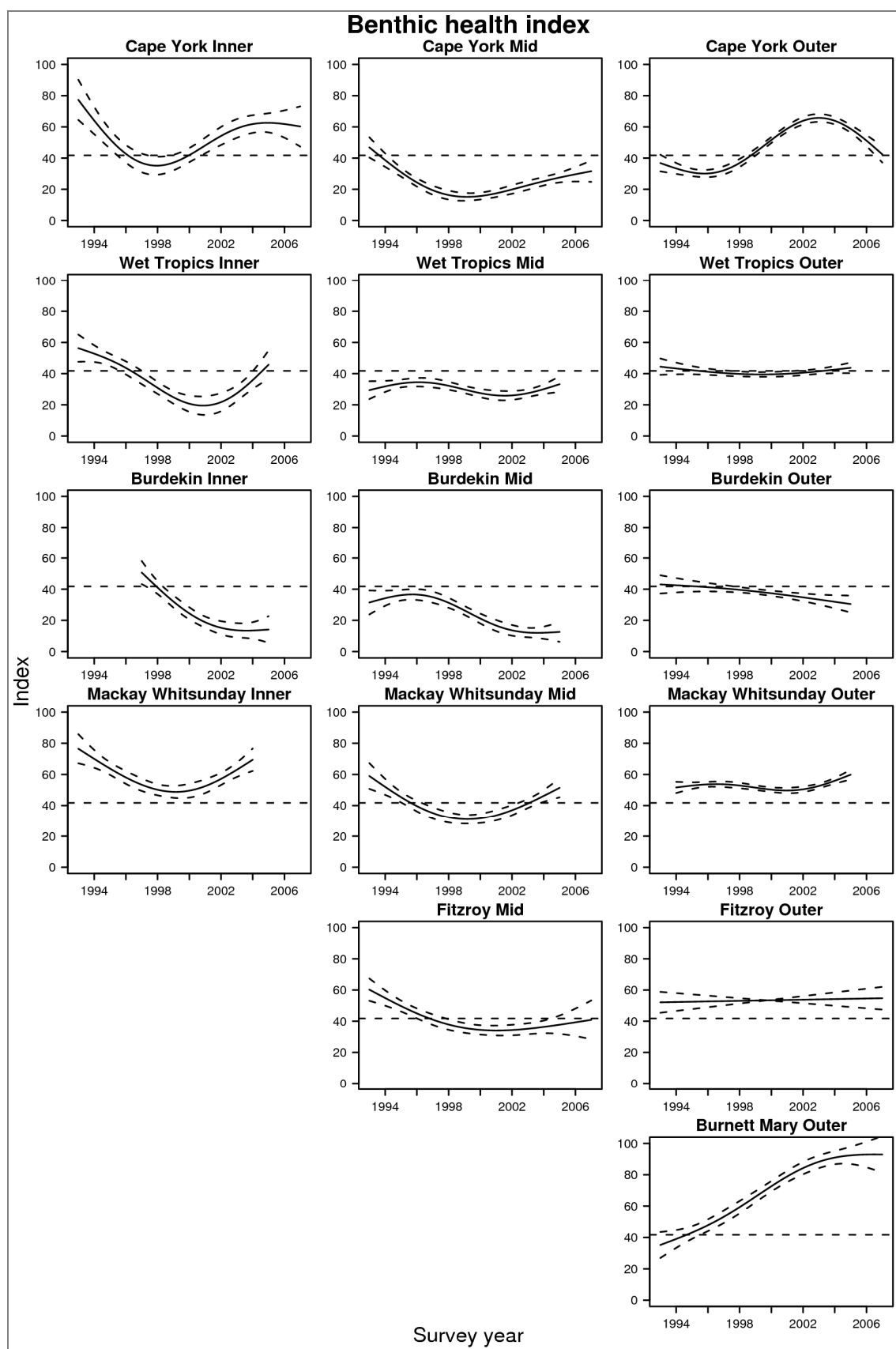


Figure 5.14: Estimated temporal trends of the benthic reef health composite index across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed lines represent GBR mean.

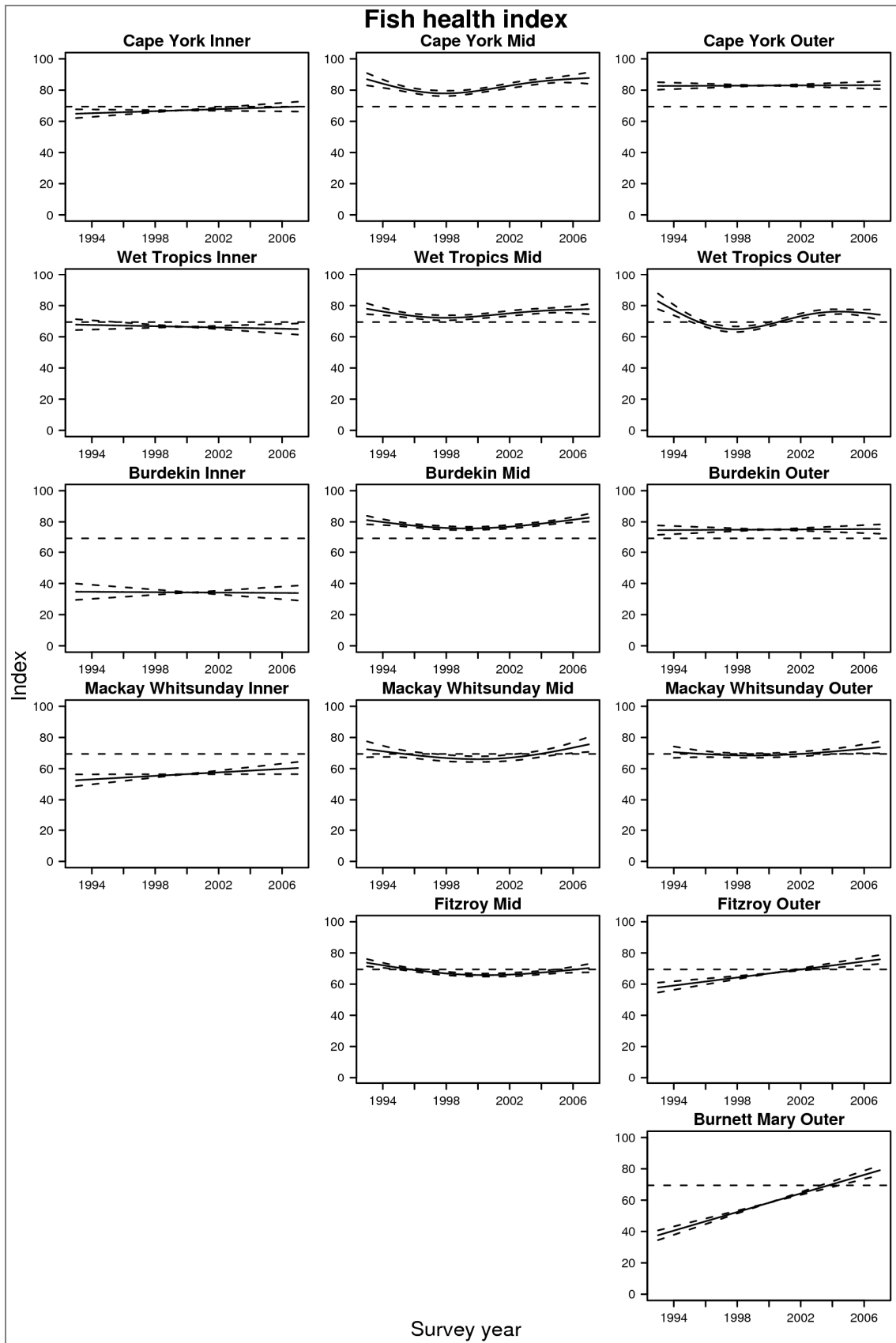


Figure 5.15: Estimated temporal trends of the fish reef health composite index across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed lines represent GBR mean.

Relationships of indicators of reef ecosystem health with water quality

Generalised additive models were used to examine additive relationships between each of the six ecosystem health indicator variables and spatial across and along shelf distances and two water quality variables. All four predictor variables were not included in a single model because of the very high correlation between the across shelf distance and water clarity (i.e. secchi disk). Therefore, two models were fitted to each response variable: (1) the additive effects of along shelf distance, secchi and chlorophyll; and (2) the additive effects of across and along shelf distance.

Hard coral cover covaried strongly along the shelf with high cover in the north and south, but low cover in the central section adjacent to the Wet Tropics and Burdekin NRM regions (Figure 5.16). Hard coral cover was weakly negatively correlated with chlorophyll at low to mid-range concentrations, but did not change with higher chlorophyll concentrations (Figure 5.16). Hard coral cover did not vary systematically across the shelf and was not correlated with water clarity (Figure 5.16). The additive effects of chlorophyll concentration and distance along the shelf explained more variation ($r^2 = 0.226$) than the additive spatial effects of distance across and along the shelf ($r^2 = 0.198$).

Macroalgae also varied strongly along the shelf and was highest adjacent to the Wet Tropics and Burdekin NRM regions, and in the southernmost Burnett Mary region (Figure 5.17). There was no strong association with across shelf distance or with either chlorophyll concentration or secchi depth (Figure 5.17), though the model with along shelf and water quality predictors was slightly better ($r^2 = 0.374$) than the purely additive spatial model ($r^2 = 0.326$).

The proportion of reefs affected by COTS increased with secchi depth (Figure 5.18), and also increased with low- to mid-range chlorophyll and decreased with mid- to high chlorophyll concentrations (Figure 5.18). There was strong spatial variation along the shelf, with higher proportions of COTS affected reefs in central to northern regions but lower numbers in the southern regions. The proportion of COTS affected reefs was independent of distance across the shelf (Figure 5.18). Consequently, the model with along shelf and water quality predictors was substantially better ($r^2 = 0.189$) than the purely additive spatial model ($r^2 = 0.065$).

Total abundance of fishes increased weakly from low- to mid-range values of chlorophyll and then decreased with increasing chlorophyll (Figure 5.19). There were also strong changes in abundance along the shelf with higher abundance in the Burnett Mary and Fitzroy regions and lower abundances in the Wet Tropics region (Figure 5.19). Abundance also increased from the inner- to mid-shelf and decreased from the mid to outer shelf. The 'spatial only' model explained slightly more variation in total abundance ($r^2 = 0.207$) than the 'water quality + along shelf' model ($r^2 = 0.193$).

Fish richness and diversity were both strongly positively correlated with secchi depth (Figures 5.20 and 5.21), and were lowest in the south-central regions of the GBR adjacent to the Burdekin-Fitzroy NRM regions and highest in the far north Cape York region (Figures 5.20 and 5.21). For richness, the 'spatial only' model explained slightly less variation ($r^2 = 0.585$) than the 'water quality plus along shelf' model ($r^2 = 0.579$). For diversity, the 'spatial only' model explained slightly more variation ($r^2 = 0.394$) than the 'water quality plus along shelf' model ($r^2 = 0.379$).

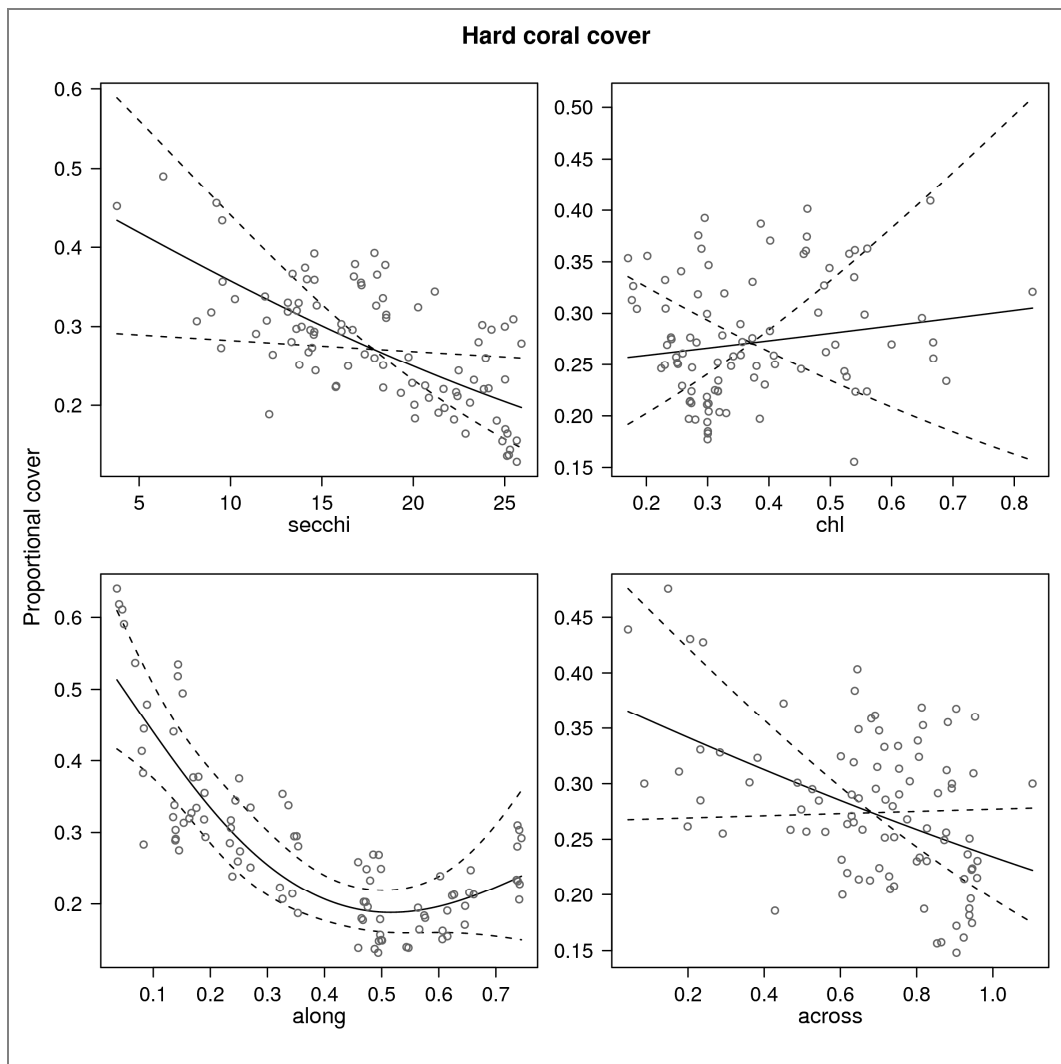


Figure 5.16: Partial effects plots of changes in hard coral cover along gradients in water clarity (secchi), chlorophyll (chl), and distance along and across the continental shelf. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals; points are partial residuals measured from the mean estimated trend.

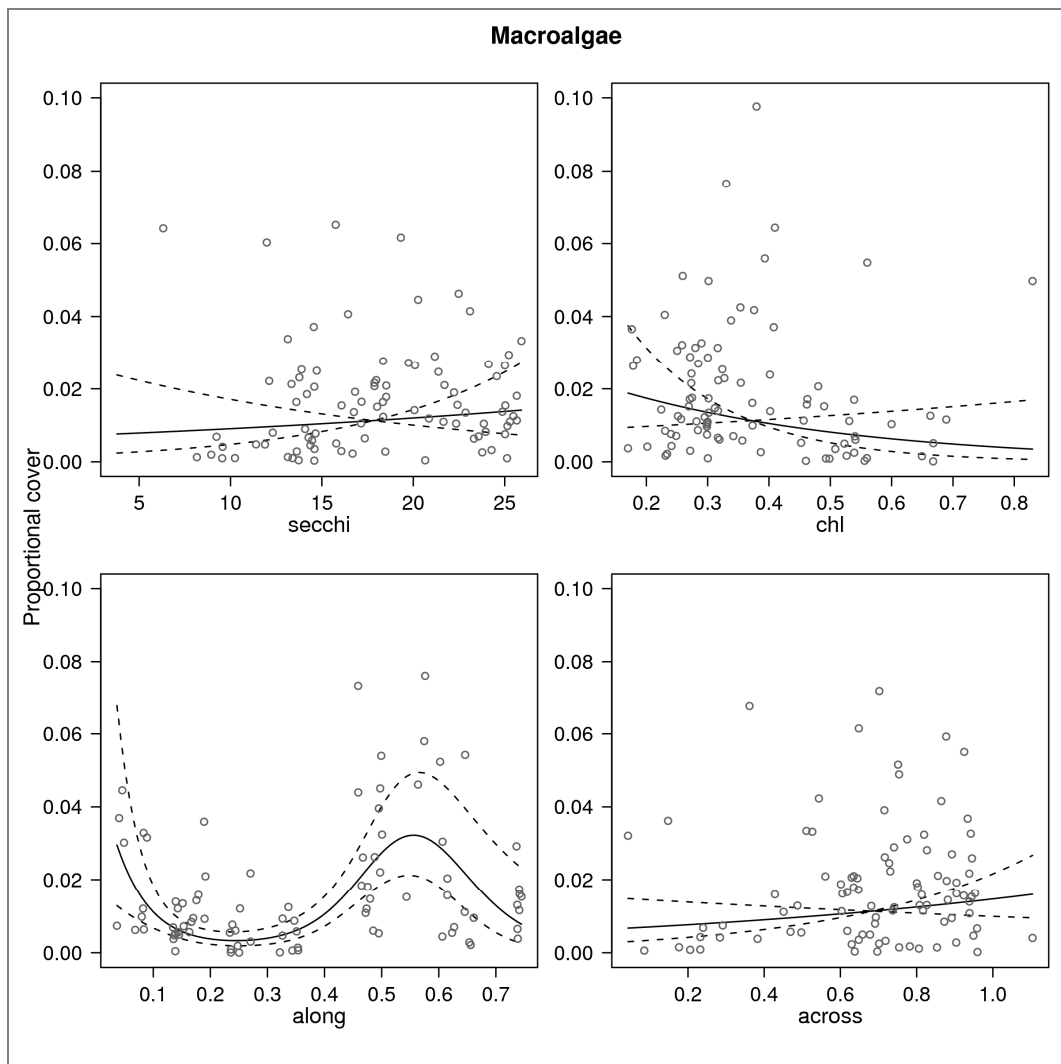


Figure 5.17: Partial effects plots of changes in macroalgae cover along gradients in water clarity (secchi), chlorophyll (chl), and distance along and across the continental shelf. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals; points are partial residuals measured from the mean estimated trend. Macroalgae was log transformed for analysis and back-transformed to proportional cover for graphical representation.

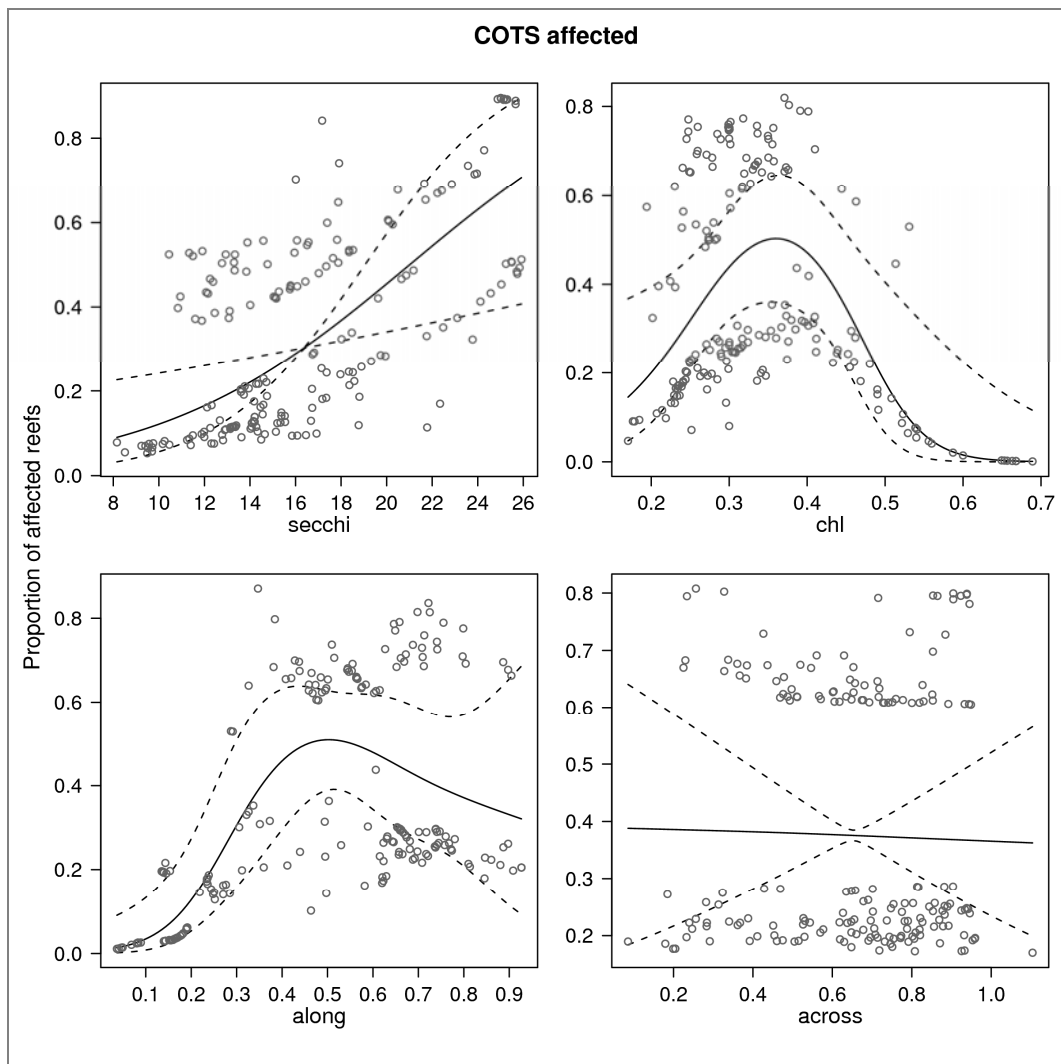


Figure 5.18: Partial effects plots of changes in the proportion of manta towed reefs sampled over 2005-2007 that were affected by COTS along gradients in water clarity (secchi), chlorophyll (chl), and distance along and across the continental shelf. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals; points are partial residuals measured from the mean estimated trend.

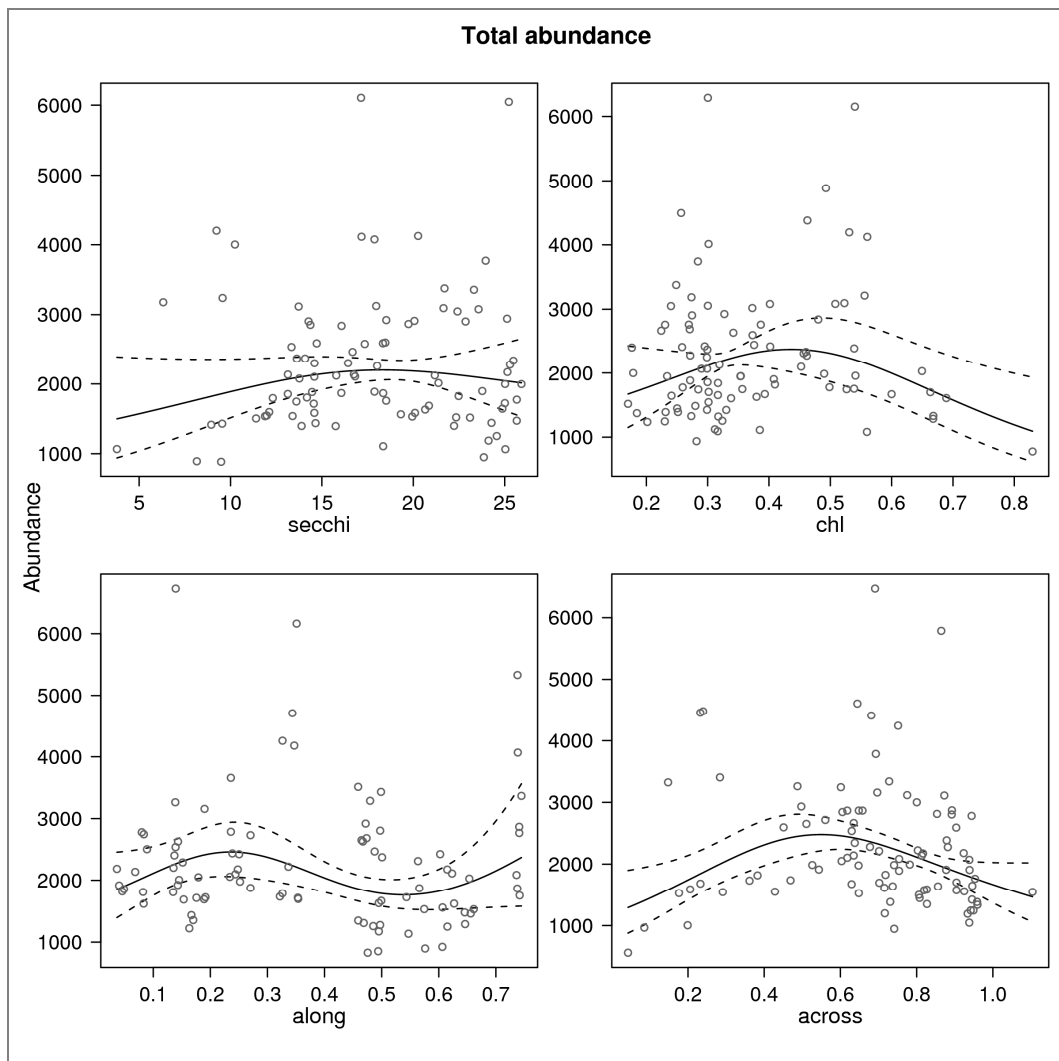


Figure 5.19: Partial effects plots of changes in total fish abundance along gradients in water clarity (secchi), chlorophyll (chl), and distance along and across the continental shelf. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals; points are partial residuals measured from the mean estimated trend.

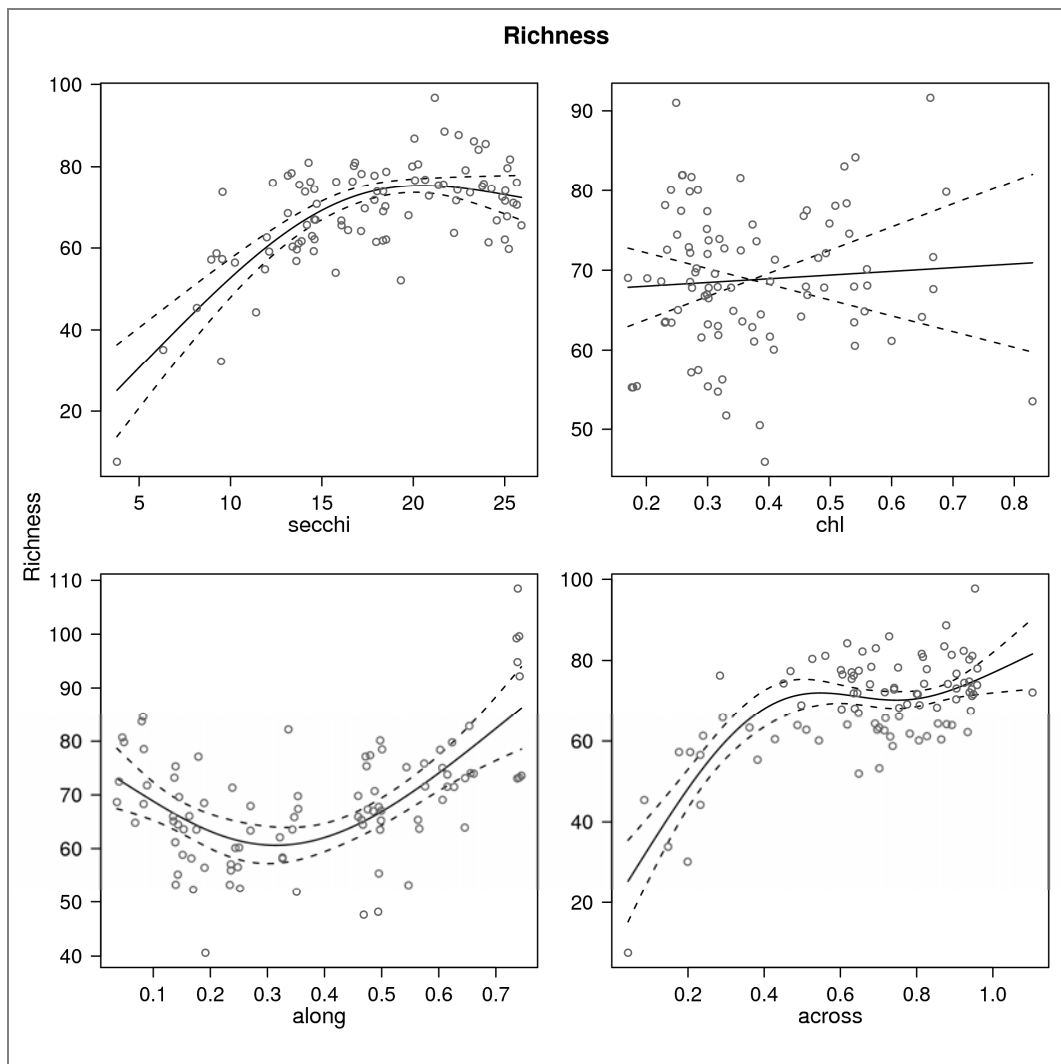


Figure 5.20: Partial effects plots of changes in fish species richness along gradients in water clarity (secchi), chlorophyll (chl), and distance along and across the continental shelf. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals; points are partial residuals measured from the mean estimated trend.

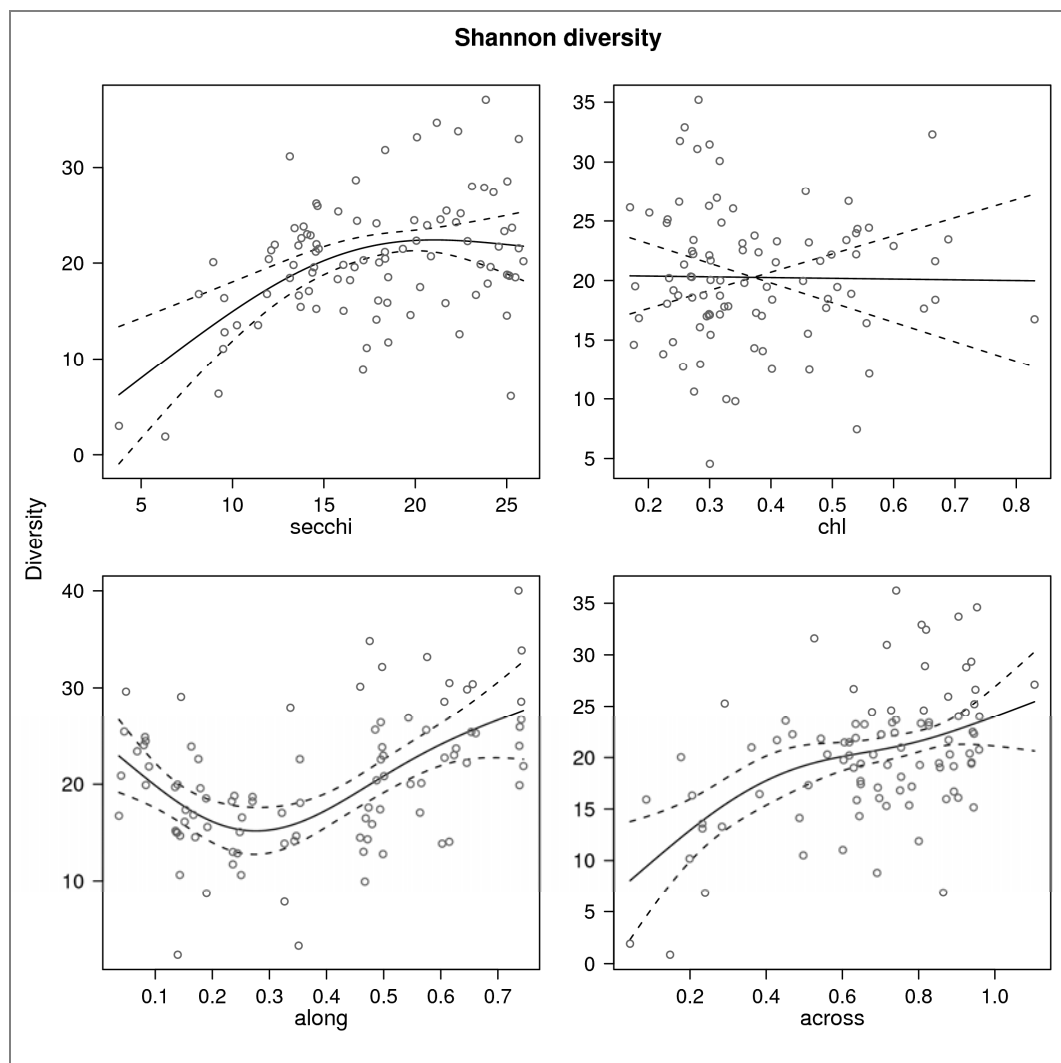


Figure 5.21: Partial effects plots of changes in fish species diversity along gradients in water clarity (secchi), chlorophyll (chl), and distance along and across the continental shelf. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals; points are partial residuals measured from the mean estimated trend.

6. Spatial patterns of reef biota on the Great Barrier Reef

Summary

This section contains graphical presentations of spatial patterns of variation of all potential reef health indicator variables examined. These spatial patterns were estimated using generalised additive models (GAM) with smooth 2D surfaces as a function of distance across and along the shelf. These models were used to predict the values of each variable for all GBR reefs ($n = 2870$) to provide spatial maps and relative health maps for the whole GBR. The three panels presented for each variable show: (1) the location of reefs surveyed for each sampling method; (2) spatial patterns of values for each variable; and (3) relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the cover of hard coral at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively. Results are summarised in Appendix 1.

Benthic cover variables

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Benthic genera cover variables

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Broadscale surveys of COTS density and coral cover

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Fish trophic group abundance

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Table 6.1: Mean annual values and 95% confidence intervals of benthic groups predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Hard coral								
GBR Mean	25.4	19.1, 33.0	26.5	22.9, 30.4	32.4	26.9, 38.4	28.6	25.5, 31.9
Cape York	29.3	19.4, 41.6	20.0	16.0, 24.8	42.1	39.8, 44.4	28.8	22.1, 36.6
Wet Tropics	13.9	7.5, 24.4	21.0	17.3, 25.3	25.0	19.7, 31.0	20.2	16.1, 25.2
Burdekin	30.1	16.4, 48.7	23.5	16.0, 33.0	28.9	25.6, 32.5	27.8	22.1, 34.3
Mackay-Whitsunday	28.9	18.8, 41.8	31.3	23.7, 40.1	25.0	14.5, 39.6	28.4	22.4, 35.2
Fitzroy			33.6	27.5, 40.3	33.6	21.0, 48.9	33.8	27.2, 41.1
Burnett-Mary					43.9	41.1, 46.6	43.9	41.1, 46.6

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) Soft coral								
GBR Mean	10.3	7.0, 14.8	5.2	3.2, 8.3	11.8	6.4, 20.9	8.4	6.1, 11.6
Cape York	4.3	3.1, 5.9	5.4	2.5, 11.6	4.6	2.5, 8.5	4.9	3.3, 7.0
Wet Tropics	10.4	5.4, 19.3	16.7	9.3, 28.1	31.8	25.3, 39.1	18.2	11.8, 26.8
Burdekin	11.2	8.8, 14.1	3.2	2.4, 4.3	12.1	8.8, 16.4	7.7	5.0, 11.8
Mackay-Whitsunday	19.9	13.4, 28.6	1.4	0.9, 2.2	32.4	18.5, 50.3	10.7	4.0, 25.8
Fitzroy			6.5	2.6, 15.3	15.3	6.0, 33.7	9.7	4.8, 18.5
Burnett-Mary					0.6	0.2, 1.6	0.6	0.2, 1.6

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(c) Algae								
GBR Mean	44.5	36.2, 53.2	57.0	52.8, 61.2	40.6	36.3, 45.1	47.8	44.0, 51.6
Cape York	47.5	41.3, 53.8	57.0	52.6, 61.2	45.3	40.7, 50.0	50.6	46.1, 55.2
Wet Tropics	57.7	44.4, 70.0	55.3	43.5, 66.5	37.3	33.5, 41.3	49.9	41.6, 58.2
Burdekin	42.3	22.5, 65.0	64.4	57.7, 70.6	52.7	44.9, 60.4	53.3	43.2, 63.2
Mackay-Whitsunday	31.1	28.4, 33.9	60.9	51.7, 69.3	25.3	22.0, 29.0	38.3	28.1, 49.7
Fitzroy			52.0	42.3, 61.7	40.2	36.2, 44.3	46.7	40.0, 53.7
Burnett-Mary					48.8	45.9, 51.7	48.8	45.9, 51.7

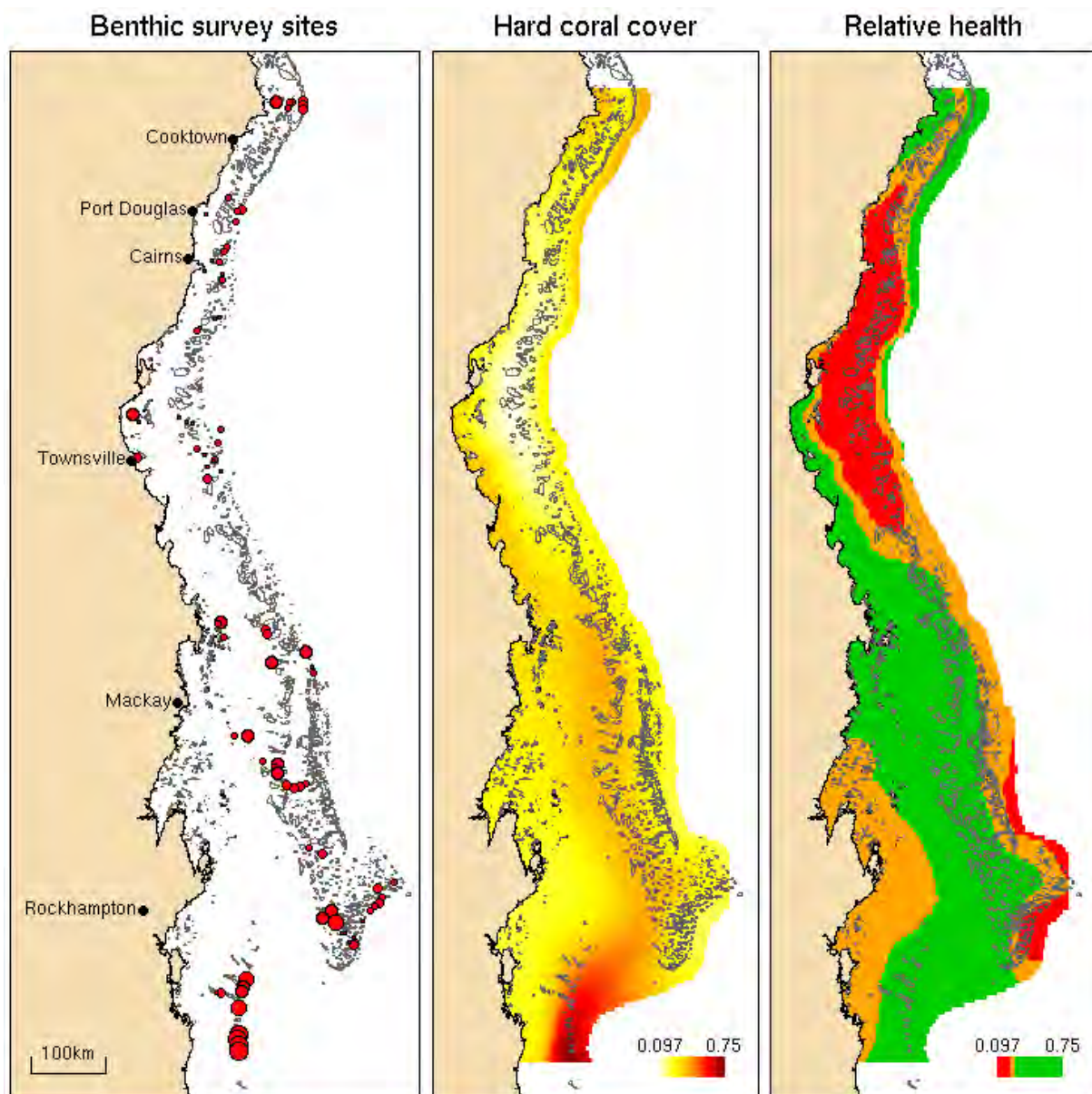


Figure 6.1: The location of reefs surveyed for benthos; spatial patterns of hard coral cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the cover of hard coral at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

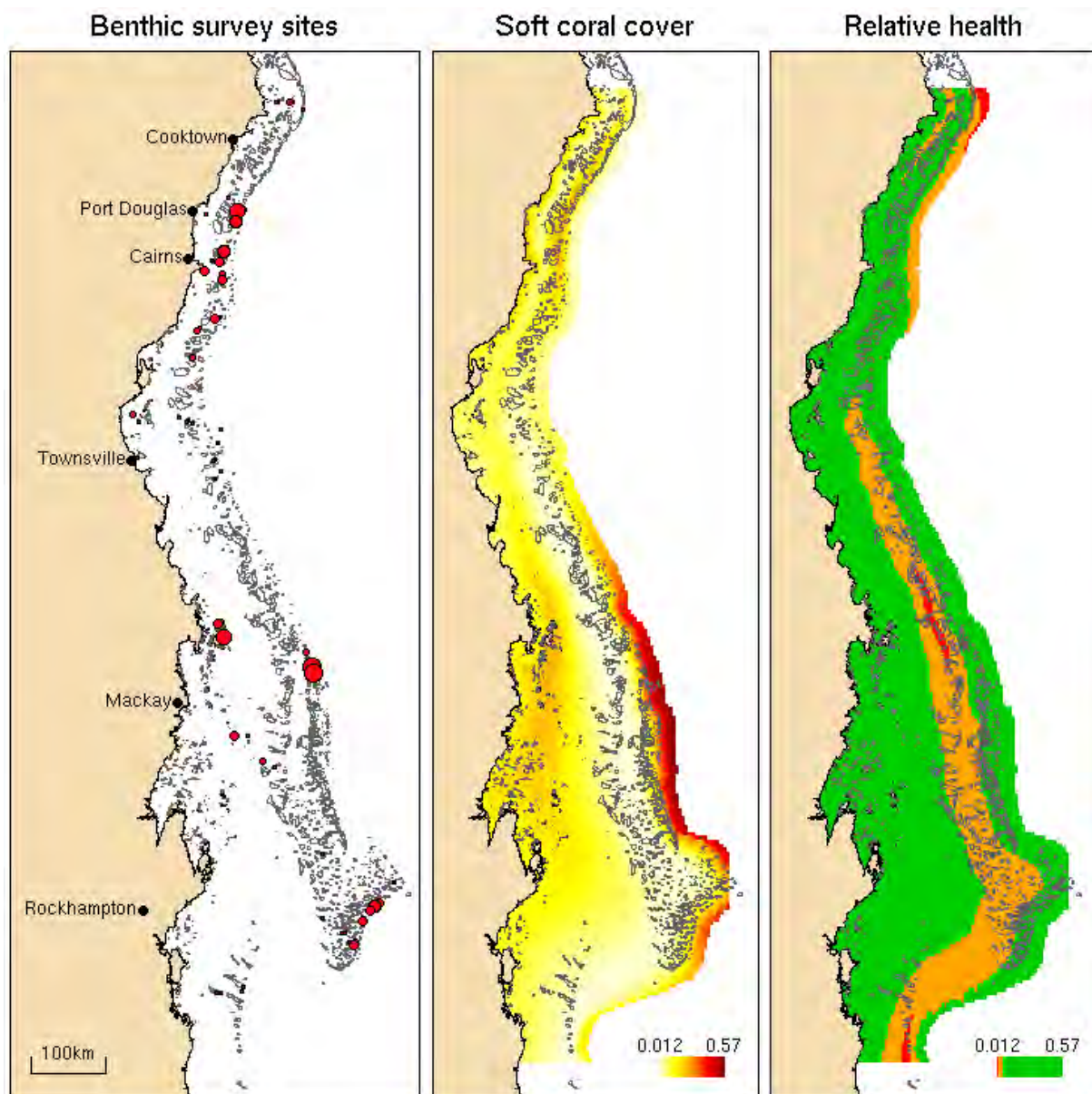


Figure 6.2: The location of reefs surveyed for benthos; spatial patterns of soft coral cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the soft coral cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

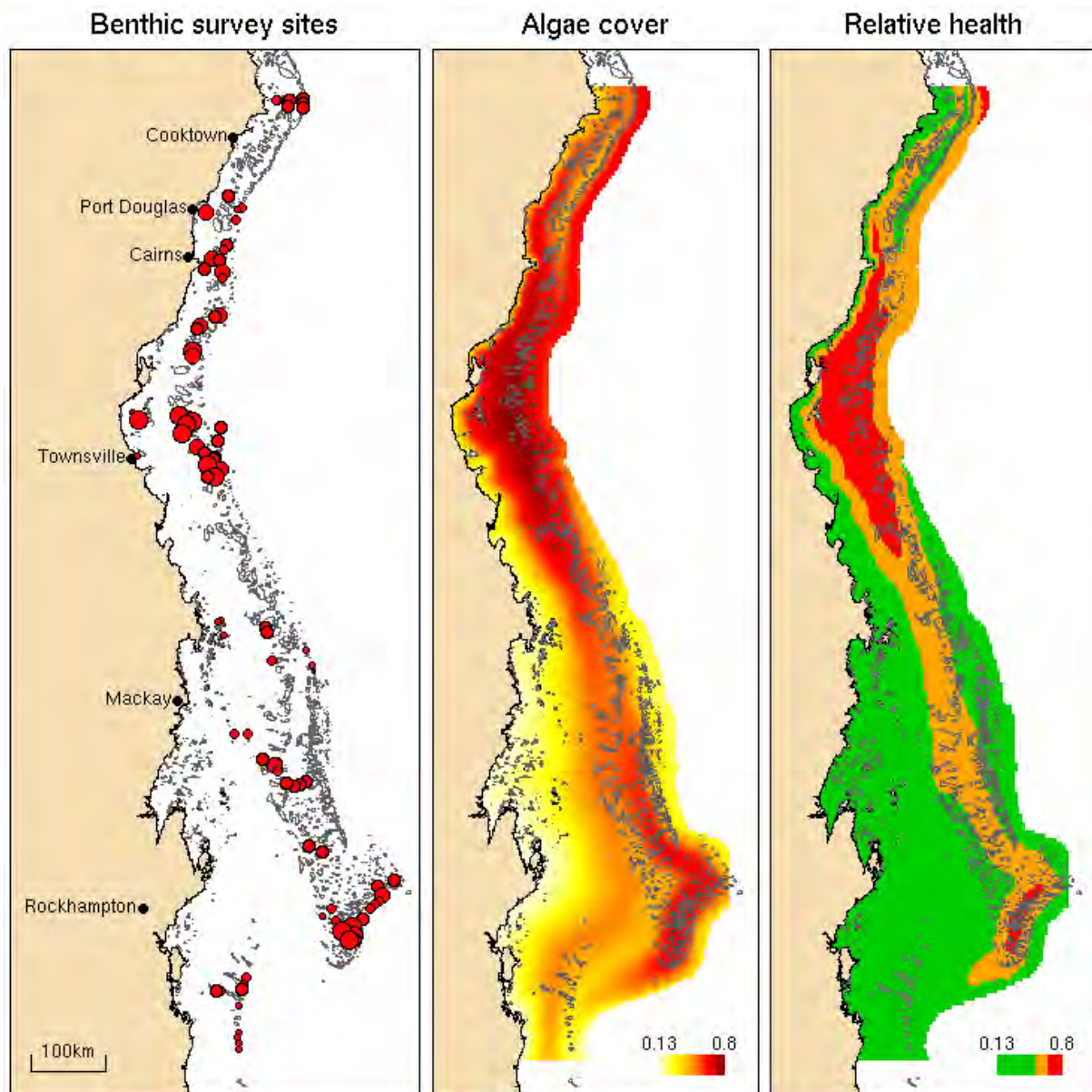


Figure 6.3: The location of reefs surveyed for fishes, spatial patterns of algae cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the algae cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 90th and 60th percentile breaks of the data respectively.

Table 6.2 (continues to page 42): Mean annual values and 95% confidence intervals of benthic genera predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Acropora								
GBR Mean	4.2	3.0, 5.8	7.6	5.4, 10.7	14.9	9.8, 22.2	8.7	6.6, 11.4
Cape York	7.2	5, 10.2	1.8	1.0, 3.4	28.9	24.7, 33.5	6.2	2.7, 13.6
Wet Tropics	1.5	0.9, 2.4	9.6	7.5, 12.4	13.9	10.2, 18.8	7.1	4.2, 11.6
Burdekin	3.5	1.6, 7.4	10.1	5.1, 18.7	8.7	6.0, 12.3	6.9	4.6, 10.4
Mackay-Whitsunday	3.9	1.8, 8.1	7.4	5.8, 9.5	7.8	2.8, 20.0	6.0	3.8, 9.4
Fitzroy			12.2	8.1, 18.1	17.4	5.8, 41.7	14.4	8.5, 23.3
Burnett-Mary					44.6	38.9, 50.5	33.3	29.7, 37.1

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) Goniopora								
GBR Mean	0.5	0.1, 2.0	0.1	0.1, 0.2	0.1	0.1, 0.2	0.0	0.0, 0.0
Cape York	0.1	0.1, 0.2	0.2	0.1, 0.4	0.0	0.0, 0.1	0.1	0.1, 0.2
Wet Tropics	0.1	0.0, 0.2	0.0	0.0, 0.1	0.1	0.0, 0.2	0.1	0.0, 0.1
Burdekin	2.5	0.1, 43.8	0.1	0.0, 0.1	0.2	0.1, 0.2	0.3	0.1, 1.3
Mackay-Whitsunday	2.7	0.5, 14	0.0	0.0, 0.1	0.6	0.4, 0.9	0.4	0.1, 1.5
Fitzroy			0.2	0.1, 0.6	0.2	0.1, 0.8	0.2	0.1, 0.5
Burnett-Mary					0.0	0.0, 0.0	0.0	0.0, 0.0

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(c) Montipora								
GBR Mean	1.9	1.1, 3.4	1.6	1.0, 2.7	1.0	0.7, 1.3	1.4	1.1, 1.9
Cape York	2.1	1.0, 4.5	0.4	0.3, 0.6	1.6	1.4, 1.8	1.0	0.6, 1.7
Wet Tropics	1.1	0.4, 3.3	1.0	0.7, 1.3	0.5	0.5, 0.7	0.9	0.6, 1.4
Burdekin	2.0	0.7, 5.3	0.8	0.5, 1.3	1.4	0.9, 2.3	1.2	0.8, 1.9
Mackay-Whitsunday	2.0	0.3, 11.7	5.5	3.0, 9.8	0.8	0.3, 2.1	2.1	0.9, 4.9
Fitzroy			4.2	2.7, 6.5	1.3	0.6, 2.5	2.6	1.5, 4.3
Burnett-Mary					0.6	0.4, 0.9	0.5	0.4, 0.8

Table 6.2 (continued):

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
(d) Pocillopora	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	0.2	0.1, 0.4	1.3	1.0, 1.8	1.5	1.0, 2.3	0.9	0.6, 1.3
Cape York	2.7	2.2, 3.2	0.6	0.3, 1.2	4.1	3.7, 4.6	1.2	0.6, 2.7
Wet Tropics	0.1	0.0, 0.1	2.5	1.8, 3.4	2.2	1.1, 4.1	0.7	0.2, 2.3
Burdekin	0.1	0.1, 0.2	1.4	0.6, 3.1	3.3	2.6, 4.2	0.9	0.3, 2.3
Mackay-Whitsunday	0.2	0.1, 0.3	1.8	1.3, 2.6	1.6	1.2, 2.2	0.8	0.4, 1.7
Fitzroy			1.3	0.8, 2.0	0.4	0.2, 0.8	0.8	0.5, 1.3
Burnett-Mary					0.7	0.5, 1.0	0.6	0.4, 0.9

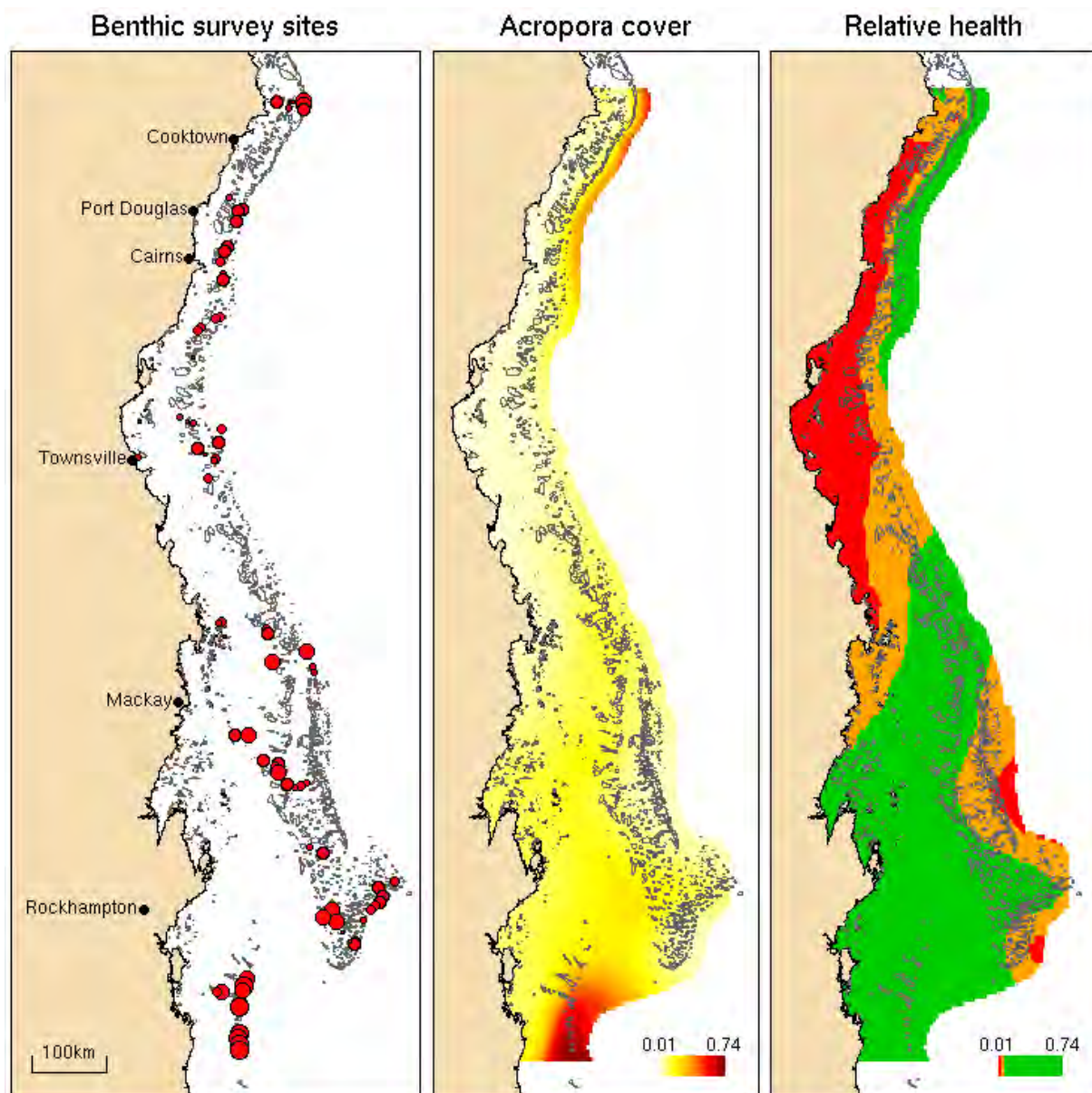


Figure 6.4: The location of reefs surveyed for benthos, spatial patterns of *Acropora* cover and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the *Acropora* coral cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

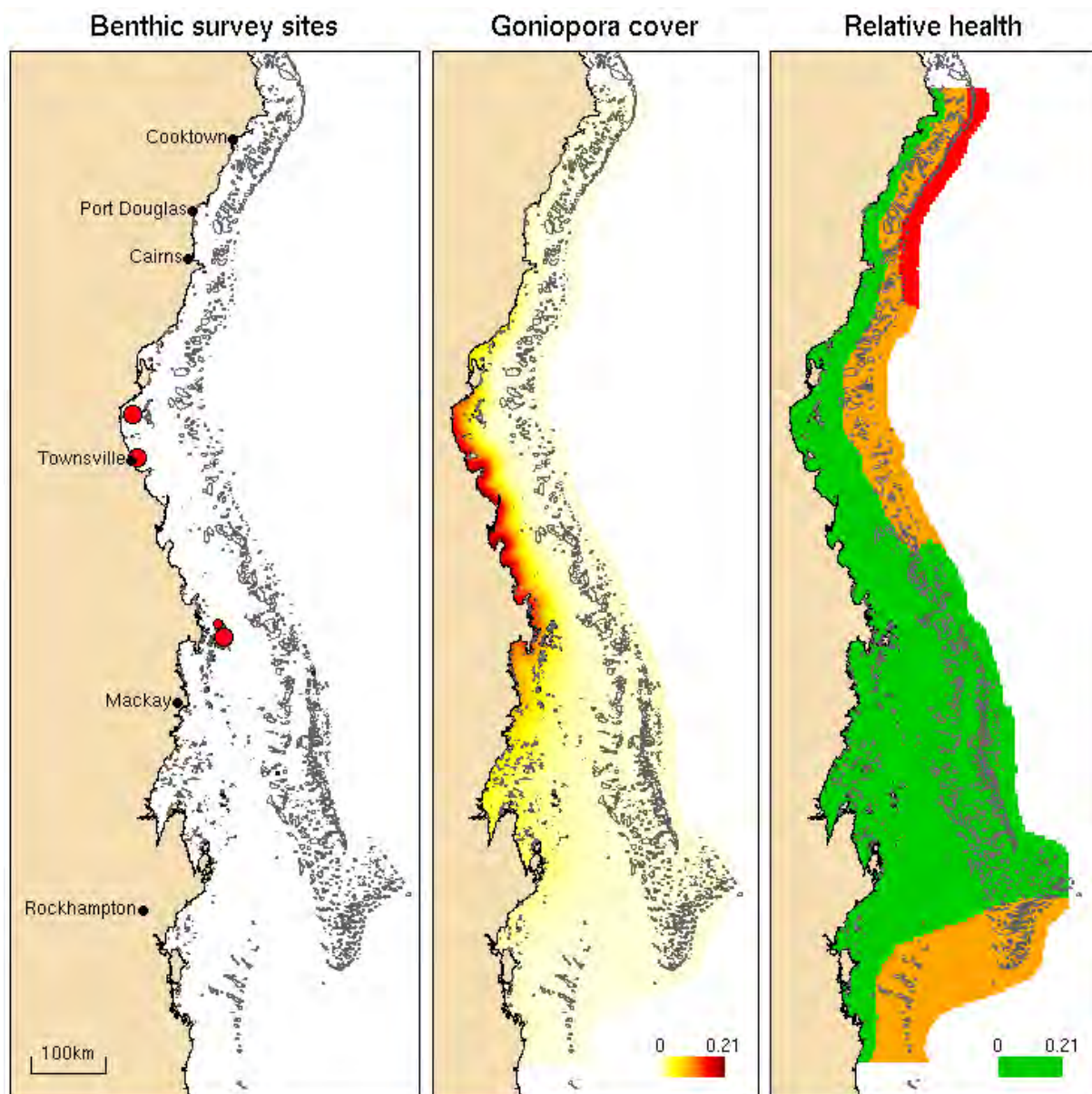


Figure 6.5: The location of reefs surveyed for benthos, spatial patterns of *Goniopora* cover and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the *Goniopora* cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

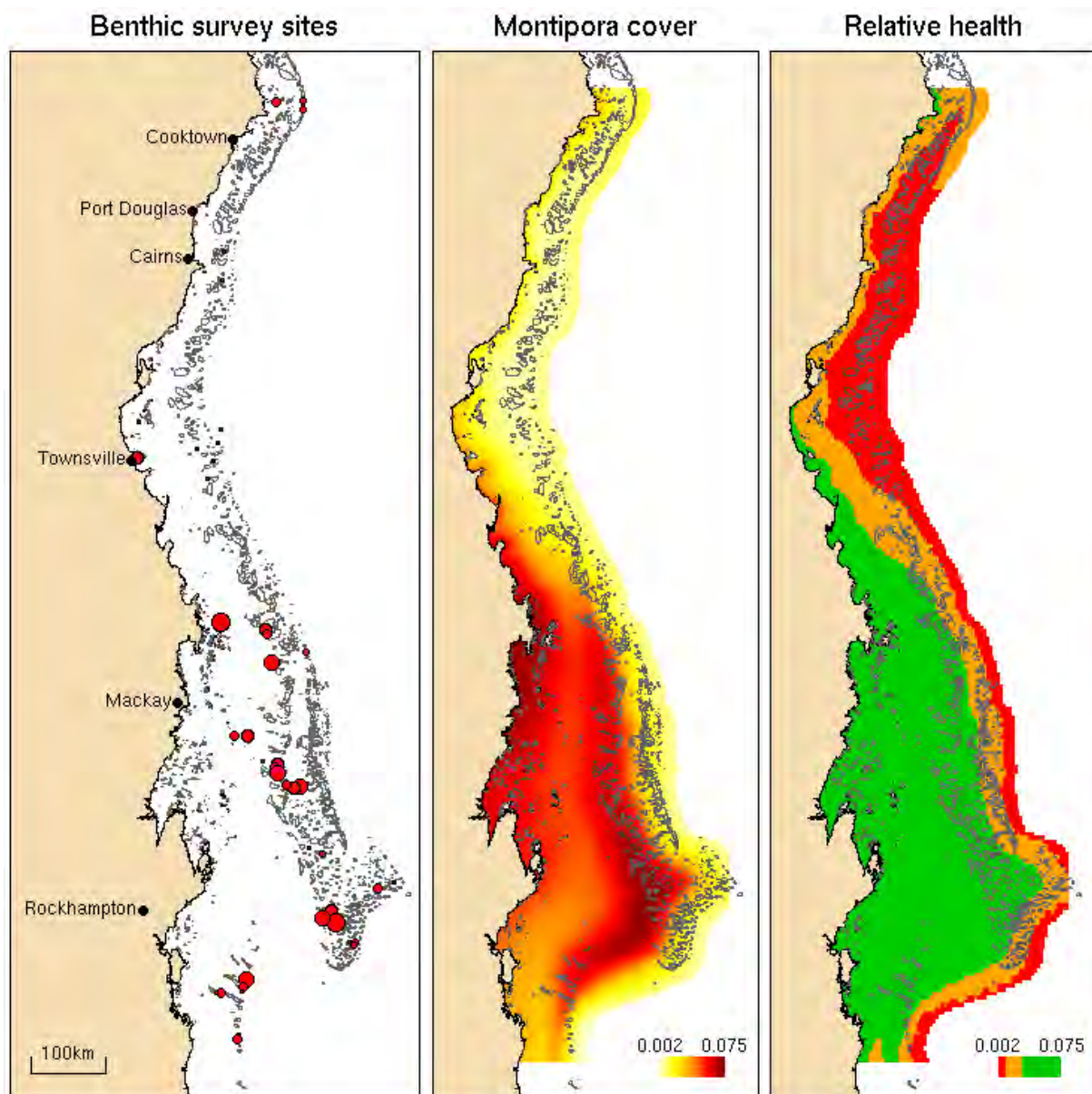


Figure 6.6: The location of reefs surveyed for benthos, spatial patterns of Montipora cover and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the Montipora cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

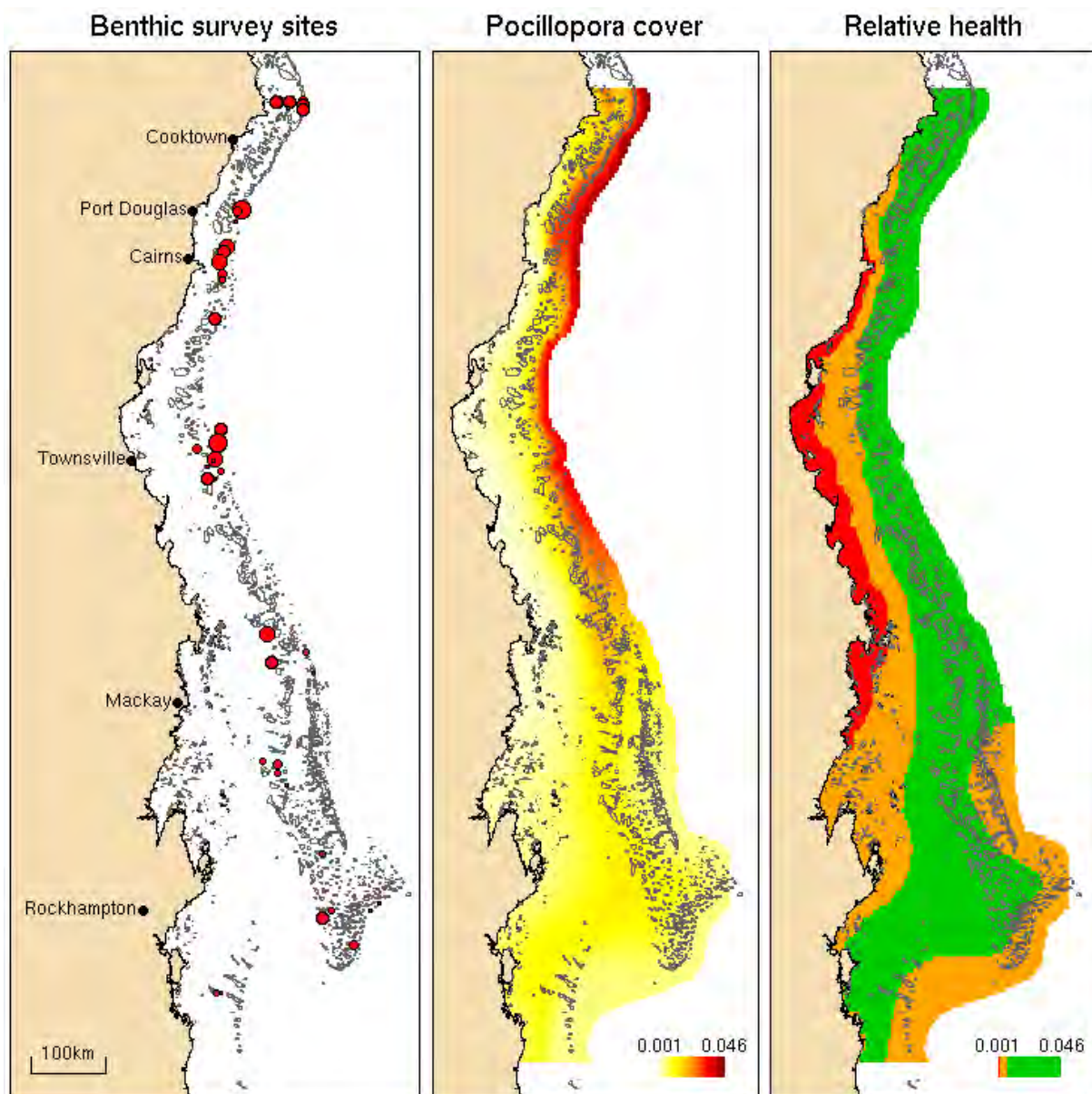


Figure 6.7: The location of reefs surveyed for benthos; spatial patterns of *Pocillopora* cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the *Pocillopora* cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

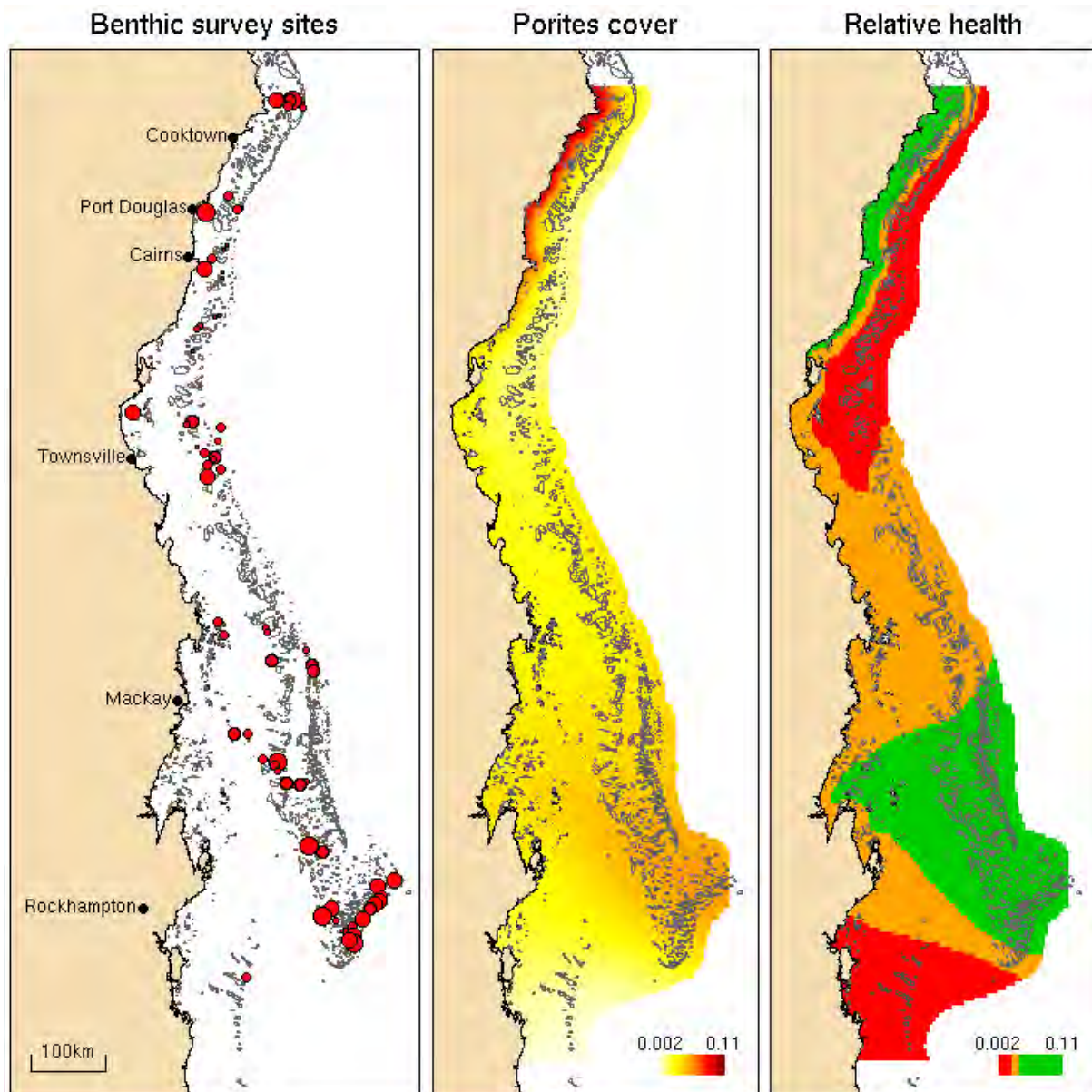


Figure 6.8: The location of reefs surveyed for benthos; spatial patterns of *Porites* cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the *Porites* cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

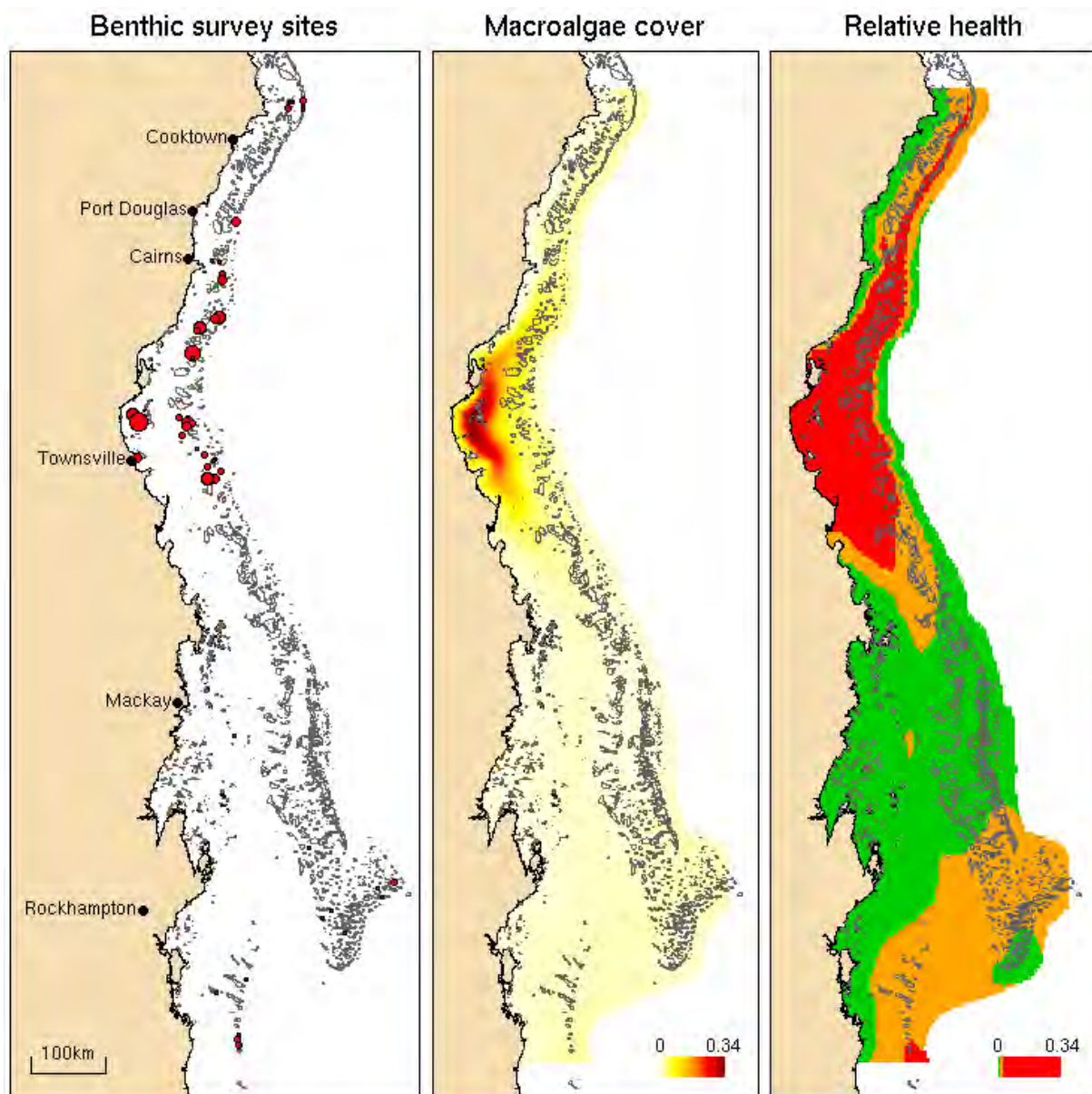


Figure 6.9: The location of reefs surveyed for benthos; spatial patterns of macroalgae cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the Macroalgae cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 90th and 60th percentile breaks of the data respectively.

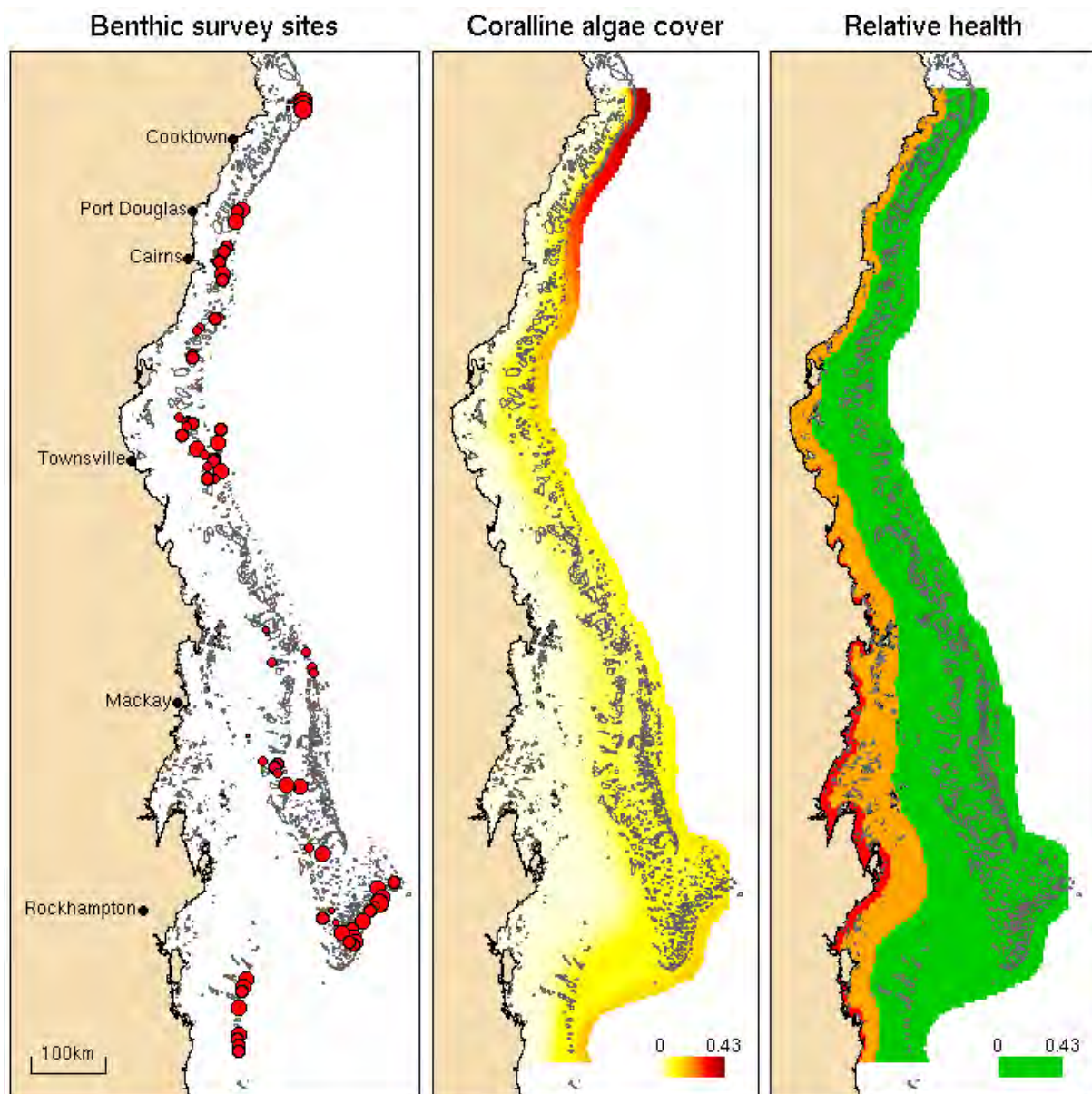


Figure 6.10: The location of reefs surveyed for benthos; spatial patterns of coralline algae cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the Coralline algae cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

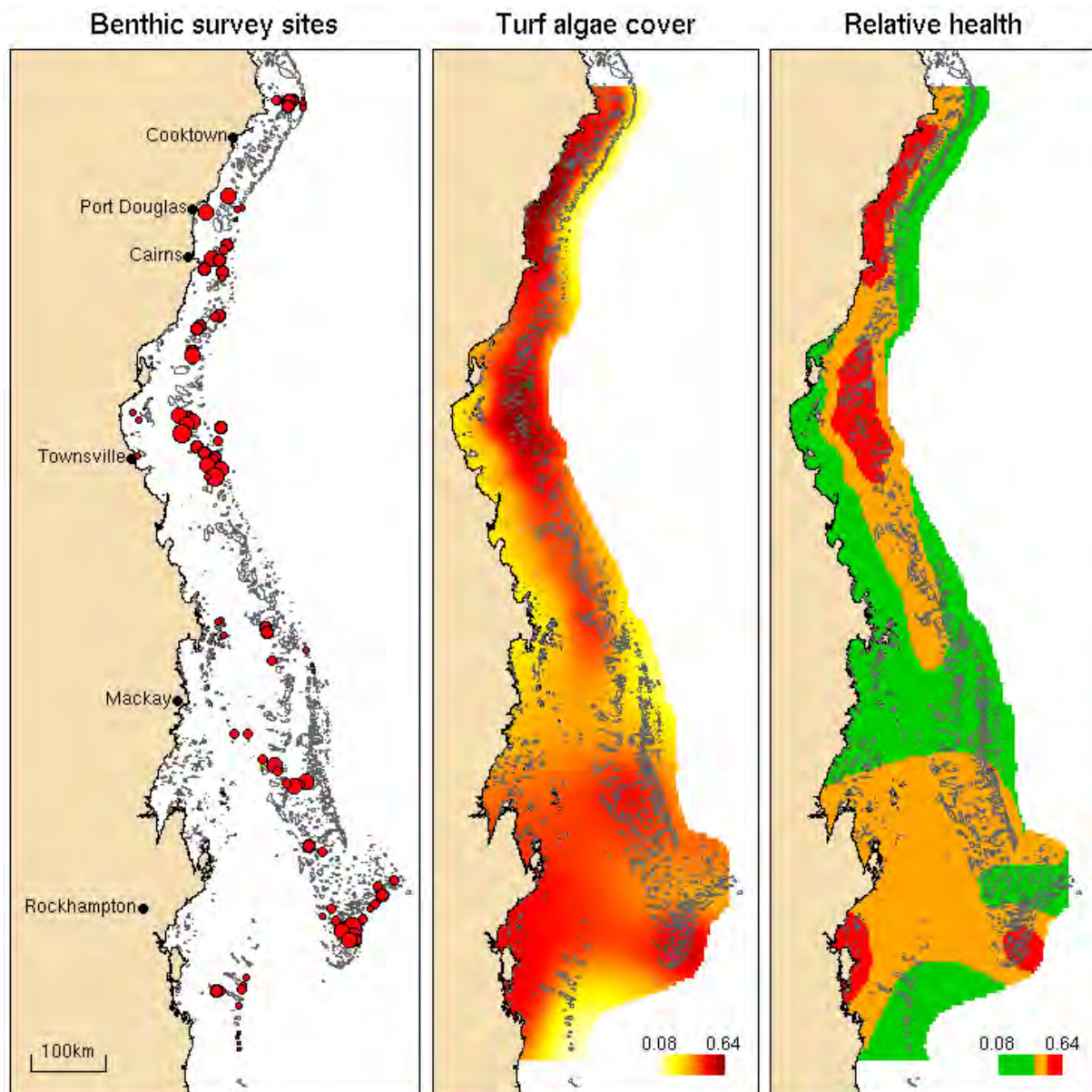


Figure 6.11: The location of reefs surveyed for benthos; spatial patterns of turf algae cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the Turf algae cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 90th and 60th percentile breaks of the data respectively.

Table 6.3: Mean annual values and 95% confidence intervals of hard coral cover and the proportion of reefs affected by COTS predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP manta tow reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
(a) Hard coral	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	18.6	15.1, 22.7	22.4	20.2, 24.7	26.8	24.9, 28.7	23.1	21.7, 24.7
Cape York	28.8	24.1, 34.0	24.2	20.4, 28.6	28.4	26.2, 30.8	26.7	24.4, 29.1
Wet Tropics	12.3	9.1, 16.6	13.4	10.8, 16.5	21.1	18.4, 24.1	15.6	13.5, 17.9
Burdekin	10.2	4.1, 23.2	17.0	14.6, 19.7	23.0	19.7, 26.6	18.1	16.0, 20.5
Mackay-Whitsunday	8.5	4.6, 15.2	28.8	24.4, 33.6	34.1	25.5, 43.8	24.9	20.9, 29.5
Fitzroy	18.6	18.6, 18.6	33.8	27.3, 41.0	30.0	25.6, 34.7	32.2	27.1, 37.8
Burnett-Mary					36.6	34.4, 38.9	36.6	34.4, 38.9

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
(b) COTS affected	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	0.1	0.0, 0.2	0.5	0.3, 0.7	0.1	0.0, 0.1	0.2	0.1, 0.3
Cape York	0.3	0.1, 0.6	0.4	0.1, 0.8	0.0	0.0, 0.2	0.2	0.1, 0.4
Wet Tropics			0.8	0.3, 1.0	0.1	0.0, 0.7	0.3	0.1, 0.7
Burdekin	1.0	0.0, 1.0	1.0	0.9, 1.0	0.1	0.0, 1.0	0.9	0.7, 1.0
Mackay-Whitsunday			0.0	0.0, 0.2			0.0	0.0, 0.0
Fitzroy			0.1	0.0, 0.6	0.0	0.0, 0.0	0.2	0.1, 0.3
Burnett-Mary								

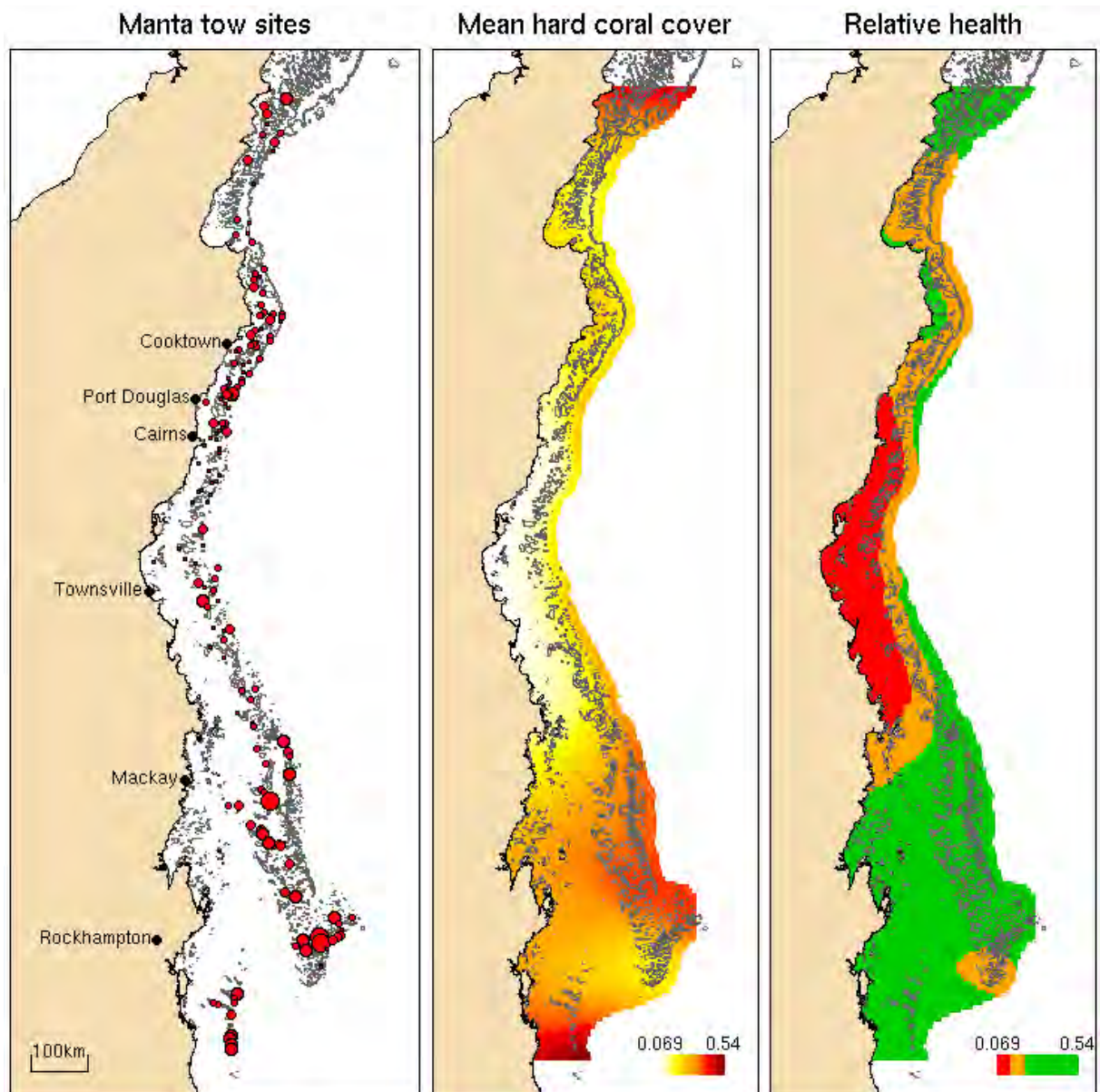


Figure 6.12: The location of reefs surveyed using manta tow; spatial patterns of live hard coral cover; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the live hard coral cover at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

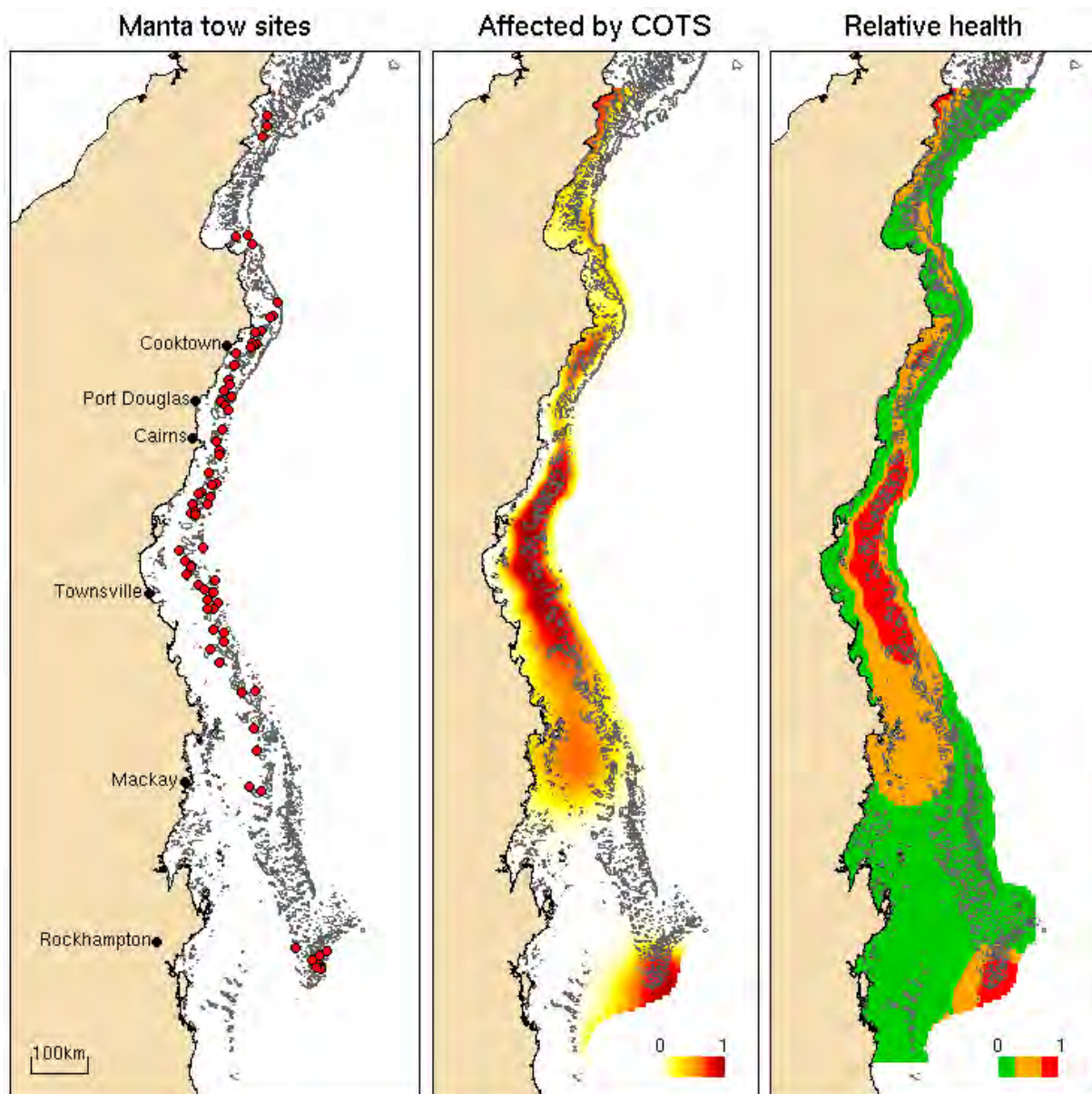


Figure 6.13: The location of reefs surveyed using manta tow; spatial patterns of the proportion of reefs affected by COTS; and relative health regions across the GBR averaged over 2005-2007. Symbols in the left panel represent reefs affected by COTS. The red, orange and green in the right panel indicate high, moderate and low affected reefs regions formed by the 90th and 60th percentile breaks of the data respectively.

Table 6.4 (continues to page 55): Mean annual values and 95% confidence intervals of fish abundance and diversity, predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

(a) Abundance	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	1657.4	1210.5, 2269.2	2561.3	2204.7, 2975.6	1711.9	1561.4, 1876.8	1980.9	1767.8, 2219.8
Cape York	2209.8	1154.9, 4228.5	1816.1	1515.7, 2176.0	2096.5	1981.3, 2218.5	2024.2	1645.6, 2490.0
Wet Tropics	1391.2	1261.5, 1534.3	2088.9	1910.1, 2284.4	1354.9	1222.0, 1502.4	1569.4	1340.8, 1837.1
Burdekin	1101.0	453.7, 2671.5	2722.7	2538.8, 2919.8	1973.4	1802.9, 2160.1	1830.7	1275.9, 2627.0
Mackay-Whitsunday	2024.0	1415.4, 2894.2	3826.7	3361.8, 4355.8	1552.6	1414.3, 1704.4	2270.1	1720.1, 2996.1
Fitzroy			2885.8	2178.6, 3822.5	1738.7	1439.5, 2100.3	2312.4	1824.5, 2930.8
Burnett-Mary					1686.8	1482.7, 1919.0	1685.3	1482.2, 1916.1

(b) Richness	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	48.6	36.2, 61.0	70.8	66.0, 75.6	69.4	65.1, 73.7	64.7	60.0, 69.4
Cape York	64.2	36.4, 91.9	81.7	72.9, 90.5	78.6	75.8, 81.5	75.5	65.7, 85.4
Wet Tropics	62.4	48.6, 76.2	75.2	73.4, 77.0	69.8	63.7, 76.0	69.1	63.2, 75.1
Burdekin	24.5	9.3, 39.7	76.7	74.0, 79.3	71.8	68.2, 75.4	57.7	41.2, 74.2
Mackay-Whitsunday	43.3	40.3, 46.3	59.6	53.3, 65.9	72.6	59.7, 85.5	58.5	49.3, 67.7
Fitzroy			62.6	57.7, 67.5	65.8	63.7, 68.0	64.0	61.1, 67.0
Burnett-Mary					53.4	42.0, 64.9	53.4	42.0, 64.9

(c) Shannon diversity	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	13.9	9.7, 18.2	17.6	13.9, 21.2	21.4	18.8, 24	18.1	15.9, 20.2
Cape York	14.1	8.9, 19.2	28.2	21.4, 35.0	27.7	25.6, 29.9	23.8	18.7, 28.9
Wet Tropics	23.2	16.9, 29.5	20.1	16.4, 23.7	25.0	23.2, 26.9	22.8	20.0, 25.6
Burdekin	5.8	0.8, 10.8	18.1	14.3, 21.9	23.0	16.0, 30.0	15.7	10.0, 21.3
Mackay-Whitsunday	12.6	10.1, 15.1	10.5	7.0, 14.0	20.0	14.8, 25.2	14.4	10.9, 17.8
Fitzroy			11.4	8.4, 14.5	17.4	15.7, 19.2	14.1	11.5, 16.8
Burnett-Mary					13.8	10.9, 16.6	13.8	10.9, 16.6

Table 6.4 (continued):

(d) Simpson diversity	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	8.0	5.5, 10.5	9.1	6.8, 11.3	11.3	9.6, 13	9.6	8.4, 10.9
Cape York	6.8	5.2, 8.4	15.6	10.4, 20.8	14.6	12.5, 16.7	12.7	9.4, 15.9
Wet Tropics	13.8	9.5, 18	9.9	8.0, 11.8	13.9	12.2, 15.5	12.5	10.5, 14.6
Burdekin	3.6	0.4, 6.9	9.0	6.4, 11.5	13.4	8.2, 18.7	8.7	5.3, 12.1
Mackay-Whitsunday	7.7	6.0, 9.5	5.5	3.7, 7.2	9.6	6.5, 12.7	7.6	5.9, 9.3
Fitzroy			5.5	4.1, 7.0	8.5	6.6, 10.3	6.8	5.4, 8.3
Burnett-Mary					7.6	6.4, 8.7	7.6	6.4, 8.7

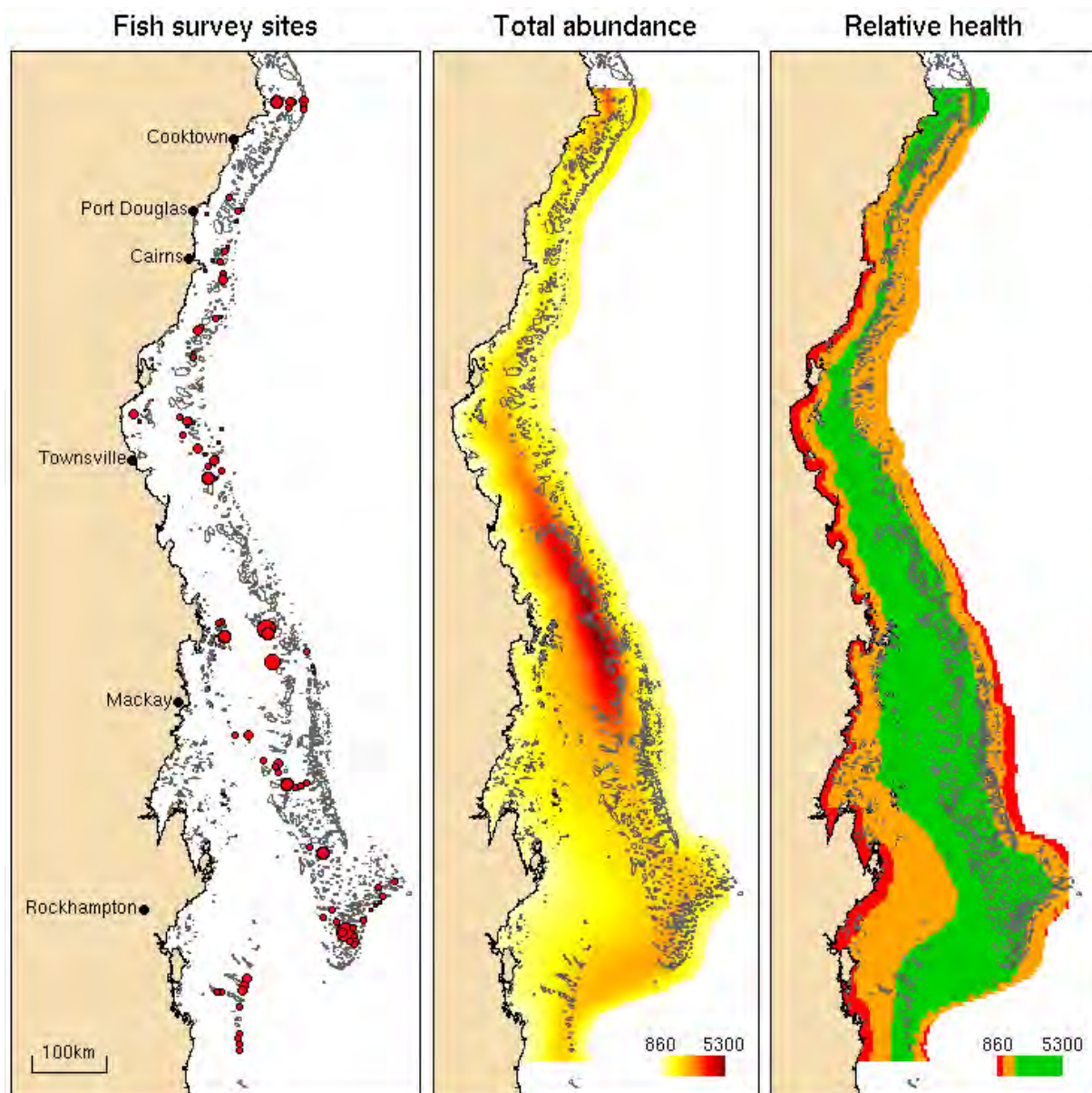


Figure 6.14: The location of reefs surveyed for fishes; spatial patterns of total fish abundance; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the abundance of fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

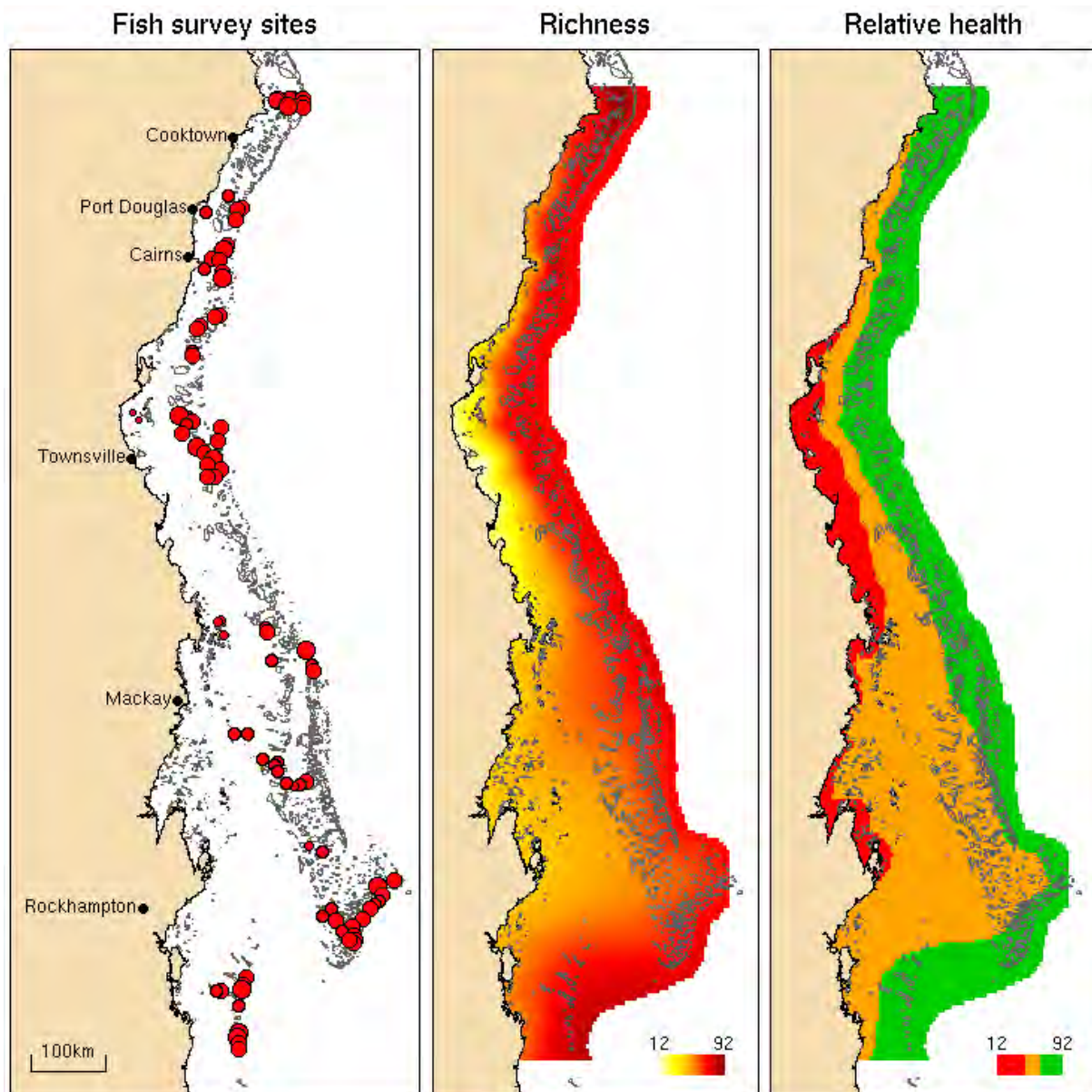


Figure 6.15: The location of reefs surveyed for fishes; spatial patterns of fish richness; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the fish richness at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

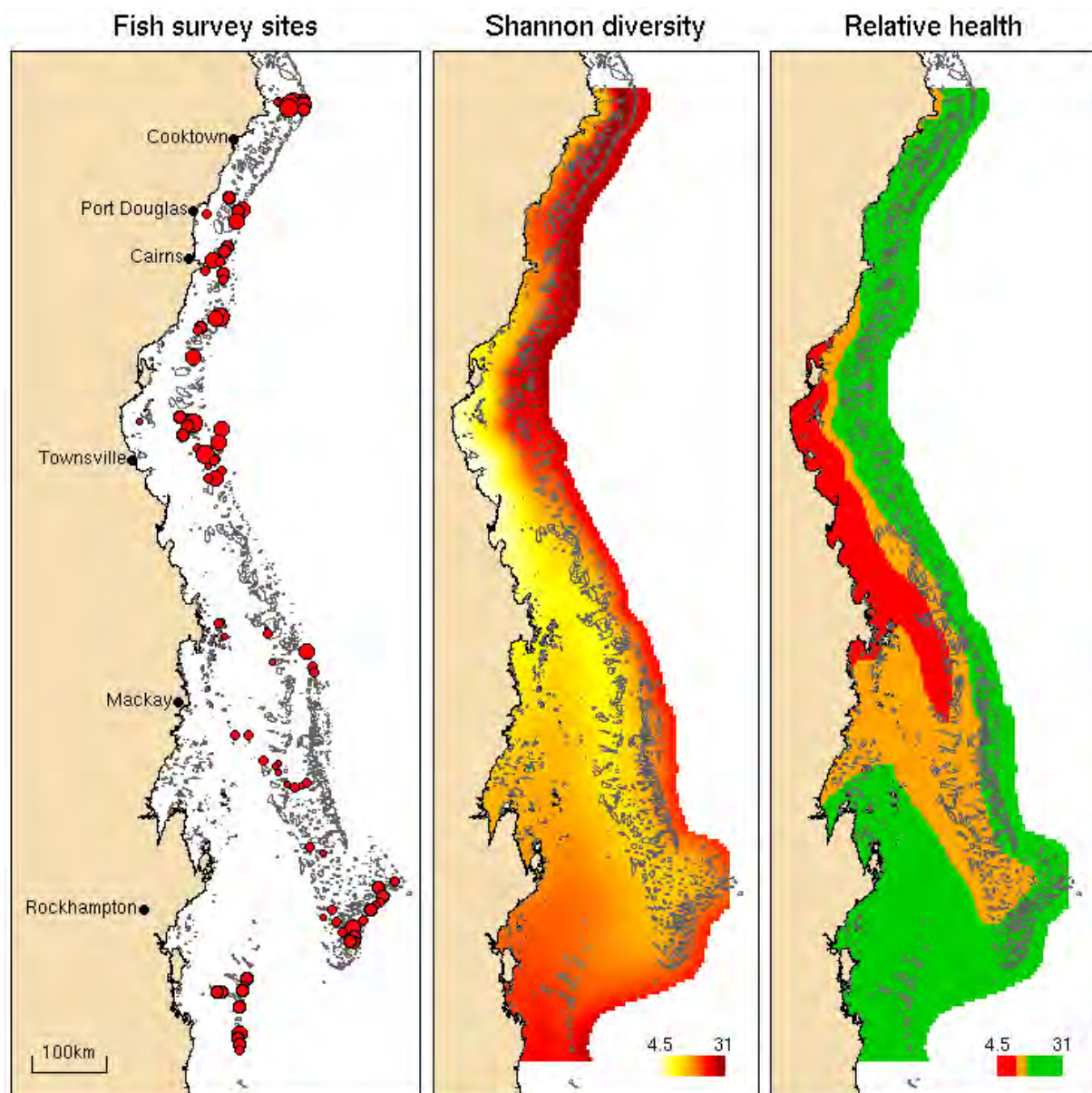


Figure 6.16: The location of reefs surveyed for fishes; spatial patterns of fish diversity (Shannon index); and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the diversity of fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

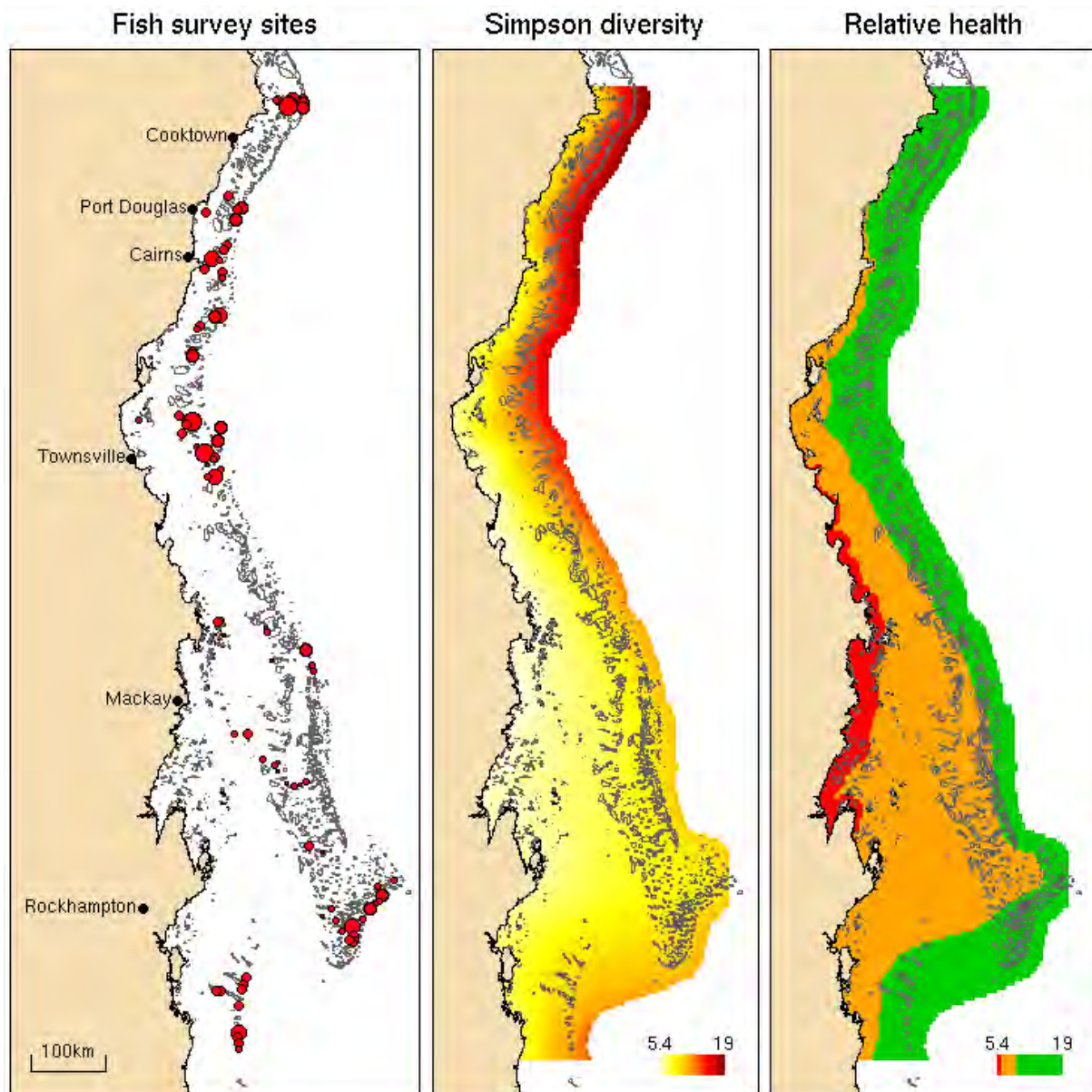


Figure 6.17: The location of reefs surveyed for fishes; spatial patterns of fish diversity (Simpson index); and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the diversity of fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

Table 6.5 (continues to page 61): Mean annual values and 95% confidence intervals of fish trophic group abundance predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

(a) Herbivores	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	235.4	159.7, 346.8	510.6	457.3, 569.9	528.5	465.1, 600.5	431.5	375.4, 496.1
Cape York	351.2	209.8, 587.9	395.7	336.4, 465.3	619.1	588.9, 650.9	444.1	355.4, 555.0
Wet Tropics	346.4	218.2, 550.0	612.0	498.2, 751.9	590.6	555.5, 627.8	502.7	395.9, 638.1
Burdekin	151.5	49.3, 465.7	548.8	476.6, 632.0	652.7	608.6, 700.1	382.6	220.9, 662.5
Mackay-Whitsunday	163.5	119.1, 224.6	484.8	443.8, 529.7	501.7	444.7, 566.1	339.4	236.7, 486.7
Fitzroy			542.5	434.4, 677.6	457.1	381.5, 547.6	511.9	437.8, 598.6
Burnett-Mary					294.4	191.6, 452.4	294.4	191.6, 452.4

(b) Planktivores	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	537.2	356.8, 808.8	1191.0	874.8, 1621.4	672.3	540.5, 836.3	789.4	645.8, 965.0
Cape York	700.3	604.4, 811.5	416.2	282.0, 614.4	979.1	891.8, 1074.8	631.7	474.0, 841.8
Wet Tropics	276.7	233.3, 328.2	1057.0	685.6, 1629.7	450.5	341.0, 595.2	511.6	330.6, 791.7
Burdekin	694.1	224.5, 2146.4	1504.7	1310.9, 1727.2	960.3	698.3, 1320.7	993.8	661.9, 1492.3
Mackay-Whitsunday	571.4	237.7, 1373.6	2670.9	2224.1, 3207.5	628.6	452.9, 872.6	977.9	576.7, 1658.4
Fitzroy			1554.2	1058.9, 2281	635.1	472.1, 854.5	1043.9	707.4, 1540.6
Burnett-Mary					185.4	122.4, 280.9	185.4	122.4, 280.9

(c) Predators	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	86.1	53.6, 138.3	94.4	83.9, 106.3	70.3	59.5, 83.2	83.1	72.6, 95.1
Cape York	100.8	55.6, 182.8	115.0	102.9, 128.6	125.2	94.0, 166.8	113.6	93.0, 138.8
Wet Tropics	164.1	146.6, 183.7	82.9	72.5, 94.7	72.2	64.0, 81.5	98.4	76.9, 126.0
Burdekin	25.2	2.0, 319.1	66.3	57.6, 76.2	50.4	38.5, 66.1	45.6	22.0, 94.5
Mackay-Whitsunday	79.2	65.9, 95.3	110.8	91.3, 134.6	55.0	47.3, 64.1	79.0	63.3, 98.6
Fitzroy			98.4	81.0, 119.6	72.1	58.8, 88.5	85.9	71.6, 103.0
Burnett-Mary					49.5	43.8, 55.9	49.5	43.8, 55.9

Table 6.5 (continued):

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
(d) Benthic feeders	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	60.5	38.3, 95.6	97.2	88.5, 106.7	140.1	117.6, 166.9	101.8	88.1, 117.8
Cape York	79.7	30.8, 206.1	102.0	89.4, 116.4	189.2	177.0, 202.2	116.0	82.2, 163.9
Wet Tropics	64.9	59.6, 70.6	87.9	63.4, 122.0	121.4	92.5, 159.3	90.9	73.1, 112.9
Burdekin	22.9	4.0, 131.4	89.7	73.0, 110.2	87.4	68.9, 110.9	58.7	31.2, 110.4
Mackay-Whitsunday	76.5	66.8, 87.6	102.3	87.2, 119.9	113.9	79.1, 164.0	96.9	80.7, 116.3
Fitzroy			95.5	77.4, 117.8	157.5	108.1, 229.5	124.2	96.3, 160.3
Burnett-Mary					255.9	204.2, 320.6	255.9	204.2, 320.6

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
(e) Benthic/plankton feeders	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	581.0	338.9, 996.1	519.6	385.7, 699.9	258.9	189.3, 354.0	412.3	326.9, 520.2
Cape York	945.5	336.7, 2655	773.1	557.2, 1072.8	159.5	128.2, 198.5	526.8	295.3, 940.0
Wet Tropics	519.4	437.1, 617.1	162.2	127.5, 206.3	146.4	121.2, 177.0	239.6	161.1, 356.4
Burdekin	143.0	37.7, 542.3	590.4	496.1, 702.5	170.8	119.2, 245.0	254.4	142.9, 452.9
Mackay-Whitsunday	1125.2	1023.9, 1236.4	641.1	556.9, 737.9	234.9	147.2, 374.9	551.5	352.2, 863.5
Fitzroy			558.0	314.3, 990.5	402.6	216.4, 749.0	485.3	318.1, 740.4
Burnett-Mary					686.1	434.3, 1083.8	686.1	434.3, 1083.8

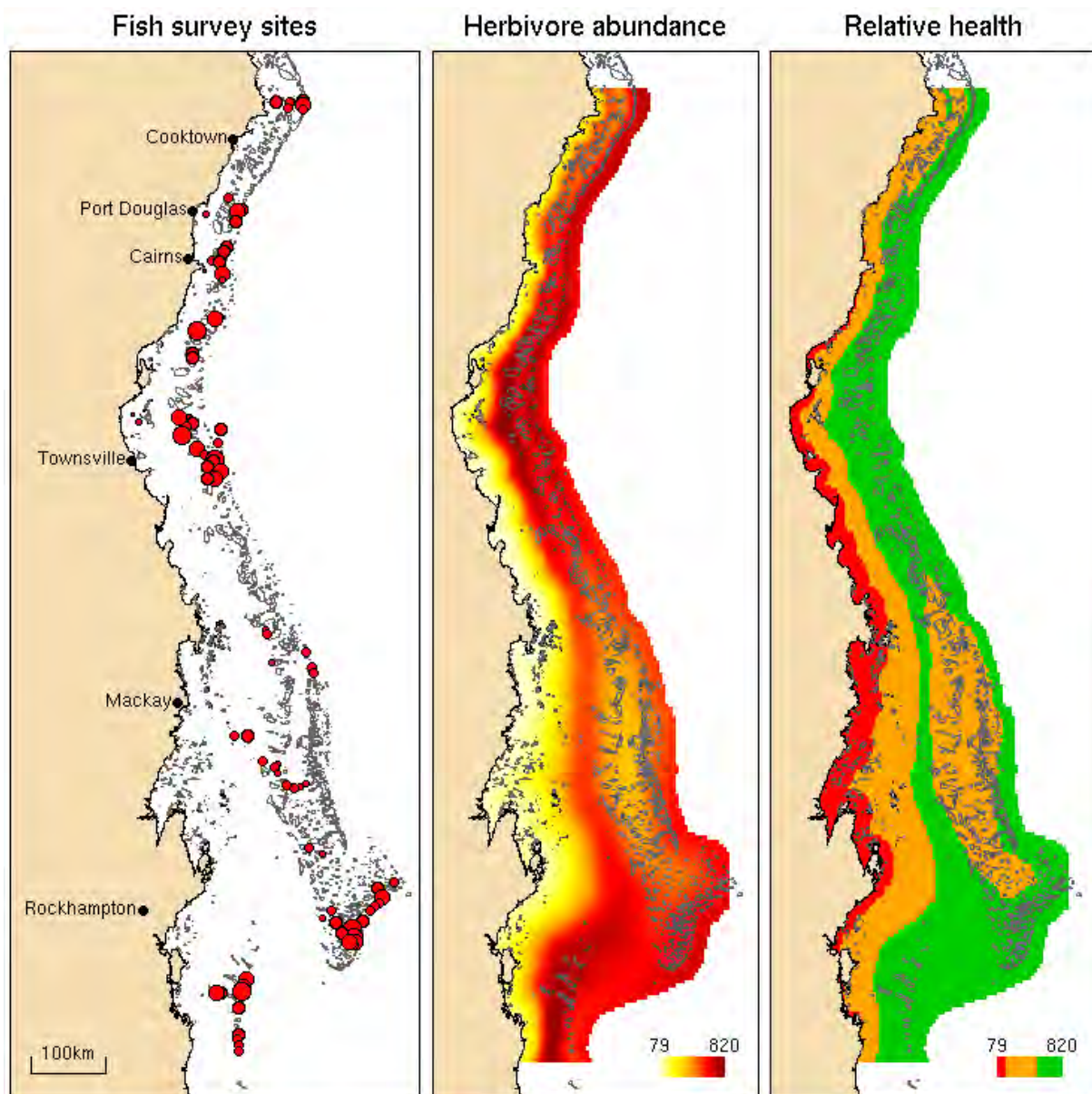


Figure 6.18: The location of reefs surveyed for fishes; spatial patterns of herbivorous fish abundance; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the abundance of herbivorous fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

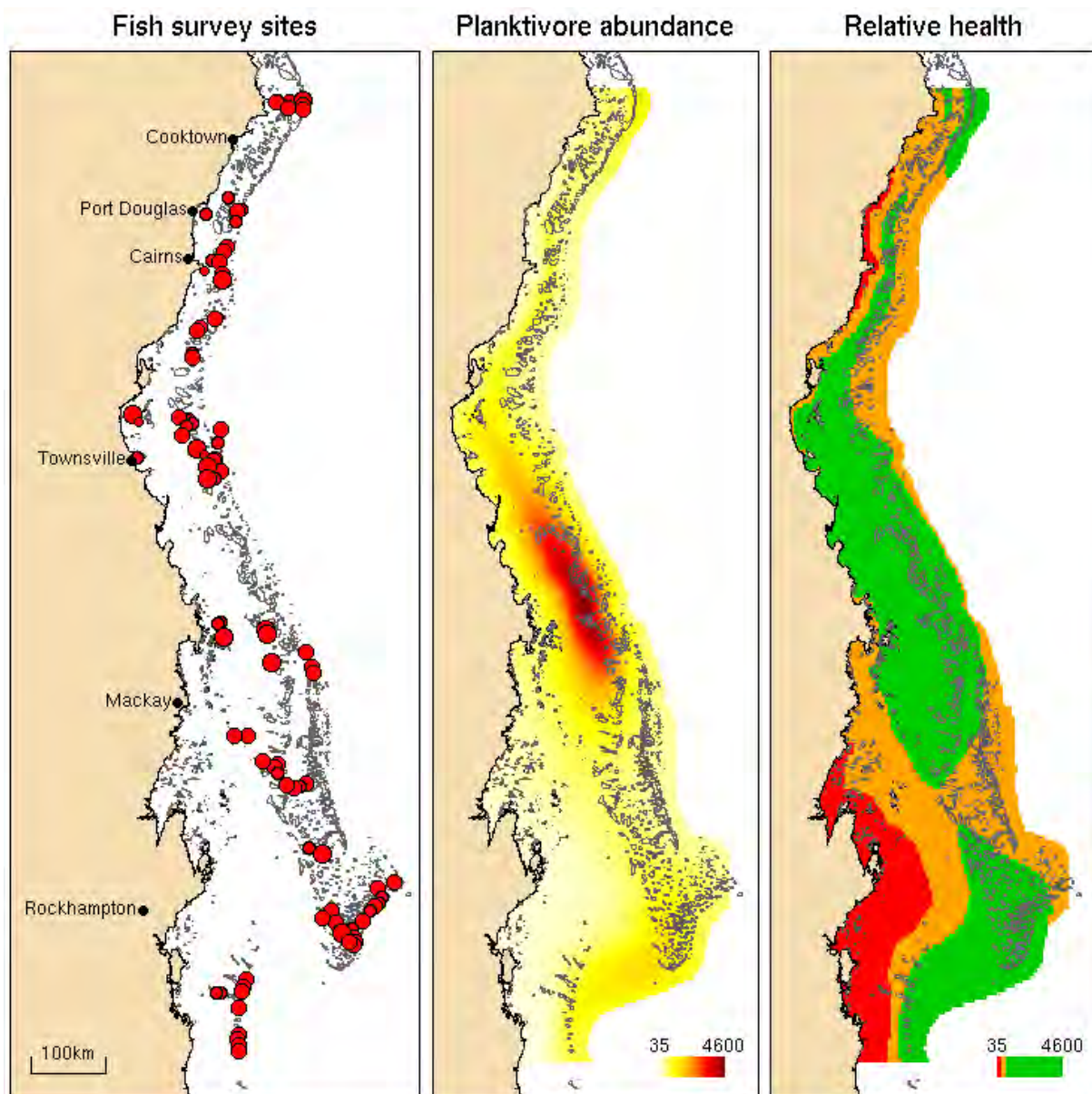


Figure 6.19: The location of reefs surveyed for fishes; spatial patterns of planktivorous fish abundance; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the abundance of planktivorous fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

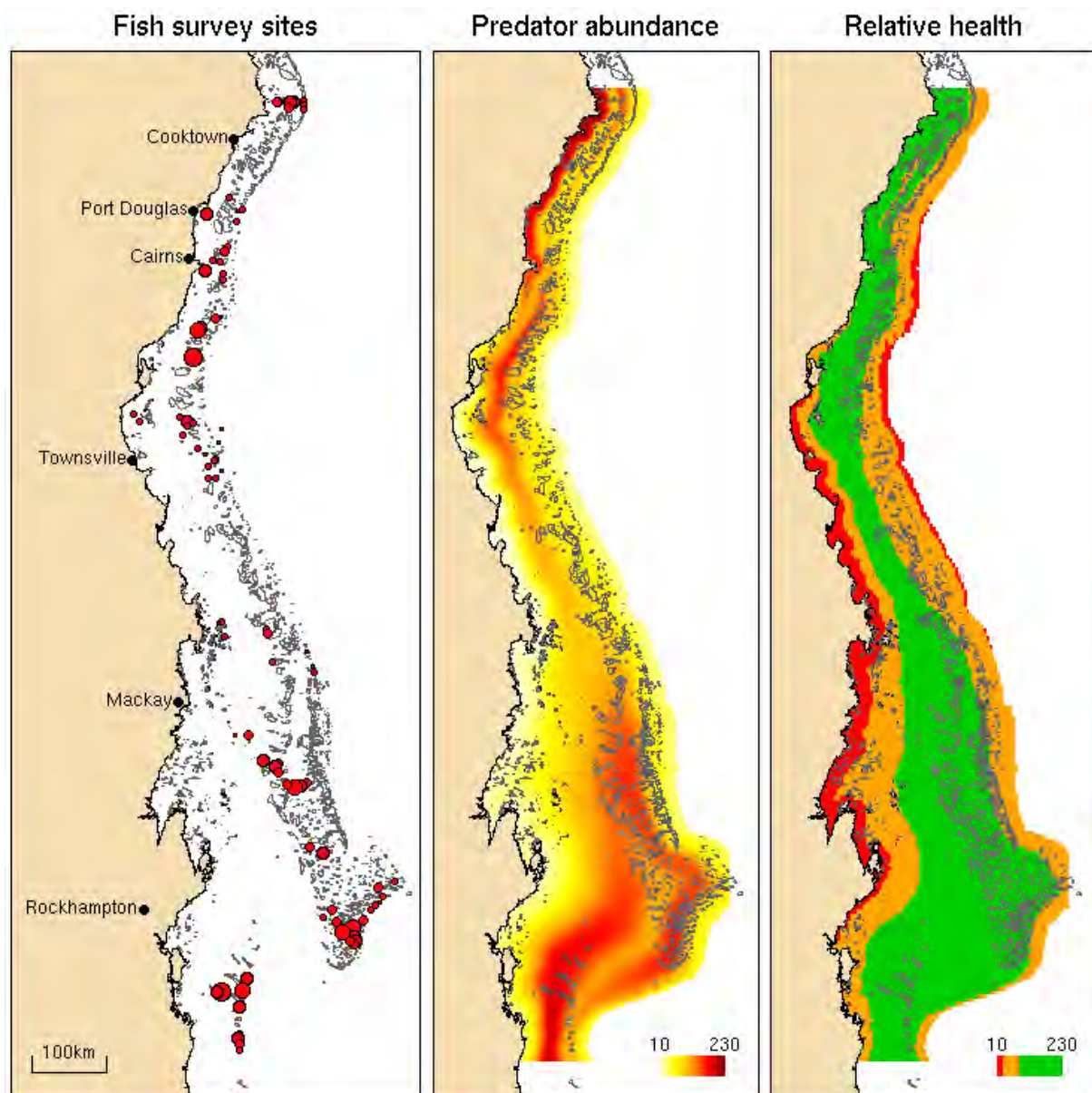


Figure 6.20: The location of reefs surveyed for fishes; spatial patterns of predatory fish abundance; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the abundance of predatory fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

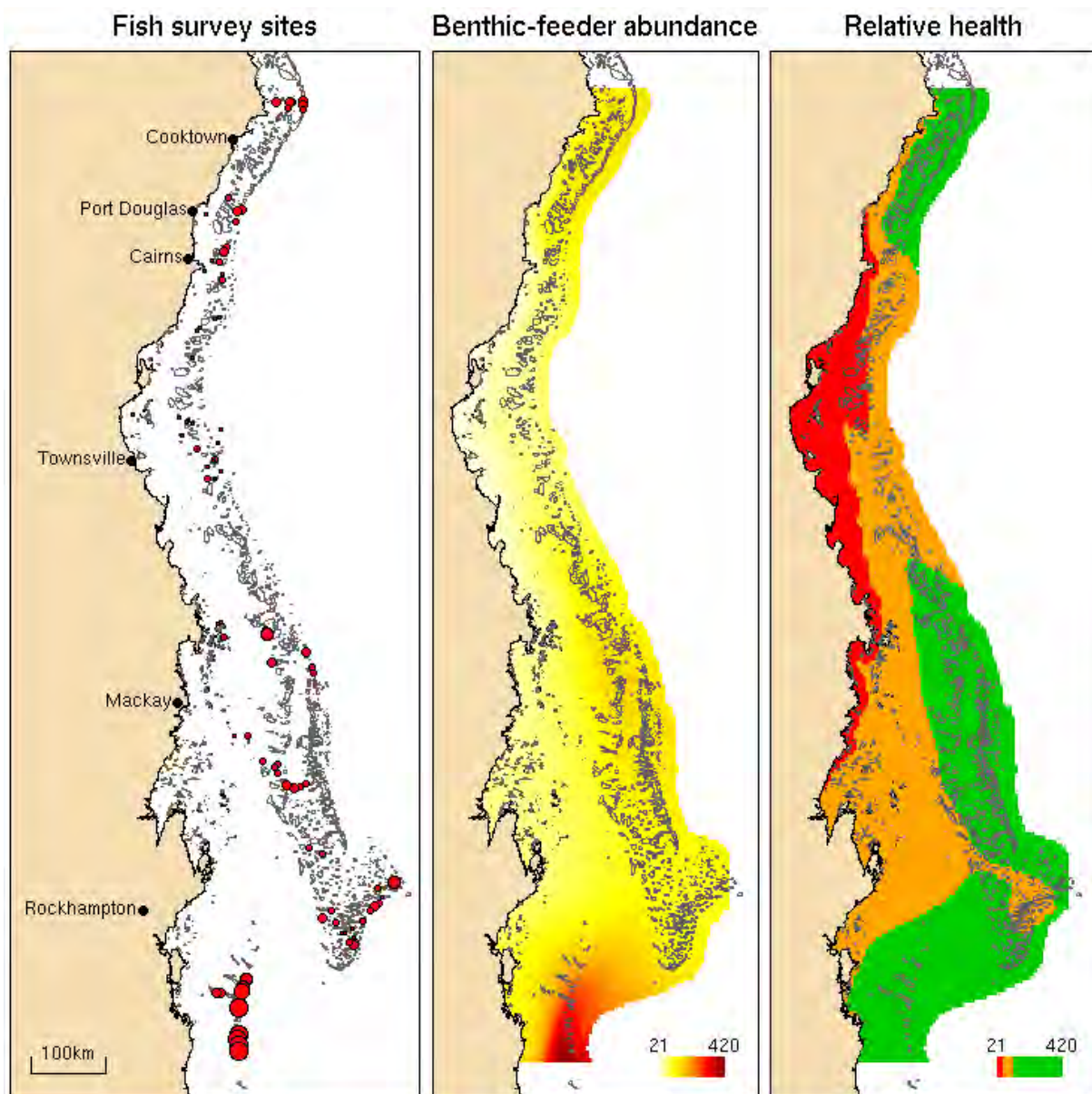


Figure 6.21: The location of reefs surveyed for fishes; spatial patterns of benthic feeder fish abundance; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the abundance of benthic feeder fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

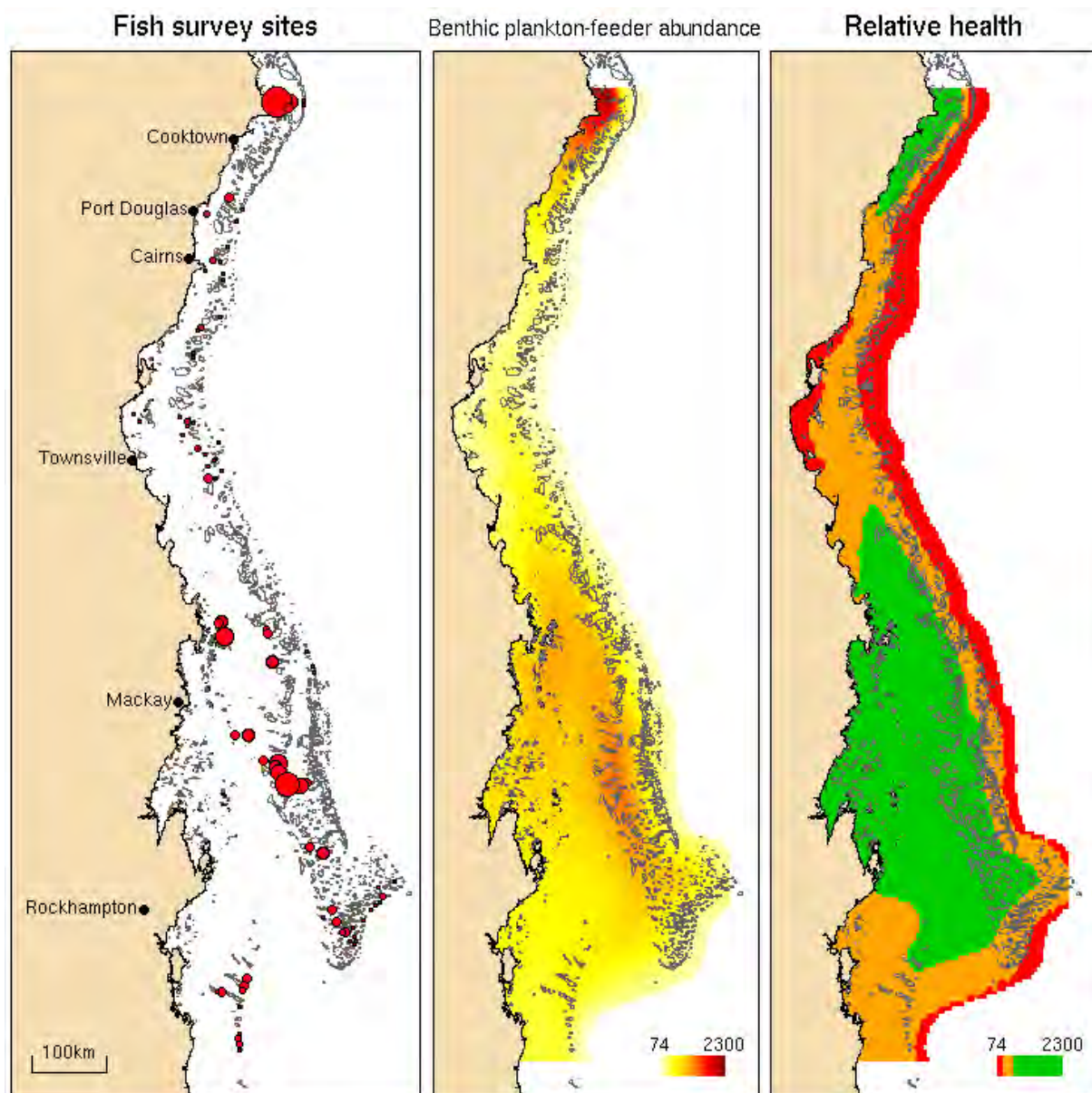


Figure 6.22: The location of reefs surveyed for fishes; spatial patterns of benthic/plankton feeder fish abundance; and relative health regions across the GBR averaged over 2005-2007. Symbol sizes in the left panel are proportional to the abundance of benthic/plankton feeder fishes at each reef. The red, orange and green in the right panel indicate poor, moderate and good relative health regions formed by the 10th and 40th percentile breaks of the data respectively.

7. Temporal trends of reef biota on the Great Barrier Reef

Summary

This section contains graphical presentations of temporal trends of reef health indicator variables examined. These temporal trends were estimated using generalised additive mixed models (GAMM) with smooth trends over years of up to four degrees of freedom. Plots for each variable are presented in a spatial grid arranged from north to south according to their adjacent NRM region and across the shelf from inner to outer. Plots are presented on the same y-scale to facilitate regional comparisons. Solid lines represent fitted trends, dashed lines are approximate 95% confidence intervals. The GBR average for each variable is shown in each plot by a horizontal dashed line.

Benthic cover variables

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Benthic genera cover variables

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Broadscale surveys of COTS density and coral cover variables

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Fish abundance and diversity

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Fish trophic group abundance

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Table 7.1: Mean percent linear change values and 95% confidence intervals of benthic groups predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Hard coral								
GBR Mean	-1.8	-3.5, 0.0	-1.8	-3.7, 0.1	7.0	5.0, 9.0	1.7	0.5, 2.8
Cape York	4.1	2.9, 5.3	1.2	-0.3, 2.8	7.2	2.0, 12.6	4.3	2.4, 6.3
Wet Tropics	-12.7	-17, -8.3	-1.6	-4.8, 1.8	2.9	1.0, 4.7	-2.7	-4.9, -0.6
Burdekin	-4.6	-8.6, -0.5	-12.3	-17.7, -6.6	-2.4	-5.3, 0.6	-6.5	-8.9, -3.9
Mackay-Whitsunday	1.9	1.0, 2.8	2.7	-1.8, 7.5	0.7	-0.2, 1.6	1.9	0.3, 3.5
Fitzroy			-0.6	-4.5, 3.6	5.4	1.5, 9.5	1.7	-1.2, 4.7
Burnett-Mary					35.6	27.7, 44.0	35.6	27.7, 44

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) Soft coral								
GBR Mean	-3.2	-4.6, -1.7	0.4	-0.3, 1.2	-1.9	-2.8, -1.0	-1.5	-2.1, -0.9
Cape York	-0.6	-2.3, 1.2	0.5	-0.5, 1.5	-4.5	-6.5, -2.4	-1.3	-2.2, -0.3
Wet Tropics	-1.8	-4.3, 0.8	0.2	-0.6, 1.0	-1.7	-3.1, -0.2	-1.0	-1.9, -0.1
Burdekin	-10.1	-13.6, -6.4	-3.7	-7.7, 0.5	-6.0	-8.9, -3.0	-7.2	-9.1, -5.2
Mackay-Whitsunday	-0.8	-2.8, 1.3	-1.2	-4.0, 1.7	3.8	2.2, 5.3	1.5	0.4, 2.6
Fitzroy			1.7	0.2, 3.3	-3.8	-5.8, -1.7	-1.4	-2.7, -0.1
Burnett-Mary					1.5	-4.3, 7.6	1.5	-4.3, 7.6

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(c) Algae								
GBR Mean	-3.2	-4.6, -1.7	0.4	-0.3, 1.2	-1.9	-2.8, -1.0	-1.5	-2.1, -0.9
Cape York	-0.6	-2.3, 1.2	0.5	-0.5, 1.5	-4.5	-6.5, -2.4	-1.3	-2.2, -0.3
Wet Tropics	-1.8	-4.3, 0.8	0.2	-0.6, 1.0	-1.7	-3.1, -0.2	-1.0	-1.9, -0.1
Burdekin	-10.1	-13.6, -6.4	-3.7	-7.7, 0.5	-6.0	-8.9, -3.0	-7.2	-9.1, -5.2
Mackay-Whitsunday	-0.8	-2.8, 1.3	-1.2	-4.0, 1.7	3.8	2.2, 5.3	1.5	0.4, 2.6
Fitzroy			1.7	0.2, 3.3	-3.8	-5.8, -1.7	-1.4	-2.7, -0.1
Burnett-Mary					1.5	-4.3, 7.6	1.5	-4.3, 7.6

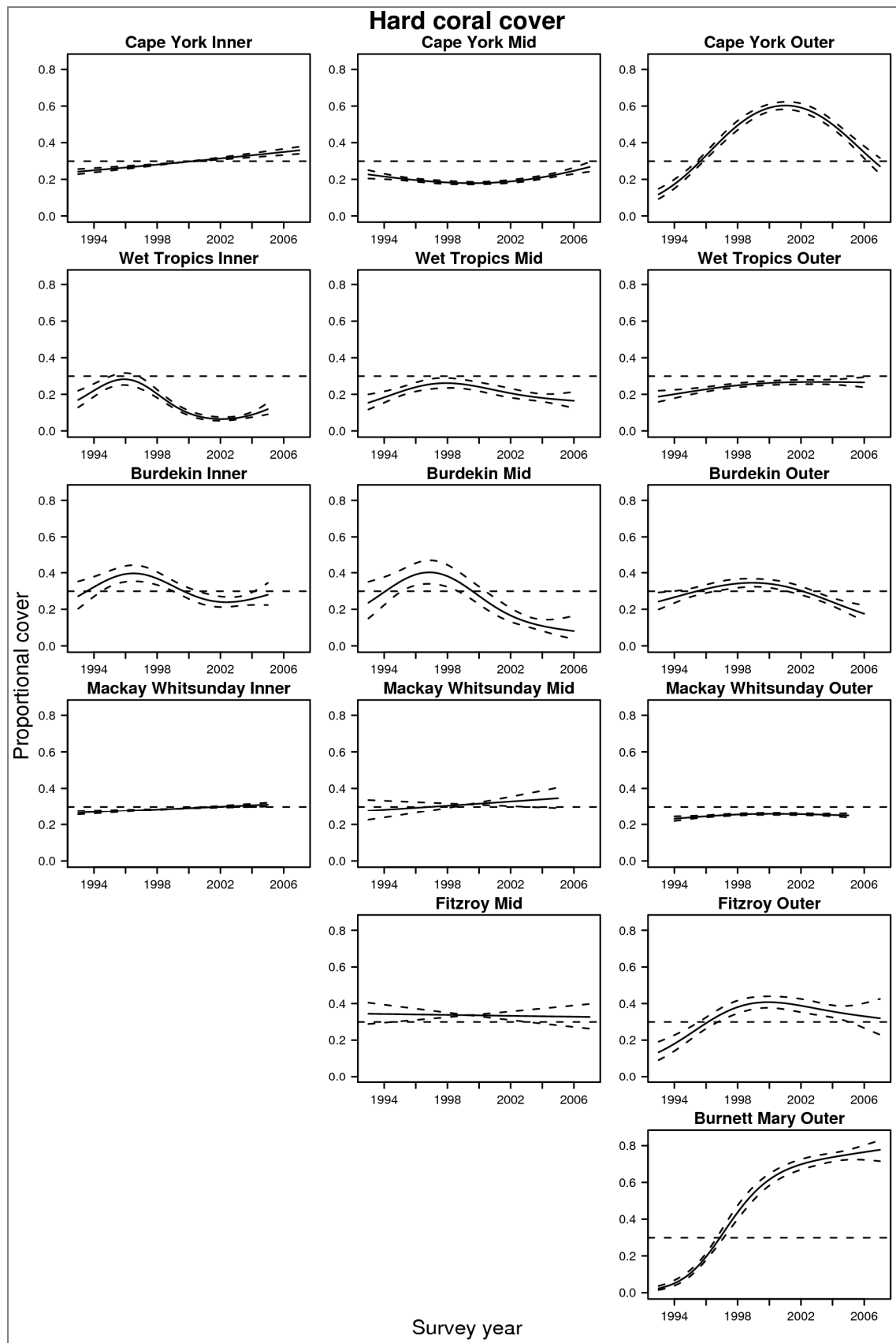


Figure 7.1: Estimated temporal trends of hard coral cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

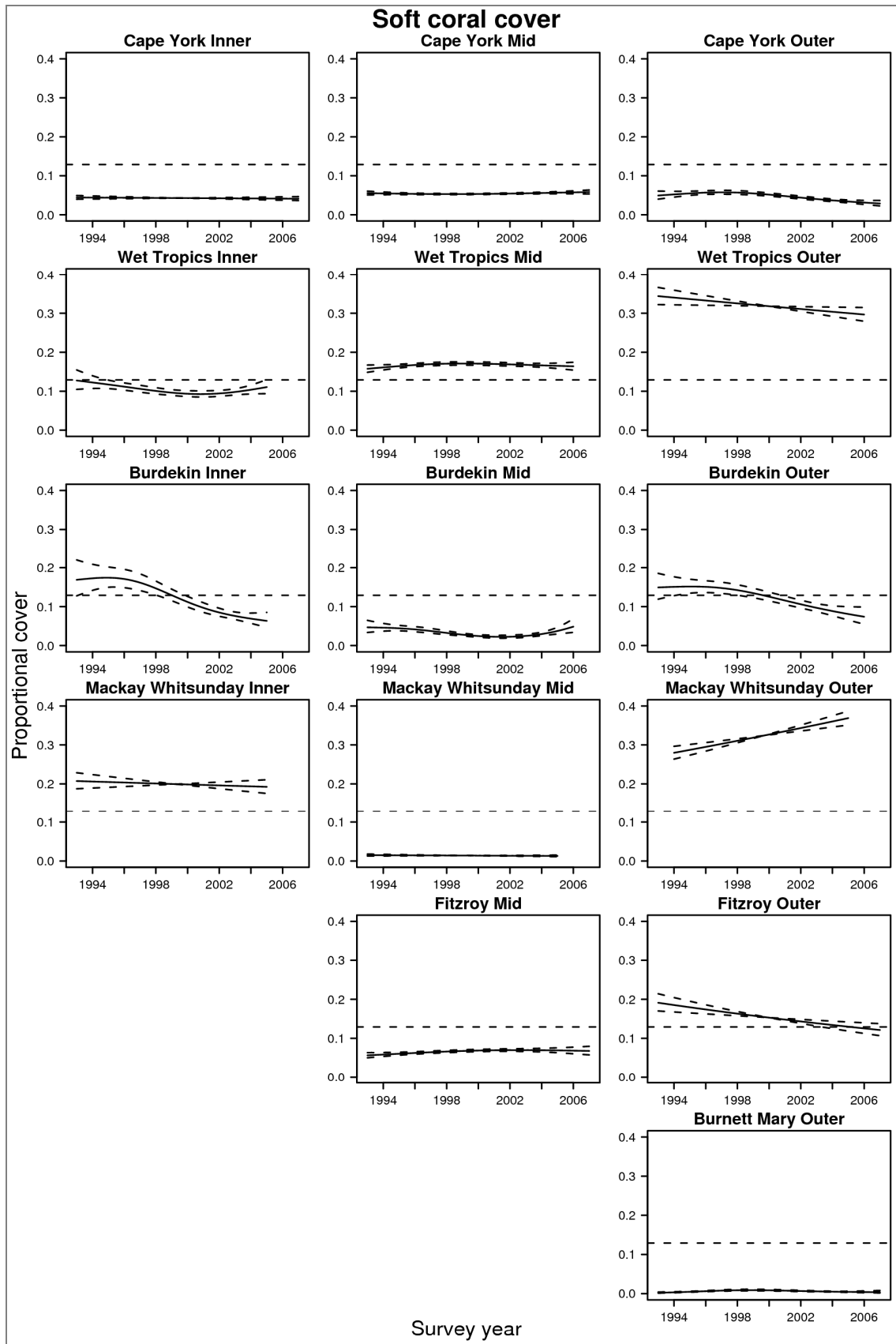


Figure 7.2: Estimated temporal trends of soft coral cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

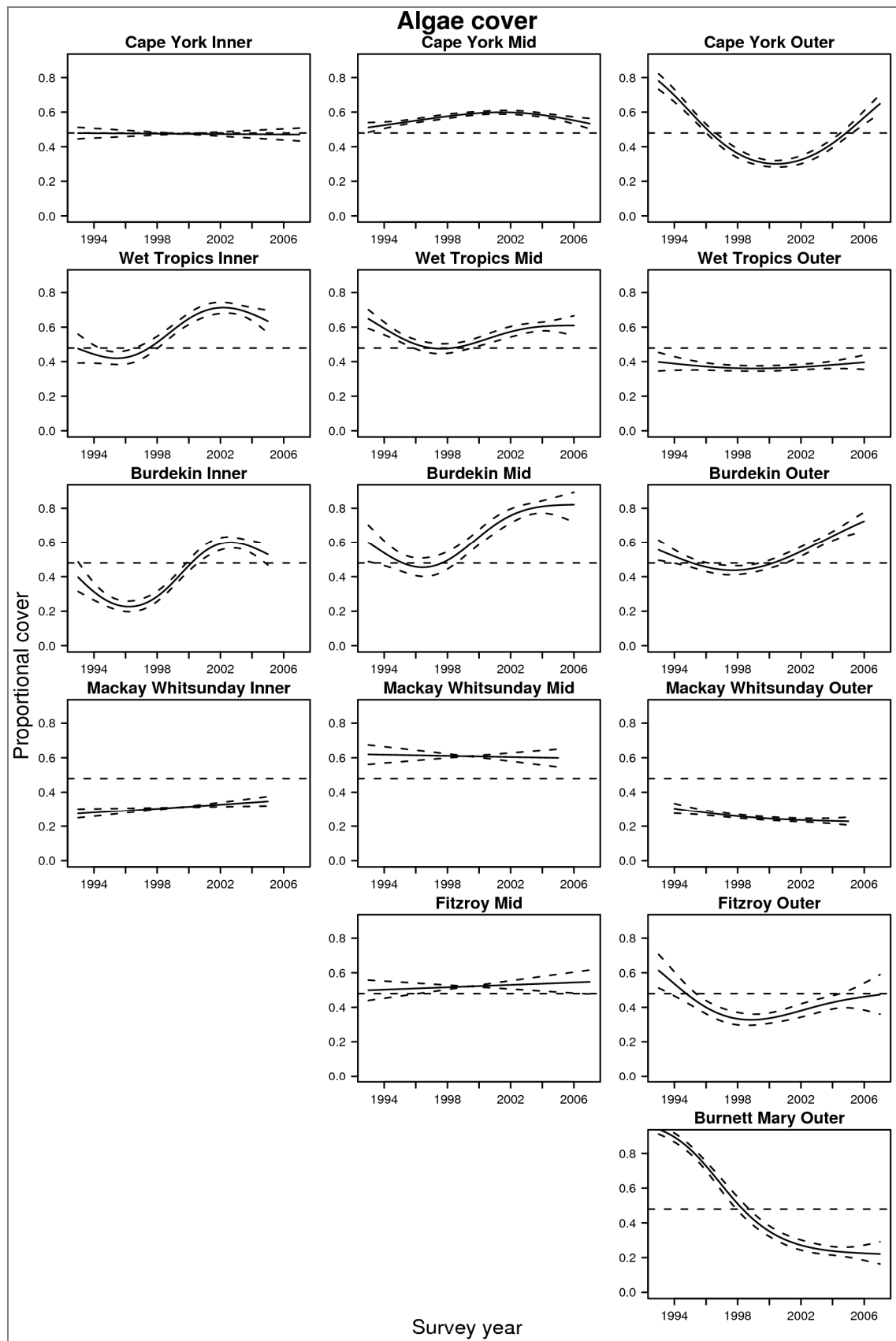


Figure 7.3: Estimated temporal trends of algae cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

Table 7.2 (continued to pages 74 and 75): Mean percent linear change values and 95% confidence intervals of benthic genera predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Acropora								
GBR Mean	-3.2	-5.9, -0.4	-2.4	-5.1, 0.4	11.9	9.5, 14.4	5.3	3.7, 7.0
Cape York	5.3	3.6, 7.1	1.6	-2.0, 5.3	8.7	3.0, 14.6	7.3	4.5, 10.2
Wet Tropics	-21.2	-28.4, -13.2	1.3	-2.8, 5.6	5.0	2.9, 7.3	1.0	-1.6, 3.6
Burdekin	-17.6	-23.7, -10.9	-16.0	-22.0, -9.6	-1.1	-5.2, 3.1	-10.8	-14.2, -7.4
Mackay-Whitsunday	2.8	0.7, 5.0	9.1	0.9, 17.9	3.5	1.7, 5.4	5.4	2.5, 8.4
Fitzroy			-0.1	-5.4, 5.5	10.8	6.0, 15.9	4.8	1.0, 8.8
Burnett-Mary					38.2	28.9, 48	38.2	28.9, 48

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) Goniopora								
GBR Mean	1.4	0.5, 2.3	-0.2	-2.2, 1.9	-3.2	-5.4, -1	0.0	0.0, 0.0
Cape York	6.6	-1.8, 15.7	-1.3	-5.3, 2.7	-14.7	-30.7, 5.1	-0.5	-4.3, 3.6
Wet Tropics	-14.1	-20.4, -7.3	-1.4	-11.2, 9.5	-11.3	-19.8, -1.8	-10.8	-15.1, -6.2
Burdekin	1.7	0.3, 3.2	-0.2	-7.9, 8.1	1.5	-4.4, 7.9	1.7	0.8, 2.7
Mackay-Whitsunday	1.0	-0.1, 2.2	8.4	-2.9, 20.9	1.9	-1.4, 5.2	1.2	0.2, 2.2
Fitzroy			0.0	-2.9, 3.0	-7.3	-10.3, -4.2	-3.3	-5.4, -1.0
Burnett-Mary					-11.4	-31.8, 15.0	-11.4	-31.8, 15

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(c) Montipora								
GBR Mean	0.2	-2.3, 2.7	-0.2	-2.0, 1.7	4.6	2.9, 6.3	0.9	-0.2, 2.1
Cape York	6.0	3.5, 8.5	10.6	5.5, 16.1	6.6	3.3, 9.9	6.8	5.0, 8.7
Wet Tropics	-16.5	-21.7, -11	0.7	-3.3, 4.9	3.2	-1.9, 8.6	-7.7	-10.9, -4.4
Burdekin	-1.8	-9.4, 6.5	0.9	-5.5, 7.7	5.6	1.0, 10.5	1.5	-2.2, 5.4
Mackay-Whitsunday	4.6	2.7, 6.4	1.1	-3.0, 5.4	5.5	1.0, 10.2	2.9	1.0, 4.9
Fitzroy			-2.0	-5.5, 1.7	1.8	-1.8, 5.6	-1.3	-3.9, 1.4
Burnett-Mary					5.2	0.7, 9.8	5.2	0.7, 9.8

Table 7.2 (continued):

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(d) Pocillopora								
GBR Mean	0.2	-1.7, 2.2	1.6	0.3, 2.9	0.4	-0.8, 1.6	0.9	0.1, 1.7
Cape York	1.4	-3.1, 6.1	6.0	2.8, 9.3	-1.0	-3.6, 1.8	0.5	-1.1, 2.1
Wet Tropics	-1.8	-12.9, 10.8	1.8	-0.2, 3.8	5.3	3.7, 7.0	3.4	2.1, 4.7
Burdekin	-14.2	-22.7, -4.8	-3.2	-6.1, -0.3	-0.2	-2.9, 2.6	-1.6	-3.4, 0.2
Mackay-Whitsunday	1.0	-3.9, 6.1	1.9	-1.8, 5.7	0.5	-1.5, 2.6	1.3	-0.5, 3.1
Fitzroy			2.8	-0.3, 6.0	-8.9	-12.5, -5.2	0.1	-2.4, 2.6
Burnett-Mary					8.1	2.1, 14.5	8.1	2.1, 14.5

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(e) Porites								
GBR Mean	3.4	2.3, 4.5	3.9	2.9, 4.8	3.0	2.0, 4.0	3.5	2.9, 4.1
Cape York	2.5	1.0, 4.1	1.0	-0.5, 2.5	7.6	4.2, 11.2	2.2	1.1, 3.3
Wet Tropics	4.8	1.9, 7.8	4.1	1.4, 6.8	1.6	-0.9, 4.2	3.7	2.1, 5.3
Burdekin	3.1	0.7, 5.5	-0.7	-2.8, 1.4	3.2	1.1, 5.3	1.8	0.6, 3.1
Mackay-Whitsunday	3.1	1.0, 5.2	6.4	3.1, 9.7	1.1	-0.7, 2.9	3.2	1.9, 4.6
Fitzroy			7.1	5.3, 9.0	3.7	1.9, 5.6	6.1	4.8, 7.5
Burnett-Mary					-3.5	-12.4, 6.2	-3.5	-12.4, 6.2

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(f) Macroalgae								
GBR Mean	7.1	0.3, 14.3	4.0	-1.2, 9.5	1.5	-1.3, 4.3	3.5	0.1, 7.0
Cape York	-7.9	-19.6, 5.7	0.0	-13.4, 15.4	2.2	-3.0, 7.6	-3.2	-10.1, 4.3
Wet Tropics	9.4	-2.9, 23.3	2.8	-4.8, 11.1	4.0	-3.0, 11.5	5.8	-0.2, 12.2
Burdekin	28.5	13.0, 46.1	14.9	6.2, 24.3	5.1	-1.5, 12.2	17.8	11.9, 24.1
Mackay-Whitsunday	-5.6	-25.4, 19.5	-1.2	-10.4, 8.9	-0.6	-7.6, 7.0	-2.8	-10.6, 5.8
Fitzroy			1.7	-4.8, 8.5	-2.2	-8.7, 4.8	0.4	-4.2, 5.3
Burnett-Mary					-11.3	-22.8, 1.9	-11.3	-22.8, 2.0

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(g) Coralline algae								
GBR Mean	9.5	4.0, 15.3	0.3	-1.2, 1.9	-1.3	-2.5, 0.0	-0.6	-1.5, 0.3
Cape York	6.1	-2.4, 15.3	-4.9	-9.5, -0.1	-2.7	-5.8, 0.5	-2.8	-4.7, -0.8
Wet Tropics	7.9	-1.4, 18.0	2.2	0.3, 4.2	-1.0	-3.7, 1.7	0.7	-0.7, 2.3
Burdekin	18.8	0.9, 40.0	-2.4	-6.1, 1.6	1.5	-1.1, 4.2	0.3	-1.8, 2.4
Mackay-Whitsunday	10.6	-4.5, 28.1	2.6	-2.8, 8.3	-2.1	-5.1, 1.0	0.4	-2.1, 2.9
Fitzroy			0.7	-2.2, 3.6	4.1	1.6, 6.7	2.1	0.2, 4.1
Burnett-Mary					-7.4	-12, -2.5	-7.4	-12.0, -2.5

Table 7.2 (continued):

(h) Turf algae	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	5.0	2.9, 7.0	3.0	1.4, 4.6	-3.8	-5.8, -1.8	1.1	0.0, 2.3
Cape York	2.2	-2.1, 6.6	2.0	-1.0, 5.0	-4.4	-9.7, 1.2	0.5	-1.7, 2.8
Wet Tropics	9.2	5.2, 13.5	0.6	-2.5, 3.9	1.0	-1.6, 3.6	3.6	1.5, 5.6
Burdekin	6.3	0.9, 11.9	9.8	5.0, 14.8	6.0	2.2, 9.8	7.2	4.6, 9.8
Mackay-Whitsunday	3.3	0.6, 6.1	2.5	-0.6, 5.8	-3.5	-6.2, -0.8	1.5	-0.2, 3.2
Fitzroy			2.0	-1.8, 6.0	-2.4	-6.8, 2.1	0.0	-2.8, 3.0
Burnett-Mary					-22.7	-27.3, -17.7	-22.7	-27.4, -17.7

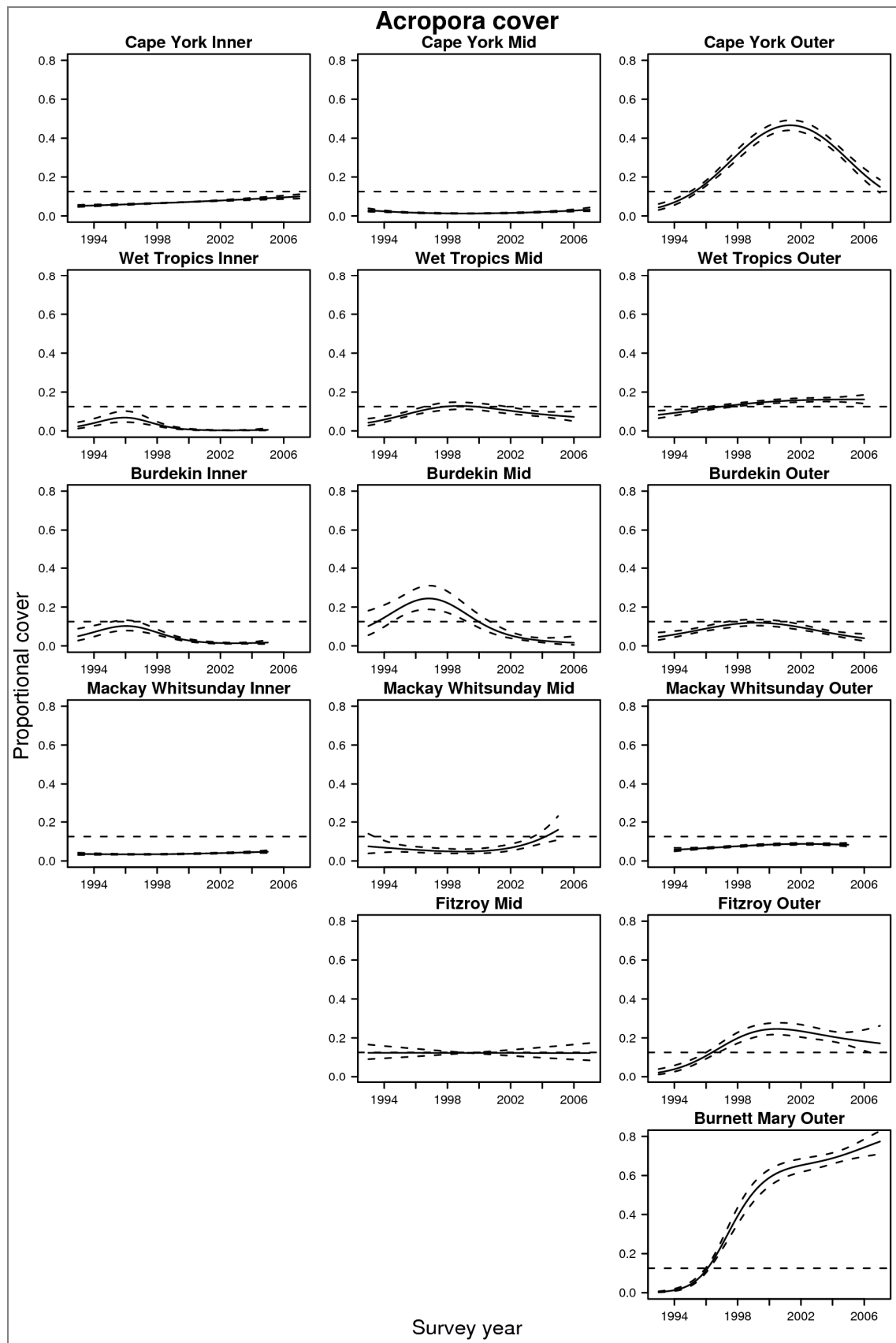


Figure 7.4: Estimated temporal trends of *Acropora* cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

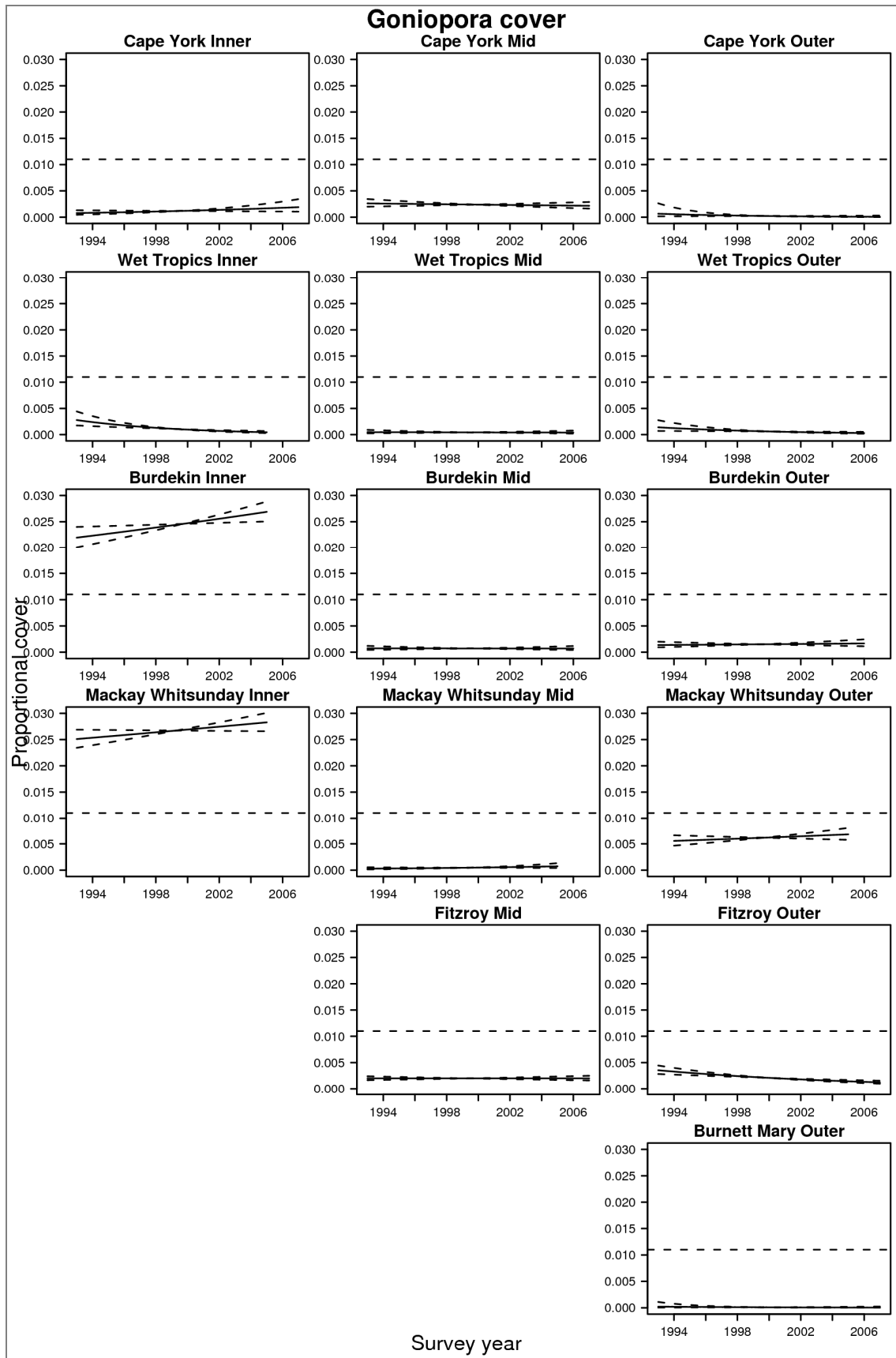


Figure 7.5: Estimated temporal trends of *Goniopora* cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

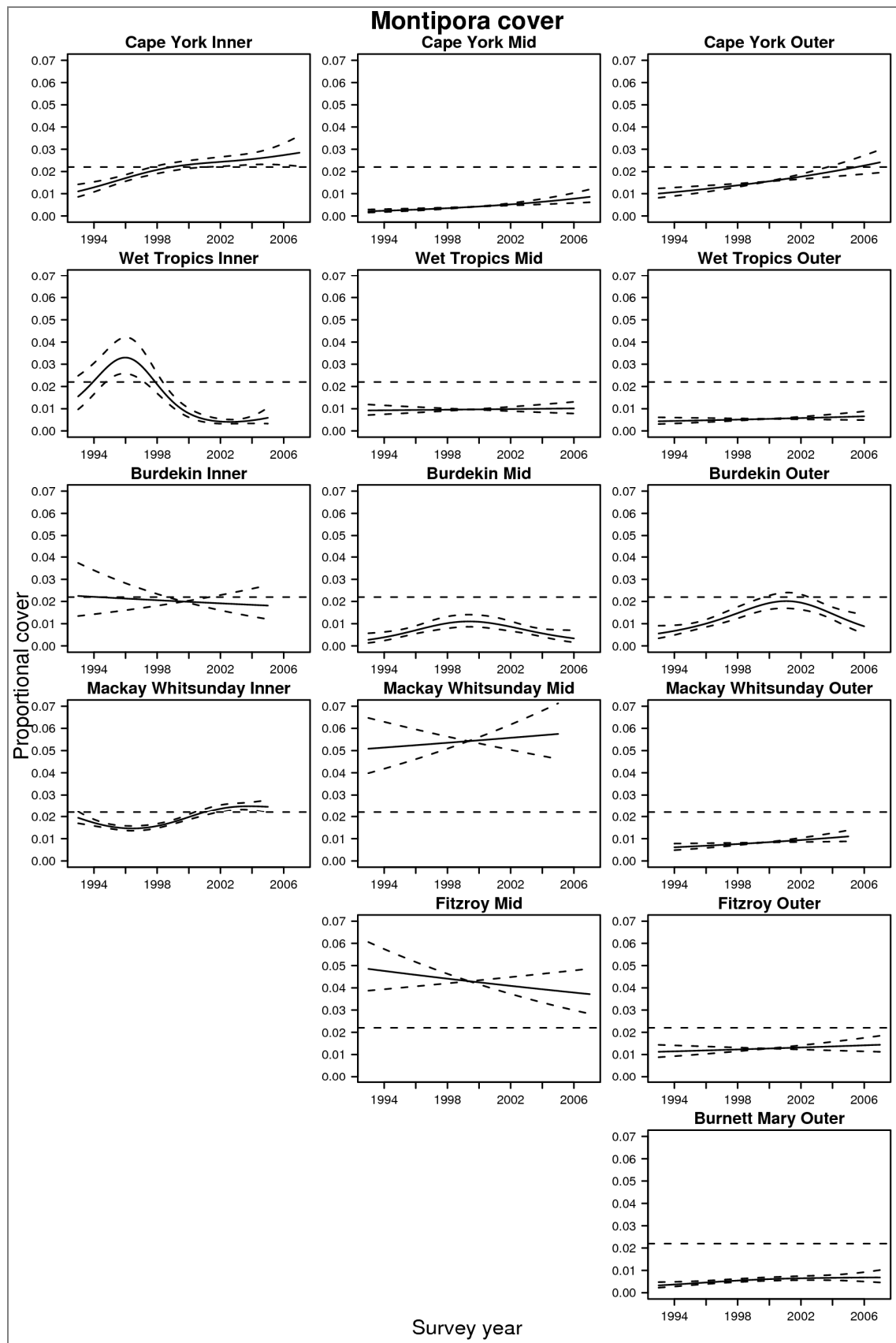


Figure 7.6: Estimated temporal trends of *Montipora* cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

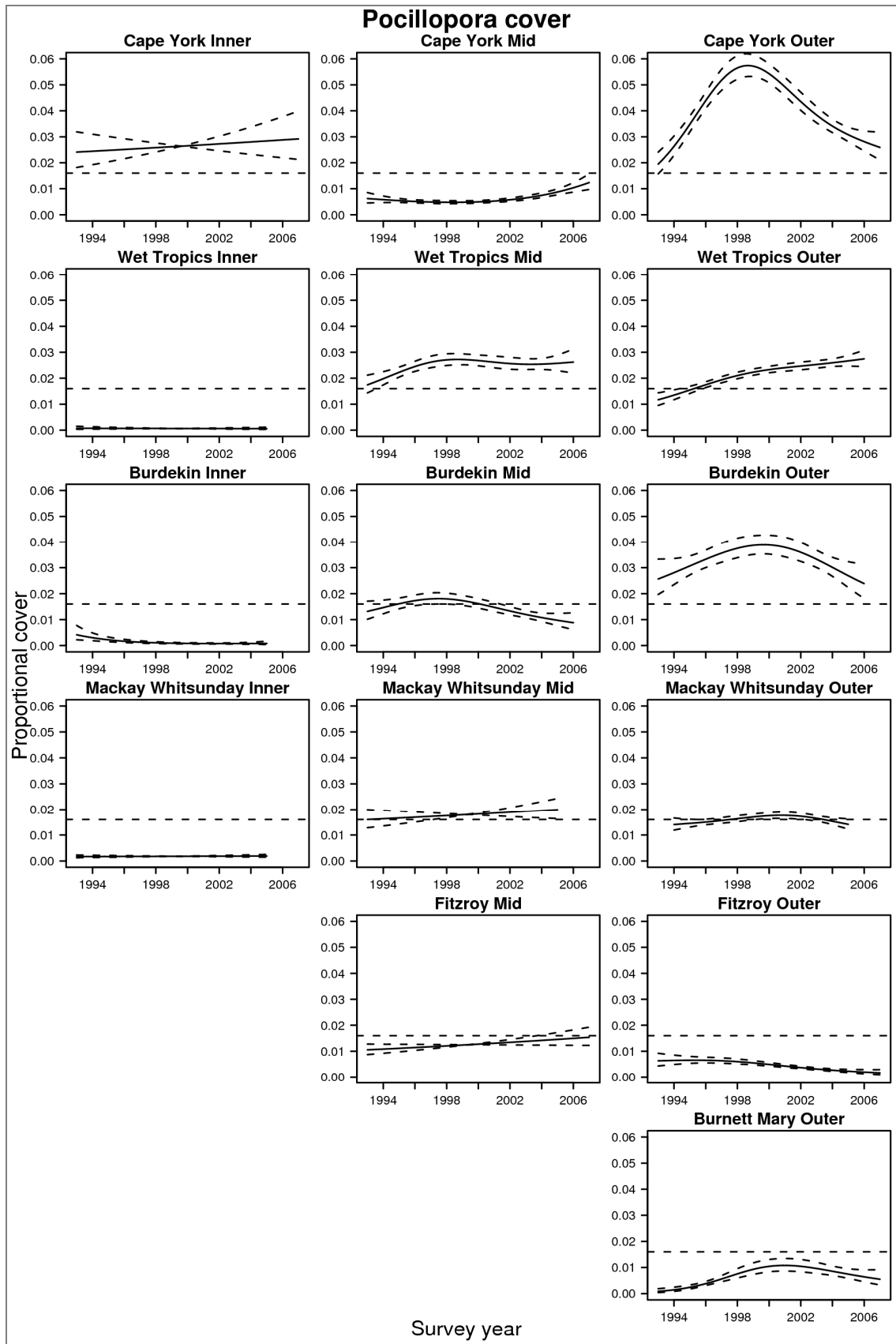


Figure 7.7: Estimated temporal trends of Pocillopora cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

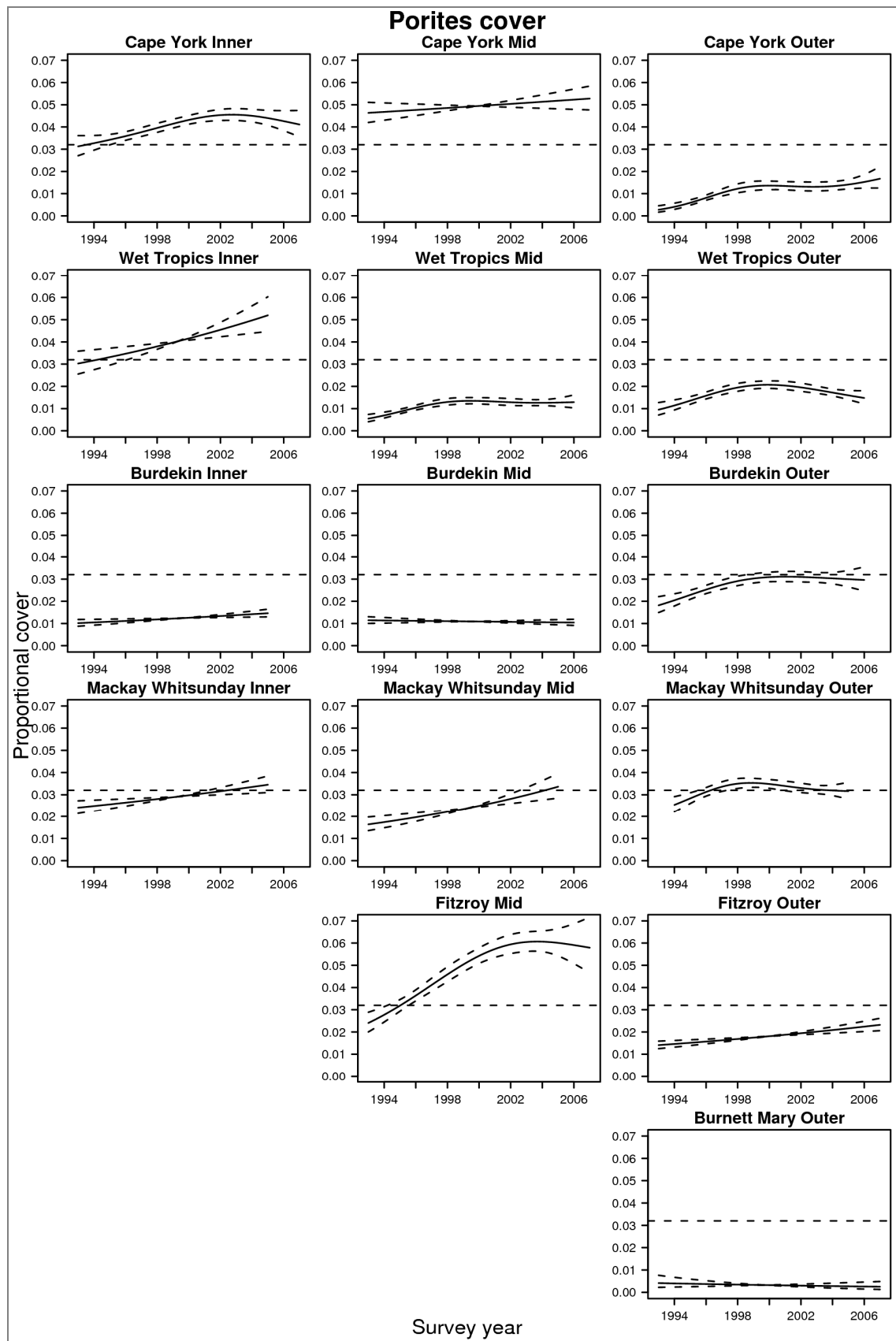


Figure 7.8: Estimated temporal trends of Porites cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

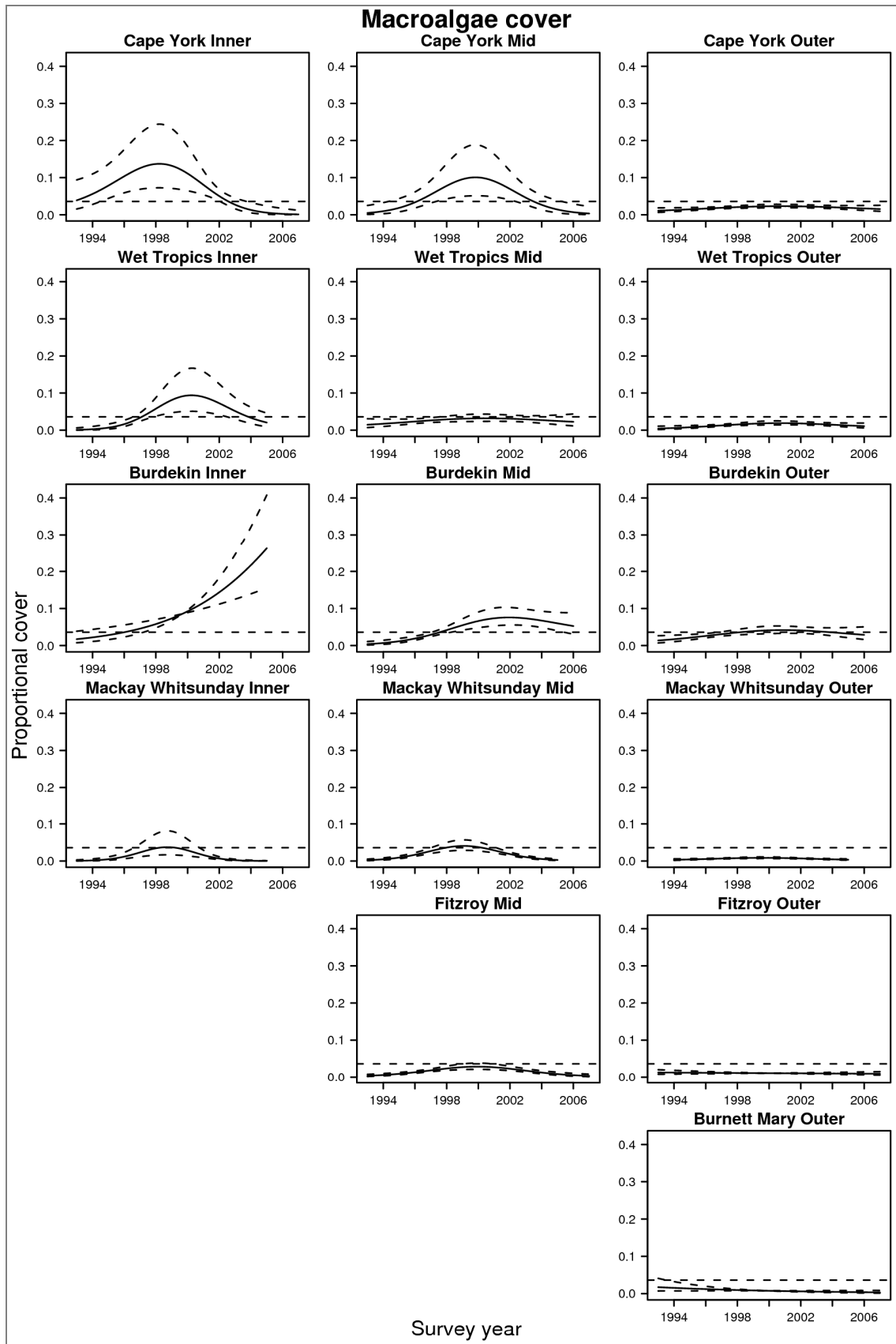


Figure 7.9: Estimated temporal trends of macroalgae cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

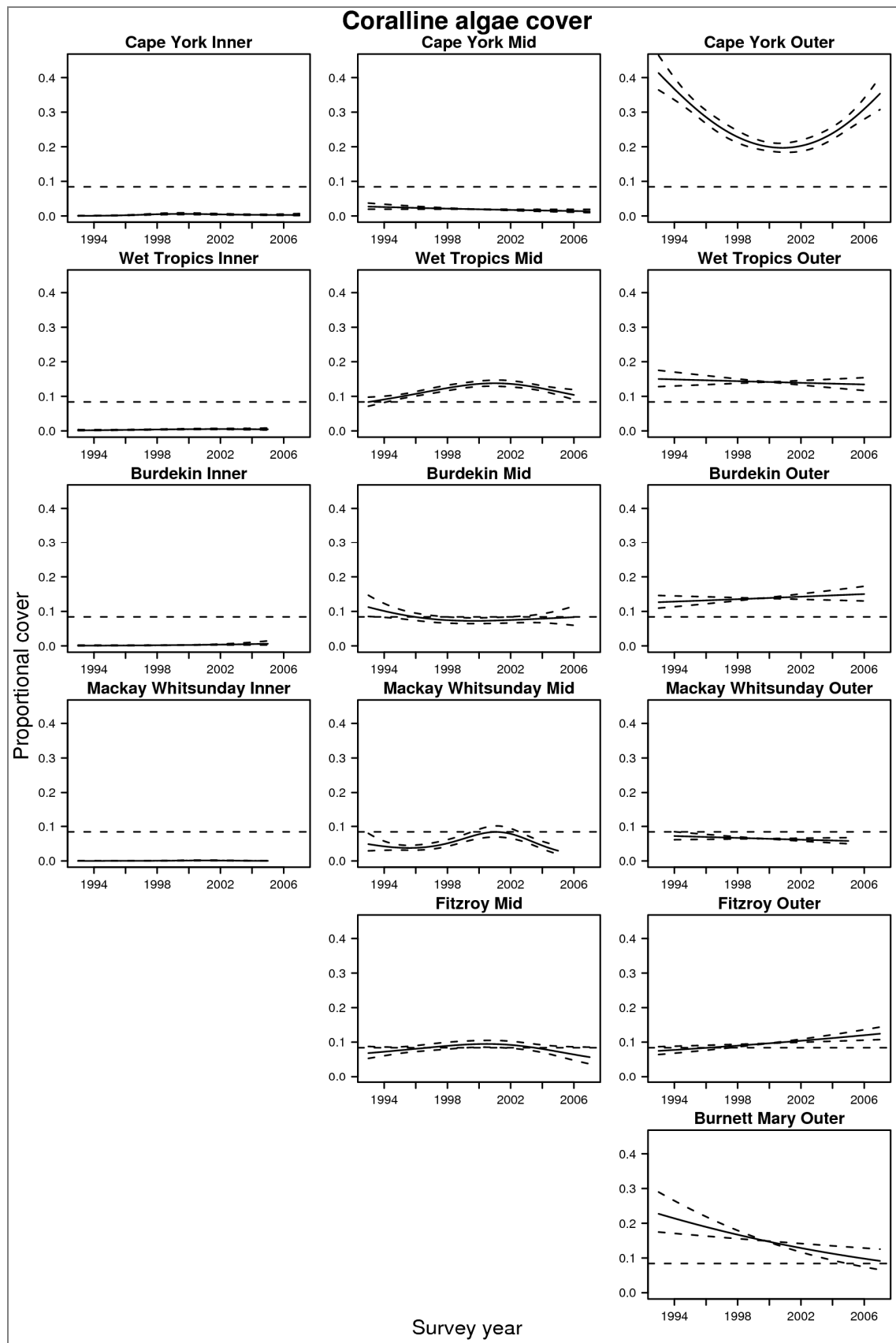


Figure 7.10: Estimated temporal trends of coralline algae cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

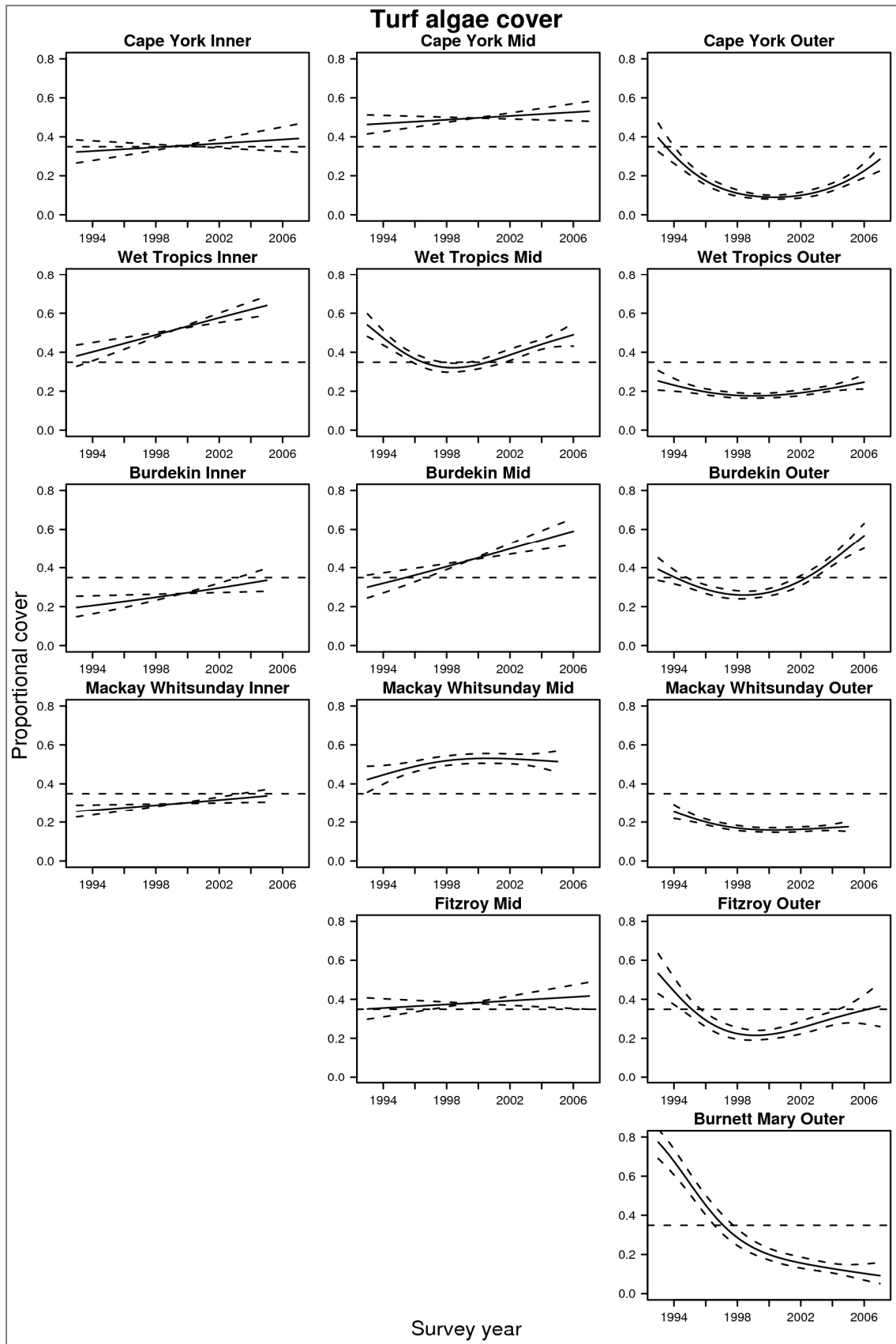


Figure 7.11: Estimated temporal trends of turf algae cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

Table 7.3: Mean percent linear change values and 95% confidence intervals of hard coral cover and the proportion of reefs affected by COTS predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP manta tow reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Hard coral								
GBR Mean	-1.5	-3.3, 0.2	-3.8	-4.7, -3.0	0.6	-0.4, 1.6	-2.0	-2.6, -1.4
Cape York	-0.7	-2.4, 1.0	-2.7	-3.9, -1.6	0.1	-1.3, 1.6	-1.3	-2.1, -0.4
Wet Tropics	-2.6	-6.9, 1.8	-5.4	-7.2, -3.5	-2.4	-4.7, -0.1	-4.0	-5.4, -2.7
Burdekin	-14.4	-29.7, 4.2	-2.5	-4.6, -0.3	-0.4	-2.6, 2.0	-2.4	-4.2, -0.5
Mackay-Whitsunday	2.8	-0.3, 6.0	-4.9	-6.9, -2.9	2.4	0.3, 4.6	-2.2	-3.6, -0.7
Fitzroy	-16.3	-83, 312.3	-3.2	-6.0, -0.3	-1.2	-4.4, 2.0	-2.4	-4.5, -0.2
Burnett-Mary					11.0	7.6, 14.5	11.0	7.6, 14.5

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) COTS affected								
GBR Mean	-8.4	-15.3, -1.0	6.4	2.1, 10.9	-4.2	-9.0, 0.9	0.1	-2.8, 3.0
Cape York	-1.9	-12.1, 9.4	0.5	-7.6, 9.3	-38.1	-48.3, -25.9	-11.2	-16.0, -6.2
Wet Tropics			1.9	-5.4, 9.9	41.2	20.4, 65.7	-0.2	-5.7, 5.7
Burdekin			-12.4	-20.3, -3.9			0.8	-6.3, 8.5
Mackay-Whitsunday							24.0	-16.1, 83.4
Fitzroy			85.1	59.0, 115.5				
Burnett-Mary								

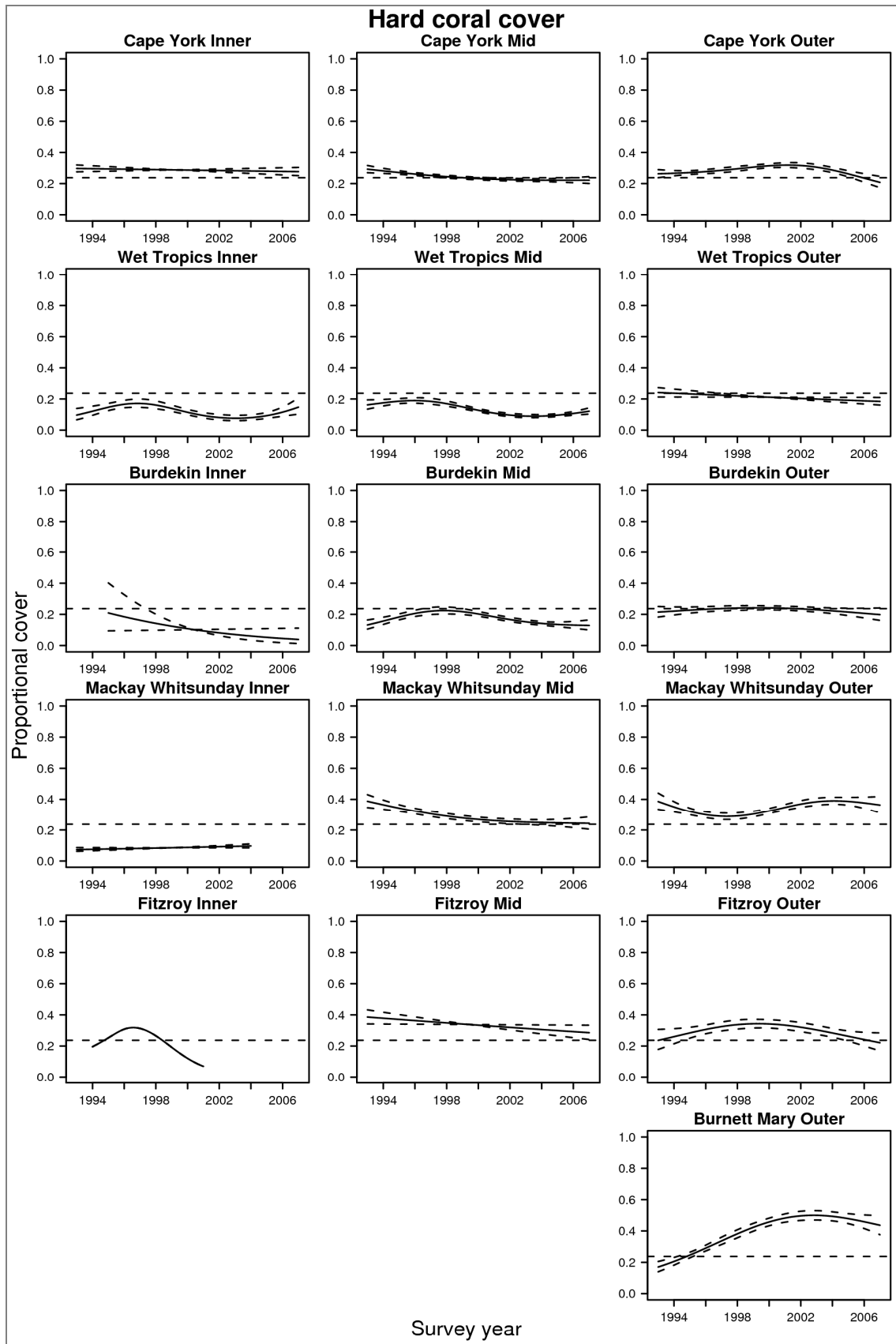


Figure 7.12: Estimated temporal trends of hard coral cover across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

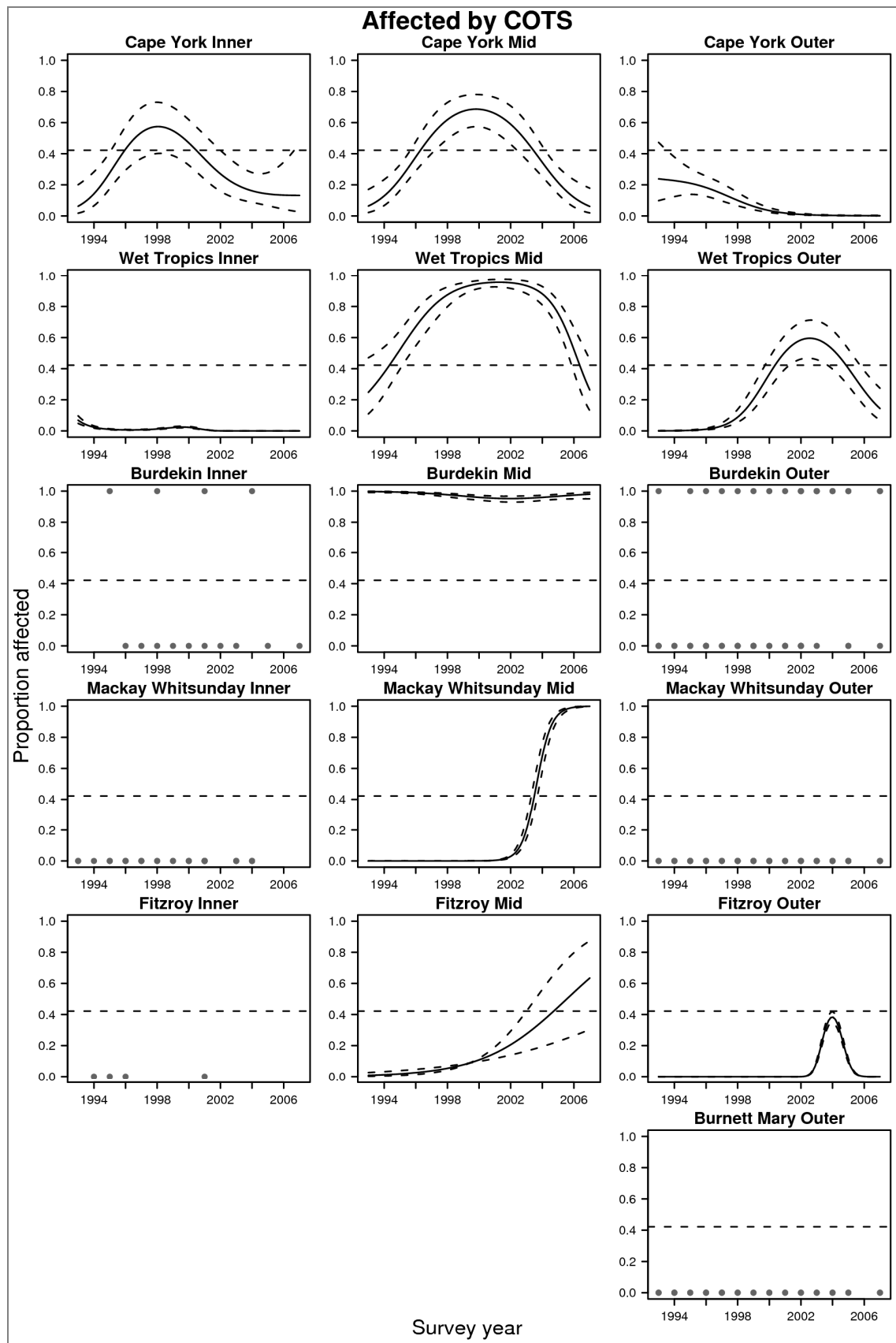


Figure 7.13: Estimated temporal trends of the proportion of reefs affected by crown-of-thorns starfish (COTS) across shelf positions by NRM zone across the GBR. Solid lines are mean trend; dashed lines are 95% confidence intervals. Horizontal dashed line is GBR mean. Points are raw affected/not affected data.

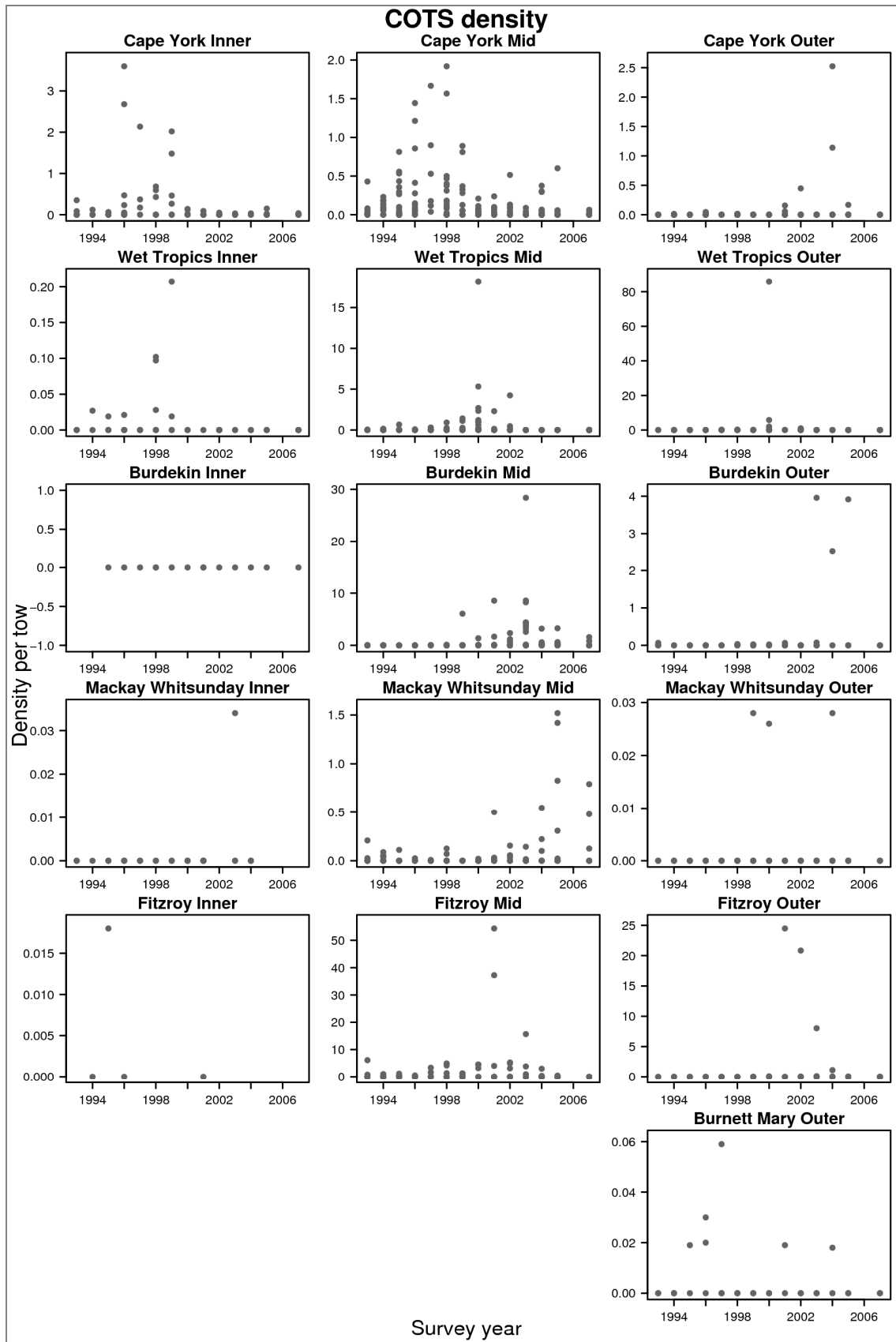


Figure 7.14: Temporal density of crown-of-thorns starfish (COTS) across shelf positions in each NRM zone across the GBR. Points represent mean COTS density per manta tow for reefs sampled in each year.

Table 7.4 (continued to page 89): Mean percent linear change values and 95% confidence intervals of fish abundance and diversity, predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Abundance								
GBR Mean	0.3	-0.9, 1.6	-1.2	-2.1, -0.3	0.9	0.1, 1.7	-0.3	-0.8, 0.3
Cape York	2.9	1.0, 4.7	1.3	-0.2, 2.8	1.6	-0.2, 3.5	1.9	1.0, 2.9
Wet Tropics	-2.2	-4.4, -0.1	0.9	-0.9, 2.7	1.2	-0.6, 3.0	0.1	-0.9, 1.2
Burdekin	0.8	-2.7, 4.5	-2.6	-4.6, -0.5	-0.9	-2.6, 0.8	-1.3	-2.6, -0.1
Mackay-Whitsunday	-0.9	-3.6, 1.8	-0.5	-4.0, 3.1	1.0	-1.0, 3.0	-0.4	-2.1, 1.3
Fitzroy			-2.9	-4.4, -1.4	0.9	-1.0, 2.7	-1.8	-3.0, -0.6
Burnett-Mary					2.0	-1.5, 5.7	2.0	-1.5, 5.7

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) Richness								
GBR Mean	0.4	0.1, 0.7	0.1	-0.1, 0.2	0.7	0.5, 0.9	0.4	0.3, 0.5
Cape York	0.3	-0.3, 0.9	0.4	0.1, 0.8	0.0	-0.4, 0.4	0.3	0.0, 0.5
Wet Tropics	-0.3	-0.7, 0.2	-0.2	-0.5, 0.2	0.1	-0.4, 0.6	-0.1	-0.4, 0.1
Burdekin	0.4	-0.2, 1.1	0.1	-0.3, 0.4	0.1	-0.4, 0.5	0.2	-0.1, 0.4
Mackay-Whitsunday	1.2	0.4, 1.9	0.2	-0.2, 0.6	0.1	-0.4, 0.6	0.5	0.2, 0.9
Fitzroy			-0.1	-0.4, 0.2	1.1	0.6, 1.5	0.4	0.1, 0.7
Burnett-Mary					3.2	2.6, 3.8	3.2	2.6, 3.8

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(c) Shannon diversity								
GBR Mean	0.1	0.0, 0.3	0.3	0.1, 0.4	0.5	0.4, 0.7	0.3	0.2, 0.4
Cape York	-0.2	-0.6, 0.3	0.2	-0.2, 0.5	-0.3	-0.5, 0.0	-0.1	-0.3, 0.1
Wet Tropics	0.3	-0.1, 0.7	0.2	-0.1, 0.5	0.3	0.1, 0.6	0.3	0.1, 0.5
Burdekin	-0.1	-0.2, 0.1	0.6	0.3, 0.9	0.2	-0.1, 0.5	0.3	0.1, 0.4
Mackay-Whitsunday	0.3	0.1, 0.5	0.2	-0.1, 0.4	0.1	-0.2, 0.4	0.2	0.1, 0.3
Fitzroy			0.2	0.0, 0.4	1.0	0.7, 1.4	0.6	0.4, 0.8
Burnett-Mary					1.8	1.3, 2.3	1.8	1.3, 2.3

Table 7.4 (continued):

(d) Simpson diversity	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	0.1	0.0, 0.3	0.2	0.1, 0.2	0.3	0.2, 0.4	0.2	0.2, 0.3
Cape York	-0.1	-0.4, 0.2	0.1	-0.2, 0.4	-0.2	-0.4, 0.0	0.0	-0.2, 0.1
Wet Tropics	0.4	0.0, 0.8	0.2	0.0, 0.4	0.3	0.1, 0.5	0.3	0.1, 0.4
Burdekin	0.0	-0.1, 0.0	0.3	0.1, 0.5	0.1	-0.1, 0.4	0.2	0.0, 0.3
Mackay-Whitsunday	0.2	0.0, 0.3	0.1	0.0, 0.2	0.0	-0.1, 0.2	0.1	0.0, 0.2
Fitzroy			0.1	0.0, 0.2	0.6	0.4, 0.8	0.3	0.2, 0.5
Burnett-Mary					1.1	0.7, 1.4	1.1	0.7, 1.4

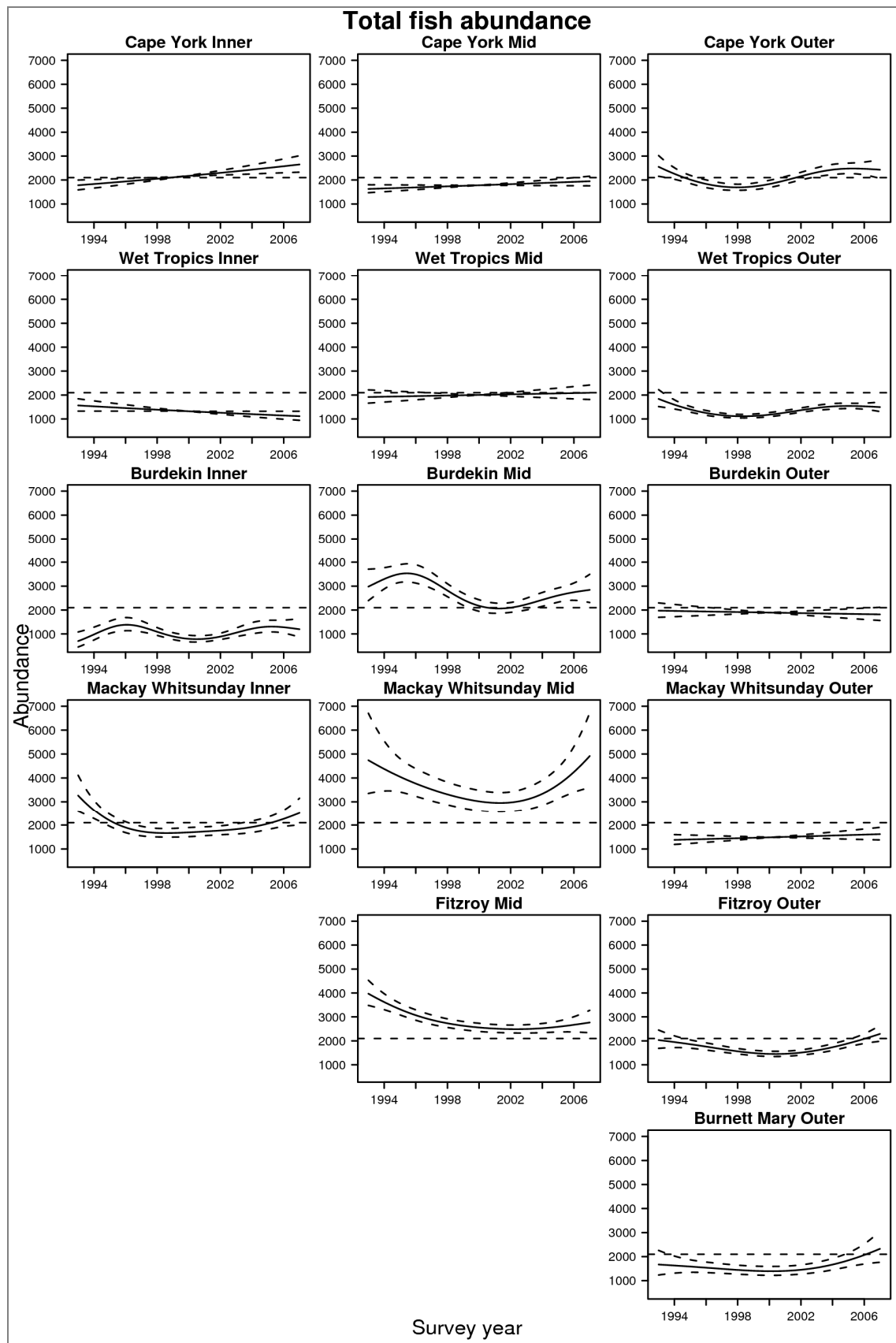


Figure 7.15: Estimated temporal trends of total fish abundance across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

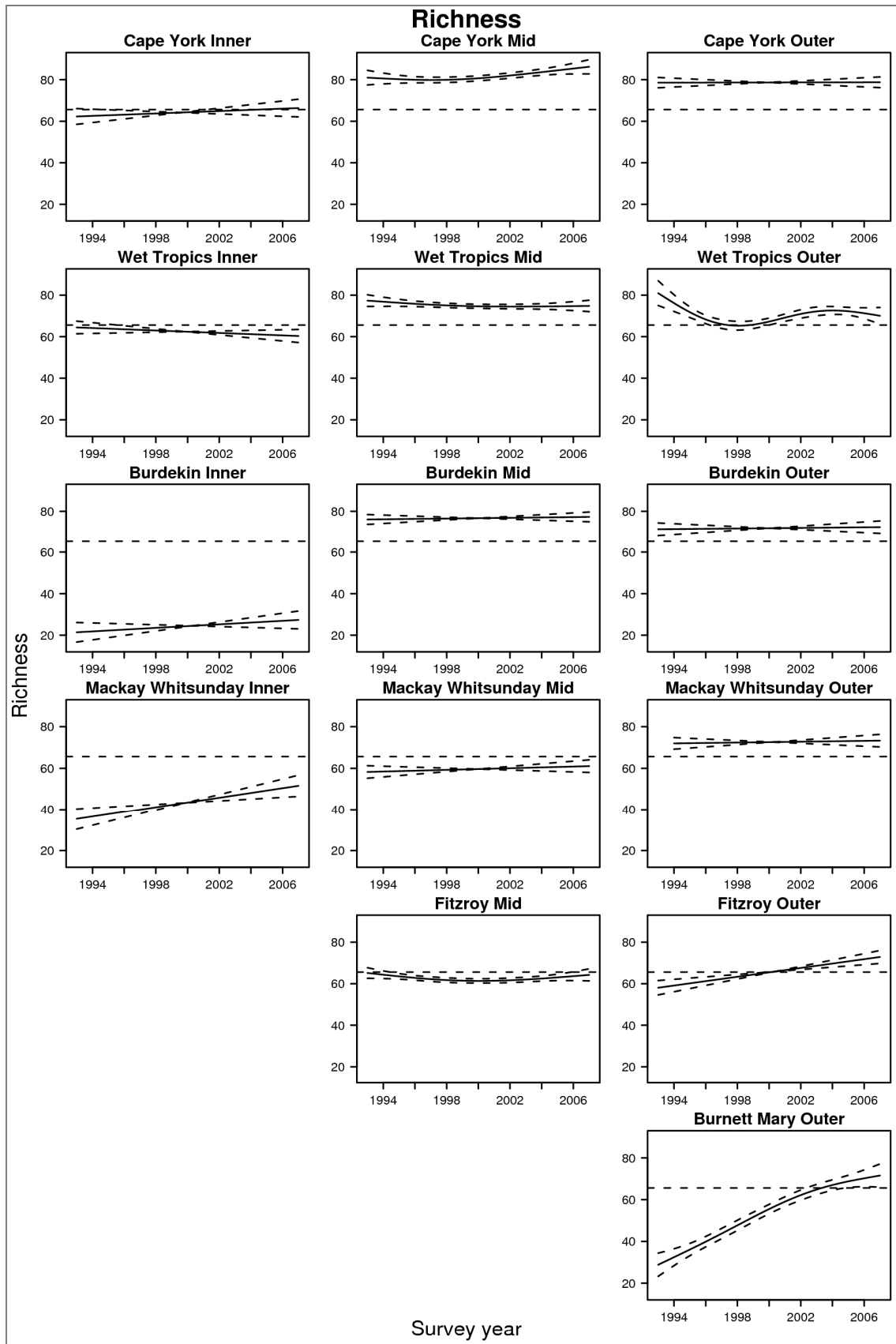


Figure 7.16: Estimated temporal trends of fish richness across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

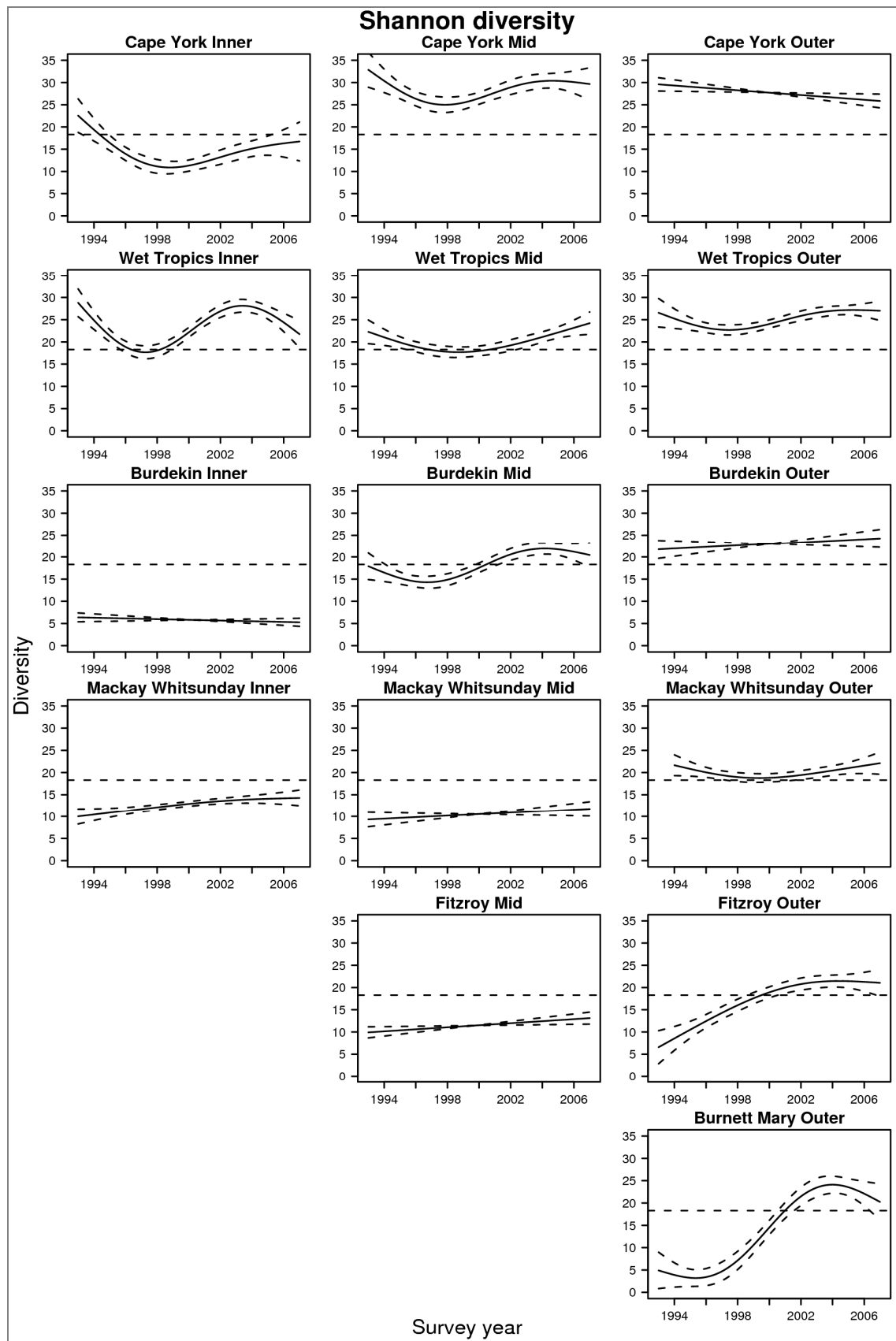


Figure 7.17: Estimated temporal trends of fish diversity (Shannon index) across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

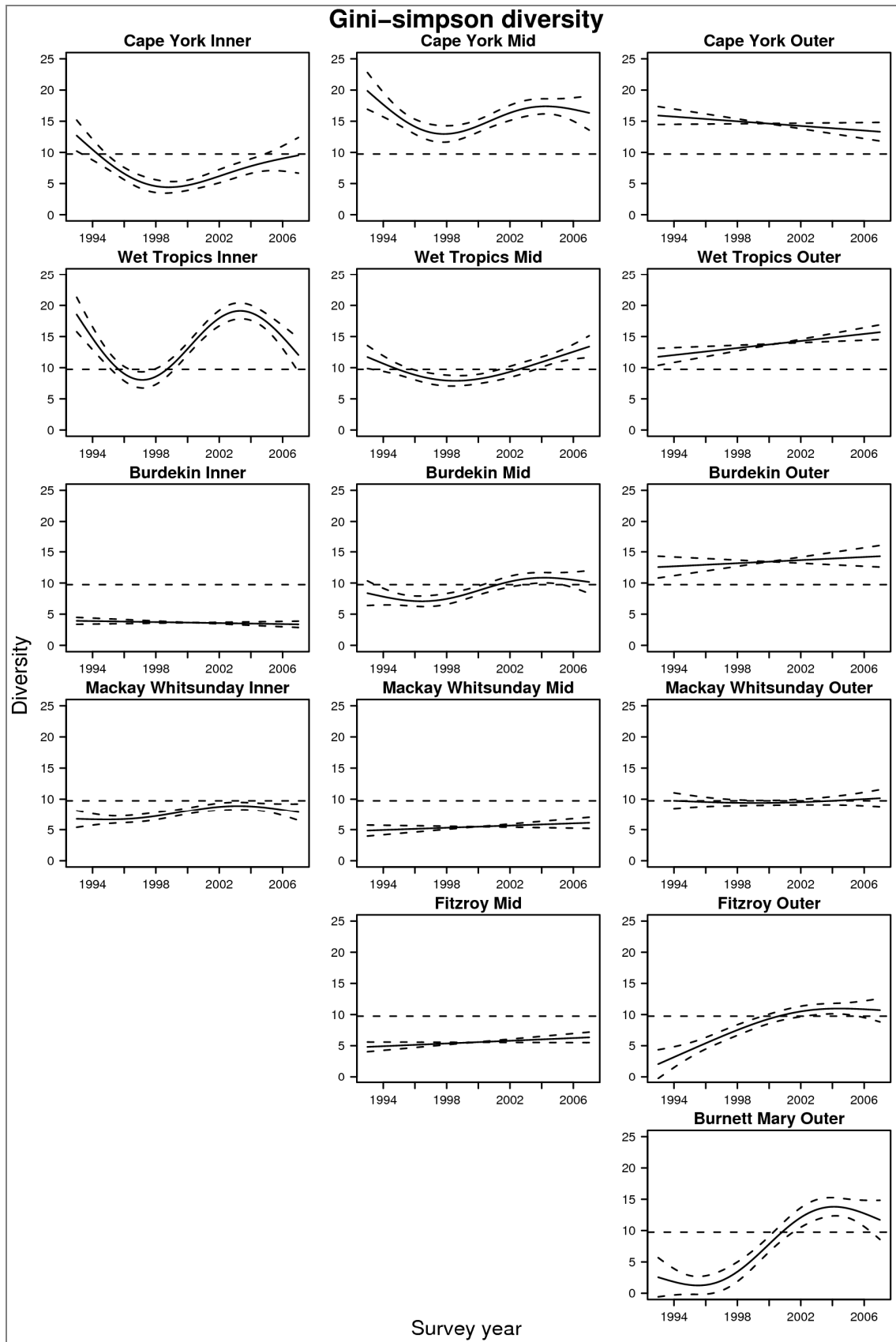


Figure 7.18: Estimated temporal trends of fish diversity (Gini-simpson index) across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

Table 7.5 (continued to page 95): Mean percent linear change values and 95% confidence intervals of fish trophic group abundance predicted across the six NRM regions and three cross-shelf positions in the GBR. Estimates are based on measurements conducted between 1993 and 2007 at LTMP core reefs.

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(a) Herbivores								
GBR Mean	0.7	-0.4, 1.9	0.0	-0.7, 0.8	1.1	-0.1, 2.3	0.6	0.0, 1.2
Cape York	1.1	-0.9, 3.1	2.0	0.4, 3.7	-4.7	-7.2, -2.1	-1.1	-2.5, 0.3
Wet Tropics	0.1	-1.8, 1.9	-0.6	-2.1, 0.9	-1.2	-3.5, 1.1	-0.7	-1.7, 0.4
Burdekin	0.4	-2.9, 3.8	3.6	1.7, 5.5	0.8	-1.1, 2.7	1.8	0.6, 3.1
Mackay-Whitsunday	1.9	-0.9, 4.9	-0.8	-3.0, 1.4	1.2	-1.9, 4.5	0.5	-1.0, 2.0
Fitzroy			-2.2	-3.3, -1.0	6.2	4.0, 8.5	0.9	-0.4, 2.3
Burnett-Mary					11.9	8.0, 15.9	11.9	8.0, 15.9

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(b) Planktivores								
GBR Mean	2.3	0.2, 4.4	-1.2	-2.6, 0.2	3.3	1.8, 4.8	0.5	-0.4, 1.4
Cape York	5.2	1.2, 9.3	0.8	-1.9, 3.5	6.4	4.1, 8.9	4.4	2.7, 6.1
Wet Tropics	-1.9	-6.0, 2.3	1.6	-1.5, 4.8	3.6	0.3, 7.1	1.6	-0.3, 3.6
Burdekin	2.7	-1.8, 7.3	-4.5	-7.4, -1.6	-2.1	-4.8, 0.6	-2.1	-3.9, -0.2
Mackay-Whitsunday	1.7	-3.0, 6.7	-0.4	-5.0, 4.5	1.5	-1.3, 4.3	0.3	-2.0, 2.6
Fitzroy			-1.7	-4.1, 0.8	1.6	-2.0, 5.3	-1.0	-2.9, 0.9
Burnett-Mary					38.7	31.7, 46.1	38.7	31.7, 46.1

	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
(c) Predators								
GBR Mean	-0.1	-1.7, 1.6	-0.5	-1.4, 0.3	1.6	0.5, 2.7	0.2	-0.4, 0.9
Cape York	-0.6	-3.0, 1.8	-0.9	-2.3, 0.5	-2.7	-4.3, -1.1	-1.4	-2.4, -0.4
Wet Tropics	-0.8	-3.6, 2.0	-0.1	-3.3, 3.1	1.2	-1.3, 3.9	-0.2	-1.8, 1.4
Burdekin	2.5	-2.3, 7.6	0.7	-0.9, 2.3	-0.9	-3.1, 1.2	0.7	-0.9, 2.3
Mackay-Whitsunday	0.9	-3.6, 5.6	-0.4	-2.6, 1.8	0.8	-1.6, 3.2	0.3	-1.5, 2.0
Fitzroy			-1.1	-2.6, 0.3	4.8	2.3, 7.3	0.8	-0.5, 2.2
Burnett-Mary					14.1	11.0, 17.3	14.1	11, 17.3

Table 7.5 (continued):

(d) Benthic feeders	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	-0.1	-1.7, 1.5	0.1	-0.9, 1.2	4.7	3.7, 5.8	2.4	1.7, 3.1
Cape York	2.6	0.7, 4.6	0.7	-1.4, 2.8	2.2	0.5, 4.0	1.8	0.7, 2.9
Wet Tropics	-6.0	-8.3, -3.5	2.1	0.6, 3.6	2.3	0.9, 3.8	0.4	-0.7, 1.6
Burdekin	-5.1	-9.5, -0.4	-4.2	-6.4, -2.0	-1.3	-2.8, 0.3	-3.1	-4.5, -1.7
Mackay-Whitsunday	4.3	0.8, 7.9	3.9	0.6, 7.2	2.1	-0.3, 4.6	3.4	1.7, 5.1
Fitzroy			-1.1	-3.4, 1.1	5.7	3.4, 7.9	2.6	0.9, 4.3
Burnett-Mary					16.1	10.8, 21.7	16.1	10.8, 21.7

(e) Benthic/plankton feeders	Inner-shelf		Mid-shelf		Outer-shelf		Across all zones	
	mean	CI	mean	CI	mean	CI	mean	CI
GBR Mean	-1.2	-2.6, 0.2	-2.6	-3.7, -1.5	-6.0	-7.4, -4.5	-2.9	-3.6, -2.2
Cape York	3.1	0.7, 5.6	1.6	-0.4, 3.6	1.7	-1.1, 4.5	2.3	1.1, 3.6
Wet Tropics	-4.0	-7.0, -0.8	1.7	-0.5, 3.9	2.8	1.0, 4.7	-1.6	-3.2, 0.0
Burdekin	-8.1	-11.4, -4.8	-3.4	-5.4, -1.4	0.5	-1.6, 2.7	-3.3	-4.7, -2.0
Mackay-Whitsunday	-3.4	-5.7, -1.1	-1.5	-5.6, 2.8	-1.7	-3.7, 0.4	-2.6	-4.3, -0.9
Fitzroy			-7.0	-8.5, -5.5	-6.8	-9.9, -3.5	-6.9	-8.4, -5.4
Burnett-Mary					-13.0	-17.0, -8.8	-13.0	-17.0, -8.8

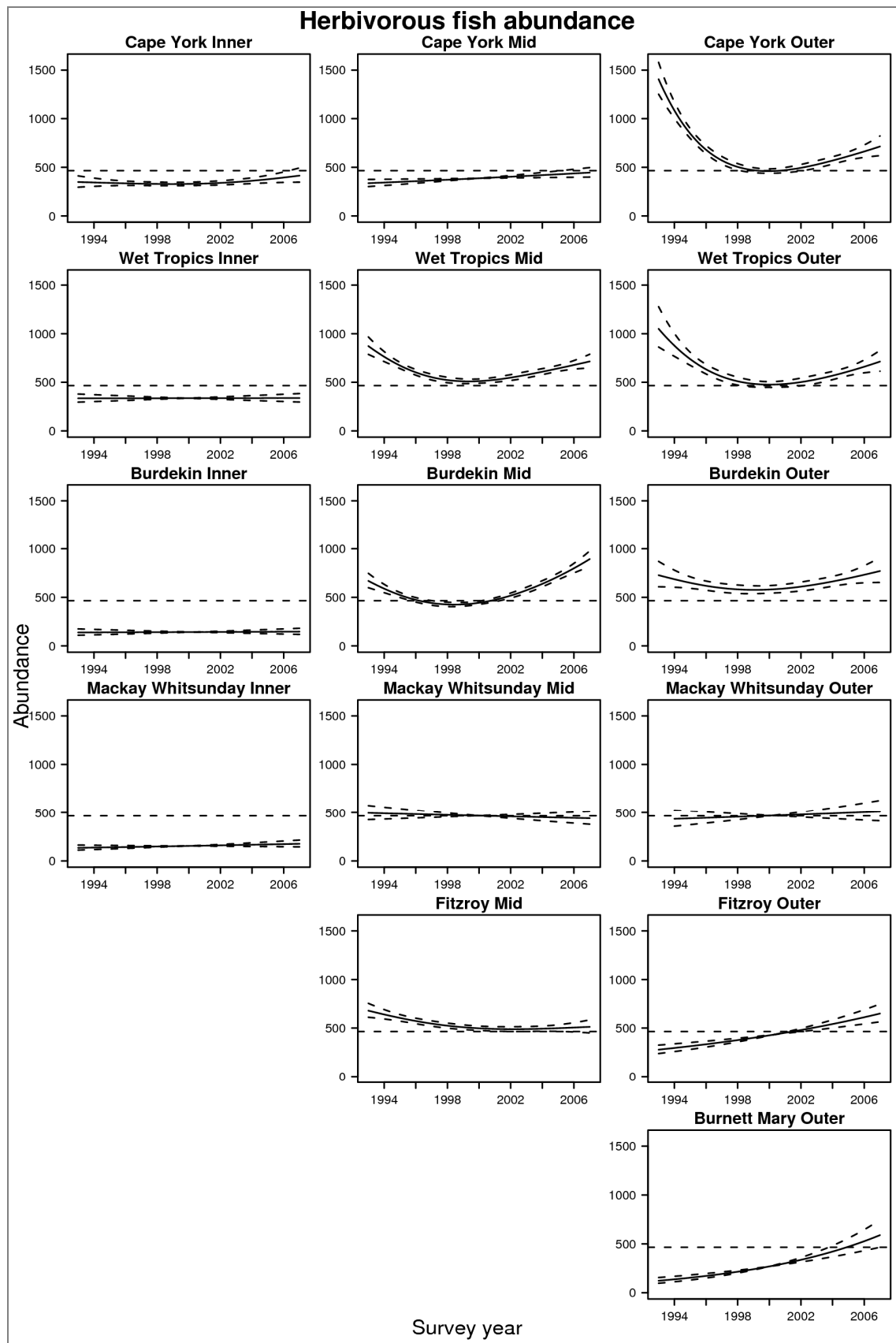


Figure 7.19: Estimated temporal trends of herbivorous fish abundance across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

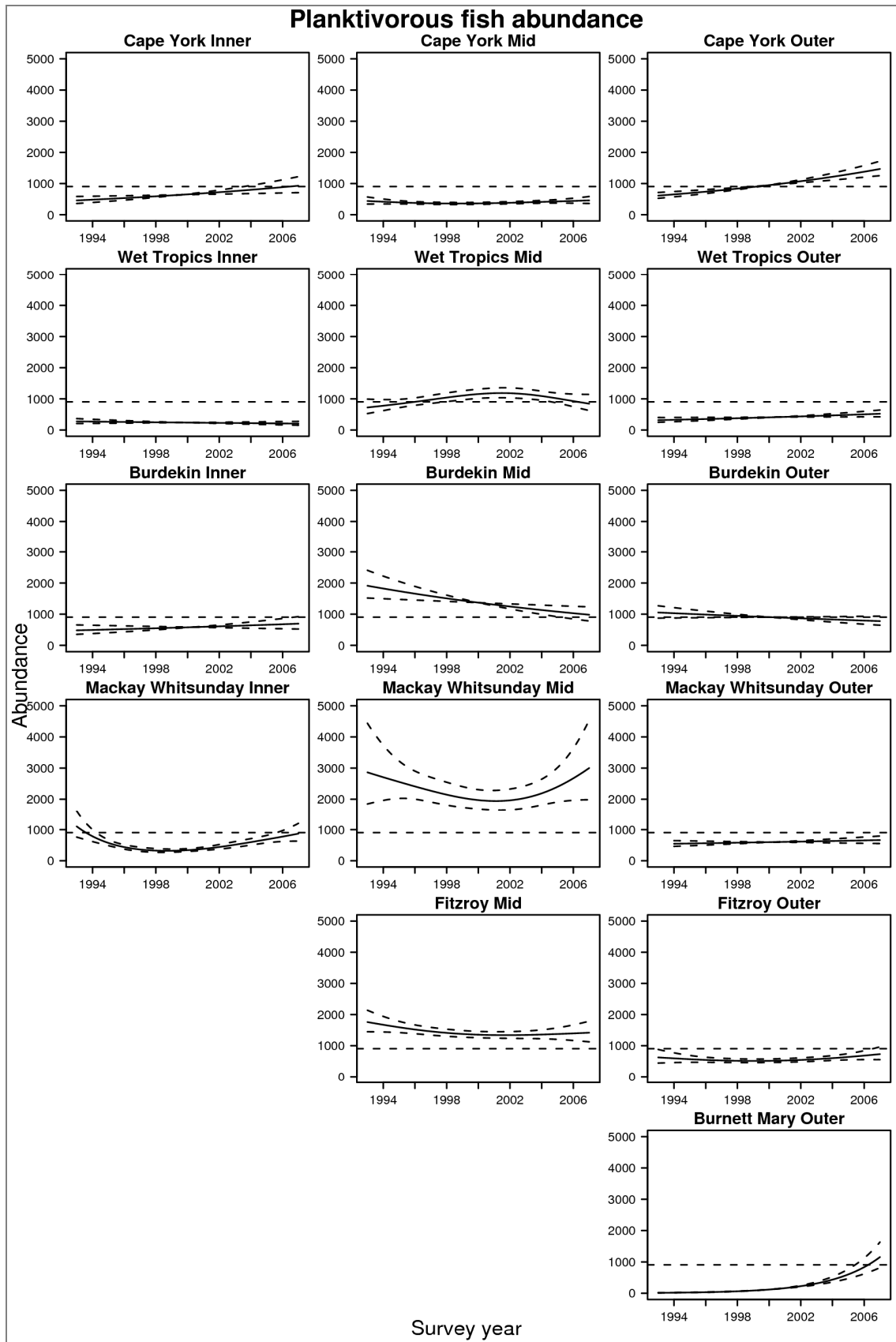


Figure 7.20: Estimated temporal trends of planktivorous fish abundance across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

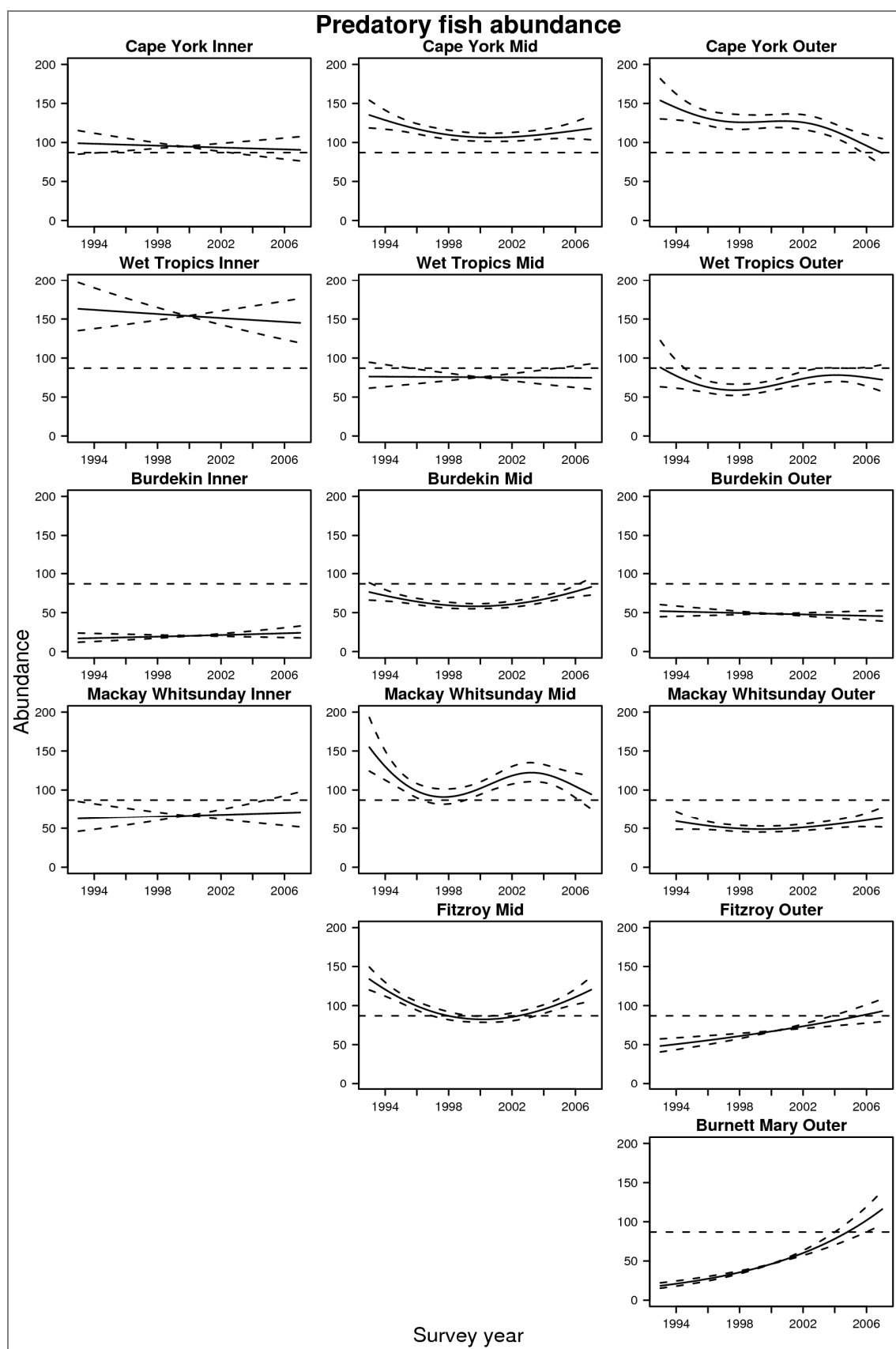


Figure 7.21: Estimated temporal trends of predatory fish abundance across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

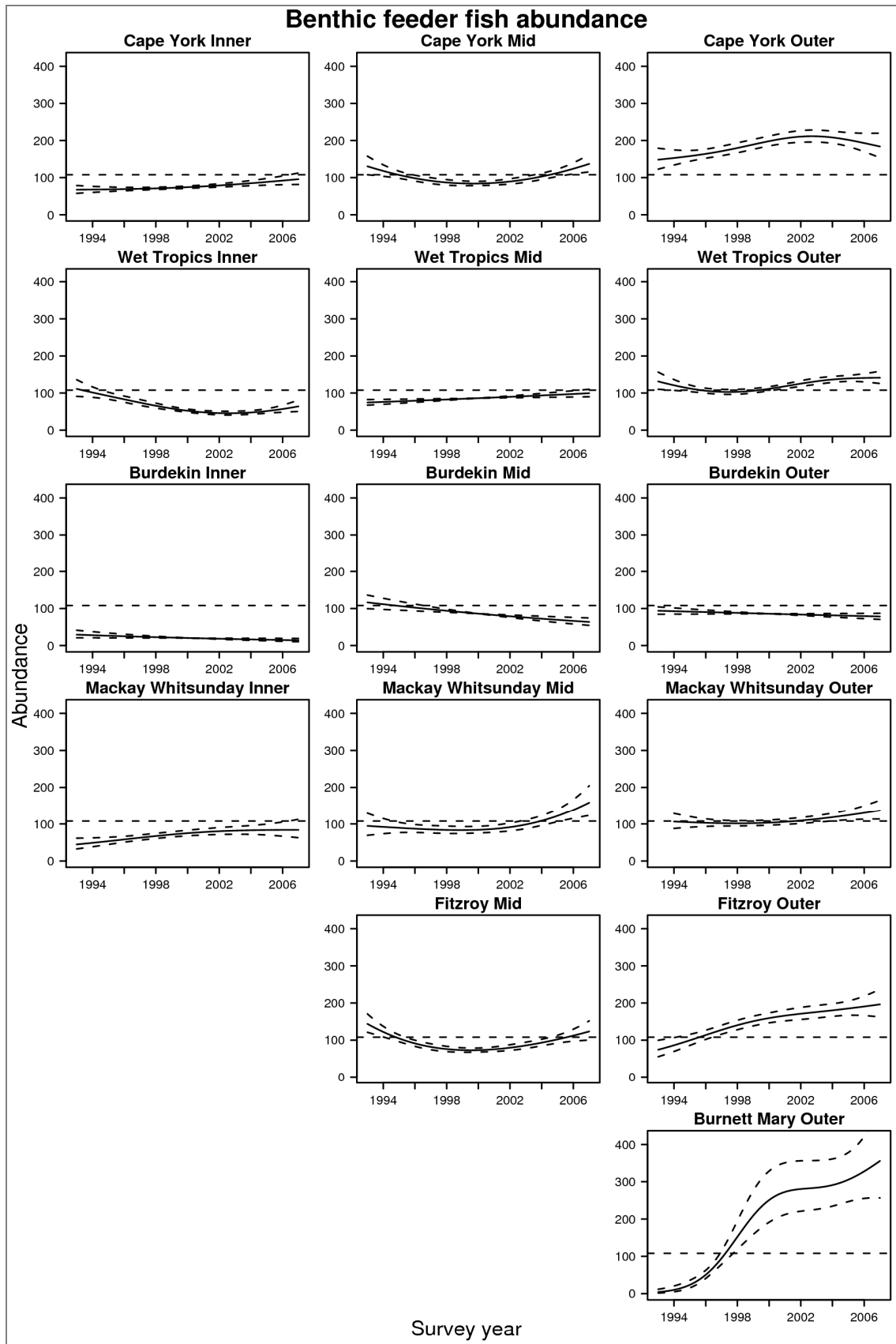


Figure 7.22: Estimated temporal trends of benthic feeder fish abundance across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

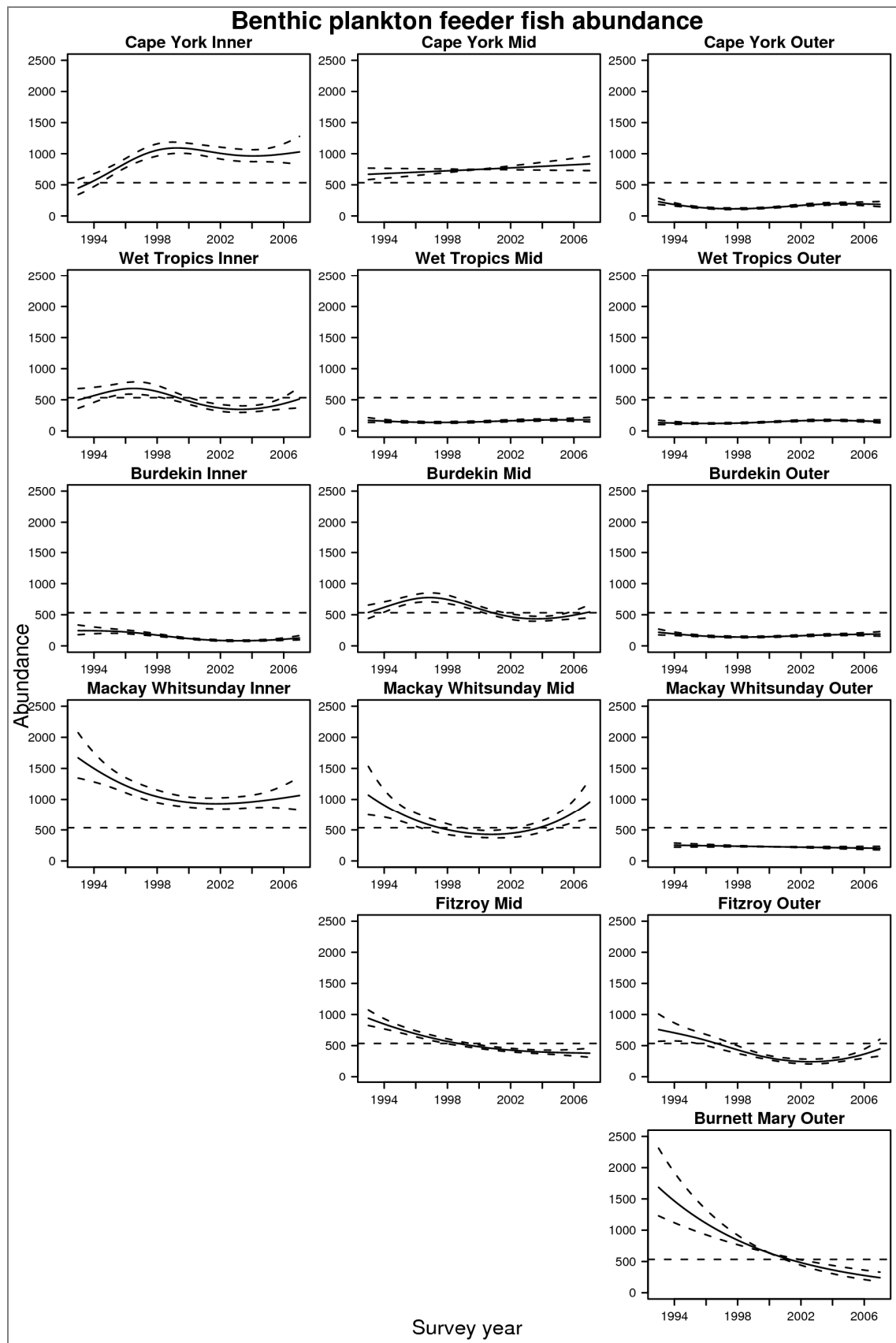


Figure 7.23: Estimated temporal trends of benthic/plankton feeder fish abundance across shelf positions in each NRM zone across the GBR. Solid lines represent mean estimated trend; dashed lines represent approximate 95% confidence intervals. Horizontal dashed line represents GBR mean.

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Appendix 1

Summary of potential indicators by geographic distribution of extreme values and by relation to water quality variables

Indicator group	Sub-categories	Biological basis	Relation to		Geographic distribution	
			Secchi depth	Chlorophyll	High	Low
➤ Benthic cover (groups)	Hard coral	Major structural component of coral reefs	None (p.35)	Weak Neg @ low-mid range (p.35)	Burnett-Mary reefs (Figure 3.1)	Inshore and mid-shelf reefs: Wet Tropics, Burdekin, Offshore reefs: Fitzroy (Figure 3.1)
	Soft coral		–	–	Offshore reefs Mackay-Whitsundays, Fitzroy (Figure 3.2)	Offshore reefs: Cape York; Midshelf reefs: Mackay-Whitsundays (Figure 3.2)
	Algae	Mixture of all types of algae with contrasting distributions	–	–		
➤ Benthic cover (hard coral genera)	<i>Acropora</i>	Preferred food of <i>Acanthaster planci</i> , susceptible to thermal bleaching	–	–	Offshore reefs: Cape York, Burnett-Mary (Figure 3.4)	Inshore and mid-shelf reefs: Cape York to Mackay-Whitsundays (Figure 3.4)
	<i>Goniopora</i>	Inshore, sediment-tolerant taxon	–	–	Inshore reefs: Wet Tropics and Burdekin (Figure 3.5)	Offshore reefs: Cape York (Figure 3.5)
	<i>Montipora</i>	Common coral taxon	–	–	All reefs Mackay-Whitsundays to Burnett-Mary (Figure 3.6)	Mid- and Offshore reefs: Cape York to Burdekin (Figure 3.6)
	<i>Pocillopora</i>	Common coral taxon, susceptible to thermal bleaching	–	–	Offshore reefs: Cape York to Burdekin (Figure 3.7)	Inshore reefs: Wet Tropics to Mackay-Whitsundays (Figure 3.7)
	<i>Porites</i>	Common and resistant coral taxon	–	–	Inshore reefs: Cape York to Wet Tropics; Outer reefs: Fitzroy (Figure 3.8)	Offshore reefs: Cape York to Burdekin; All reefs Burnett-Mary (Figure 3.8)
➤ Benthic cover 2	Reef-wide hard coral cover (from manta tow – for comparison)					

Indicator group	Sub-categories	Biological basis	Relation to		Geographic distribution	
			Secchi depth	Chlorophyll	High	Low
➤ Crown-of-thorns starfish (COTS)	Proportion of reefs 'COTS affected'		Major predator of hard corals	Positive (p. 35)	Positive low-mid; negative mid-high (p. 35)	Midshelf reefs: Wet Tropics and Burdekin; Offshore reefs: Fitzroy (Figure 3.13)
➤ Algae cover	Macroalgae	Thrives in conditions of high nutrients with low herbivory, excludes coral recruits	None (p. 35)	None (p. 35)	Inshore reefs: Wet Tropics; Burdekin (Figure 3.9)	All reefs: Mackay-Whitsundays (Figure 2.6)
	Coralline algae	Sensitive to sediment? Settlement cue for some hard corals and COTS	–	–	Offshore reefs: Cape York to Wet Tropics (Figure 3.10)	Inshore reefs: Mackay-Whitsundays, Fitzroy (Figure 3.10)
	Turf algae	Rapidly occupies vacant space	–	–	Inshore reefs: Cape York, Wet Tropics; Mid-shelf reefs: Wet Tropics to Burdekin, Fitzroy; Offshore reefs: Fitzroy (Figure 3.11)	All reefs: Mackay-Whitsundays; Offshore reefs: Cape York, Wet Tropics, Burnett-Mary; Inshore reefs: Burdekin (Figure 3.11)
➤ Fish abundance (by trophic group)	Herbivores	Role in regulation of macroalgae, relationship with sedimentation	–	–	Offshore reefs: except in Mackay-Whitsundays and Fitzroy (Figure 3.18)	Inshore reefs: Burdekin to Fitzroy (Figure 3.18)
	Planktivores	Large component of many fish assemblages, visual predators?	–	–	Mid- and Outer-reefs: Burdekin and Mackay-Whitsundays (Figure 3.19)	Inshore reefs: Wet Tropics, Fitzroy and Burnett-Mary (Figure 3.19)
	Predators	Includes many fishery target spp.	–	–	Inshore reefs: Cape York; Mid-shelf reefs: Wet Tropics; Offshore reefs: Fitzroy and Burnett-Mary (Figure 3.20)	Inshore reefs: Burdekin to Fitzroy (Figure 3.20)
	Benthic feeders	Includes some fishery target spp.	–	–	Outer-reefs: Burnett-Mary (Figure 3.21)	Inshore reefs: Wet Tropics to Mackay-Whitsunday; Midshelf reefs: Burdekin (Figure 3.21)
	Benthic plankton feeders		–	–	Inshore reefs: Cape York (Figure 3.22)	Inshore reefs: Wet Tropics; Offshore reefs generally (Figure 3.22)

Indicator group	Sub-categories	Biological basis	Relation to		Geographic distribution	
			Secchi depth	Chlorophyll	High	Low
➤ Fish community	Total abundance	Common indicators of ecosystem integrity, often related to coral cover and/or structural complexity	Positive (p. 35)	Positive low-mid; negative mid - high (p. 35)	Mid-shelf and Offshore reefs: Burdekin and Mackay-Whitsunday (Figure 3.14)	Inshore: Wet Tropics, Burdekin, Fitzroy, Burnett-Mary; Offshore: Mackay-Whitsundays (Figure 3.14)
	Richness		Positive (p. 35)	None	Offshore reefs generally (Figure 3.15)	Burdekin; Fitzroy (Figure 3.15)
	Shannon diversity		Positive (p. 35)	None	All reefs: Cape York; Offshore reefs generally: Burnett-Mary (Figure 3.16)	Inshore reefs: Burdekin, Mid-shelf reefs: Mackay-Whitsundays (Figure 3.16)
	Simpson diversity		–	–	Outer reefs: Cape York, Wet Tropics (Figure 3.17)	Inshore reefs: Burdekin, Mackay-Whitsundays (Figure 3.17)
➤ Composite indices	Benthic		–	–	Inshore and offshore reefs: Cape York; Outer reefs: Mackay-Whitsunday, Fitzroy and Burnett-Mary (Figure 2.12)	Inshore and mid-shelf reefs: Wet Tropics and Burdekin (Figure 2.10)
	Fish		–	–	Outer reefs generally (Figure 2.12)	Inshore reefs: Burdekin (Figure 2.10)

Further Information

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