Technical information supporting the 2023 Seagrass: cover within sampling sites environmental trend and condition report card

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Acknowledgement of Country

We acknowledge and respect the Traditional Custodians whose ancestral lands we live and work upon and we pay our respects to their Elders past and present. We acknowledge and respect their deep spiritual connection and the relationship that Aboriginal and Torres Strait Islanders people have to Country. We also pay our respects to the cultural authority of Aboriginal and Torres Strait Islander people and their nations in South Australia, as well as those across Australia.

Acknowledgements

The current version of this report and associated report card was prepared by Nigel Willoughby (DEW) and Craig Meakin (DEW). Simon Bryars (DEW) provided principal oversight throughout and technical review of this report. Tom Prowse (The University of Adelaide) provided an early sounding board regarding the general analysis methods used, their interpretation into classes and basic diagnostic checks on the results of Bayesian analyses. Improvements were made to this report, and associated report cards, based on reviews by: Fi Taylor (DEW); Sandy Carruthers (DEW); Amy Ide (DEW); Matt Nelson (Environment Protection Authority); Sam Gaylard (Environment Protection Authority); and Warwick Noble (Environment Protection Authority) with prior contributions by Jason Vanlaarhoven (DEW).

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Summary

The 2023 release of South Australia's environmental trend and condition report cards summarises our understanding of the current condition of the South Australian environment, and how it is changing over time.

This document describes the indicators, information sources, analysis methods and results used to develop this report and the associated 2023 Seagrass: cover within sampling sites report card. The reliability of information sources used in the report card is also described.

The Seagrass: cover within sampling sites report card sits within the report card Biodiversity theme and Coastal and marine sub-theme. Report cards are published by the Department for Environment and Water and can be accessed at www.environment.sa.gov.au.

1 Introduction

1.1 Environmental trend and condition reporting in SA

The Minister for Climate, Environment and Water under the *Landscape South Australia Act 2019* is required to 'monitor, evaluate and audit the state and condition of the State's natural resources, coasts and seas; and to report on the state and condition of the State's natural resources, coasts and seas' (9(1(a-b)). Environmental trend and condition report cards are produced as the primary means for the Minister to undertake this reporting. Trend and condition report cards are also a key input into the State of the Environment Report for South Australia, which must be prepared under the *Environment Protection Act 1993*. This Act states that the State of the Environment Report must:

- include an assessment of the condition of the major environmental resources of South Australia (112(3(a))), and
- include a specific assessment of the state of the River Murray, especially taking into account the Objectives for a Healthy River Murray under the *River Murray Act 2003* (112(3(ab))), and
- identify significant trends in environmental quality based on an analysis of indicators of environmental quality (112(3(b))).

1.2 Purpose and benefits of SA's environmental trend and condition report cards

South Australia's environmental trend and condition report cards focus on the state's priority environmental assets and the pressures that impact on these assets. The report cards present information on trend, condition, and information reliability in a succinct visual summary.

The full suite of report cards captures patterns in trend and condition, generally at a state scale, and gives insight to changes in a particular asset over time. They also highlight gaps in our knowledge on priority assets that prevent us from assessing trend and condition and might impede our ability to make evidence-based decisions.

Although both trend and condition are considered important, the report cards give particular emphasis to trend. Trend shows how the environment has responded to past drivers, decisions, and actions, and is what we seek to influence through future decisions and actions.

The benefits of trend and condition report cards include to:

- provide insight into our environment by tracking its change over time
- interpret complex information in a simple and accessible format
- provide a transparent and open evidence base for decision-making
- provide consistent messages on the trend and condition of the environment in South Australia
- highlight critical knowledge gaps in our understanding of South Australia's environment
- support alignment of environmental reporting, ensuring we 'do once, use many times'.

Environmental trend and condition report cards are designed to align with and inform state of the environment reporting at both the South Australian and national level. The format, design and accessibly of the report cards has been reviewed and improved with each release.

1.3 Seagrass

Seagrasses are flowering plants that grow underwater in coastal and marine environments. They evolved from land plants and adapted to marine life around 100 million years ago. Seagrasses are a valuable coastal resource, forming extensive beds or meadows comprising many individual plants. Around 40 times more animals occur in seagrass than in adjacent bare sand. They are often regarded as a marine forest and play a vital role in maintaining the marine food web and coastal stability. Seagrasses are found growing on sandy or muddy bottoms in estuaries, coastal lagoons, gulfs and sheltered bays, and at the base of exposed cliffs. Eleven species of seagrasses are known to occur in South Australia covering an area of approximately 9620 km^2. This report focuses on two genera of seagrass: *Posidonia* and *Amphibolis* as these are key genera in forming large, stable meadows.

Seagrasses are very important sediment stabilisers and trappers but a third of seagrass meadows along the Adelaide metropolitan coast have died since 1950. Most of the seagrass has been lost within two kilometers from shore. At a distance of four kilometers offshore, seagrasses appear to be relatively healthy. Extensive offshore loss occurred around the Port Adelaide and Glenelg wastewater treatment plant sludge outfalls, but these are no longer in use. Poor water quality resulting from stormwater run-off and effluent disposal has most likely been the initial cause of seagrass loss. Once there are gaps in the seagrass meadows, the sand below the meadow edge can be eroded by waves. This is thought to have increased the rate of seagrass loss and made it difficult for plants to recolonise the seafloor, even though water quality has improved. Fine-grained sand that was once trapped by seagrass meadows has been released and washed ashore. Because the sand is fine, it accumulates in the sandbars and washes north to Largs Bay. Although in the short term this sand has added to protection of the coast, it is unsuitable for replenishing Adelaide’s beaches in the longer term. This is because it tends to remain in the underwater part of the beach and is moved too quickly by waves.

As a result of the loss of sand from the seabed, the level of the seabed has steadily become up to one metre deeper and the wave energy reaching our beaches has increased. This causes a larger quantity of sand to drift north along the coast.

2 Methods

2.1 Indicator

The indicator used for this seagrass report card is cover within sampling sites.

2.2 Data sources

All seagrass cover data was obtained from the the 'nearshore program' of the South Australian Environment Protection Authority's monitoring, evaluation and reporting program for aquatic ecosystems (AECRs). The rationale and methods guiding the collection of the nearshore program are provided in Gaylard *et al.* (2013). Briefly, South Australian nearshore marine waters are sampled based upon bioregions published by Integrated Marine and Coastal Regionalisation of Australia (IMCRA v4.0) and biounits published by Edyvane (1999). A risk-based, three-tiered framework for assessing condition according to an ecological condition gradient is applied within Bioregions and Biounits. This approach ensures that the nearshore program is:

- efficient with respect to the targeting of onground sampling resources
- making more effective use of historical data
- flexible in terms of the nature of the sampling with a capacity to incorporate existing monitoring frameworks
- capable of identifying and responding to knowledge gaps and driving research priorities
- supportive of higher level State of the Environment/State of the Region reporting (such as the LSA Region reporting undertaken by this assessment)
- capable of promoting and prioritising longer-term monitoring (Gaylard *et al.* 2013).

Sites were assigned to South Australian landscape regions (LSA) on the basis of latitude and longitude coordinates. The list of sites and their associated region is given in the [Appendix] (Table 6.1).

2.3 Analysis

Cover of seagrass species (from the genera *Posidonia* and *Amphibolis*) that are not considered to fluctuate too much seasonally, and that are key species in forming large, stable meadows were used in analyses. Other seagrass species were not included in the analysis.

At each visit to a site the seafloor was videoed. Many frames in each video were analysed by the AECRs program. In each frame the percentage cover of reef, seagrass taxa and algae taxa were recorded. Visits in which more than 90% of frames contained reef were omitted from analysis, as were frames from any site that contained any reef cover. The cover of *Posidonia* and *Amphibolis* were then summed in each of the remaining frames and the mean for a visit was used as a data point in the analysis. Sites that were only visited in one year were also removed from the analysis.

A South Australian landscape region needed to have at least five sites and a span of at least five years in order to be included in the analysis.

Analyses were undertaken at the following spatial scales: statewide and LSA regions. At each level of the two spatial scales (statewide and LSA Region [8 levels]), Bayesian generalised linear mixed models were used to test the following:

- for statewide, the effect of time on seagrass cover within sampling sites
- for region, the effect of time and LSA Region on seagrass cover within sampling sites

Figure 2.1 shows the location of LSA Regions.

The following values were estimated using the results of the analysis:

- distribution of credible values for slope (trend)
- distribution of credible values at the last data point (current value = condition)

Analyses were run using the `rstanarm` package (Brilleman *et al.* 2018; Gabry and Goodrich 2020) in `R` (R Core Team 2020). As the response variable was percentage cover, beta regression was used. To account for any dependence in the data, caused by some sites being visited more than once and spatial correlation within marine bioregions, both marine bioregions (Edyvane 1999) and site were included in the analysis as random factors (Zuur *et al.* 2009; Zuur *et al.* 2010).

Generic definitions for trend and condition are provided in Table 2.1 and Table 2.2 respectively, including the specific values used here as thresholds to define the classes. Trend was assigned based on the posterior distribution of credible slope values from a linear regression. There are no established benchmarks against which to classify the condition of seagrass cover within sampling sites.

Table 2.1: Definition of trend classes used

Trend	Description	Threshold
Getting better	Over a scale relevant to tracking change in the indicator it is improving in status with good confidence	Greater than 90% likelihood that cover within sampling sites of seagrass was increasing
Stable	Over a scale relevant to tracking change in the indicator it is neither improving or declining in status	Less than 90% likelihood that cover within sampling sites of seagrass was increasing or decreasing
Getting worse	Over a scale relevant to tracking change in the indicator it is declining in status with good confidence	Greater than 90% likelihood that cover within sampling sites of seagrass was decreasing
Unknown	Data are not available, or are not available at relevant temporal scales, to determine any trend in the status of this resource	-
Not applicable	This indicator of the natural resource does not lend itself to being classified into one of the above trend classes	-

Table 2.2: Definition of condition classes used

Condition	Description	Threshold
Very good	The natural resource is in a state that meets all environmental, economic and social expectations, based on this indicator. Thus, desirable function can be expected for all processes/services expected of this resource, now and into the future, even during times of stress (e.g. prolonged drought)	No agreed threshold
Good	The natural resource is in a state that meets most environmental, economic and social expectations, based on this indicator. Thus, desirable function cannot be expected for all processes/services expected of this resource, now and into the future, even during times of stress (e.g. prolonged drought)	No agreed threshold
Fair	The natural resource is in a state that does not meet some environmental, economic and social expectations, based on this indicator. Thus, desirable function cannot be expected from many processes/services expected of this resource, now and into the future, particularly during times of stress (e.g. prolonged drought)	No agreed threshold

Condition	Description	Threshold
Poor	The natural resource is in a state that does not meet most environmental, economic and social expectations, based on this indicator. Thus, desirable function cannot be expected from most processes/services expected of this resource, now and into the future, particularly during times of stress (e.g. prolonged drought)	No agreed threshold
Unknown	Data are not available to determine the state of this natural resource, based on this indicator	-
Not applicable	This indicator of the natural resource does not lend itself to being classified into one of the above condition classes	-

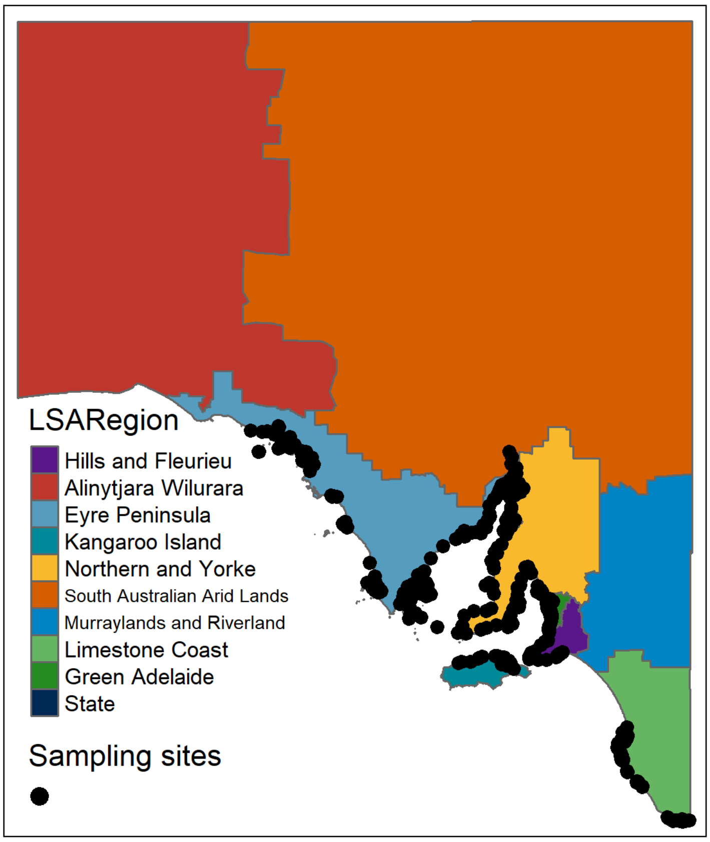

Figure 2.1: South Australian LSA regions including seagrass sampling sites

2.4 Reliability

Information is scored for reliability based on subjective scores (1 [worst] to 5 [best]) given for information currency, applicability and level of spatial representation. Where there is information available regarding accuracy, this is included as well. Definitions guiding the application of these scores are provided in Table 2.3 for currency, Table 2.4 for applicability and Table 2.5 for spatial representation.

The reliability score given on a report card is the minimum of any of those scores. Minimum is used as the average can mask a very low reliability for one of the scores (say, currency if the information is quite old) if other scores are not as low.

Table 2.3: Guides for applying information currency

Currency score	Criteria
1	Most recent information >10 years old
2	Most recent information up to 10 years old
3	Most recent information up to 7 years old
4	Most recent information up to 5 years old
5	Most recent information up to 3 years old

Table 2.4: Guides for applying information applicability

Applicability score	Criteria
1	Data are based on expert opinion of the measure
2	All data based on indirect indicators of the measure
3	Most data based on indirect indicators of the measure
4	Most data based on direct indicators of the measure
5	All data based on direct indicators of the measure

Table 2.5: Guides for applying spatial representation of information (sampling design)

Spatial score	Criteria
1	From an area that represents less than 5% the spatial distribution of the asset within the region/state or spatial representation unknown
2	From an area that represents less than 25% the spatial distribution of the asset within the region/state
3	From an area that represents less than half the spatial distribution of the asset within the region/state
4	From across the whole region/state (or whole distribution of asset within the region/state) using a sampling design that is not stratified
5	From across the whole region/state (or whole distribution of asset within the region/state) using a stratified sampling design

2.5 Workflow

The data import, cleaning, analysis and report writing were done in a scripted workflow using the programs `R` and 'R-studio Desktop'. R (R Core Team 2020) is an open source software environment for statistical computing and graphics. Base R can be extended via a range of open source packages to enable specific tasks or analyses. The packages used to produce this report are listed in Table 2.6.

R-studio Desktop is a set of open source tools built to facilitate interaction with `R`.

A workflow diagram (managing environmental knowledge chart) is provided in Figure 2.2.

Table 2.6: R (R Core Team 2020) packages used in the production of this report

package	citation	loadedversion	date	source
base	R Core Team (2020)	4.0.2	2020-06-22	local
knitr	Xie (2021a)	1.33	2021-04-24	CRAN (R 4.0.5)
bookdown	Xie (2021b)	0.24	2021-09-02	CRAN (R 4.0.5)
devtools	Wickham *et al.* (2021)	2.4.2	2021-06-07	CRAN (R 4.0.5)
dplyr	Wickham *et al.* (2022)	1.0.8	2022-02-08	CRAN (R 4.0.5)
tidyr	Wickham and Girlich (2022)	1.2.0	2022-02-01	CRAN (R 4.0.5)
purrr	Henry and Wickham (2020)	0.3.4	2020-04-17	CRAN (R 4.0.5)
tibble	Müller and Wickham (2021)	3.1.6	2021-11-07	CRAN (R 4.0.5)
readr	Wickham and Hester (2021)	2.0.1	2021-08-10	CRAN (R 4.0.5)
forcats	Wickham (2021)	0.5.1	2021-01-27	CRAN (R 4.0.5)
stringr	Wickham (2019)	1.4.0	2019-02-10	CRAN (R 4.0.5)
lubridate	Spinu *et al.* (2021)	1.7.10	2021-02-26	CRAN (R 4.0.5)
fs	Hester *et al.* (2021)	1.5.2	2021-12-08	CRAN (R 4.0.5)
readxl	Wickham and Bryan (2019)	1.3.1	2019-03-13	CRAN (R 4.0.5)
rio	Chan and Leeper (2021)	0.5.27	2021-06-21	CRAN (R 4.0.5)
svSocket	Grosjean (2022)	1.1.0	2022-05-09	CRAN (R 4.0.2)
GGally	Schloerke *et al.* (2021)	2.1.2	2021-06-21	CRAN (R 4.0.5)
gridExtra	Auguie (2017)	2.3	2017-09-09	CRAN (R 4.0.5)
ggridges	Wilke (2021)	0.5.3	2021-01-08	CRAN (R 4.0.5)
rstan	Guo *et al.* (2020)	2.21.2	2020-07-27	CRAN (R 4.0.5)
rstanarm	Gabry and Goodrich (2020)	2.21.1	2020-07-20	CRAN (R 4.0.5)
sf	Pebesma (2021)	1.0-4	2021-11-14	CRAN (R 4.0.5)

package	citation	loadedversion	date	source
tmap	Tennekes (2021)	3.3-2	2021-06-16	CRAN (R 4.0.5)
envFunc	Willoughby (2023a)	0.0.0.9000	2023-05-31	Github (acanthiza/envFunc@bbeb4c1)
envReport	Willoughby (2023b)	0.0.0.9000	2023-05-31	Github (acanthiza/envReport@bd9b258)

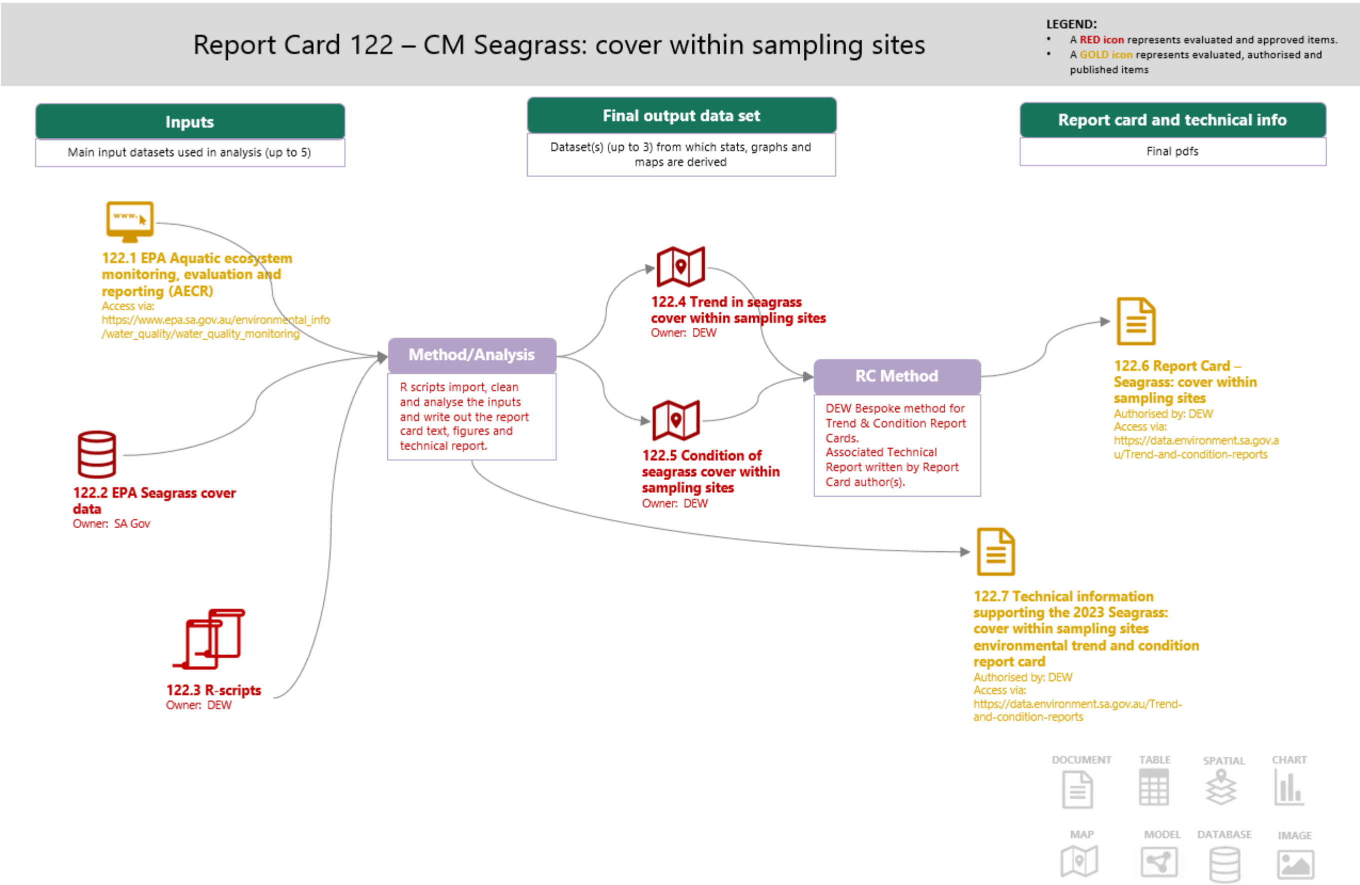

Figure 2.2: Workflow diagram (managing environmental knowledge chart) for seagrass

3 Results

Data cleaning and exploration were based on the process suggested by Zuur *et al.* (2010). Figure 3.1 shows a summary figure of the data remaining after this process. The number of sites in each LSA Region and Year at which seagrass data were available is given in Table 3.1.

Table 3.2 shows a summary of the model outputs and Figure 3.2 shows the mean credible estimate and 90% credible intervals for seagrass cover within sampling sites along with the original data points.

For more detail on data exploration and model specification, diagnostics and summary, see the Appendix.

Table 3.1: Sites at which seagrass cover was measured in each LSA Region and Year.

Year	Season	Total	EP	NY	GA	KI	LC	HF	SAAL
2009	Spring	61	-	26	25	10	-	-	-
2010	Autumn	199	30	35	25	10	-	-	-
2010	Spring	199	30	33	26	10	-	-	-
2011	Autumn	123	-	20	26	10	-	-	-
2011	Spring	123	-	27	30	10	-	-	-
2012	Autumn	46	17	5	-	-	-	-	1
2012	Spring	46	17	5	-	-	-	-	1
2014	Autumn	61	31	-	-	-	-	-	-
2014	Spring	61	30	-	-	-	-	-	-
2015	Autumn	37	-	-	-	-	15	4	-
2015	Spring	37	-	-	-	-	14	4	-
2016	Autumn	36	27	9	-	-	-	-	-
2017	Autumn	74	-	24	28	10	-	-	-
2017	Spring	74	12	-	-	-	-	-	-
2018	Autumn	35	29	5	-	-	-	-	1
2019	Autumn	31	31	-	-	-	-	-	-
2021	Autumn	19	-	-	-	-	15	4	-

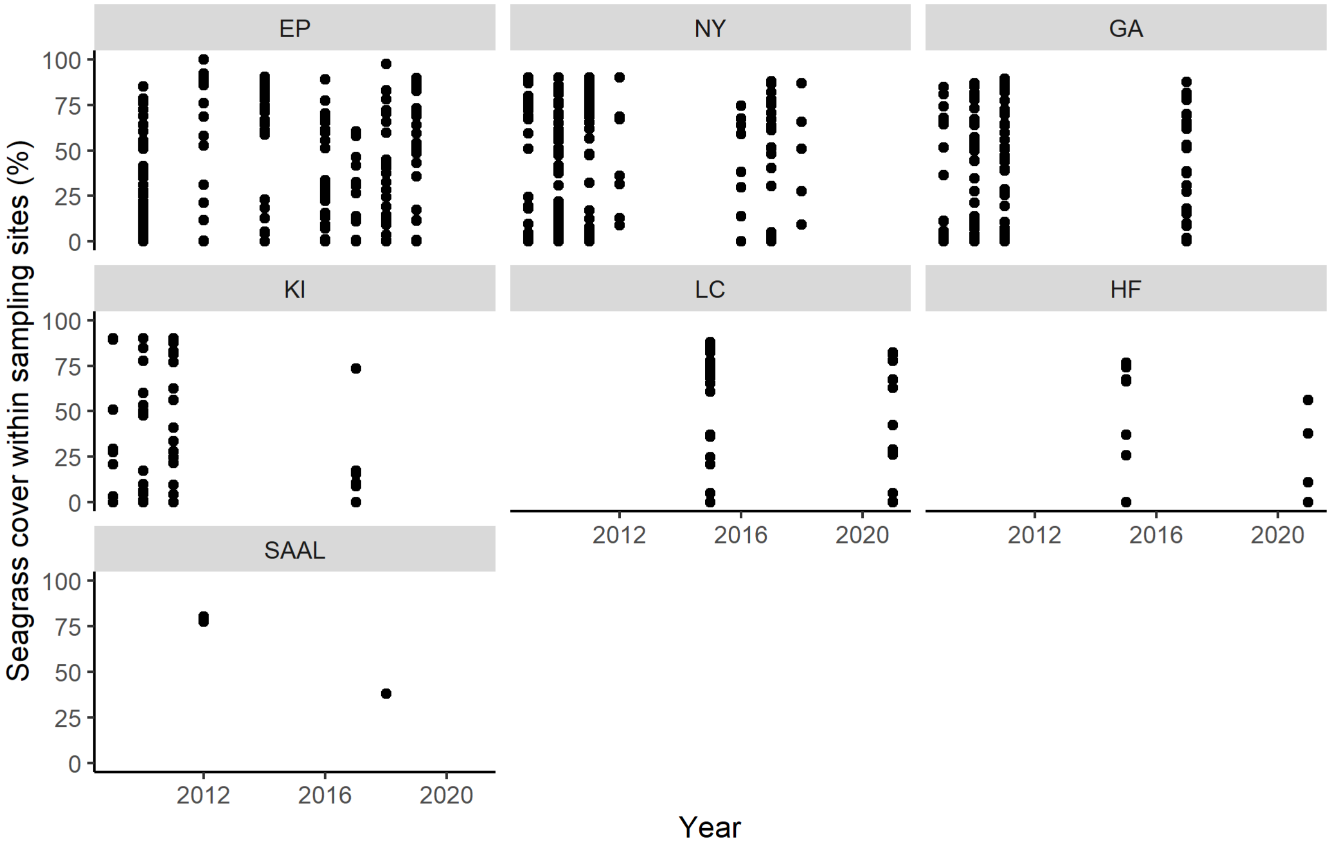

Figure 3.1: Cleaned seagrass cover within sampling sites data ready for analysis

Table 3.2: Posterior description for each parameter in the model. See bayestestR::describe_posterior for definitions of the descriptions and further information

Parameter	Median	CI	CI_low	CI_high	pd
(Intercept)	-1.1	0.9	-2.8	1.5	0.9
LSANY	0.3	0.9	-1.0	1.7	0.7
LSAGA	-0.6	0.9	-2.1	1.1	0.8
LSAKI	-0.7	0.9	-3.8	2.5	0.7
LSALC	0.1	0.9	-2.2	2.3	0.6
LSAHF	0.6	0.9	-3.0	4.3	0.6
LSASAAL	2.6	0.9	-2.0	7.4	0.9
time	0.0	0.9	-0.1	0.1	0.7
LSANY:time	0.0	0.9	-0.1	0.1	0.6
LSAGA:time	0.1	0.9	0.0	0.2	1.0
LSAKI:time	-0.2	0.9	-0.4	0.0	1.0
LSALC:time	-0.1	0.9	-0.2	0.1	0.8
LSAHF:time	-0.1	0.9	-0.4	0.1	0.8
LSASAAL:time	-0.3	0.9	-0.8	0.1	0.9

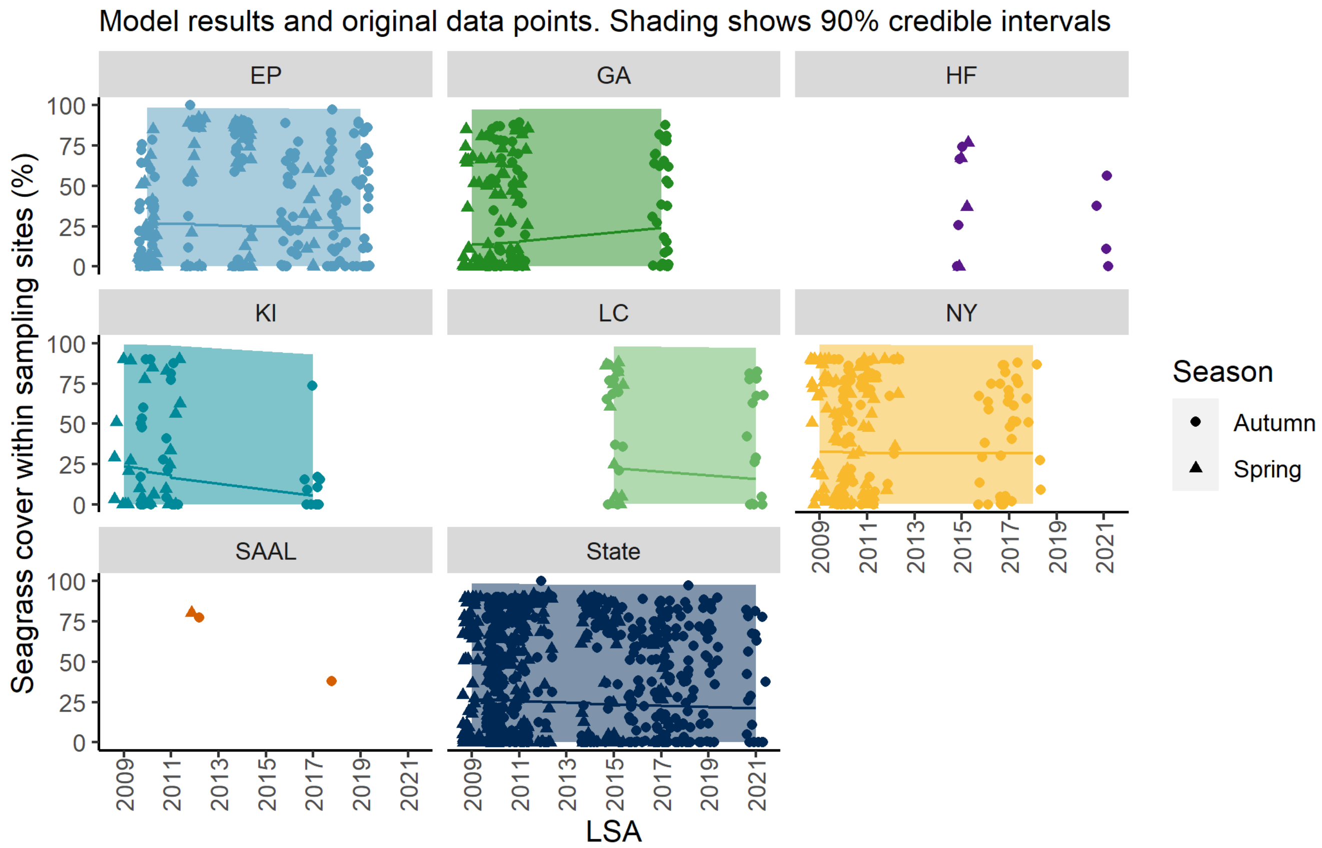

Figure 3.2: Plot of model results, including original data points (jittered slightly)

3.1 Trend

Table 3.3 gives the likelihood of the getting better or getting worse trend classes based on the posterior distribution of slope over all years (Figure 3.3). The distribution relative to zero (which would represent a stable trend) suggests the cover within sampling sites of seagrass across South Australia is stable.

Table 3.3: Likelihood of each trend class for seagrass

LSARegion	Likelihood of getting worse	Likelihood of getting better	Trend
Hills and Fleurieu	-	-	Unknown
Alinytjara Wilurara	-	-	Not applicable
Eyre Peninsula	0.697	0.303	Stable
Kangaroo Island	0.986	0.014	Getting worse
Northern and Yorke	0.515	0.485	Stable
South Australian Arid Lands	-	-	Unknown
Murraylands and Riverland	-	-	Not applicable
Limestone Coast	0.882	0.118	Stable
Green Adelaide	0.029	0.971	Getting better
State	0.817	0.183	Stable

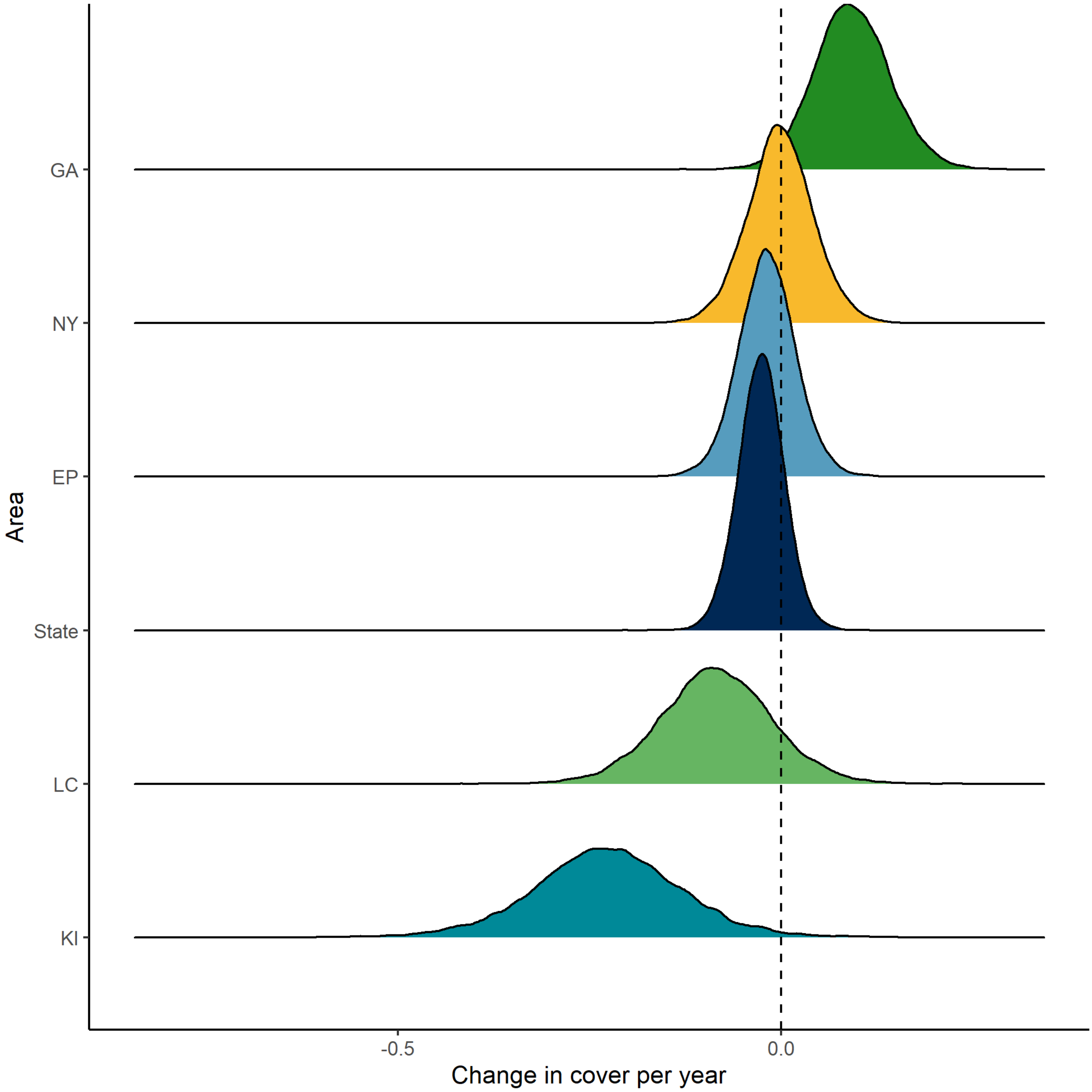

Figure 3.3: Distribution in credible values for trend in seagrass cover within sampling sites

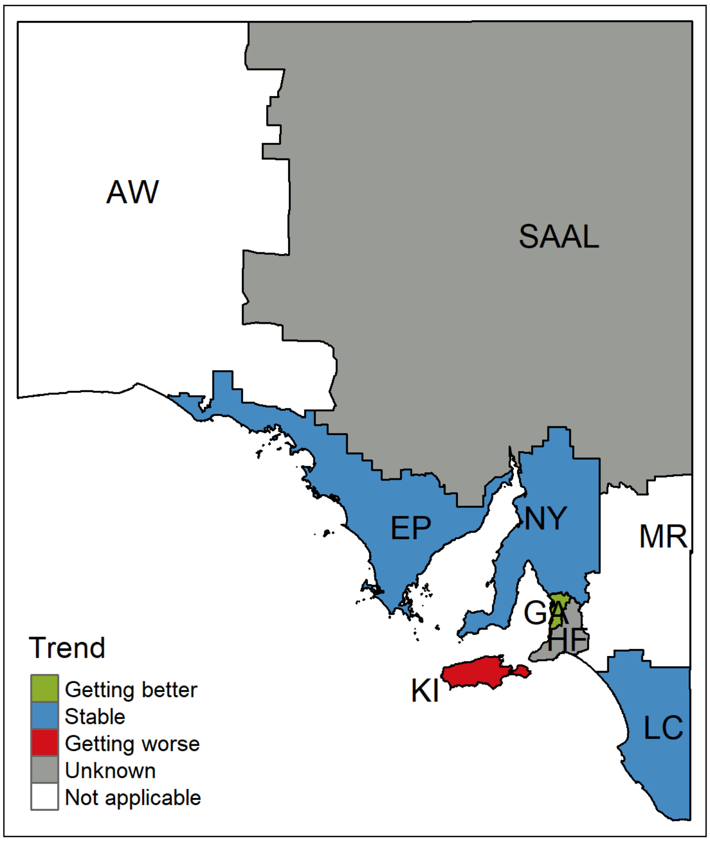

Figure 3.4: Trend in seagrass cover within sampling sites

3.2 Condition

Table 3.4 gives the likelihood of seagrass percentage cover based on the posterior distribution of regional value at the last data point (also see Figure 3.5).

Table 3.4: Estimated seagrass cover within sampling sites at the time of last survey (and 90% credible intervals). The wide credible intervals reflect the wide distribution of cover values (also see Figure 3.5). Condition classes were not assigned as there are no agreed thresholds.

LSA	Last survey	Estimated percentage cover	90% credible interval	Condition
HF	2021	16.6	0.1 to 98.3	Unknown
EP	2019	23.6	0.3 to 97.8	Unknown
KI	2017	5.4	0.0 to 93.3	Unknown
NY	2018	31.9	0.4 to 98.6	Unknown
SAAL	2018	41.2	0.2 to 99.8	Unknown
LC	2021	15.8	0.1 to 97.0	Unknown
GA	2017	23.9	0.3 to 98.1	Unknown
State	2021	21.1	0.2 to 97.7	Unknown

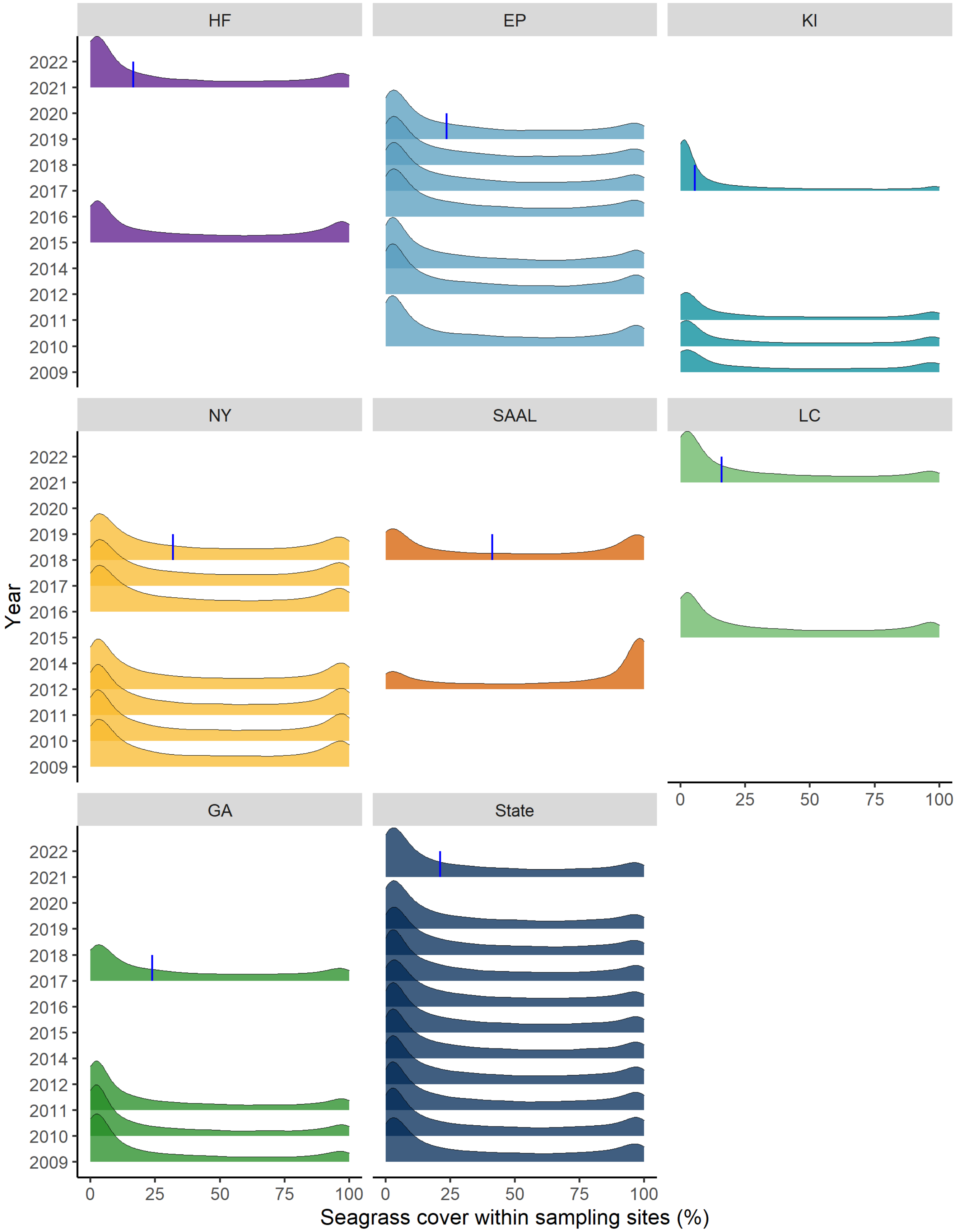

Figure 3.5: Distribution of credible values for seagrass cover within sampling sites (%). Vertical blue line shows the median credible estimate in the last year with data. The wide distribution of credible estimates for seagrass cover within sampling sites highlight the wide distributions in the original data (see Figure 3.1).

3.3 Reliability

The overall reliability score for this report card is 3 out of 5, based on Table 3.5. This is considered to be 'Good' reliability. The data are: a direct measure of the indicator giving a score of 5; with a minimum year of last visit to a LSA Region of 2017 giving a score of 3; and with enough data to generate a trend from 71% of LSA Regions (Edyvane 1999) giving a score of 3.6.

Table 3.5: Information reliability scores for seagrass cover within sampling sites

Indicator	Currency score	Applicability score	Spatial score	Overall
Cover within sampling sites	3	5	3.6	3

4 Discussion

Statewide cover within sampling sites of seagrass was **stable** between 2009 and 2021. The 2021 condition of cover within sampling sites of seagrass was **unknown**, as there are no agreed benchmarks for assigning condition to seagrass cover within sampling sites in South Australia (Table 2.2).

In each of the South Australian landscape regions seagrass cover within sampling sites was getting better in one region [Green Adelaide (GA)], stable in three regions [Eyre Peninsula (EP), Limestone Coast (LC) and Northern and Yorke (NY)], getting worse in one region [Kangaroo Island (KI)], unknown in two regions [Hills and Fleurieu (HF) and South Australian Arid Lands (SAAL)] and not applicable in two regions [Alinytjara Wiluṟara (AW) and Murraylands and Riverland (MR)]. The variable response suggests that seagrass is responding to local catchment conditions.

In the Green Adelaide LSA Region, seagrass cover within sampling sites has been improving after historical losses (e.g. at Grange), most likely due to investment in improved coastal water quality through reduced nutrient loads.

On Kangaroo Island the declining trend and poor condition was previously report by the Environment Protection Authority. Seagrass decline was consistent among all sites within Nepean Bay between survey periods. Epiphytic algae reduced in cover between surveys, however is still an indication of elevated nutrients in freshwater flowing into Nepean Bay. Several sources of elevated nutrients and sediment were identified (agricultural runoff, wastewater treatment and urban runoff) each with associated management actions.

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6 Appendices

6.1 Sites

Table 6.1: List of sites used in this analysis and their South Australian landscape region

LSA	Site	Biounit	Description	Depth (m)	Earliest visit	Last visit	Total visits
EP	m0100	Jussieu	Tulka	5.5	2010	2016	3
EP	m0101	Jussieu	Murray Point	5.0	2010	2016	3
EP	m0102	Jussieu	East of Horse Rock	7.0	2010	2018	5
EP	m0103	Jussieu	Axel Stenross	12.0	2010	2016	3
EP	m0104	Jussieu	Lincoln town jetty	8.0	2010	2018	5
EP	m0105	Jussieu	North Shields	7.5	2010	2018	5
EP	m0106	Jussieu	Inside Boston Bay	14.0	2010	2016	3
EP	m0107	Jussieu	West Maria Point	7.0	2010	2016	3
EP	m0108	Jussieu	Billy Lights Point	11.0	2010	2018	5
EP	m0109	Jussieu	Inside Boston Island	9.0	2010	2018	5
EP	m0110	Jussieu	Rotten Bay	9.0	2010	2018	5
EP	m0111	Jussieu	Louth Island	6.0	2010	2018	5
EP	m0112	Jussieu	Louth Bay	10.0	2010	2016	3
EP	m0113	Jussieu	Point Boston	14.0	2010	2018	5
EP	m0114	Jussieu	Peake Point	10.0	2010	2016	3
EP	m0115	Jussieu	Peake Bay inner	7.5	2010	2018	5
EP	m0116	Jussieu	Point Warna	9.0	2010	2016	3
EP	m0117	Jussieu	Inside Bolingbroke	12.0	2010	2018	4
EP	m0118	Jussieu	Spalding Cove	7.0	2010	2018	5
EP	m0119	Franklin	Franklin Harbour	3.0	2010	2016	3
EP	m0120	Franklin	Cowell inner	12.0	2010	2016	3
EP	m0121	Franklin	Cowell outer	3.0	2010	2016	3
EP	m0122	Jussieu	Cape Donington	7.5	2010	2016	3
EP	m0123	Franklin	Arno Bay	4.5	2010	2016	3
EP	m0124	Jussieu	Taylor Island	12.5	2010	2016	3
EP	m0125	Jussieu	Tumby Bay	7.0	2010	2018	4
EP	m0126	Jussieu	Thistle Island	7.0	2010	2016	3
EP	m0200	Yonga	Pines	4.5	2012	2018	3
EP	m0201	Yonga	Plank point	5.5	2012	2018	3
EP	m0206	Yonga	Shoalwater Point Nth	5.5	2012	2018	3
EP	m0208	Yonga	Shoalwater Point Sth	10.5	2012	2018	3
EP	m0209	Yonga	Lucky Bay W	4.5	2012	2018	3
EP	m0217	Winninowie	Fitzgerald Bay Sth	10.0	2012	2018	3
EP	m0243	Yonga	Black Point	10.0	2012	2018	3

LSA	Site	Biounit	Description	Depth (m)	Earliest visit	Last visit	Total visits
EP	m0244	Yonga	Stony Point	8.0	2012	2018	3
EP	m0245	Yonga	One Steel	4.0	2012	2018	3
EP	m0246	Yonga	False Bay outer	6.5	2012	2018	3
EP	m0250	Yonga	Black Point inner	7.0	2012	2018	3
EP	m0252	Yonga	Whyalla Sth	9.0	2012	2018	3
EP	m0254	Yonga	Eight Mile Creek Beach Nth	13.0	2012	2018	3
EP	m0255	Yonga	Eight Mile Creek Beach Sth	3.5	2012	2018	3
EP	m0256	Yonga	Murrippi Beach	3.0	2012	2018	3
EP	m0258	Yonga	Western Shoal Sth	14.0	2012	2018	3
EP	m0259	Yonga	Cowleds Landing	10.0	2012	2018	3
EP	m0400	Douglas	West Rabbit Island	3.5	2010	2019	5
EP	m0401	Douglas	Farm Beach	4.0	2010	2019	5
EP	m0402	Douglas	North Brothers	2.5	2010	2019	5
EP	m0403	Douglas	Kellidie Bay	3.0	2010	2019	5
EP	m0404	Douglas	East Rabbit Island	4.0	2014	2019	3
EP	m0407	Douglas	West Dutton Bay	6.0	2014	2019	3
EP	m0408	Douglas	West Coffin Bay	6.0	2014	2019	3
EP	m0409	Douglas	Bulldog Point	4.0	2014	2019	3
EP	m0411	Douglas	Outside Longnose	4.0	2014	2019	3
EP	m0412	Douglas	Point Sir Issac	4.0	2014	2019	3
EP	m0413	Douglas	Outside Coffin Bay	7.0	2014	2019	3
EP	m0421	Yanerbie	Port Kenny	2.0	2014	2019	3
EP	m0422	Yanerbie	Venus Bay Islands	3.0	2014	2019	3
EP	m0423	Yanerbie	Venus Bay	3.0	2014	2019	3
EP	m0425	Yanerbie	West Venus Bay	3.0	2014	2019	3
EP	m0427	Streaky	Blanche Port	2.0	2014	2019	3
EP	m0428	Streaky	Point Gibson	2.0	2014	2019	3
EP	m0429	Streaky	Pigface Island	3.0	2014	2019	3
EP	m0432	Streaky	Inside Dashwood rock	12.0	2014	2019	3
EP	m0433	Streaky	Warburton Channel	11.0	2014	2019	3
EP	m0434	Streaky	West of Point Lindsay	5.0	2014	2019	3
EP	m0435	Nuyts	Franklin Islands South	10.0	2014	2019	3
EP	m0437	Streaky	Cape Missiessy	4.0	2014	2019	3
EP	m0438	Streaky	Smoky Bay	2.0	2014	2019	3
EP	m0440	Streaky	Eyre Island	2.0	2014	2019	2
EP	m0442	Streaky	Laura Bay	5.0	2014	2019	3
EP	m0443	Streaky	St Peter Island	3.0	2014	2019	3
EP	m0447	Streaky	Ceduna	5.0	2014	2019	3

LSA	Site	Biounit	Description	Depth (m)	Earliest visit	Last visit	Total visits
EP	m0448	Streaky	Murat Bay North	4.0	2014	2019	3
EP	m0449	Fowlers	East of Point Bell	8.0	2014	2019	3
EP	m0450	Nuyts	Franklin Islands North	12.0	2014	2019	3
NY	m0001	Clinton	Port Clinton	3.5	2009	2017	5
NY	m0002	Clinton	Sandy Point	4.0	2009	2017	5
NY	m0003	Clinton	Proof Range	5.0	2009	2017	5
NY	m0004	Clinton	Price	5.5	2009	2017	5
NY	m0005	Clinton	Bald Spit	7.0	2009	2017	5
NY	m0006	Clinton	Sandy Point Sth	8.0	2009	2011	4
NY	m0007	Clinton	Ardrossan Nth	12.0	2009	2017	6
NY	m0008	Orontes	Rouges Point	10.5	2009	2017	6
NY	m0009	Orontes	Pine Point Nth	5.5	2009	2017	6
NY	m0010	Orontes	Pine Point	7.5	2009	2017	6
NY	m0011	Orontes	Pt Julia	6.5	2009	2017	6
NY	m0012	Orontes	Red Cliffs	6.0	2009	2011	5
NY	m0013	Orontes	Vincent outer	5.0	2009	2011	5
NY	m0014	Orontes	Vincent inner	8.0	2009	2017	6
NY	m0015	Orontes	Stansbury	5.5	2009	2017	6
NY	m0016	Orontes	Orontes Bank	6.5	2009	2017	6
NY	m0017	Orontes	Stansbury Nth	6.5	2009	2017	6
NY	m0018	Orontes	Klein Point	10.0	2009	2017	6
NY	m0019	Orontes	Wool Bay	5.0	2009	2017	6
NY	m0020	Orontes	Edithburgh	12.0	2009	2017	6
NY	m0021	Orontes	Troubridge Island	3.5	2009	2017	6
NY	m0066	Orontes	Coobowie Bay Sth	3.5	2011	2017	3
NY	m0068	Clinton	Pt Gawler outer	10.0	2009	2017	6
NY	m0069	Clinton	Pt Gawler Sth	11.0	2009	2017	6
NY	m0070	Clinton	Pt Gawler Nth	6.0	2009	2017	6
NY	m0071	Clinton	Port Prime	3.0	2009	2017	5
NY	m0072	Clinton	Parham Sth	3.5	2009	2017	6
NY	m0127	Wardang	Corny Point	4.0	2010	2016	2
NY	m0128	Wardang	Point Souttar	11.5	2010	2016	3
NY	m0129	Wardang	Point Pearce	4.5	2010	2016	3
NY	m0130	Wardang	Hardwicke Bay	9.0	2010	2016	2
NY	m0131	Wardang	Port Victoria	10.5	2010	2016	3
NY	m0132	Tiparra	Moonta inner	7.0	2010	2016	3
NY	m0133	Tiparra	Cape Elizabeth	7.0	2010	2016	3
NY	m0134	Tiparra	Moonta Bay	5.5	2010	2016	3
NY	m0135	Tiparra	Wallaroo	6.5	2010	2016	3
NY	m0218	Winninowie	Ward Point	5.5	2012	2018	3

LSA	Site	Biounit	Description	Depth (m)	Earliest visit	Last visit	Total visits
NY	m0220	Yonga	Woods Point Nth	5.5	2012	2018	3
NY	m0222	Yonga	Fisherman Bay Nth	10.5	2012	2018	3
NY	m0229	Yonga	Myponie Point	8.0	2012	2018	3
NY	m0234	Yonga	Germein Bay	6.5	2012	2018	3
GA	m0022	Yankalilla	Sellicks	6.5	2009	2011	4
GA	m0023	Clinton	Pt Gawler	4.5	2009	2017	6
GA	m0024	Clinton	Outer Harbour	11.5	2009	2017	5
GA	m0025	Adelaide Metro	Barker Inlet	3.0	2009	2017	6
GA	m0026	Clinton	Outer Harbour Nth	10.5	2009	2017	6
GA	m0027	Clinton	Outer Harbour Sth	11.5	2009	2017	6
GA	m0028	Adelaide Metro	Semaphore Pk inner	6.0	2009	2017	6
GA	m0029	Clinton	Semaphore Pk outer	12.0	2009	2017	6
GA	m0030	Clinton	West Lakes	6.5	2009	2017	6
GA	m0031	Clinton	Tennyson	10.5	2009	2017	6
GA	m0032	Clinton	Henley	9.0	2009	2017	5
GA	m0033	Adelaide Metro	Henley Beach Sth	1.5	2009	2010	3
GA	m0034	Clinton	West Beach outer	7.5	2009	2017	6
GA	m0035	Adelaide Metro	West Beach inner	3.5	2009	2017	6
GA	m0036	Adelaide Metro	Glenelg	2.5	2009	2010	3
GA	m0037	Clinton	Somerton outer	10.0	2009	2017	6
GA	m0038	Clinton	Somerton inner	6.5	2009	2017	6
GA	m0039	Yankalilla	Hallet Cove	6.0	2009	2017	6
GA	m0040	Yankalilla	Southport	12.0	2010	2011	3
GA	m0041	Yankalilla	Seaford	12.0	2009	2011	4
GA	m0042	Yankalilla	Maslin Beach	11.0	2009	2017	6
GA	m0043	Adelaide Metro	Grange Nth	5.5	2009	2017	6
GA	m0044	Adelaide Metro	Grange	6.0	2009	2017	5
GA	m0045	Clinton	Brighton	9.5	2009	2017	6
GA	m0046	Yankalilla	Port Stanvac	11.0	2009	2017	6
GA	m0047	Yankalilla	O'Sullivans Beach	5.5	2009	2010	3
GA	m0058	Adelaide Metro	Black Pole inner	3.0	2011	2017	3
GA	m0059	Clinton	Black Pole outer	8.0	2011	2017	3
GA	m0060	Adelaide Metro	Torrens	6.0	2011	2017	3

LSA	Site	Biounit	Description	Depth (m)	Earliest visit	Last visit	Total visits
GA	m0061	Adelaide Metro	Glenelg	6.0	2011	2017	3
GA	m0062	Yankalilla	O'Sullivans Beach outer	10.0	2011	2017	3
GA	m0063	Yankalilla	Southport outer	13.0	2011	2017	3
GA	m0064	Yankalilla	Seaford outer	12.0	2011	2017	3
GA	m0067	Yankalilla	Sellicks outer	12.5	2011	2017	2
KI	m0048	Nepean	Outside Spit	5.5	2009	2017	6
KI	m0049	Nepean	Bay of Shoals	2.0	2009	2017	6
KI	m0050	Nepean	Eastern Cove	9.0	2009	2017	6
KI	m0051	Nepean	Inside Spit	4.5	2009	2017	6
KI	m0052	Nepean	Nepean offshore	10.0	2009	2017	6
KI	m0053	Nepean	Kingscote	6.0	2009	2017	6
KI	m0054	Nepean	Western Cove Outer	6.0	2009	2017	6
KI	m0055	Nepean	Point Morrison	10.0	2009	2017	6
KI	m0056	Nepean	Western Cove Inner	3.0	2009	2017	6
KI	m0057	Nepean	Frenchmans	6.0	2009	2017	6
LC	m0505	Coorong	Maria south	3.0	2015	2021	3
LC	m0517	Coorong	Port Caroline	7.0	2015	2021	3
LC	m0523	Coorong	Hog Lake	4.5	2015	2021	3
LC	m0525	Coorong	Cape Jaffa Jetty	2.5	2015	2021	3
LC	m0526	Canunda	Bernouilli	4.0	2015	2021	3
LC	m0528	Canunda	Boatswain Point	5.0	2015	2021	3
LC	m0534	Coorong	Butchers Drain south	3.5	2015	2021	3
LC	m0536	Canunda	Stinky Beach	4.2	2015	2021	3
LC	m0543	Canunda	Nora Creina north	3.2	2015	2021	3
LC	m0544	Coorong	Butchers Drain	4.0	2015	2021	3
LC	m0545	Coorong	Blackford Drain North	3.0	2015	2021	2
LC	m0546	Nene	Douglas Point	6.0	2015	2021	3
LC	m0548	Canunda	Umperhstone Bay	4.0	2015	2021	3
LC	m0550	Piccaninnie	Cape Northumberland	12.5	2015	2021	3
LC	m0560	Coorong	Maria	2.5	2015	2021	3
HF	m0506	Encounter	West Island	-	2015	2021	3
HF	m0507	Encounter	Wright Island	4.0	2015	2021	3
HF	m0509	Encounter	Granite Island	-	2015	2021	3
HF	m0510	Encounter	Causeway	-	2015	2021	3
SAAL	m0211	Winninowie	Miranda	4.0	2012	2018	3

6.2 Model evaluation

6.2.1 Data exploration

Figures 6.1 and 6.2 show the distribution of levels and values within each of the variables.

Figures 6.3 and 6.4 show the response variable (seagrass cover within sampling sites) against each of the variables in the data.

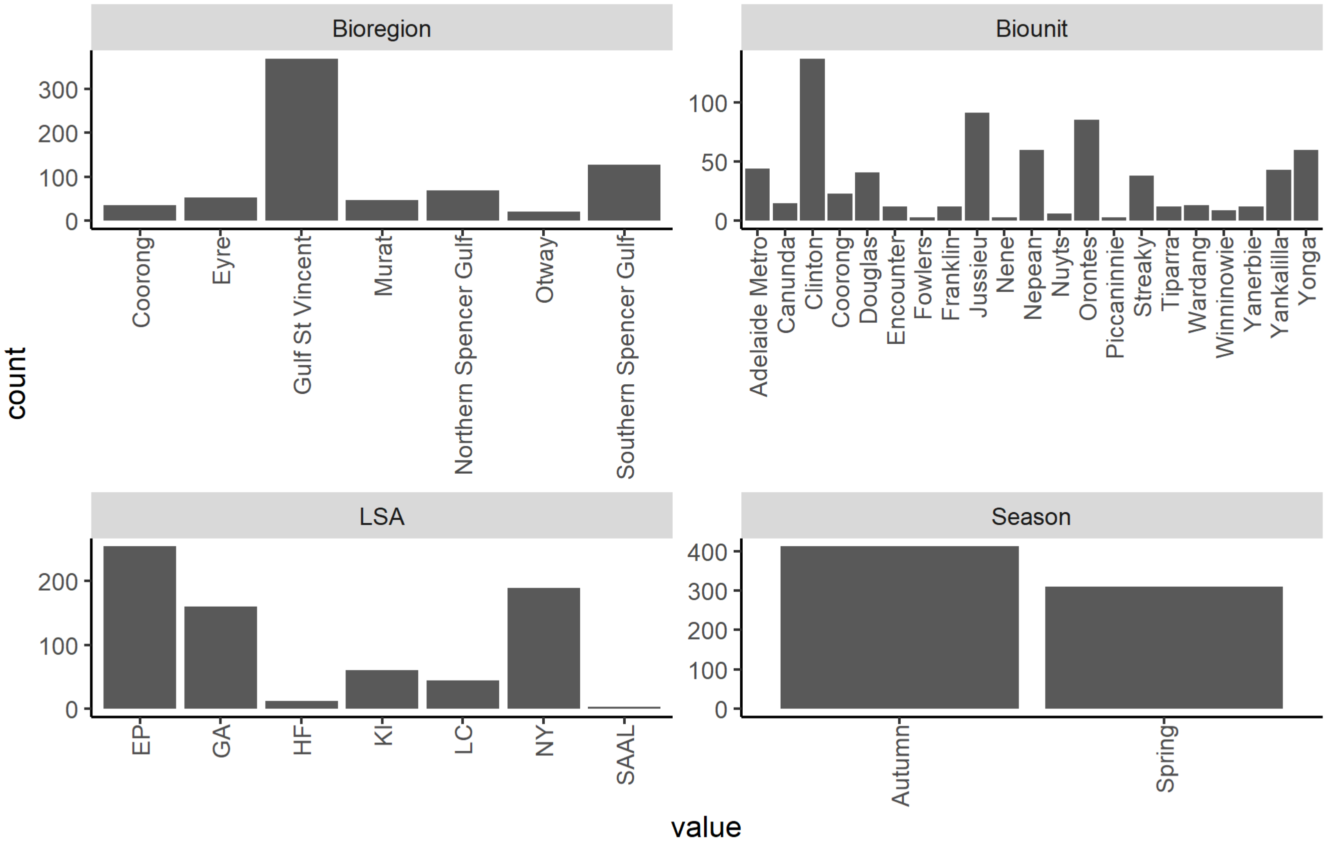

Figure 6.1: Count at each level within discrete variables

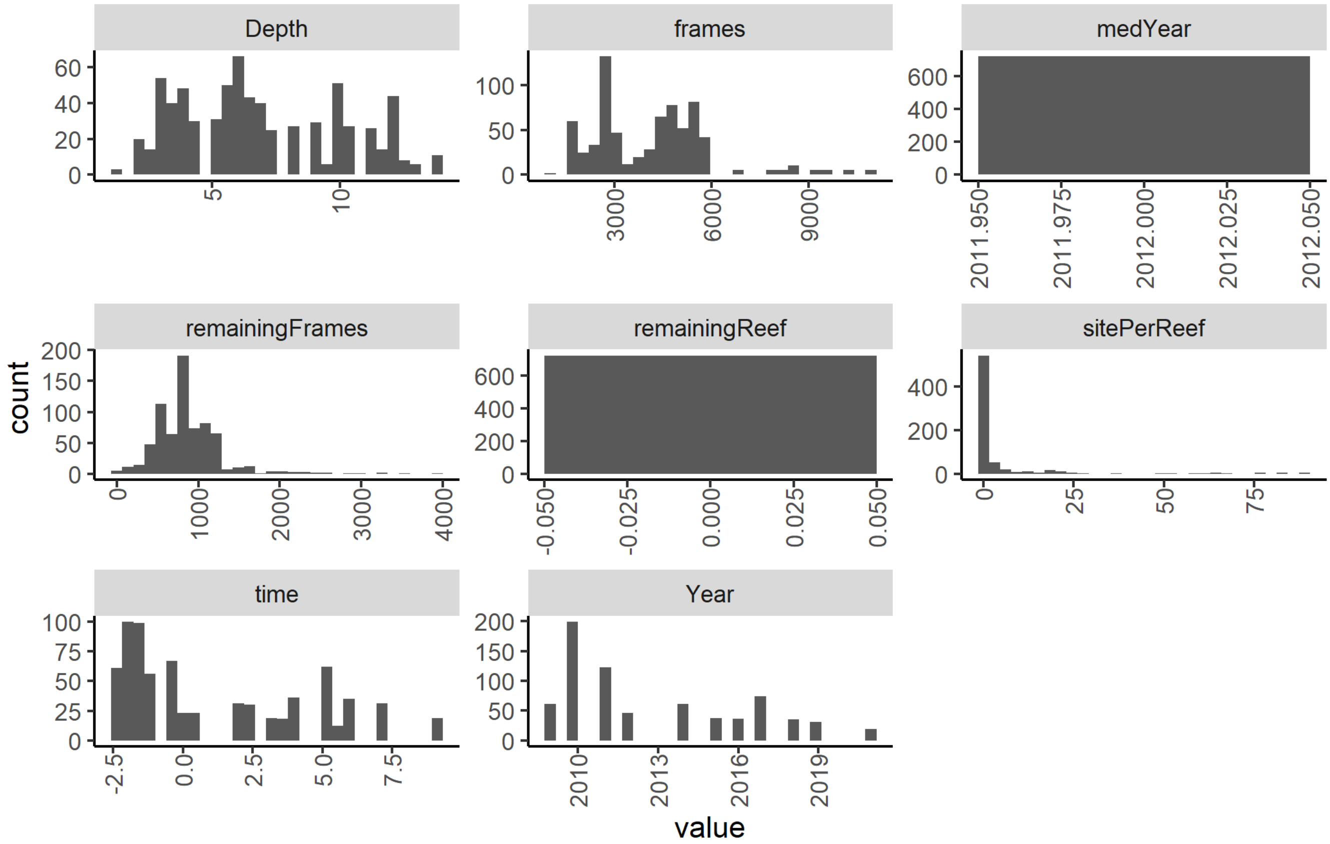

Figure 6.2: Distribution of values within continuous variables

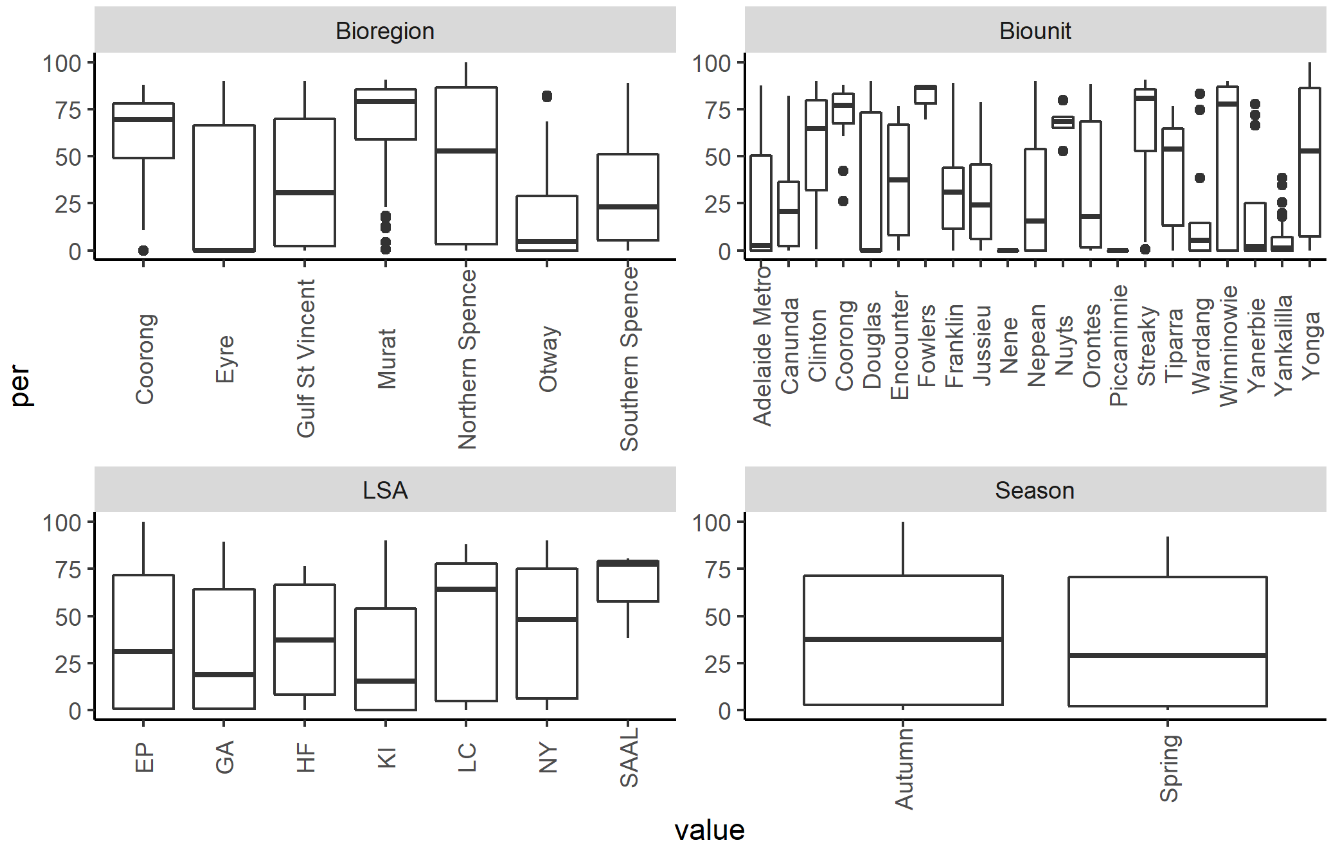

Figure 6.3: Discrete variables against per

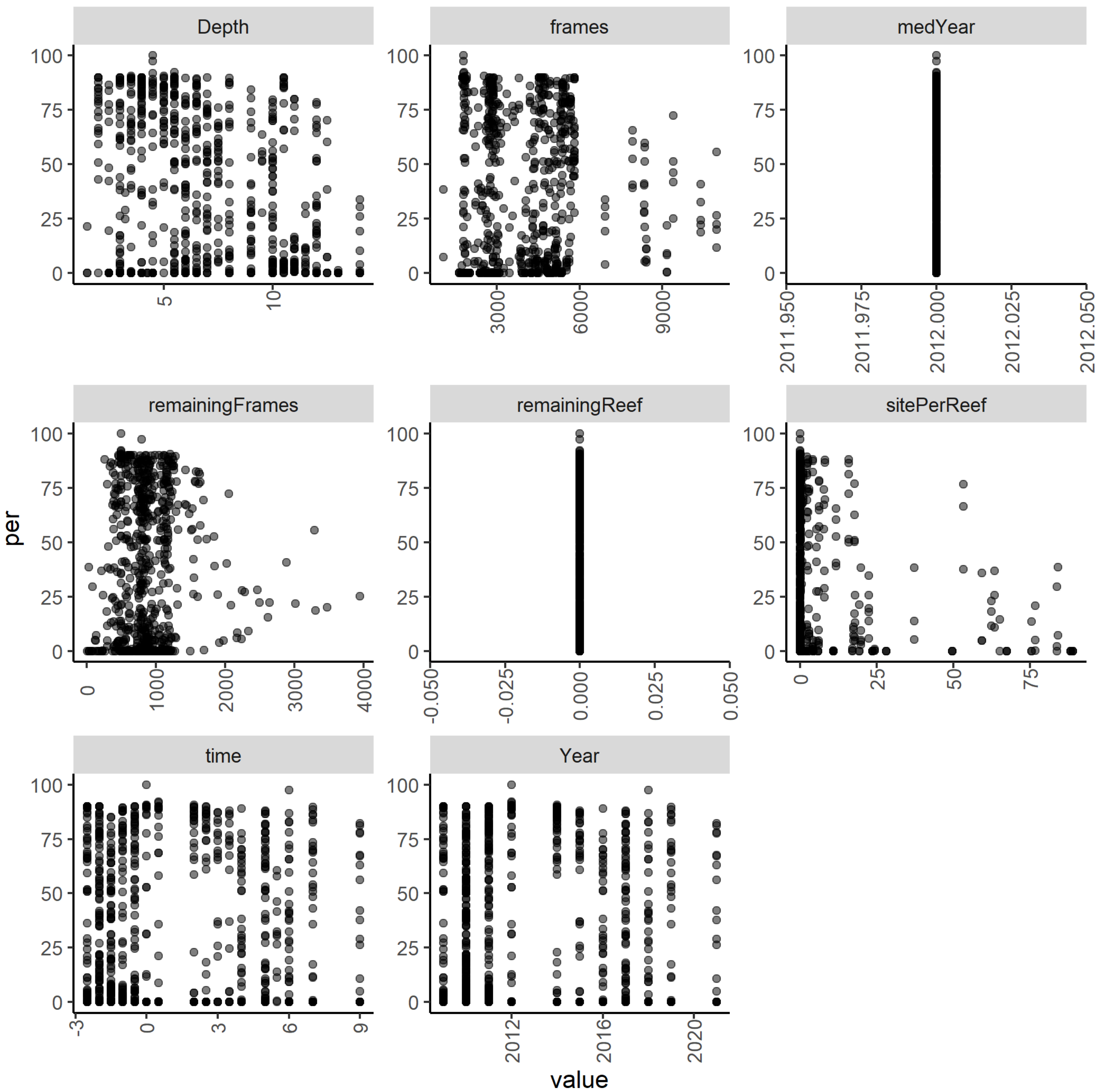

Figure 6.4: Continuous variables against per

6.2.2 Specification

The model specification was:

```
prop ~ LSA * time + (1 | Season) + (time | Site) + (time | Biounit)
```

This required the estimation of 15 parameters (see Figure 6.5) based on 722 data points.

6.2.3 Diagnostics

Two common visual checks were used to evaluate the Monte Carlo Markov-chain samples: trace plots and $\hat{R}$ values (Zuur and Ieno 2016; James 2019).

Figure 6.5 shows trace plots for each of the six chains (run for 6000 iterations with 3000 warmup). Each chain should be stable and well-mixed (all chains centered around the same value) showing 'random noise' around the parameter value with no step change or trend evident.

Figure 6.6 shows the $\hat{R}$ values. At convergence $\hat{R}$ is one.

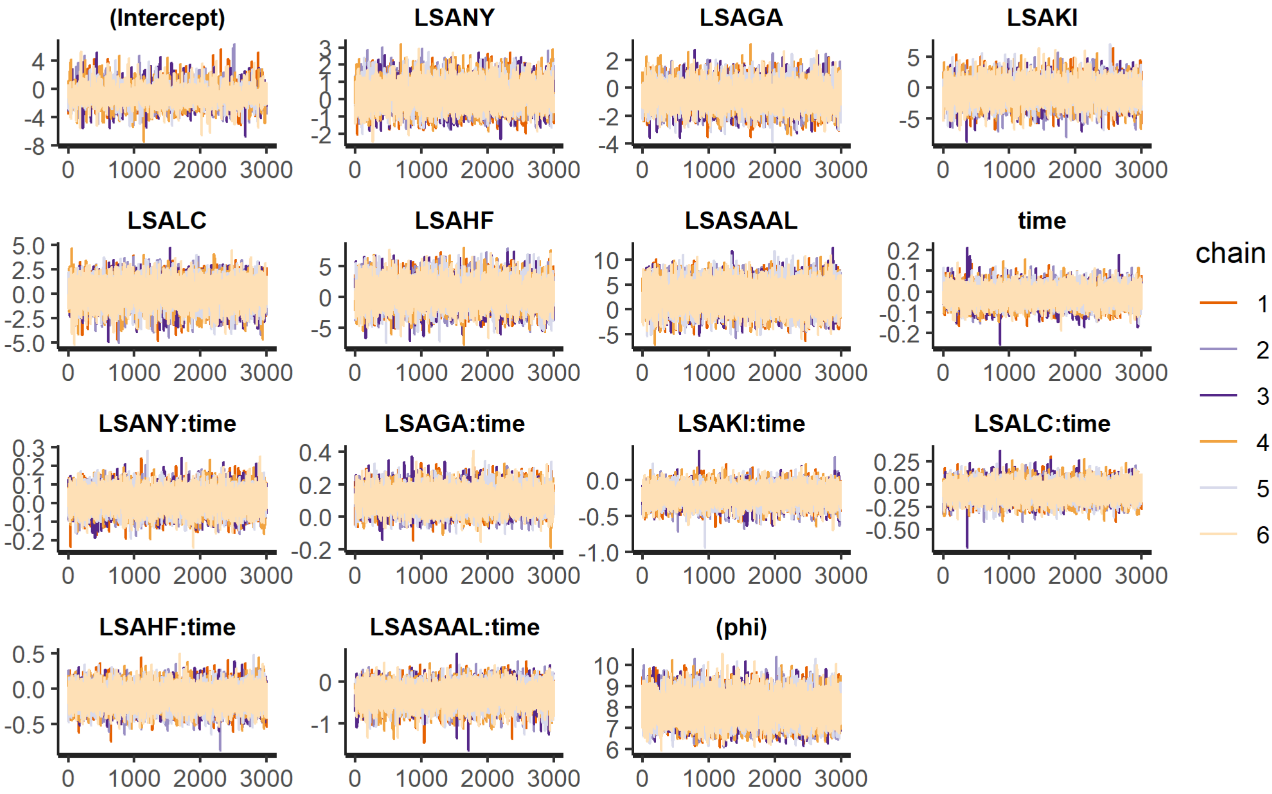

Figure 6.5: Trace plots: stable, well-mixed chains indicate convergence

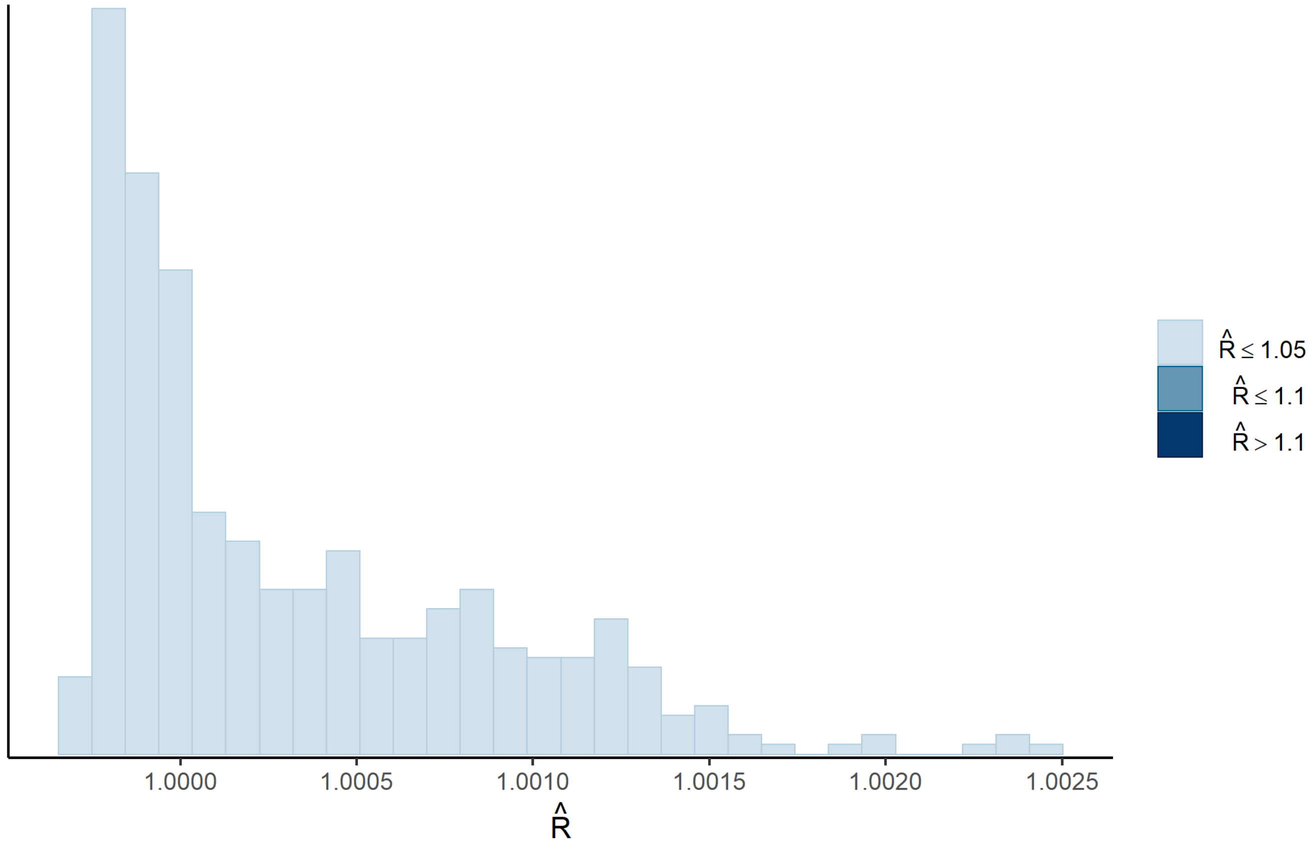

Figure 6.6: $\hat{R}$ values close to one indicate convergence

6.2.3.1 Model fit

Figure 6.7 shows a comparison of the observed data (dark line) with a sample of 50 of the model runs (light lines). The model runs should largely follow the shape of the observed data.

Figure 6.8 shows how the mean and standard deviation of the observed data (dark dot) compares with a sample of 50 of the model runs (light dots). The model runs should be centred on the observed data.

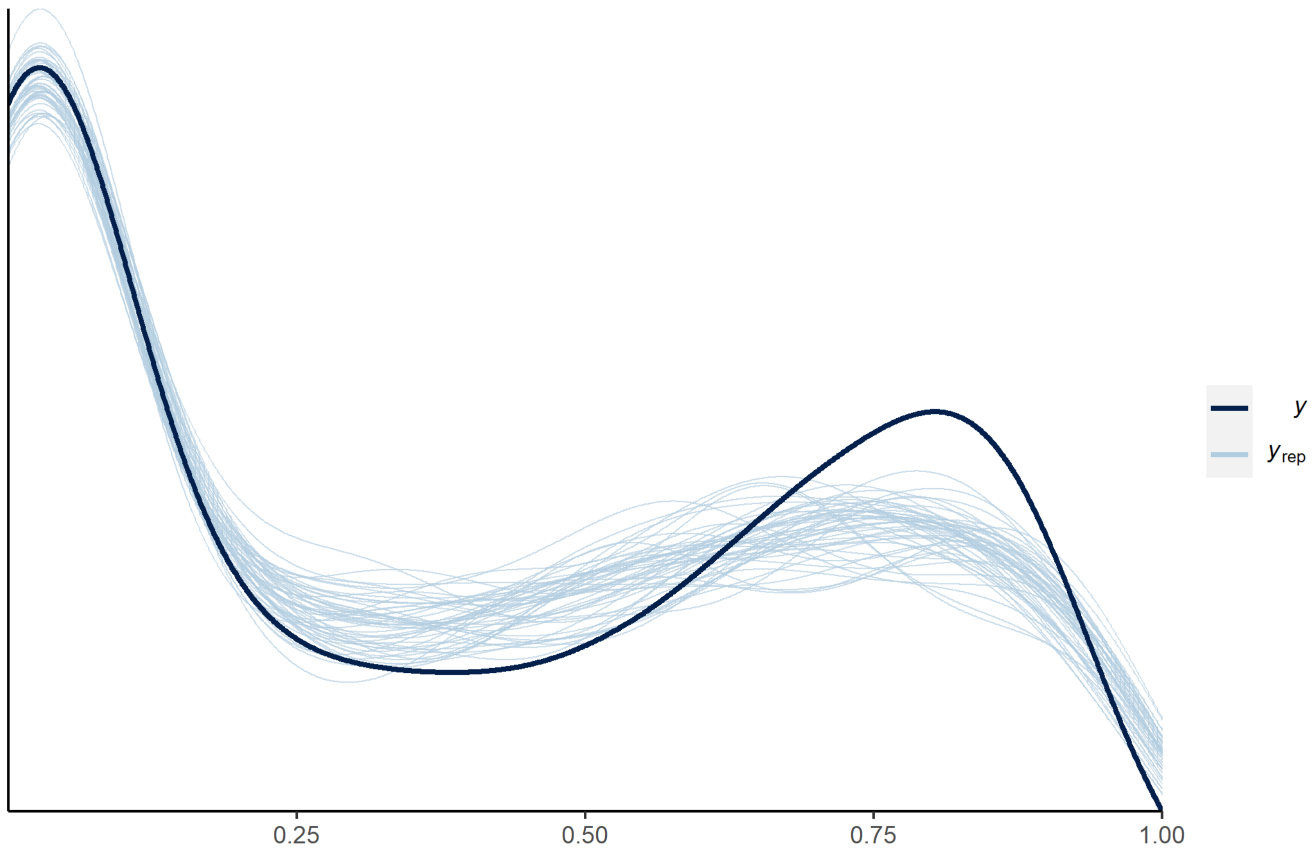

Figure 6.7: Random selection of model runs (light blue) and actual values (dark blue)

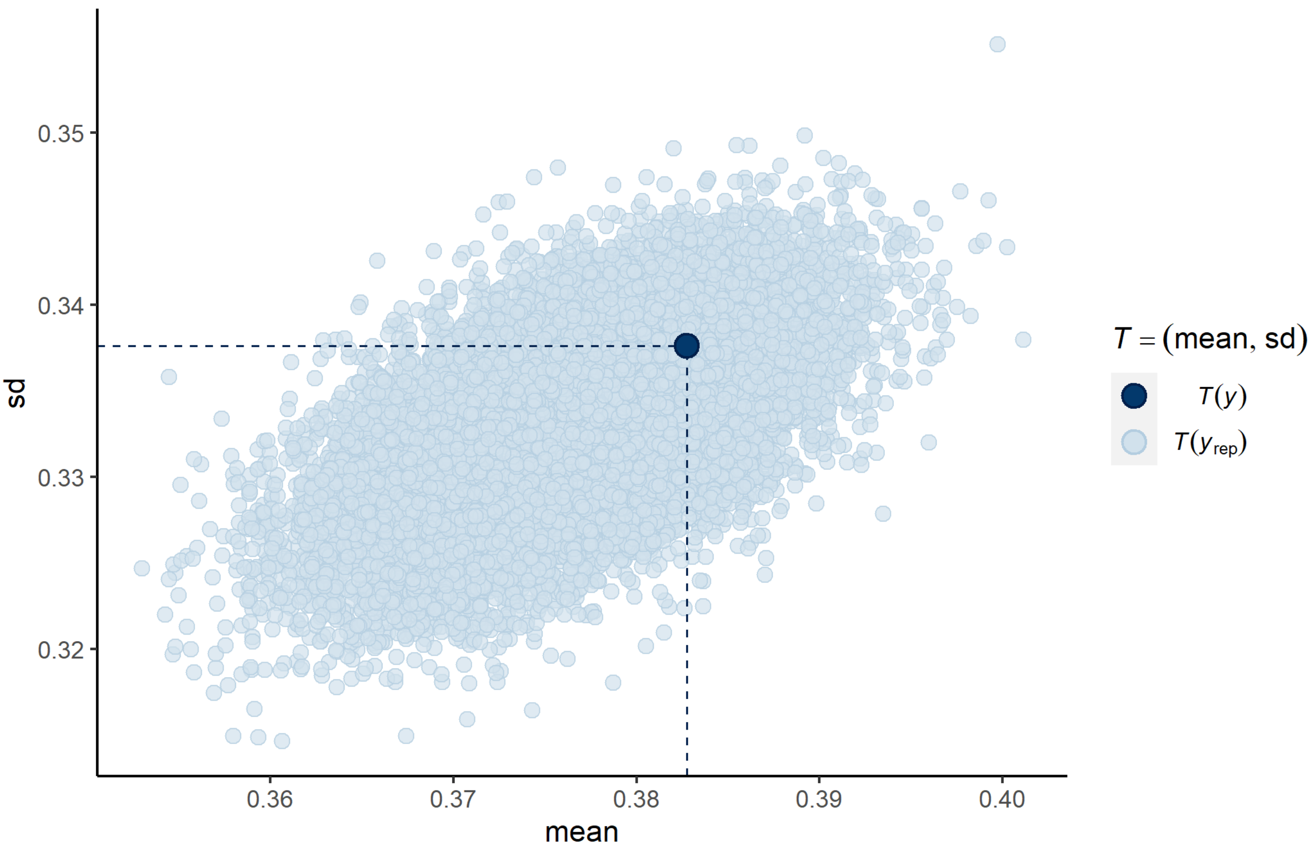

Figure 6.8: Plot of model run mean and standard deviation (light blue dots) against the values from the data (dark blue dots)

6.2.3.2 Residuals

In regression-type models, verification of homogeneity of variance is best done by plotting residuals vs. fitted values (Zuur *et al.* 2010). Figure 6.9 shows the fitted values versus the residuals. Ideally, there should be no pattern evident in these residual plots and the residuals at all values should be centred around zero.

A further check on the model assumptions is that the residuals are normally distributed (Zuur *et al.* 2010). Figure 6.10 shows the distribution of standardised residuals in comparison to a normal distribution.

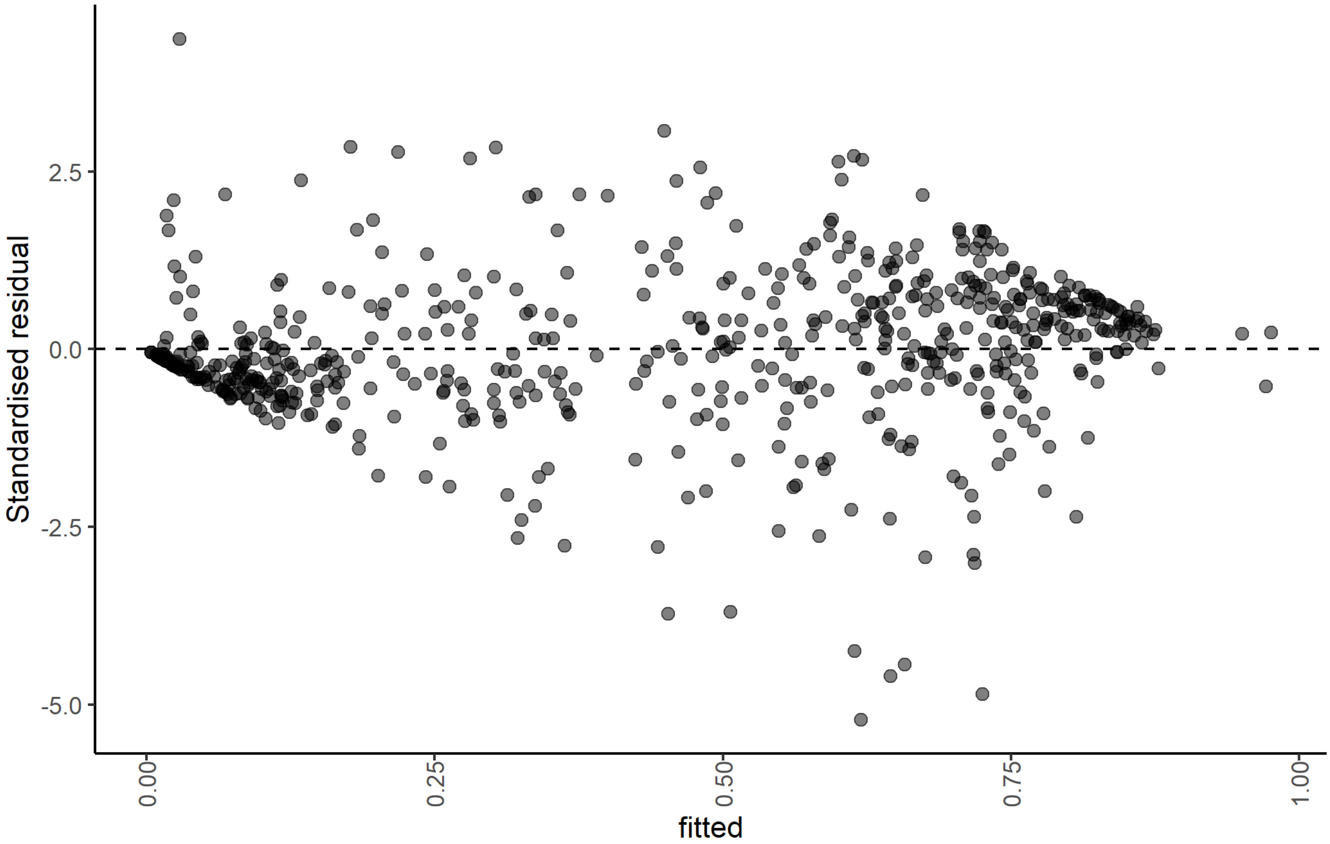

Figure 6.9: Fitted values vs residuals

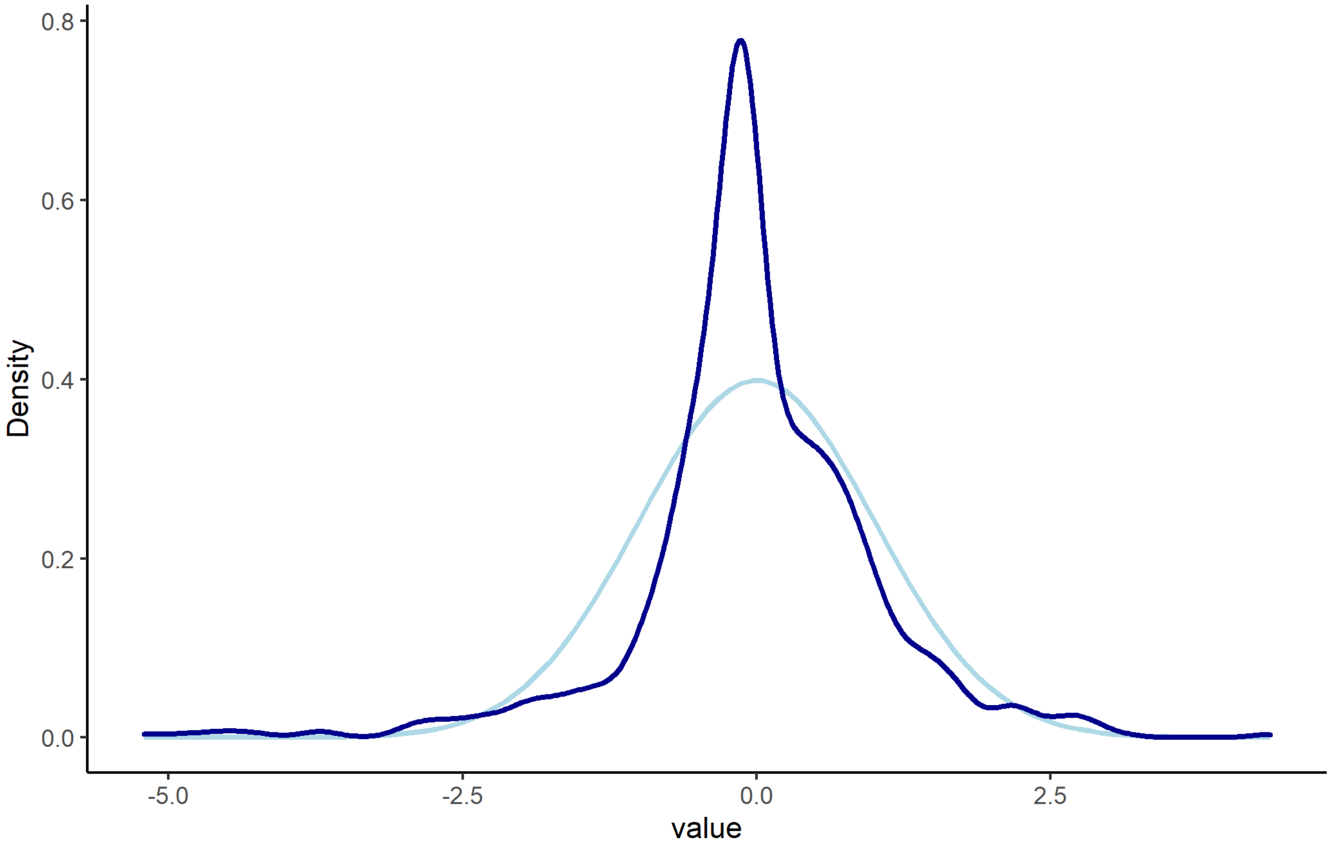

Figure 6.10: Density of standardised residuals (dark blue) overlain on a normal distribution (light blue)

6.2.4 Results

Table 6.2 shows diagnostics metrics for each parameter in the model.

The model results and original data points are shown in Figure 3.2.

Table 6.2: Diagnostics metrics for each parameter in the model. See bayestestR::diagnostic_posterior for definitions of the diagnostics and further information

	Parameter	Rhat	ESS	MCSE
1	(Intercept)	1.0012071	6357.273	0.0127913
406	LSAGA	1.0019875	4246.422	0.0125843
407	LSAGA:time	1.0006935	8939.477	0.0006323
408	LSAHF	1.0003638	9541.785	0.0189462
409	LSAHF:time	0.9999839	15040.487	0.0010881
410	LSAKI	1.0002275	7152.367	0.0187906
411	LSAKI:time	0.9999902	11119.558	0.0010049
412	LSALC	1.0005238	7613.279	0.0130930
413	LSALC:time	1.0008216	11087.072	0.0007788
414	LSANY	1.0023551	4578.832	0.0102563
415	LSANY:time	1.0011436	9461.288	0.0005450
416	LSASAAL	0.9999516	13701.162	0.0203563
417	LSASAAL:time	0.9999064	20990.897	0.0015279
425	time	1.0009627	8961.559	0.0003969

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