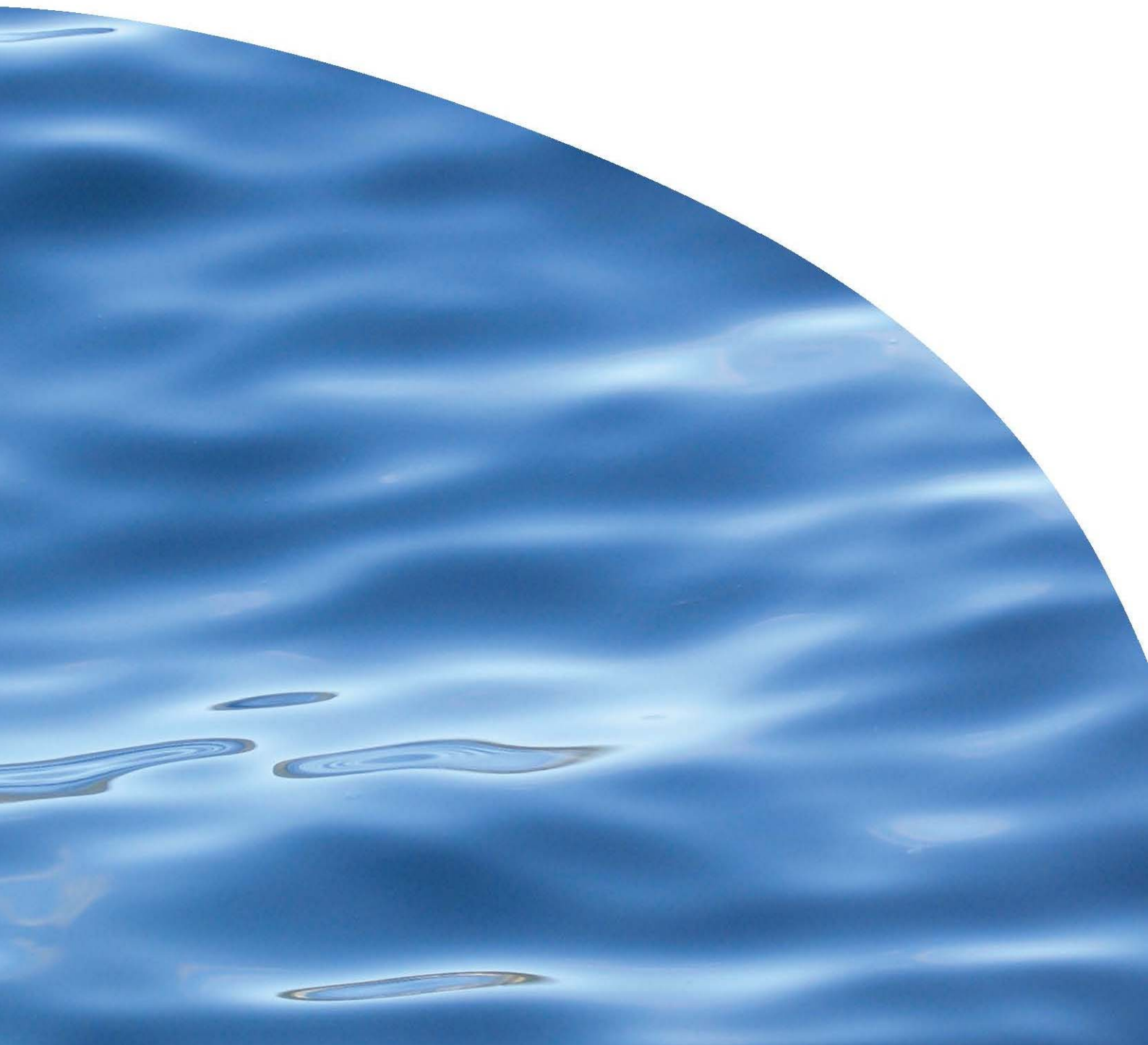




REPORT NO. 2493

**NATIONAL OBJECTIVES FRAMEWORK FOR
FRESHWATER: AN ASSESSMENT OF BANDING
STATISTICS FOR PLANKTONIC CYANOBACTERIA**



NATIONAL OBJECTIVES FRAMEWORK FOR FRESHWATER: AN ASSESSMENT OF BANDING STATISTICS FOR PLANKTONIC CYANOBACTERIA

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Prepared for the Ministry for the Environment



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1. INTRODUCTION

The National Objectives Framework (NOF) is part of the proposed amendments to the National Policy Statement for Freshwater Management 2011. It aims to help councils and communities set objectives in regional plans that reflect their values for freshwater. Attributes will be used to set objectives for each water management unit in regional plans, and limits must then be set that will achieve the objectives. Objectives and limits based on a common set of attributes will help communities make long-term resource management decisions that enable the sustainable use of their freshwater resources.

Planktonic cyanobacteria have been identified as an attribute to use when setting objectives for secondary contact recreation under the NOF. The current planktonic cyanobacteria NOF bands use threshold values slightly modified from those in the 'New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters' (Ministry for the Environment and Ministry of Health, 2009), as recommended by Wood *et al.* (2013; Table 1).

The sample statistic used to assign a 'band state' or 'bottom line' is very important as it is used as a basis to assess risk of secondary contact in relation to human health. For planktonic cyanobacteria, it also influences the certainty and reliability of the reported risks to human health. The threshold values in the 'New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters' (Ministry for the Environment and Ministry of Health, 2009), were designed to trigger a series of management actions when there is a single measurement exceedance. In the proposed NOF it was indicated that these same trigger values be applied to two-year moving averages. This statistic is important for setting and assessing progress towards an objective and thus the use of a two-year average is likely to be inappropriate. Testing by Wood *et al.* (2013) showed that, when using a two-year average, sites that pose a significant health risk for extended periods of time were commonly categorised within a higher (*i.e.* better) band than was conveyed by the level of risk to human health at these sites. Wood *et al.* (2013) also investigated using an exception-based approach. Using monthly samples, if the biovolume of one or two of the monthly samples (or a month's average if more than one sample was taken in a month) in a hydrological year deviated below the designated banding, then the waterbody was deemed not to have met its objective banding. This method resulted in some waterbodies moving between bands on an annual basis. These fluctuations may have reflected changes in climatic or environmental conditions rather than sensitivity to adverse changes in the waterbody, and could therefore create difficulties when trying to set and achieve management objectives.

Table 1. Proposed planktonic cyanobacterial attribute table (Ministry for the Environment 2013).

Value	Human health (secondary contact)	
Freshwater body type	Lakes and rivers	
Attribute	Planktonic cyanobacteria	
Attribute unit	Biovolume	
Attribute state	Numeric attribute state	Narrative attribute state
	Two year average	
A	Biovolume equivalent for the combined total of all cyanobacteria does not exceed 0.5 mm ³ /L OR The cell concentration of total cyanobacteria does not exceed 500 cells/mL.	Risk exposure from cyanobacteria is no different to that in natural conditions.
C*	Biovolume equivalent of 0.5 to < 1.8 mm ³ /L of potentially toxic cyanobacteria OR 0.5 to < 10 mm ³ /L total biovolume of all cyanobacteria.	Low risk of health effects from exposure to cyanobacteria
National bottom line#	Biovolume equivalent of ≥ 1.8 mm ³ /L of potentially toxic cyanobacteria OR ≥10 mm ³ /L total biovolume of all cyanobacteria	Potential health risks (e.g. respiratory, irritation and allergy symptoms) exist from exposure to cyanobacteria.
D	Biovolume equivalent of ≥ 1.8 mm ³ /L of potentially toxic cyanobacteria OR ≥10 mm ³ /L total biovolume of all cyanobacteria	

* could also be denoted by B/C

For toxic cyanobacteria exposure to biovolumes higher than 1.8 mm³/L (assuming 100 mL of water is ingested which estimated to be the amount that can be accidentally swallowed during recreational activities) would exceed the tolerable daily intakes for recreational exposure to microcystins. For non-toxic cyanobacteria when biovolumes exceed 10 mm³/L mild respiratory or skin irritation may occur. See MfE & MoH 2009 for further details.

Cawthron Institute (Cawthron) and the University of Waikato were tasked by the Ministry of the Environment to use planktonic cyanobacterial data collected by Regional Councils from both lakes and rivers throughout New Zealand to investigate an appropriate statistic with which to define the planktonic cyanobacteria attribute. The Ministry of the Environment noted that there are statistical implications associated with different banding options, and these implications need to be considered in the context of:

- describing community values, setting objectives and limits, and making resource management decisions
- incorporation of natural variability

- understanding where the risk from statistical uncertainty lies (burden of proof)
- defining what is the health risk, and to whom, from that uncertainty?
- the practicalities of monitoring
- attainability of the meeting the attribute bands.

2. METHODOLOGY

2.1. Datasets

Waikato Regional Council (WRC) supplied data for eight lakes in the Waikato region (three hydro lakes; Karapiro, Ohakuri, and Maraetai and five shallow peat lakes; Hakanoa, Waahi, Ngaroto, Whangape, and Waikare). Waikato Regional Council collects samples (usually monthly) at the shoreline of each lake for the purpose of assessing human health risk. The available datasets were from 2003, however, prior to 2010 only cell counts were provided. Post 2010, biovolumes for each species were provided and these data (28 months) were used to assess the suggested bands. For three lakes, Waahi, Waikare and Whangape the entire dataset was converted to biovolumes. For each sampling date monthly biovolumes for each species were summed to give the total cyanobacterial biovolume. Due to time constraints, all cyanobacteria in the samples were considered to be potentially toxic. This assumption was deemed to be reasonable as the dominant species are all known toxin producers, e.g. *Cylindrospermopsis*, *Anabaena* and *Microcystis* species.

Data were provided by the Bay of Plenty Regional Council (BoPRC) for seven lakes; Rotoehu (four sites), Rotoiti (11 sites), Rotorua (six sites), Tarawera (two sites), Okaro (one site), Okeraka (one site), and Rotokakahi (one site) and the Kaituna River (four sites). Sample collection started in 1996, although it was sporadic in the early years. Some sites have long datasets, whilst at others monitoring stops or has only recently been initiated. Sampling frequency also varied among years and sites and in recent years samples have been collected weekly. A total biovolume for each sample location was provided by BoPRC. Due to time constraints, all cyanobacteria in the samples were presumed to be potentially toxic.

2.2. Development of a statistic — tolerance interval compared to percentiles

Statistical analyses were undertaken using R (<http://www.r-project.org>). As suggested in McBride (2014) we assess 80, 90 and 95 tolerances intervals and percentiles. McBride (2014) gives the following definition of a tolerance interval:

A statistical interval within which, with a stated confidence level, a specified proportion of a sampled population falls (the proportion is denoted as β). We commonly use " β -content" intervals, constructed so that they contain at least $100\beta\%$ of the population, with a given confidence. The interval's "coverage" is $100\beta\%$. Like confidence intervals they can be one-sided or two-sided. In NOF assessments they should be taken as one-sided, because our interest is whether or not a breakpoint has been exceeded (cf. two-sided intervals, where we are

interested in departures from the breakpoint in either direction). One-sided β -content tolerance intervals are calculated from the same formula as is used for one-sided confidence intervals (Conover 1980, Millard 2001, McBride 2005).

and a percentile as:

...the numeric value of a variable below which a given percentage of observations in a group of observations fall.

McBride (2014) suggests that statisticians may prefer the use of tolerance limits over percentiles. However, he then states that it may be appropriate (under a *Fail-safe* stance) to use sample percentiles. An advantage in doing so is that percentiles allows use of the same sample metric (95 percentile) to that used for grading recreational water sites in the national and international guidelines for microbial primary contact (MfE/MoH 2003, WHO 2003), and New Zealand's Drinking-water Standards.¹

A full description of how tolerance intervals and percentiles are calculated is given in Appendix C of McBride (2014).

In this report we tested the applicability of using 80, 90 and 95 tolerance intervals and percentile values. These were calculated from all data points for up to five years, and, when the data series extended to greater than five years' duration, for the proceeding five years of data. In New Zealand cyanobacterial blooms generally occur in summer during periods of warmer water temperatures and stratification (Oliver *et al.* 2013). In general most Regional Councils which monitor water bodies to assess the human health risks posed by cyanobacterial blooms only collect samples during summer. Analysis was undertaken separately for datasets that either included or excluded winter (May to September inclusive). We also evaluated the effect of sampling frequency. The 'New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh water' (Ministry for the Environment and Ministry of Health. 2009) recommend that when the "Alert or Action" thresholds are exceeded consideration should be given to increasing sampling frequency to weekly. This results in differences in sample collection frequencies within and among datasets. To investigate the influence of this we pre-calculated monthly averages (geometric averages, *i.e.* the average of the log-transformed values, which were then transformed to unlogged values) and analysed these data with and without winter data points. Use of monthly geometric means has the effect of reducing the influence of particularly high or low observations on the overall monthly statistic.

¹ <http://www.health.govt.nz/publication/drinking-water-standards-new-zealand-2005-revised-2008>

3. COMPARISONS OF METHODOLOGIES AND OPTIONS

The analysis was undertaken on the 39 datasets. A selection of the results is shown in Figures 2 to 11 to illustrate the benefits and limitations of the proposed methods and options. The plots for the remaining sites are given in Appendix 1.

The sites below were chosen to represent a cross-section of locations where we have previously, or are currently, undertaking research in order to assist with expert knowledge to assess the accuracy of the outputs. The selected sites include where there have been:

- moderate (Rotoiti — Hinehopu) or severe (Okawa Bay) cyanobacterial blooms, and water quality has improved and bloom intensity and/or duration has decreased
- historically moderate-intensity blooms, and where sporadic blooms still occur (Rotoehu — Kennedy Bay, Rotorua — Holdens Bay, Lake Waahi)
- implementation of remediation options that have resulted in fluctuations in cyanobacterial bloom intensity (Lake Okaro)
- dense blooms that have persisted throughout the monitoring period (Lakes Waikare and Whangape)
- no blooms, generally (Kaituna River — Maungarangi).

In general the use of either tolerance intervals or percentiles did not result in different 'bandings' for a given percentile interval (80, 90 and 95), especially when the dataset extended for greater than five years (Figures 2 to 11). There are exceptions to this for some sites, however, and in these cases the percentile method usually resulted in a higher (*i.e.* better) banding than the equivalent tolerance interval, *e.g.* Lake Rotoiti — Te Weta Bay (95 percentile; Figure 3) and Rotoehu — Kennedy Bay (90 percentile, winter data included (Figure 5).

At most sites the percentage (*i.e.* 80, 90 or 95) used for the percentile or tolerance interval impacted upon the 'band'. In the most extreme scenarios this resulted in three different bandings. For example, in 2013, at Lake Rotoiti — Okawa Bay and Kaituna River — Maungarangi, the percentage of tolerance interval used resulted in different 'bandings' — 95% = D, 90% = C and 80% = A (Figure 4 and Figure 8). This highlights the need for careful consideration when choosing the appropriate band metric.

In general, including winter data points had no effect on the banding when either tolerance intervals or percentiles were used (Figures 2 to 11). There were a few exceptions to this, *e.g.* Lake Rotoehu — Kennedy Bay, when using monthly average data (see below), 90% tolerance limits and with winter data excluded. In this case the band moved from C to a D.

The use of monthly geometric means impacted the banding in some instances. In most cases this resulted in a higher (*i.e.* better) band. For example, in Lake Rotoiti — Hinehopu between c. 2005–2009 when data are averaged across months and the 90 percentiles are used. This site falls into band C as opposed to band D when data are not averaged (Figure 1). In some cases monthly averaging has the effect of ‘flattening’ out peaks in data, which are most likely the results of increased sampling frequenting related to bloom events (Lake Rotoiti — Hinehopu; Figure 2).

McBride (2014) notes that percentiles should be calculated from at least five years’ data and that determining these on 12 or less data points is “*fraught with impression.*” This is apparent in almost all datasets (Figures 2 to 11, and Appendix 1), where initially both tolerance intervals and percentiles (regardless of the percentage used) fluctuate markedly. We assessed the effect of using shorter-duration time series for three lakes; Waahi, Waikare and Whangape (Figure 9 to Figure 11). In these datasets the effects were minimal, with only one difference noted (Lake Waahi, 90% tolerance in 2013 = band D using the 10-year dataset versus band C using the 3-year dataset).

4. RECOMMENDATIONS

Based of the above analysis we suggest that:

- Pre-calculated monthly geometric averages are used. Increased sampling frequency associated with bloom events can skew the data, potentially causing the site to shift to a lower (i.e. worse) band.
- Winter data (if available) is included. The inclusion of winter data had minimal effect on the banding and sporadic blooms events can occur in winter.

Based on the recommendation of McBride (2014) we suggest that the percentile approach is used, and that consideration be given to use of either 80 or 90 percentile limits. Communications among McBride and MfE suggest a minimum of three years data and at least 12 (but ideally 30) samples should be used. In this study we assessed the effect of using three versus five years of data for three Waikato lakes and this resulted in different bandings in 2013 for one of three lakes, highlighting that careful consideration to the number of samples and length of datasets is required.

Table 2 shows the percentage of lakes/sites that would be categorised into each band if each of these banding statistics were applied in 2013. Only sites where data up to 2013 was available were included in this analysis (21 sites for Rotorua and eight Waikato). These bandings are based on the assumption that all species in the samples are toxic. However, if cyanotoxin analysis showed that no toxins were present, the non-toxic bands would more appropriately be implemented (*i.e.* $c = 0.5$ to $< 10 \text{ mm}^3/\text{L}$ total biovolume of all cyanobacteria and $D = > 10 \text{ mm}^3/\text{L}$ total biovolume of all cyanobacteria). We assessed the impact of using these thresholds and the percentile approach on this dataset. Table 2 shows the percentage of lakes/sites that would be categorised into each band (assuming all species are non-toxic) if each of these banding statistics were applied in 2013. An example from Lake Whangape using these thresholds is given in Figure 1.

Table 2. Percentage of sites in the Rotorua (only the 21 sites that had data up to 2013 were included) and Waikato (eight sites) regions that would be categorised into each band (assuming all species were toxic or non-toxic) if 80 and 90 percentile banding statistics were applied using five years of data.

	80 percentile		90 percentile	
Rotorua lakes (n = 21)				
	Toxic	Non toxic	Toxic	Non toxic
A	62%	60%	52%	52%
C	33%	40%	43%	48%
D (bottom line)	5%	0%	5%	0%
Waikato lakes (n = 8)				
A	25%	38%	12%	13%
C	25%	62%	38%	87%
D (bottom line)	50%	0%	50%	0%

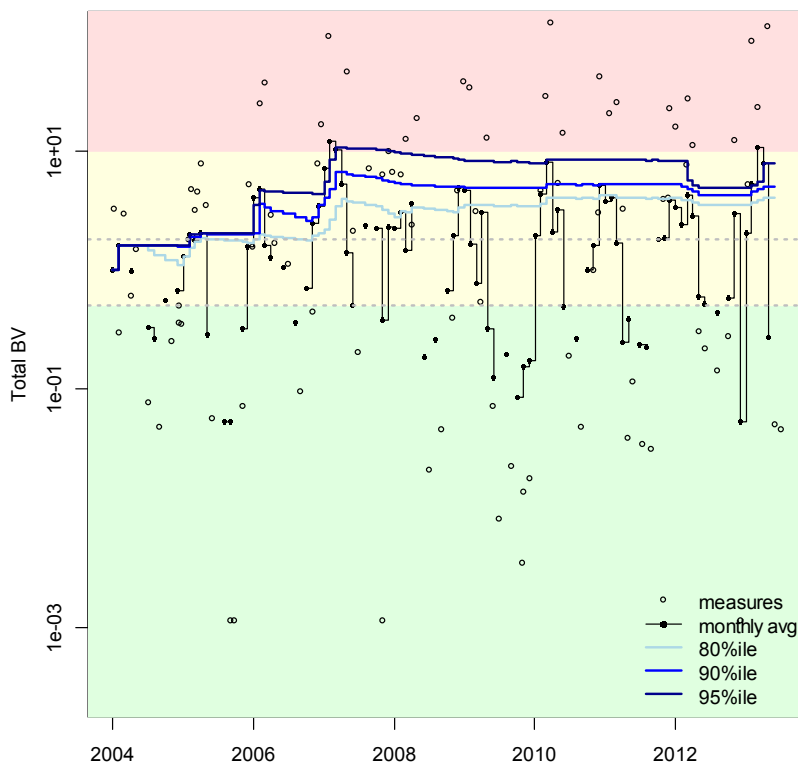


Figure 1. Total biovolumes (BV) in Whangape. Lines show 80, 90 and 95 percentiles including winter. Monthly averages are pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A', assuming all cyanobacteria are non-toxic.

When assuming all cyanobacteria were toxic, amongst the Rotorua sites, Lake Okaro was identified as receiving a D-banding under the two percentile categories. For the Waikato lakes the lakes with a D-banding included Waikare, Whangape, Ngaroto and Hakanoa. Each of the sites in these two regions has a long history of health warnings associated with cyanobacterial blooms. The allocated banding is also consistent with our knowledge of cyanobacterial blooms in these lakes. It should also be noted that if recent trends of improvement (lower cyanobacteria biovolumes) in lakes Okaro and Hakanoa continue, these lakes would be expected to move to a C-banding category in forthcoming years.

When assuming all cyanobacteria were non-toxic, no lakes in either dataset were identified as receiving a D-banding in 2013 under the 80 or 90 percentile categories. The differences between applying the toxic and non-toxic bandings highlight the need for an in-depth understanding of the presence of toxins (or potentially toxic species) in lakes when making informed risk assessments. This could also provide more incentive for monitoring agencies to test for cyanotoxins, providing a better understanding of the presence of toxin producing species and better assessment of health risks associated with recreational contact.

5. ACKNOWLEDGEMENTS

We thank Bill Vant (Waikato Regional Council) and Alastair Suren (Bay of Plenty Regional Council), for provision of data, and enthusiastic support of this project. We thank Brent King (Ministry for the Environment) for assistance and constructive feedback during this project.

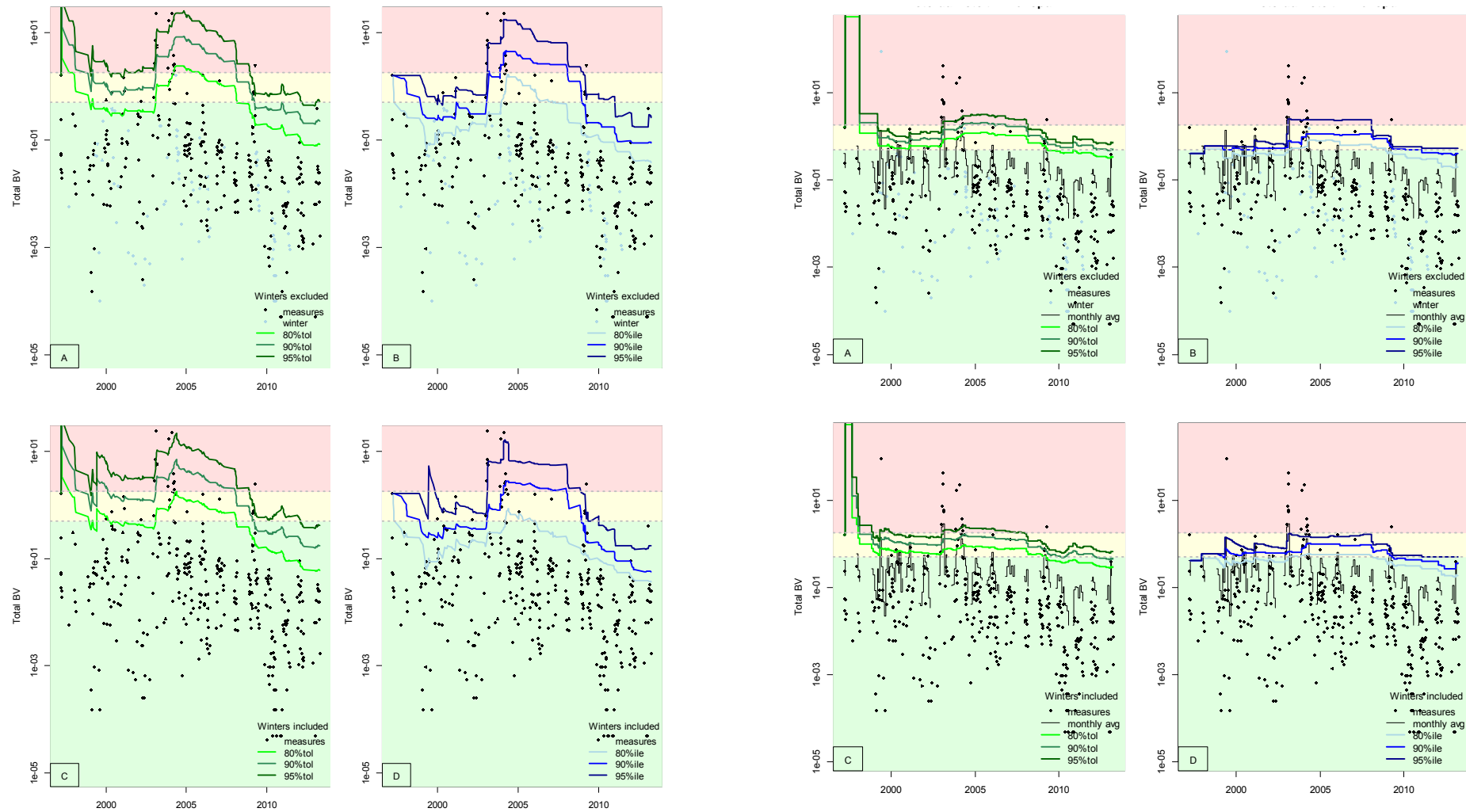


Figure 2. Total biovolumes (BV) in Lake Rotoiti — Hinehopu. Left side of page: (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

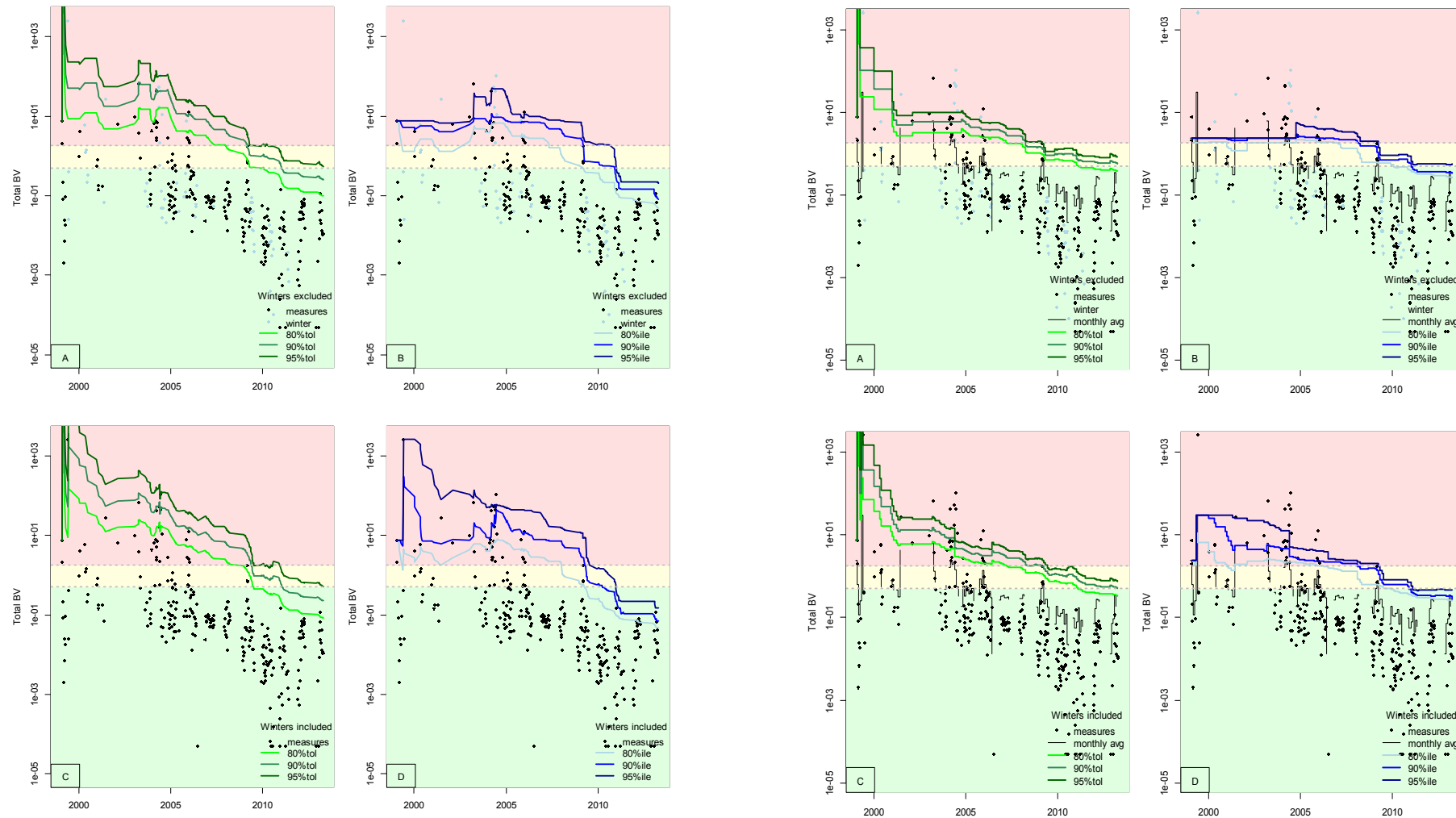


Figure 3. Total biovolumes (BV) in Lake Rotoiti — Te Weta Bay. Left side of page: (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

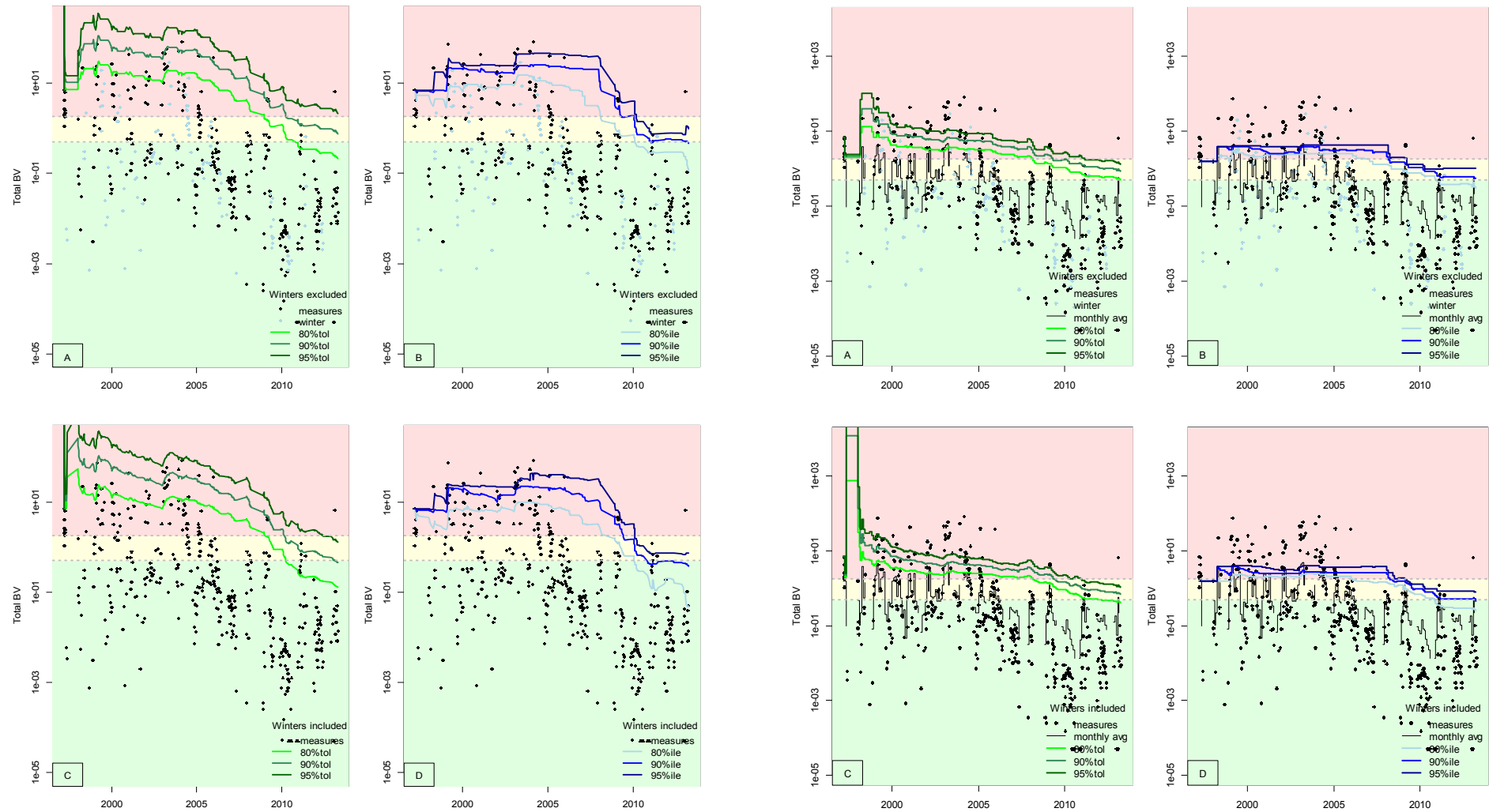


Figure 4. Total biovolumes (BV) in Lake Rotoiti — Okawa Bay. Left side of page: (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

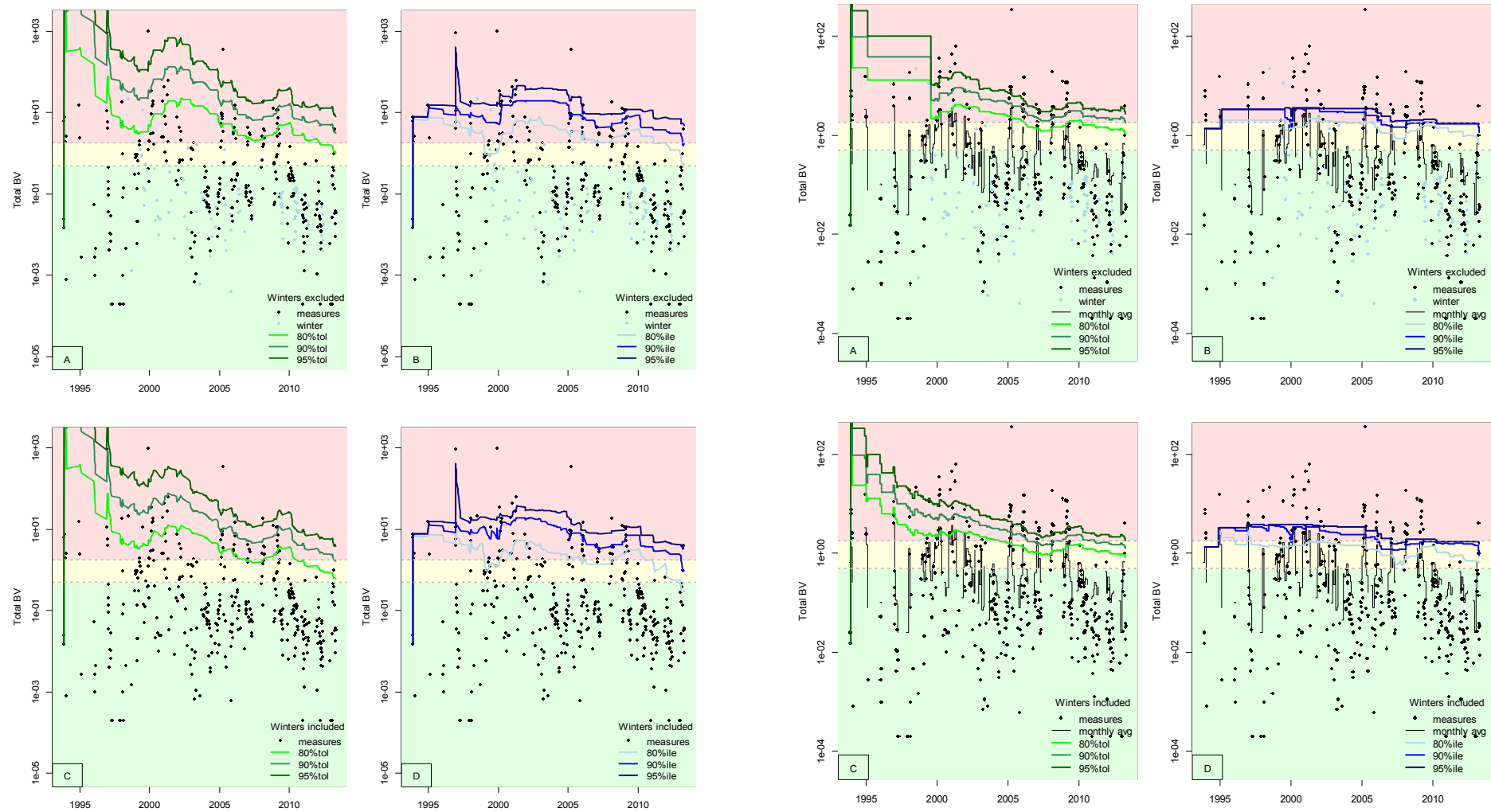


Figure 5. Total biovolumes (BV) in Lake Rotoehu — Kennedy Bay. Left side of page: (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

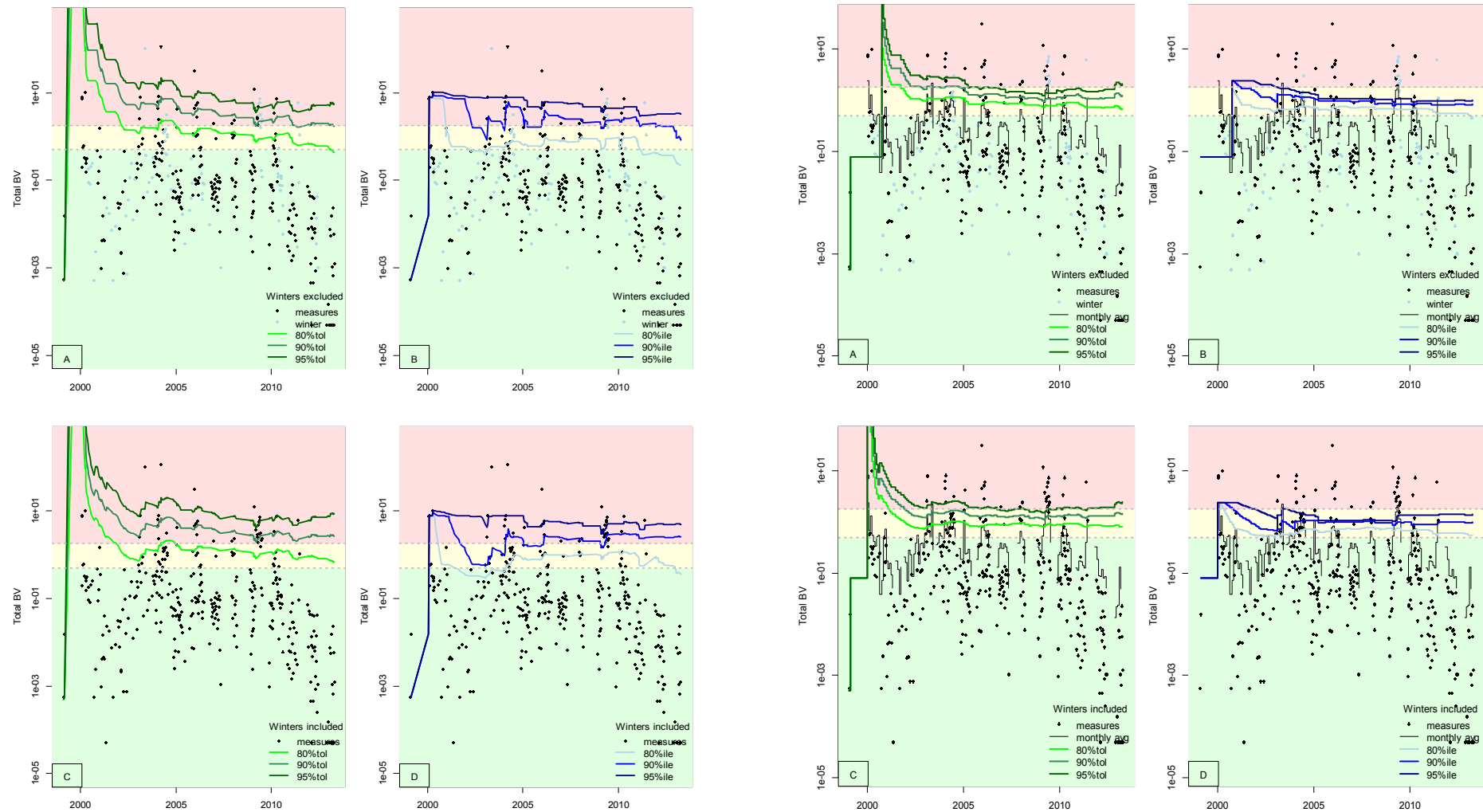


Figure 6. Total biovolumes (BV) in Lake Rotorua — Holdens Bay. Left side of page: (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

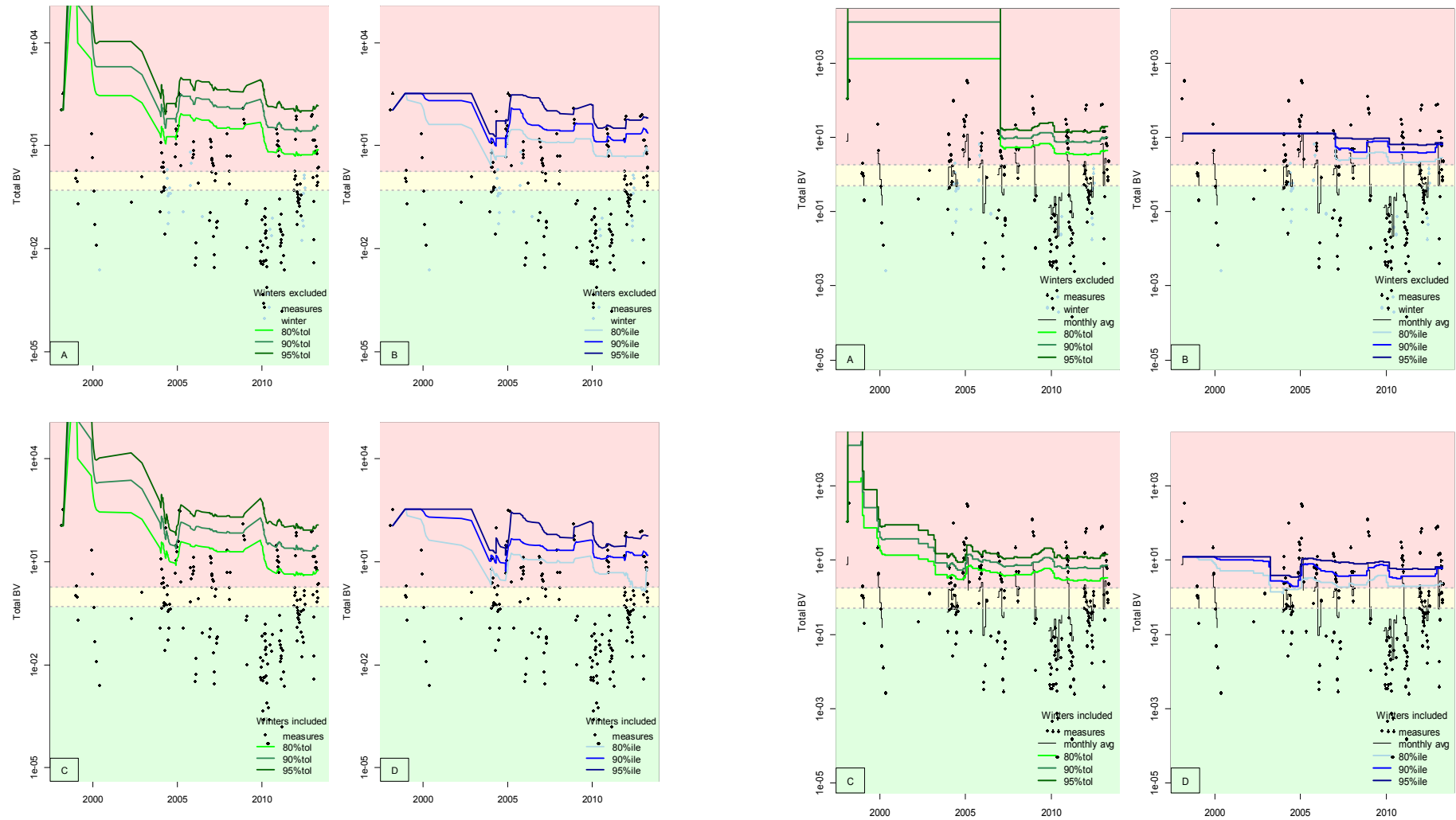


Figure 7. Total biovolumes (BV) in Lake Okaro. Left side of page: (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A'.

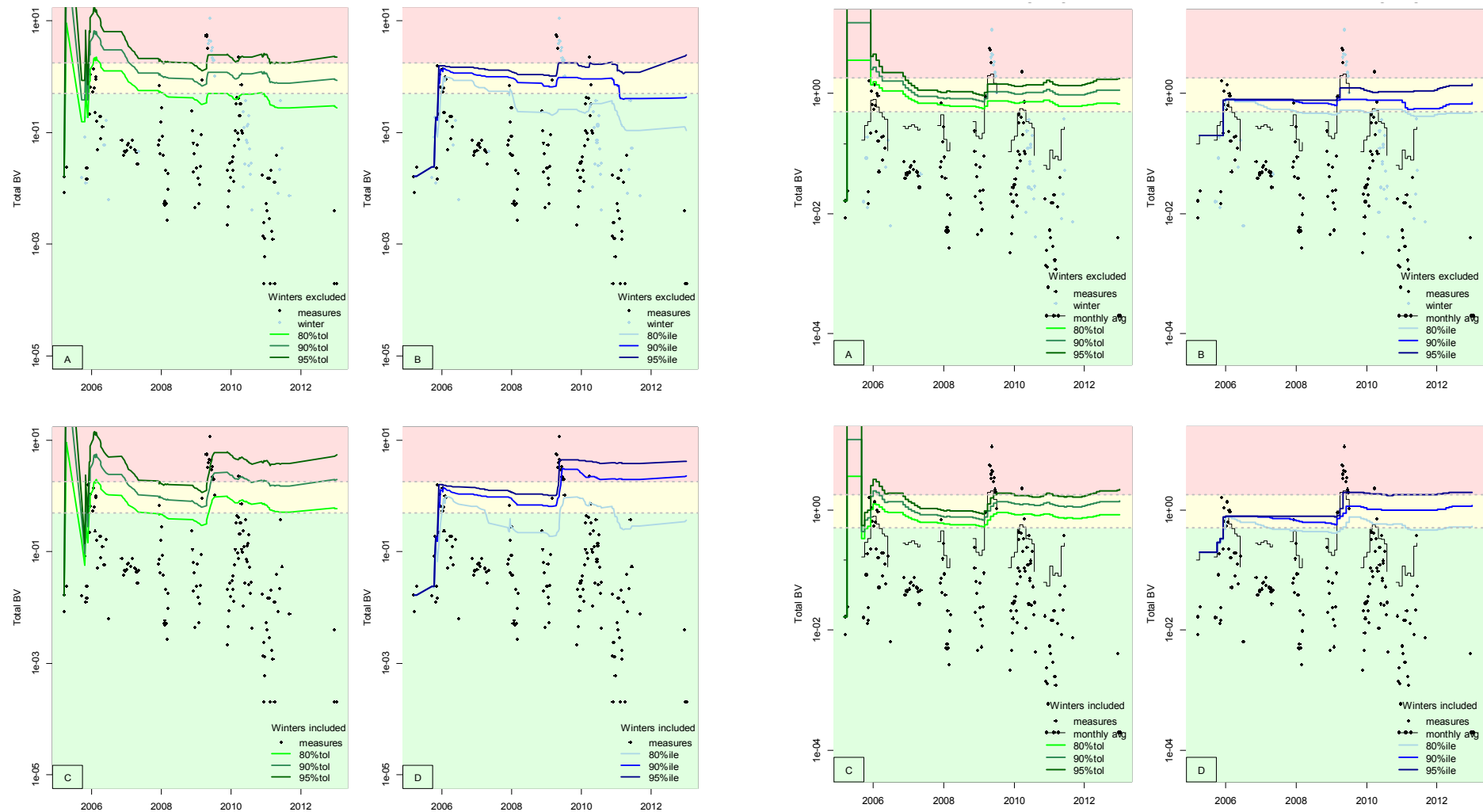


Figure 8. Total biovolumes (BV) in Kaituna River — Maungarangi Bay. Left side of page: (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

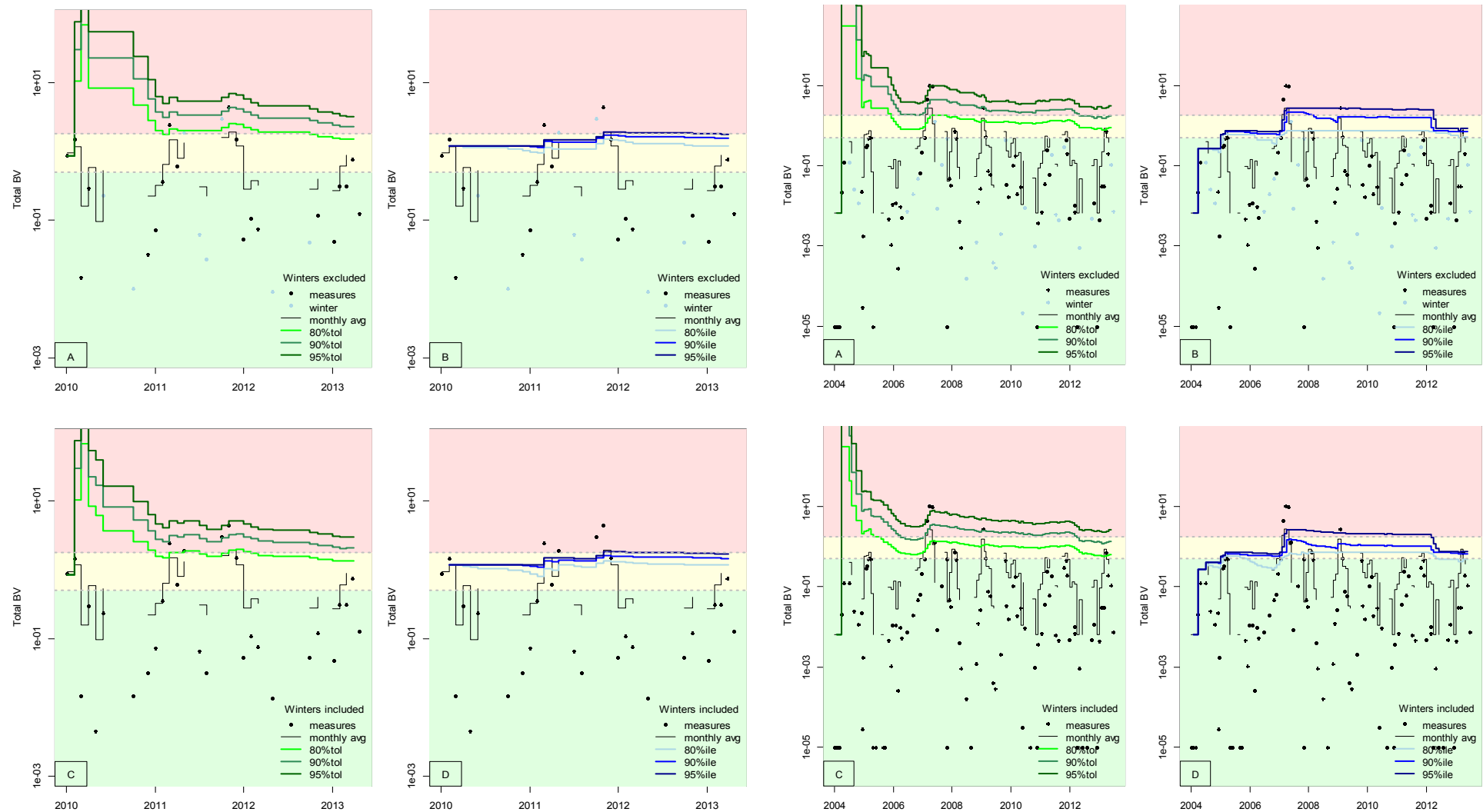


Figure 9. Total biovolumes (BV) in Lake Waahi. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data for the last three years of data.

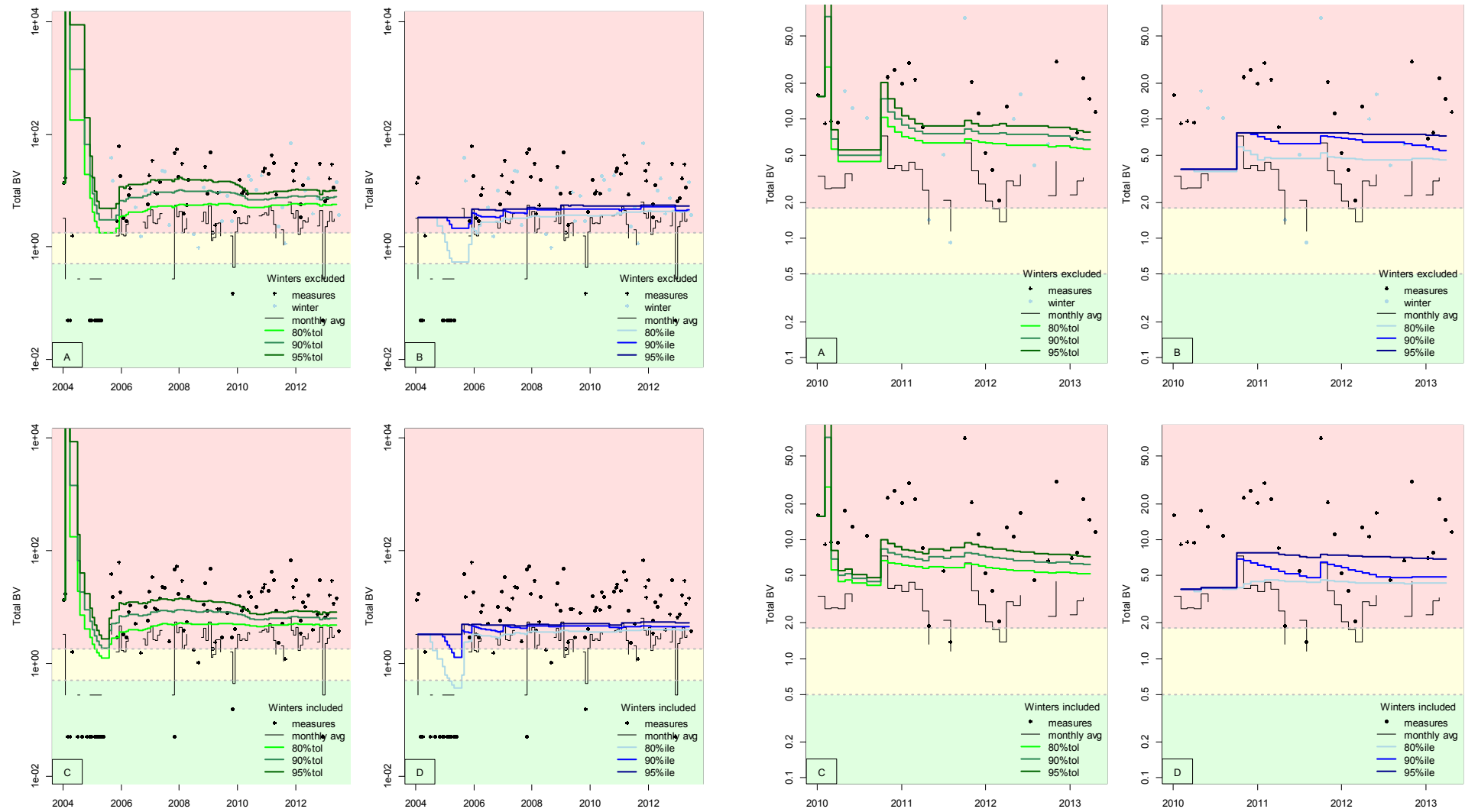


Figure 10. Total biovolumes (BV) in Lake Waikare. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data for the last three years of data.

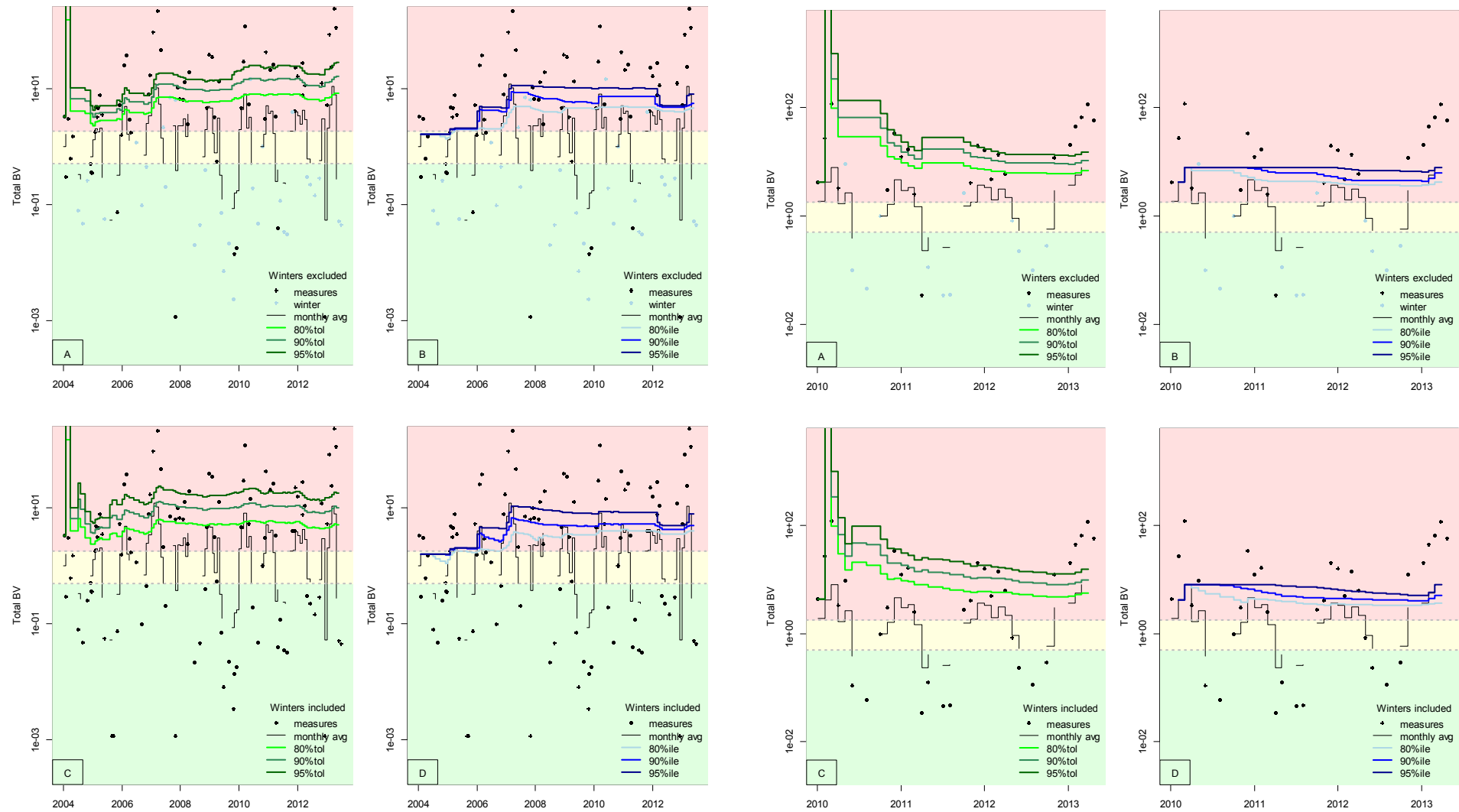


Figure 11. Total biovolumes (BV) in Lake Whangape. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data for the last three years of data.

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http://www.who.int/water_sanitation_health/bathing/srwe1/en/

7. APPENDICES

Appendix 1. Total biovolumes in lakes from the Rotorua and Waikato regions.

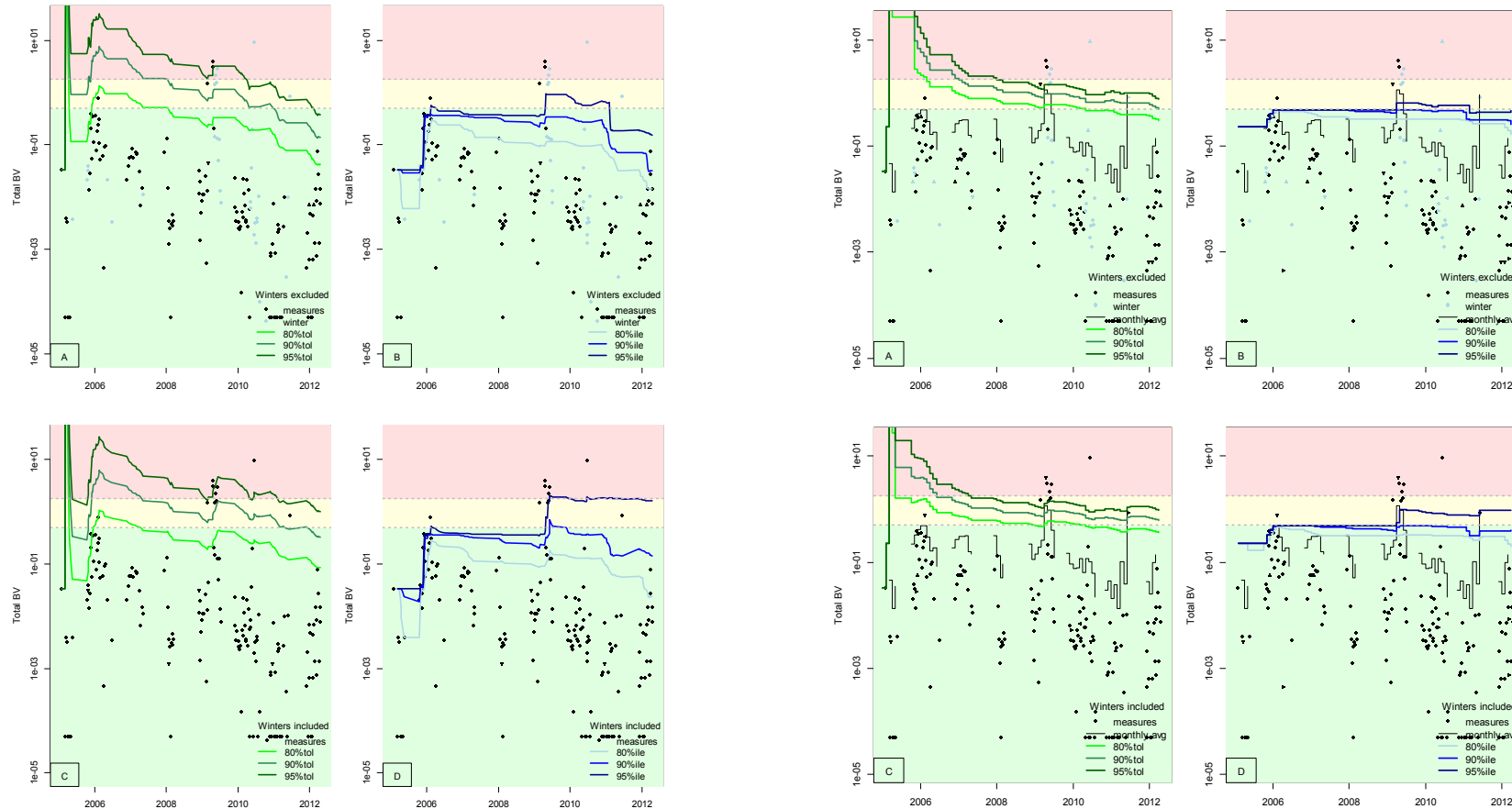


Figure 12. Total biovolumes (BV) in Kaituna — Te Timu. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

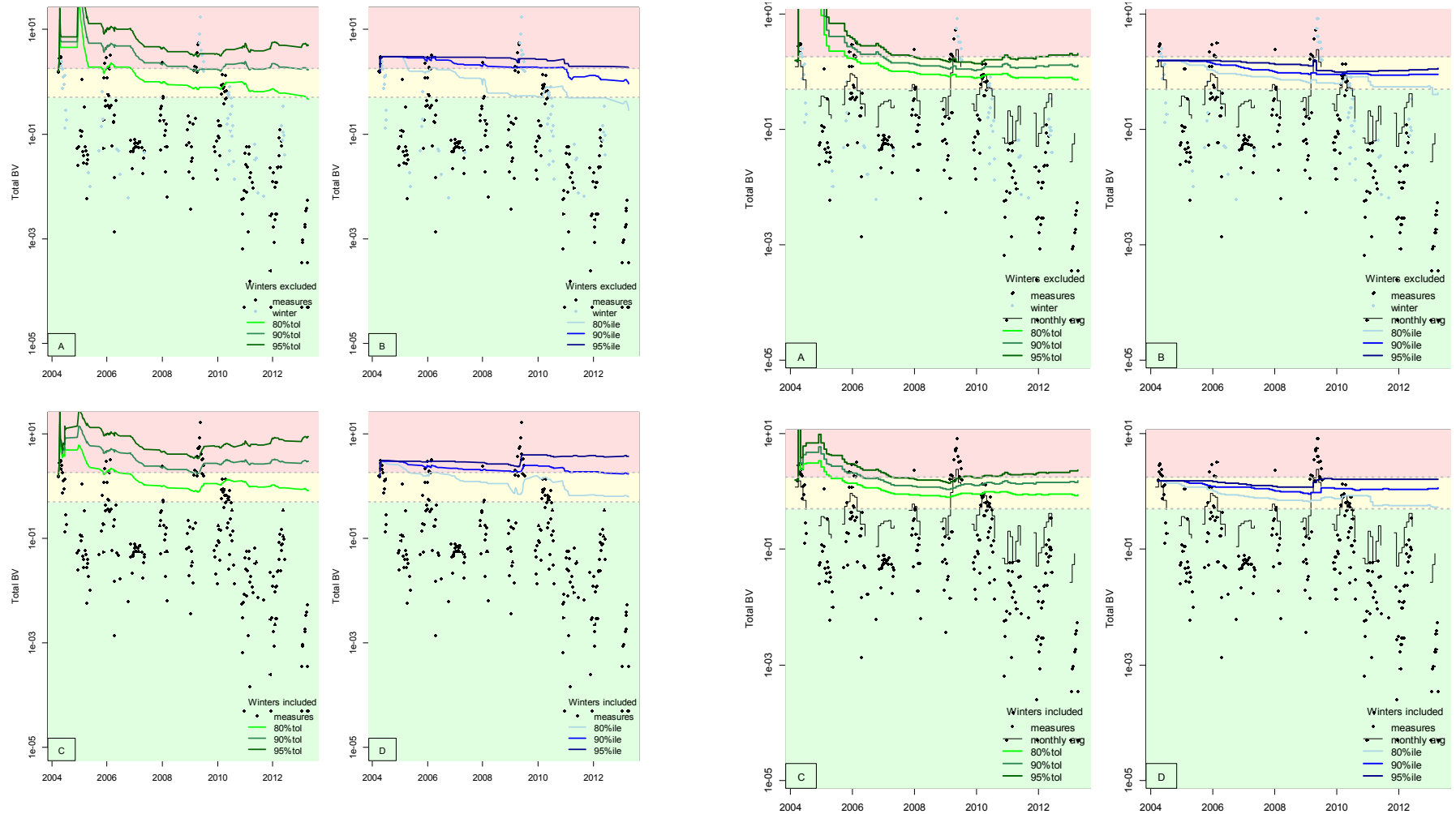


Figure 13. Total biovolumes (BV) in Kaituna — Trout Pool. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

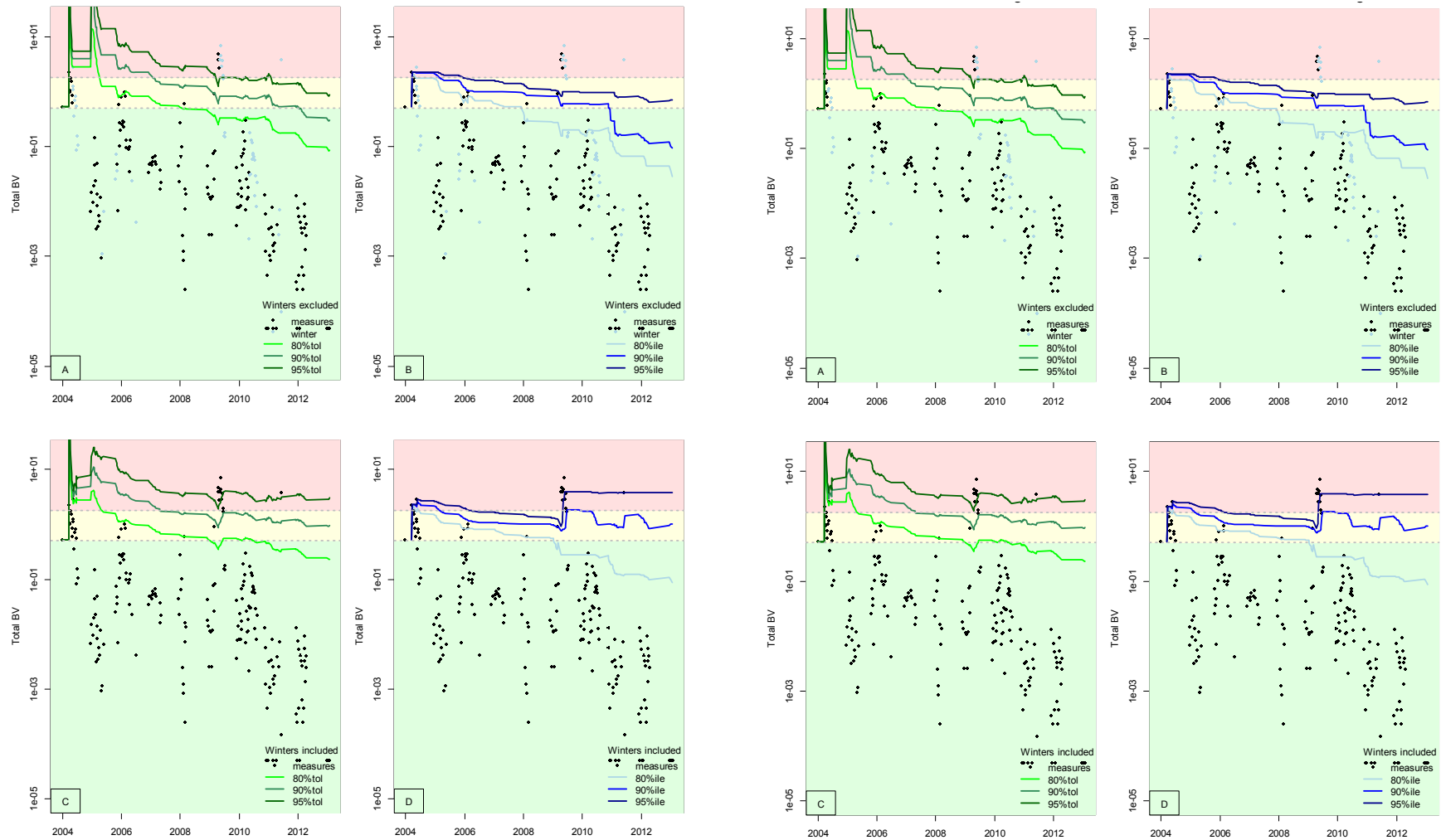


Figure 14. Total biovolumes (BV) in Kaituna — Waitangi. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

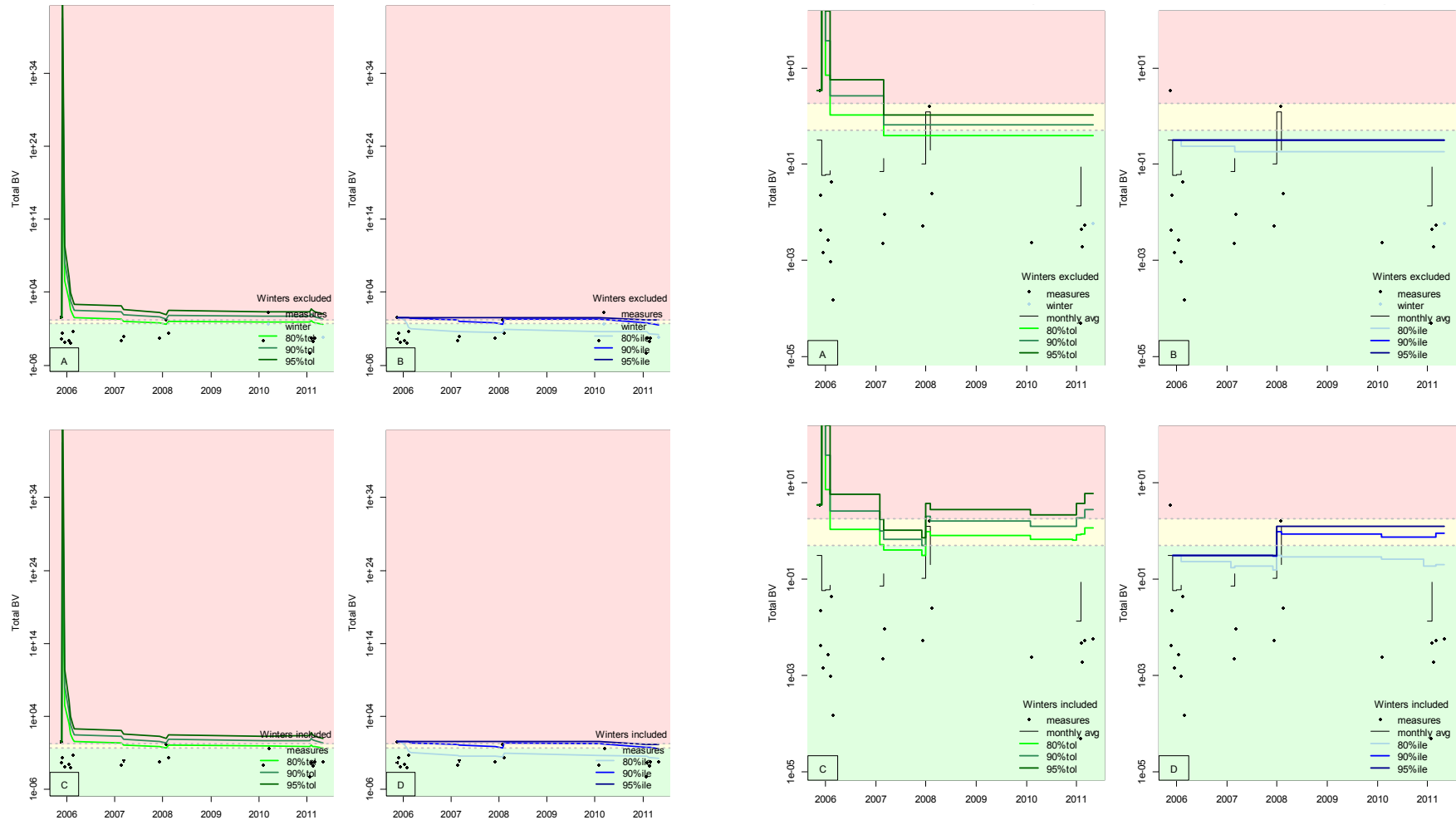


Figure 15. Total biovolumes (BV) in Lake Okareka — Boat ramp. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

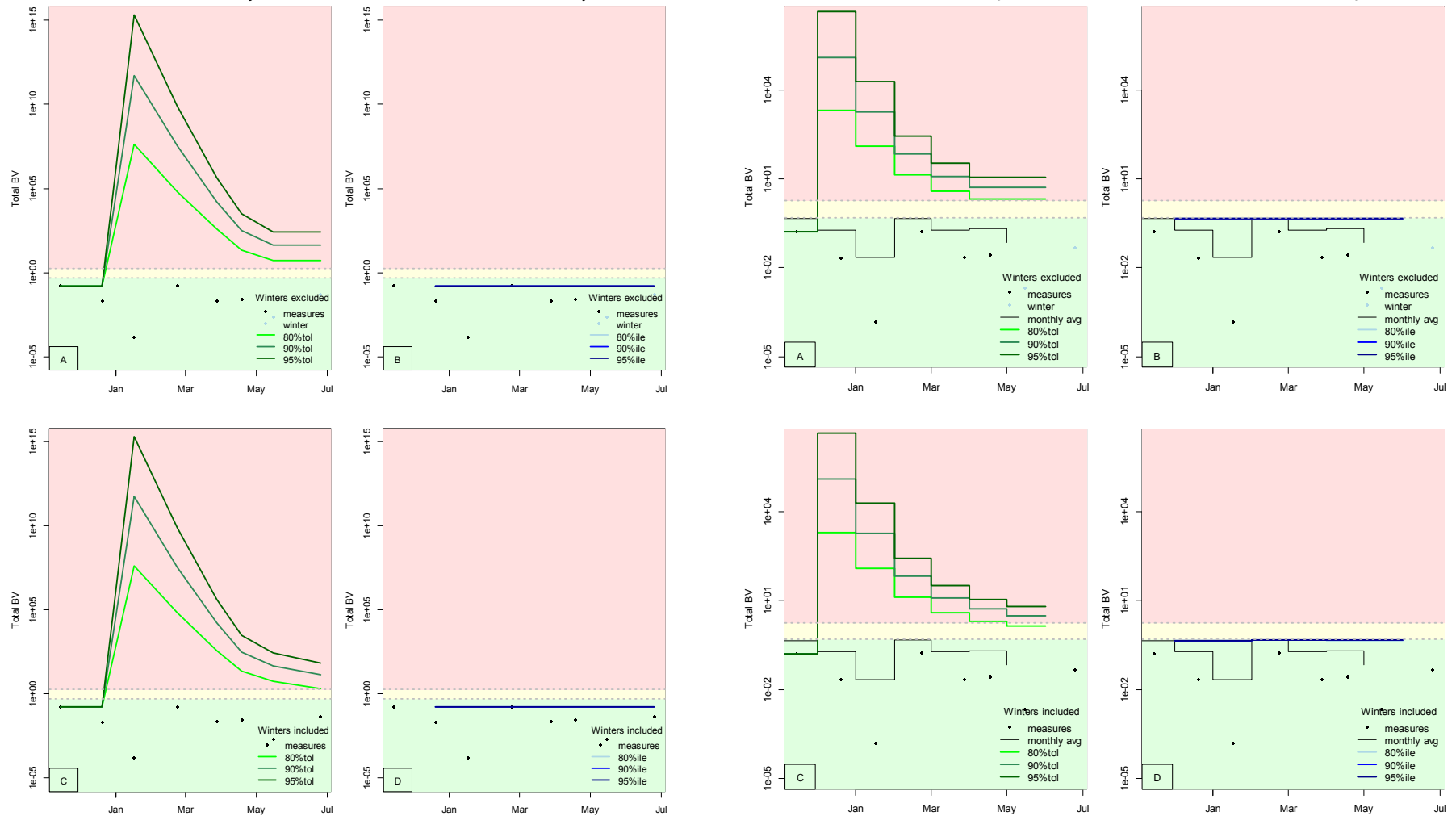


Figure 16. Total biovolumes (BV) in Lake Rotoehu — Buoy. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

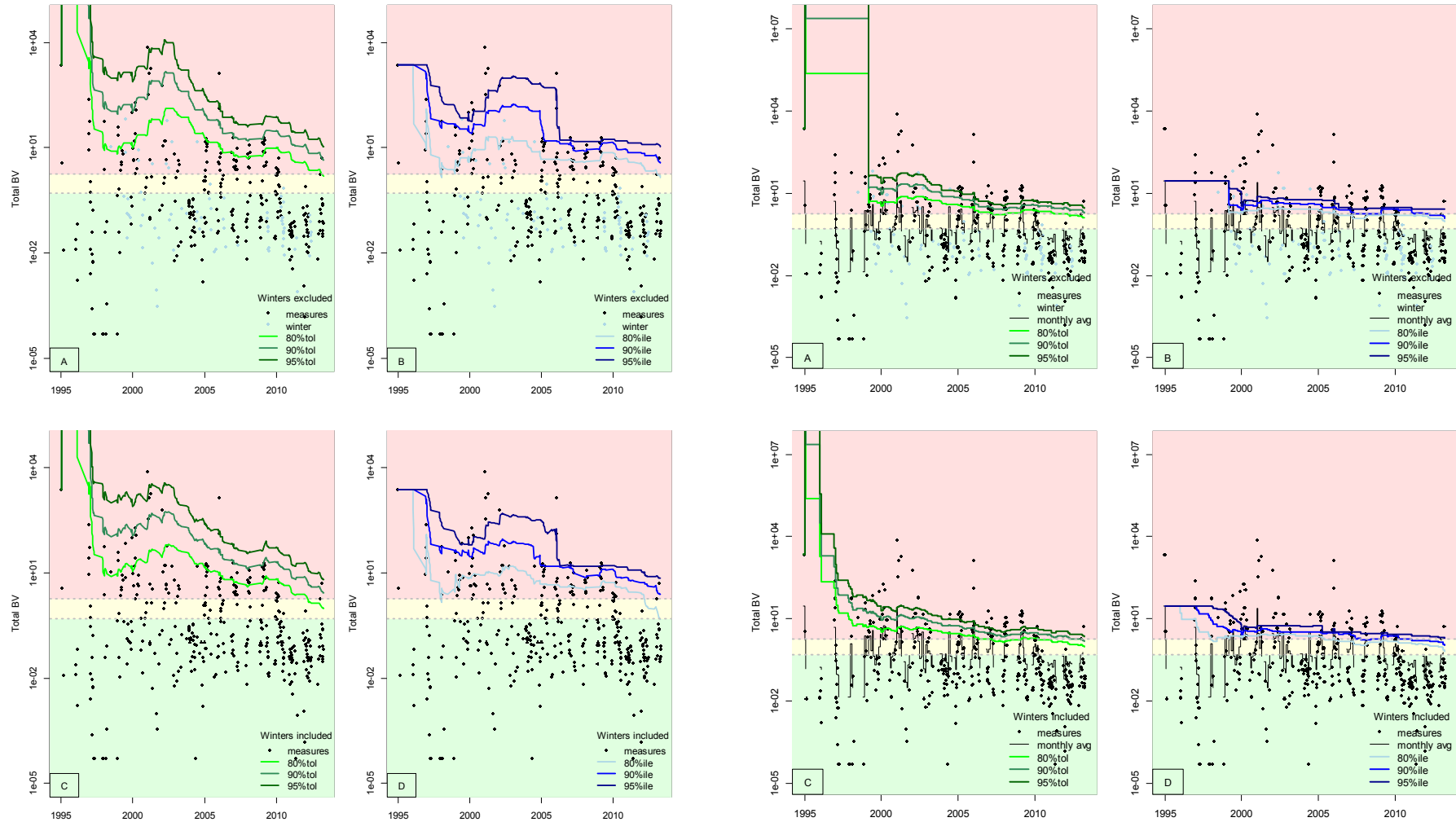


Figure 17. Total biovolumes (BV) in Lake Rotoehu — Otautu. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

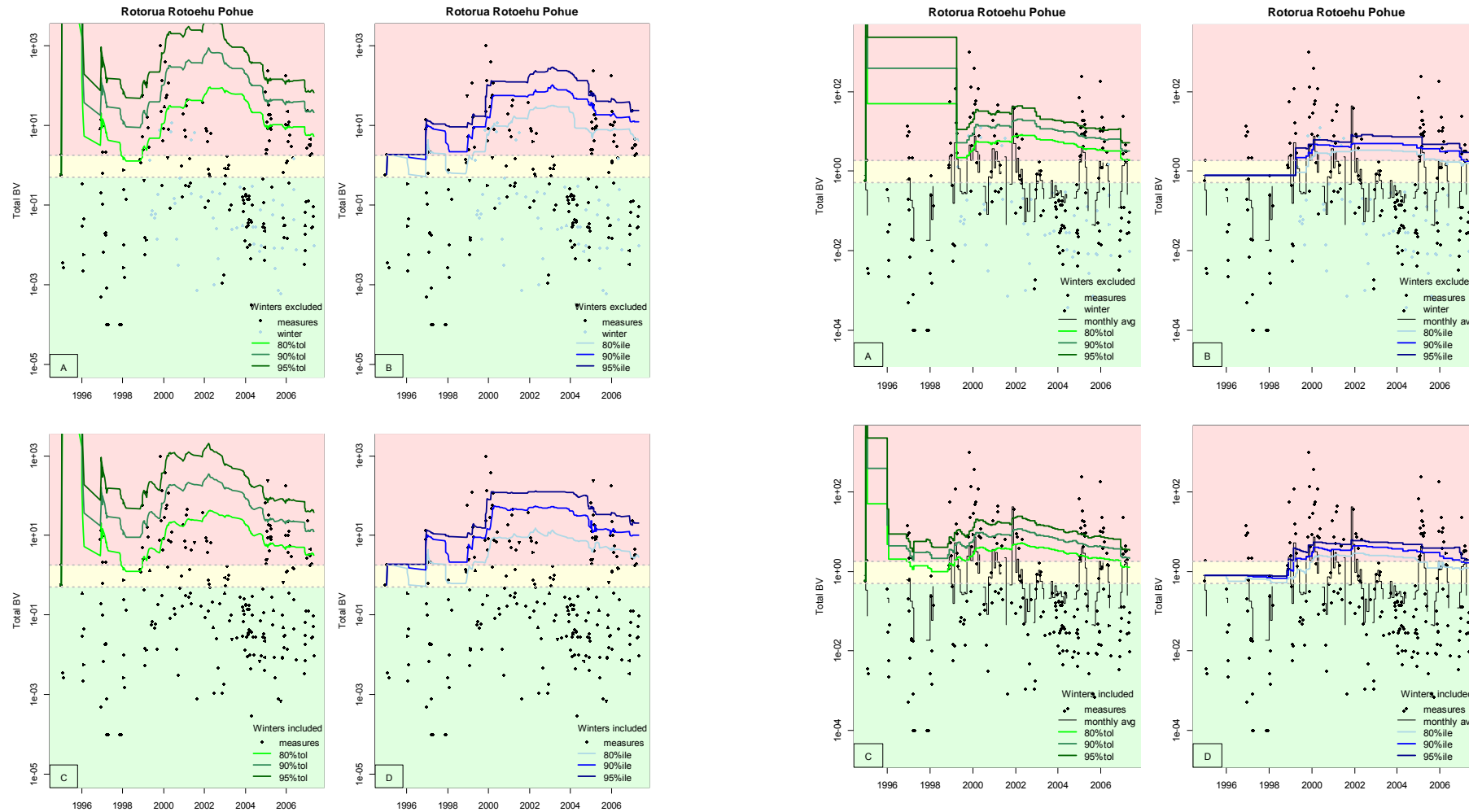


Figure 18. Total biovolumes (BV) in Lake Rotoehu — Pohue. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

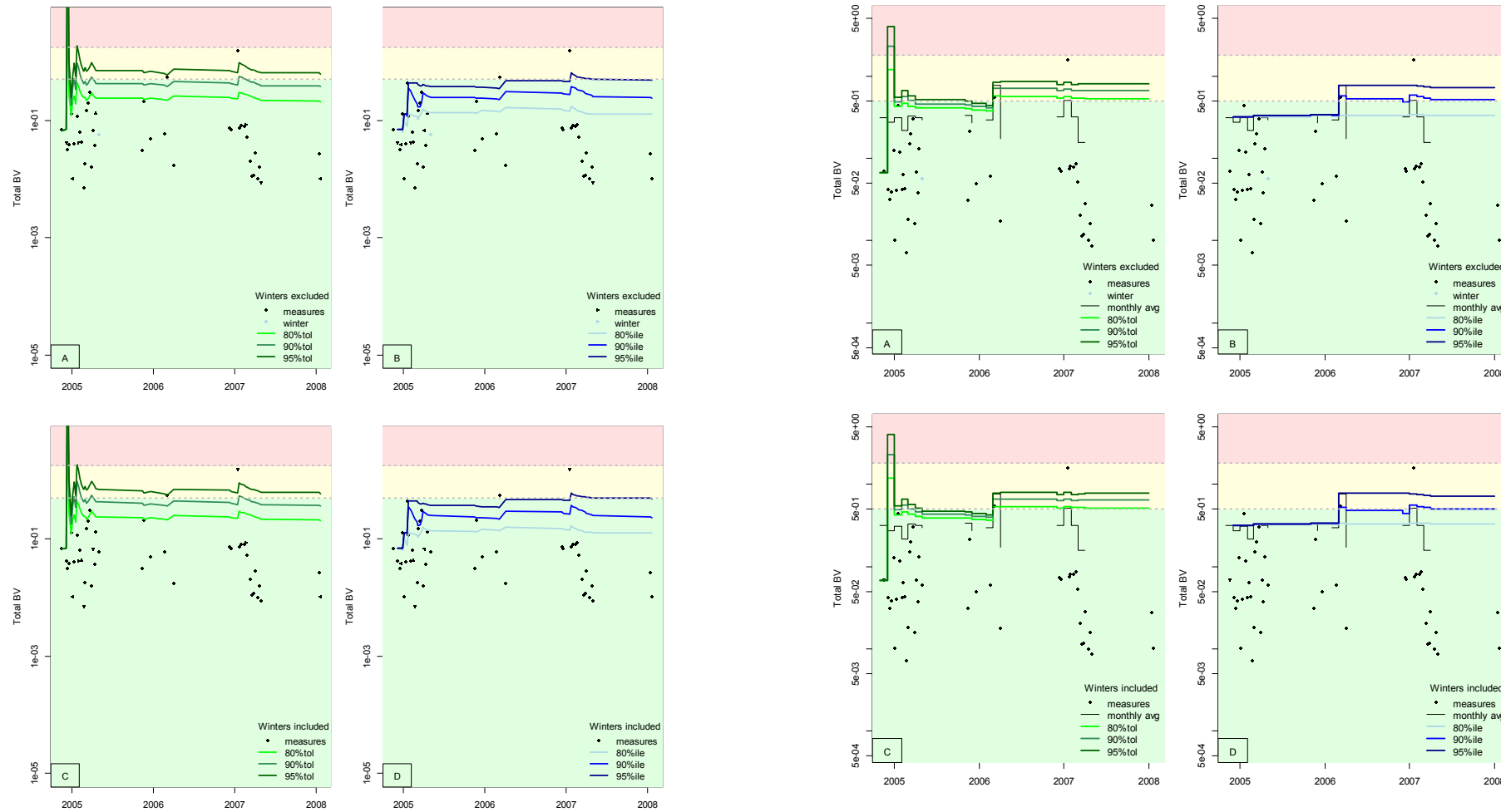


Figure 19. Total biovolumes (BV) in Lake Rotiti — Central. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

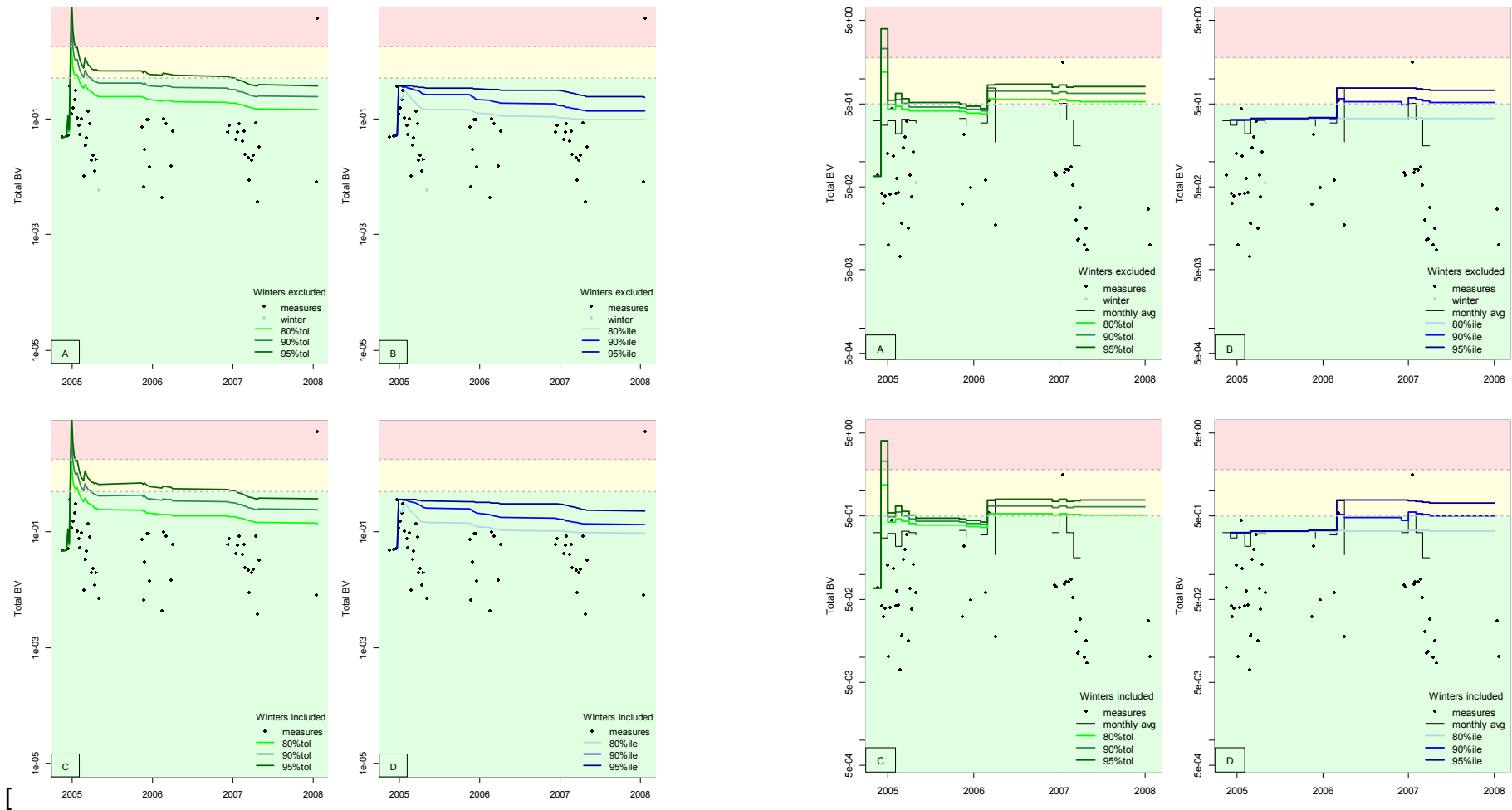


Figure 20. Total biovolumes (BV) in Lake Rotoiti — Eastern. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

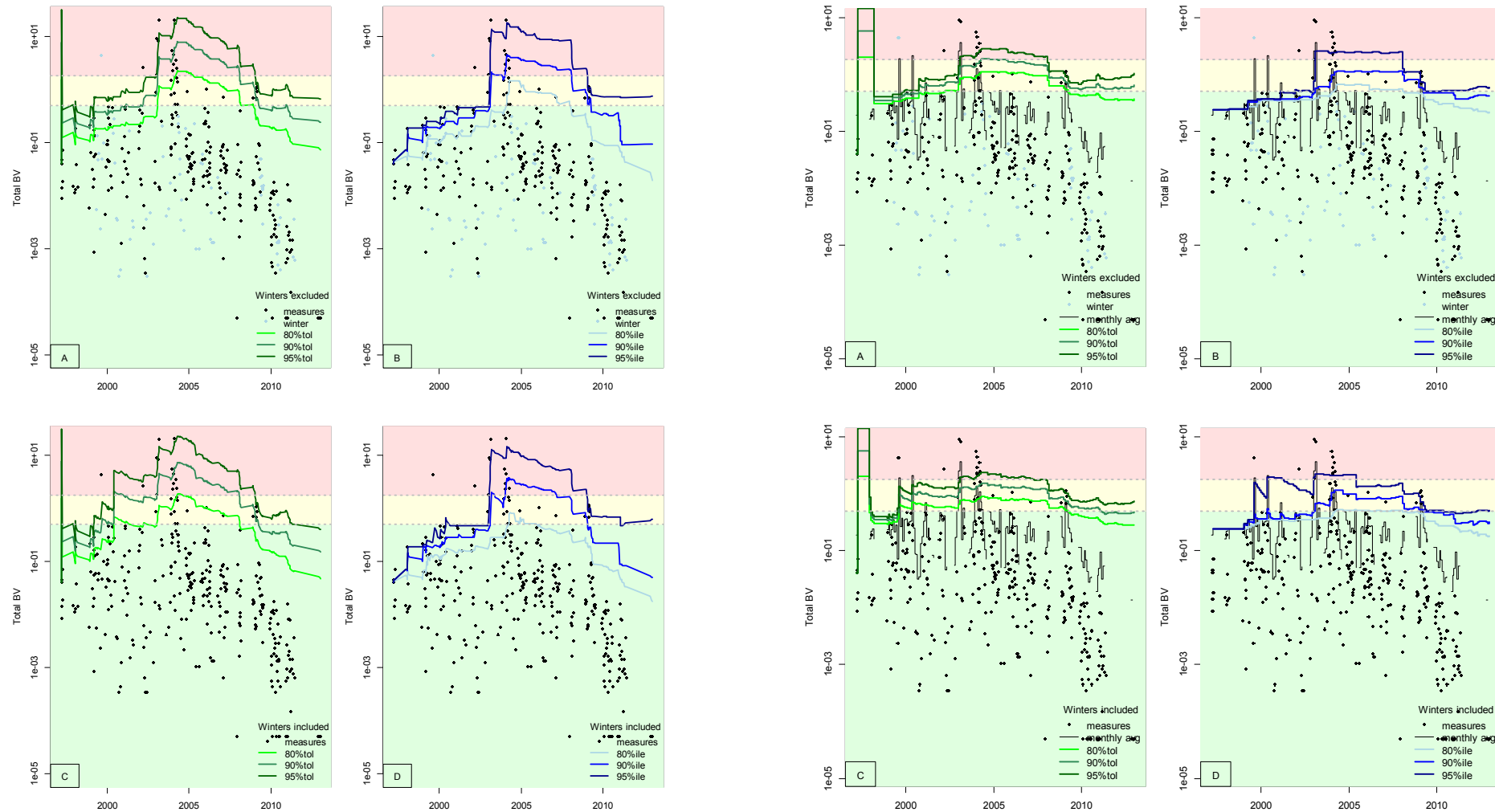


Figure 21. Total biovolumes (BV) in Lake Rotoiti — Gisbourne. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

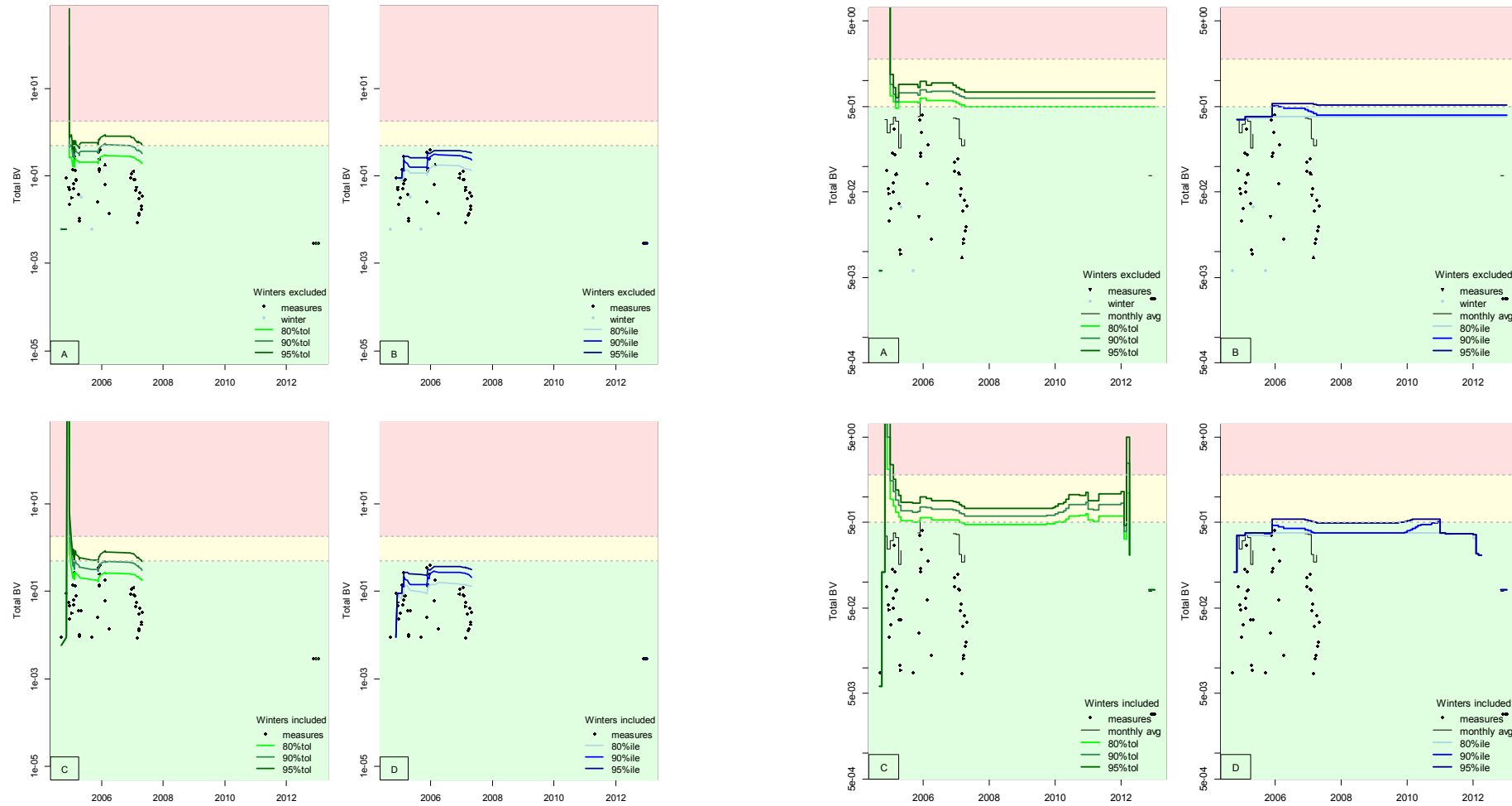


Figure 22. Total biovolumes (BV) in Lake Rotoiti — Manupriua. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

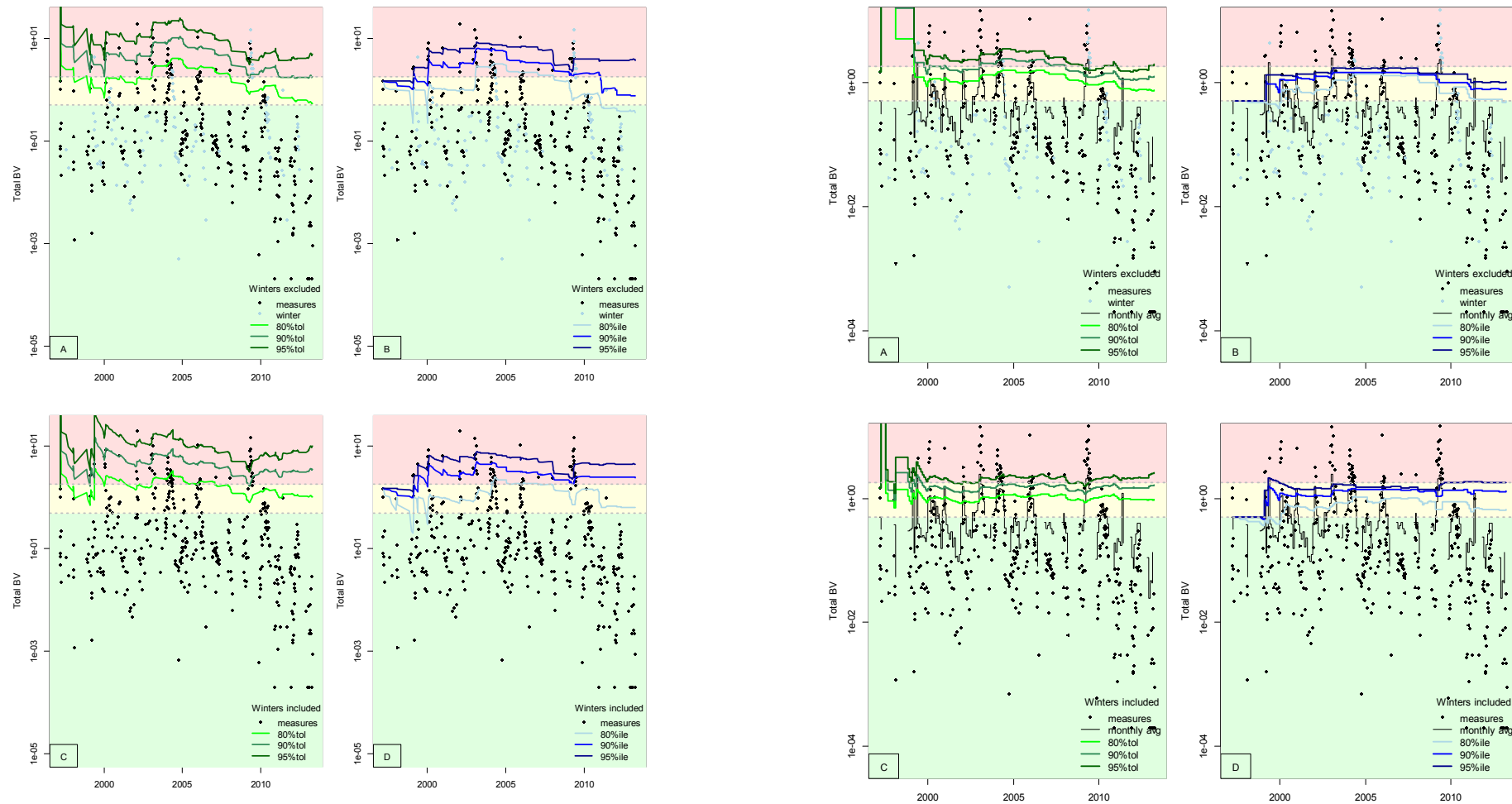


Figure 23. Total biovolumes (BV) in Lake Rotoiti — Okere. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

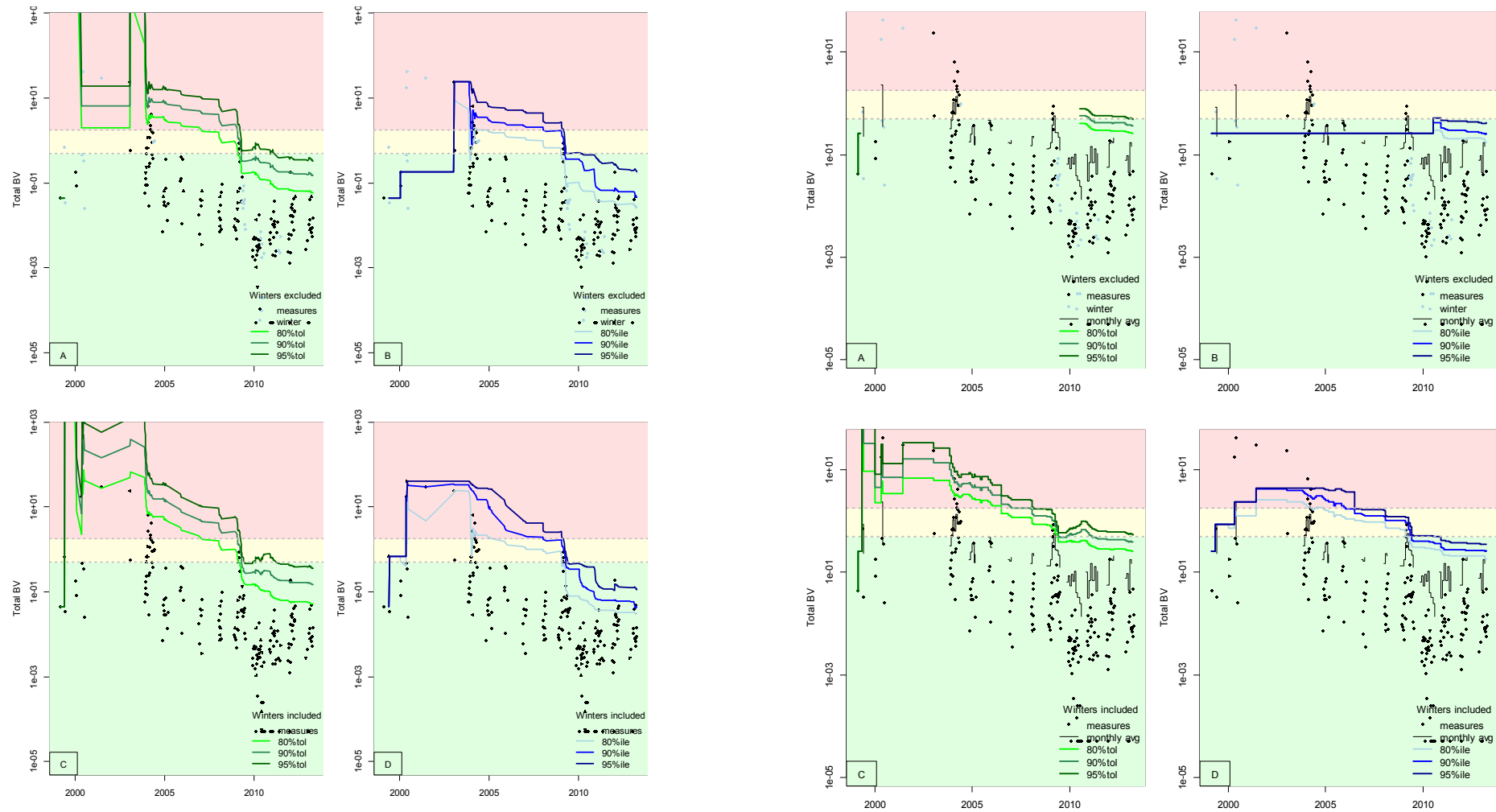


Figure 24. Total biovolumes (BV) in Lake Rotoiti — Otaramara. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

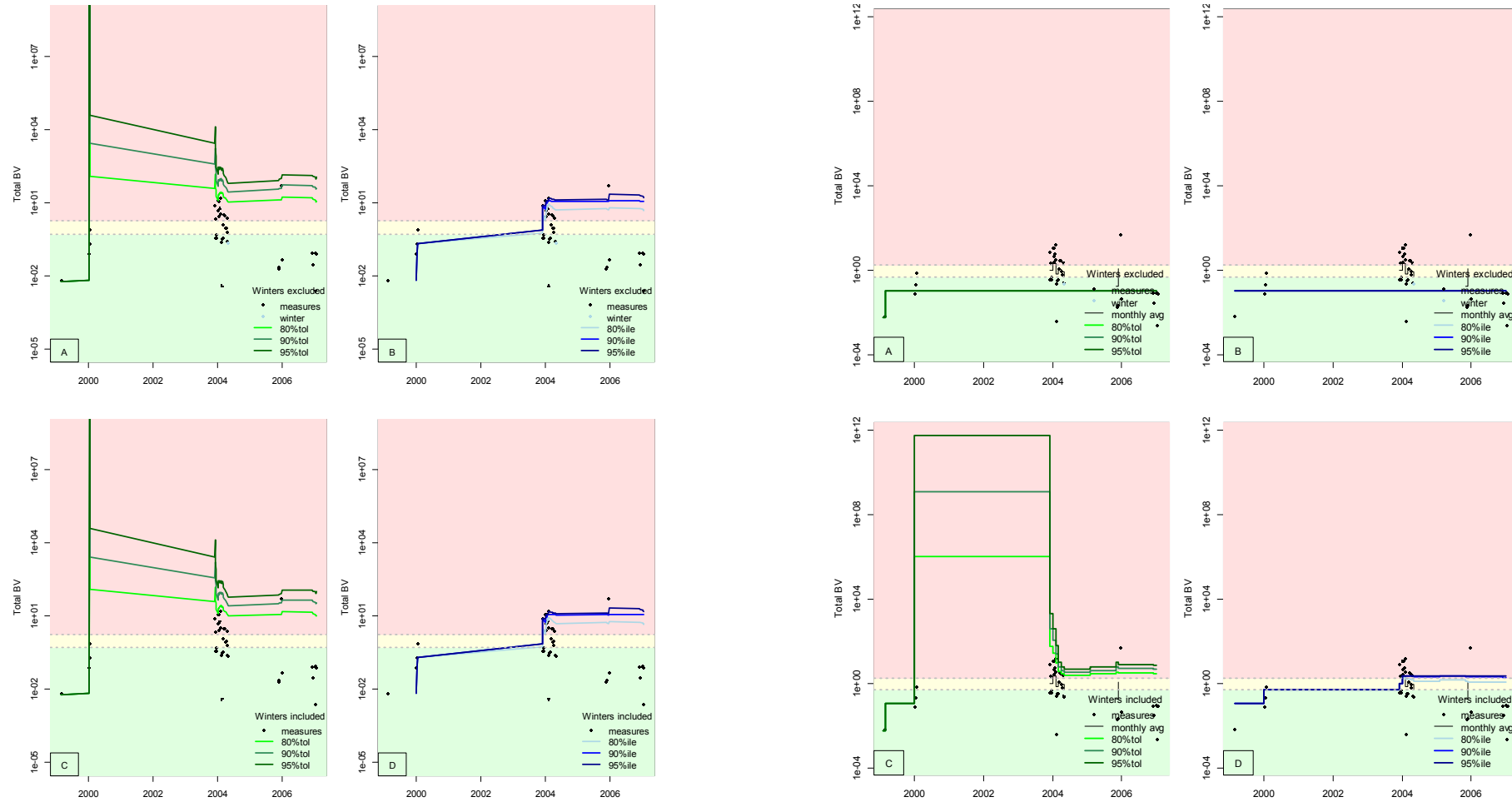


Figure 25. Total biovolumes (BV) in Lake Rotoiti — Ruato. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

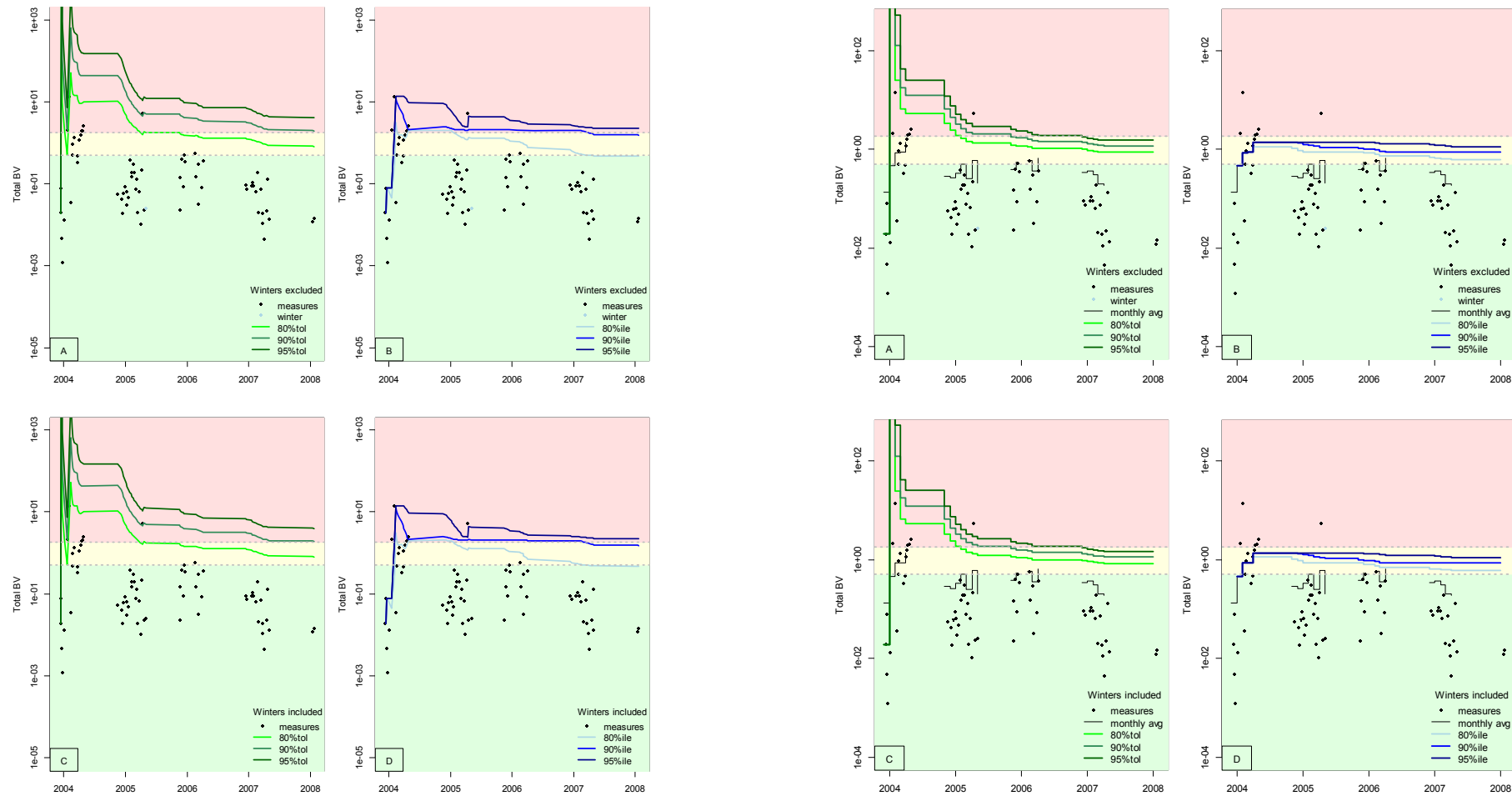


Figure 26. Total biovolumes (BV) in Lake Rotoiti — Western. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

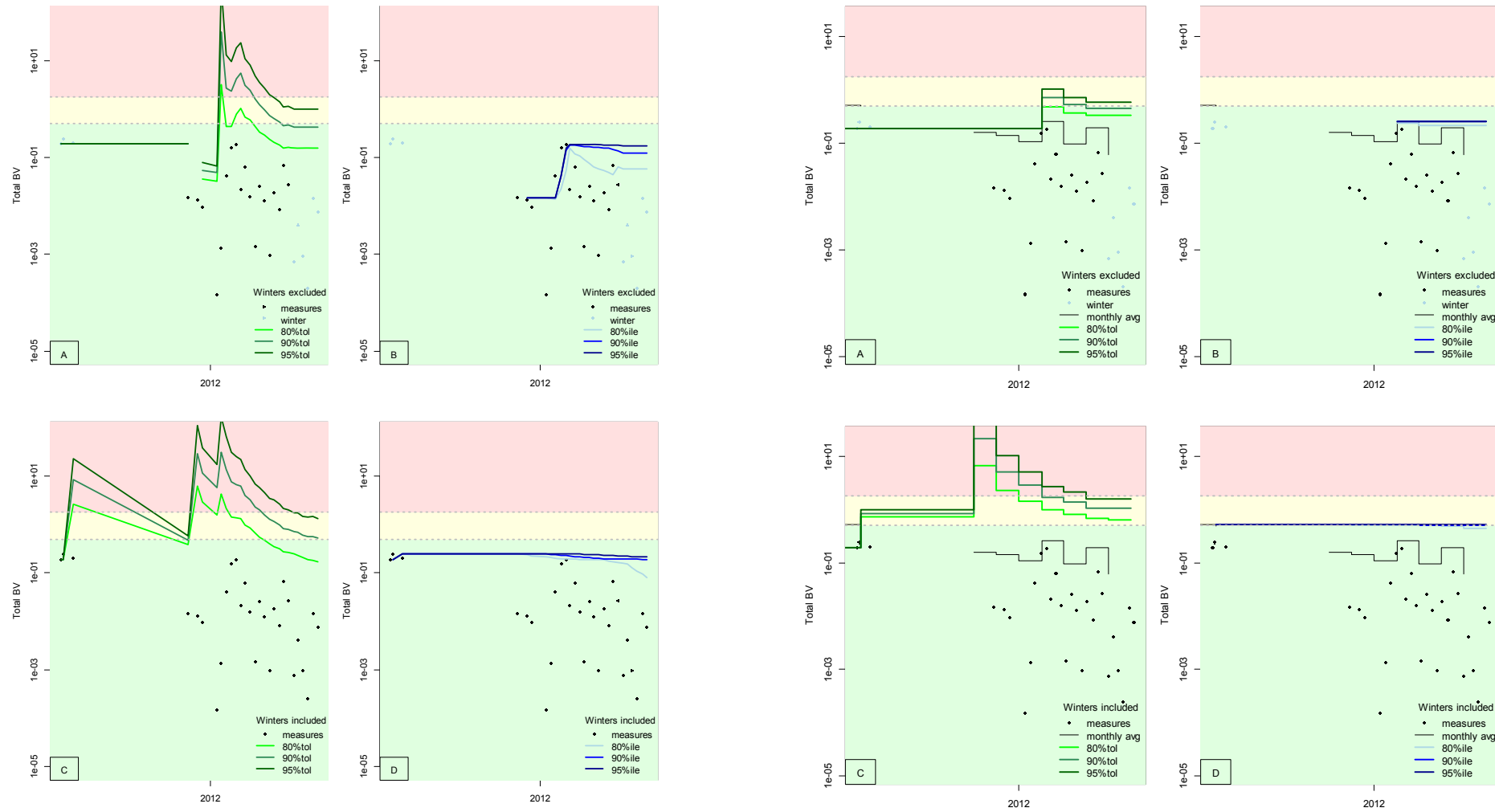


Figure 27. Total biovolumes (BV) in Lake Rotokakahi. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

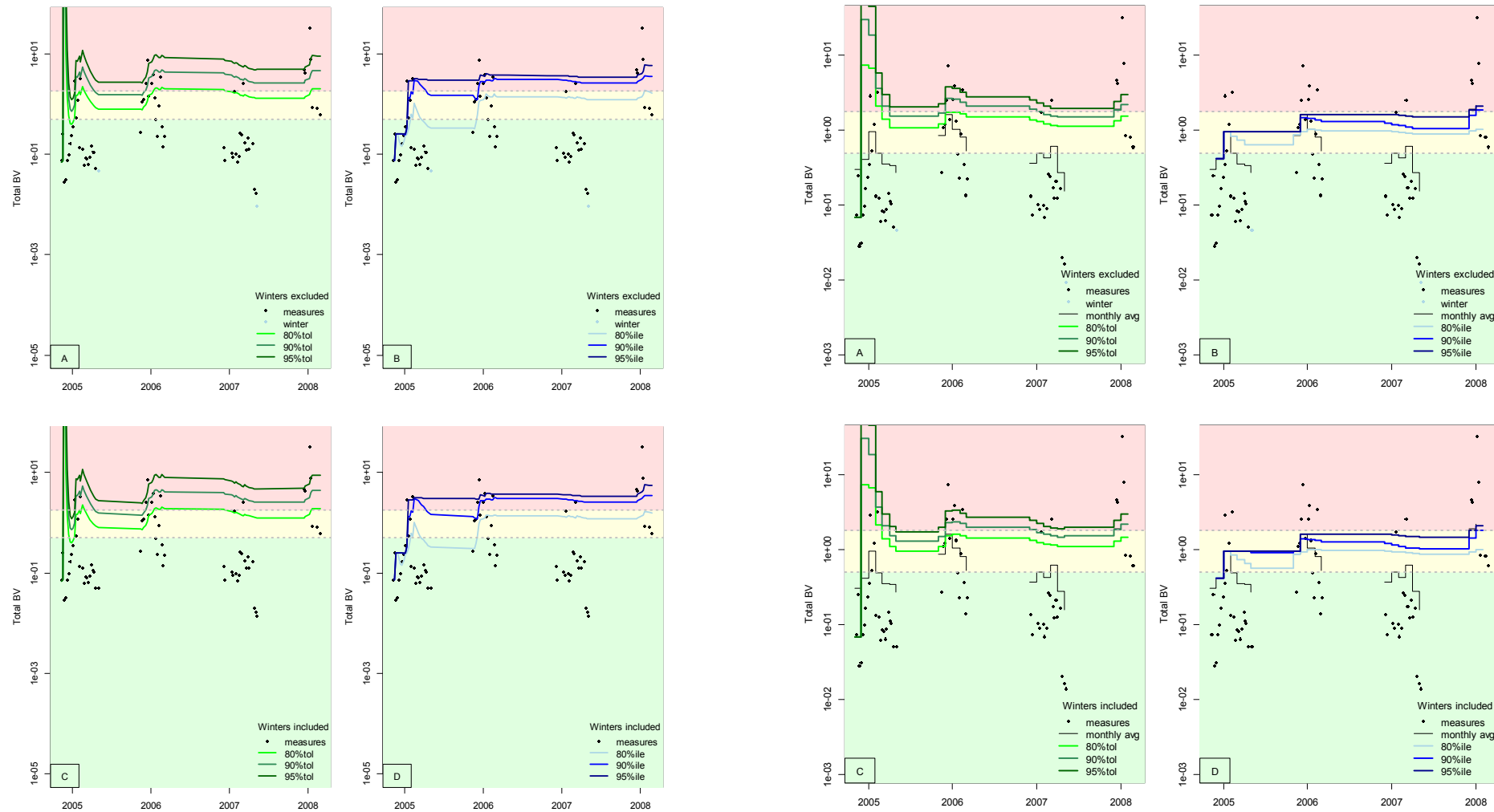


Figure 28. Total biovolumes (BV) in Lake Rotorua — Central. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

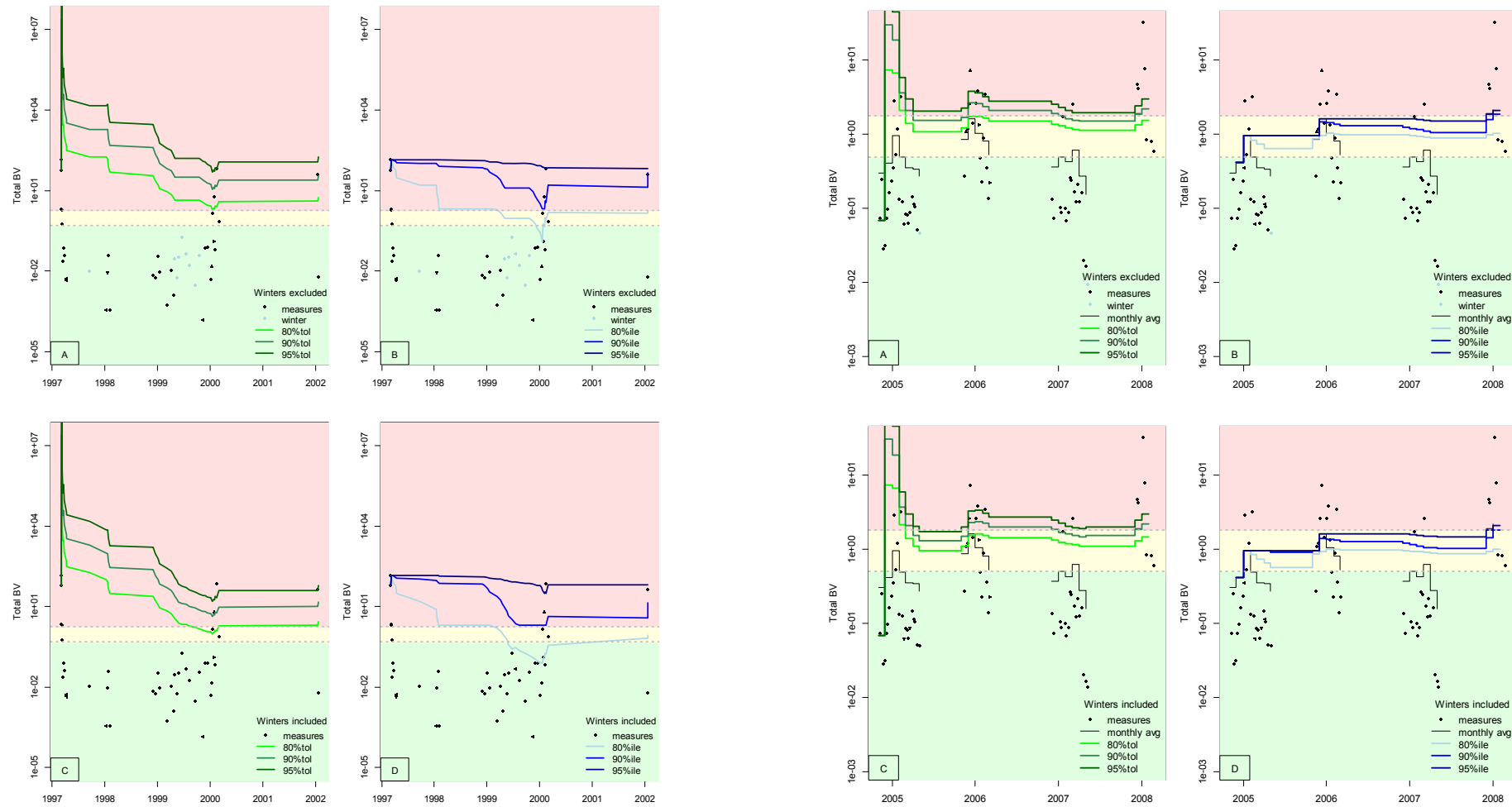


Figure 29. Total biovolumes (BV) in Lake Rotorua — City. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

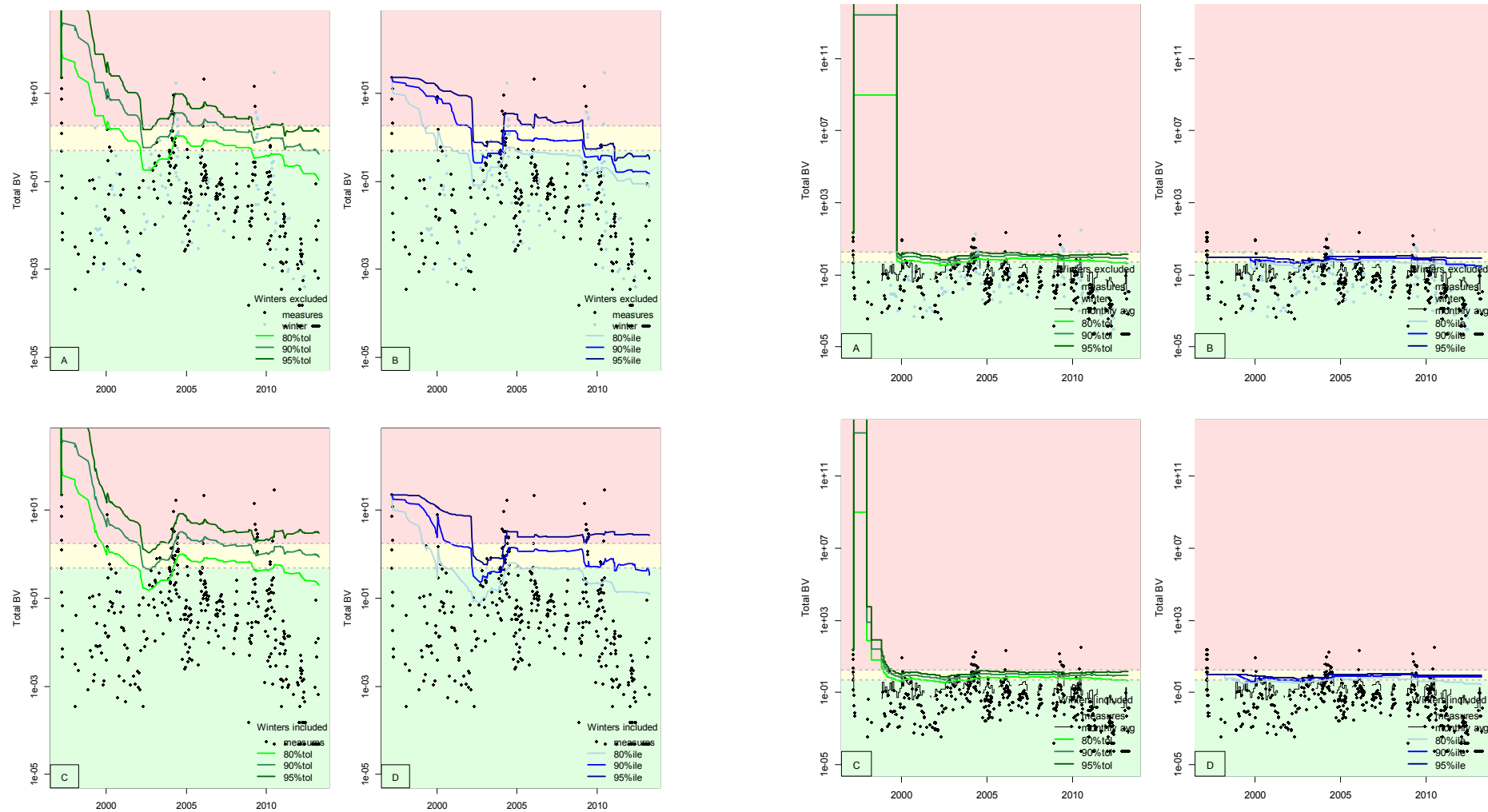


Figure 30. Total biovolumes (BV) in Lake Rotorua — Hamuranal. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

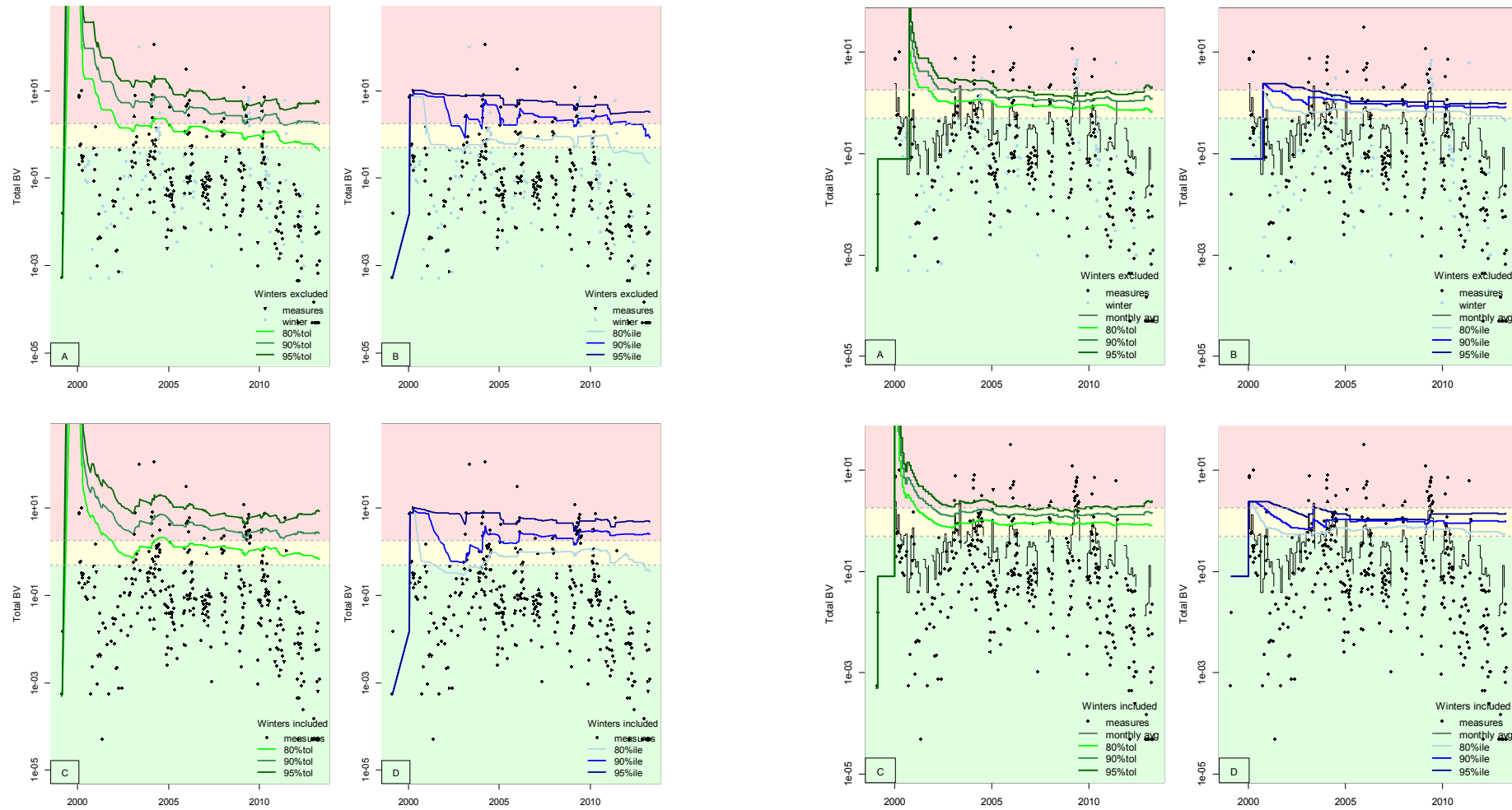


Figure 31. Total biovolumes (BV) in Lake Rotorua — Holdens. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

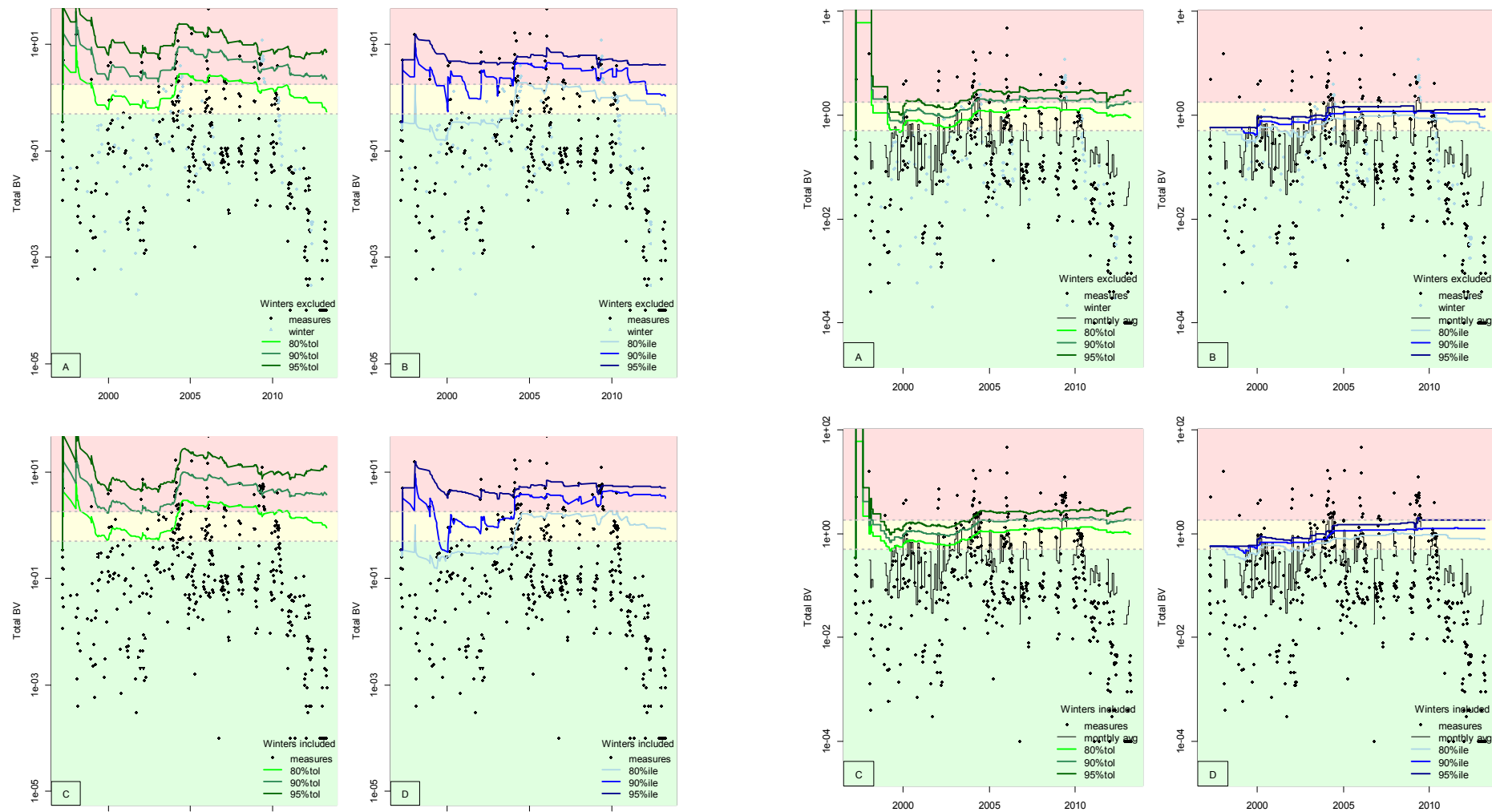


Figure 32. Total biovolumes (BV) in Lake Rotorua — Ohau. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black continuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

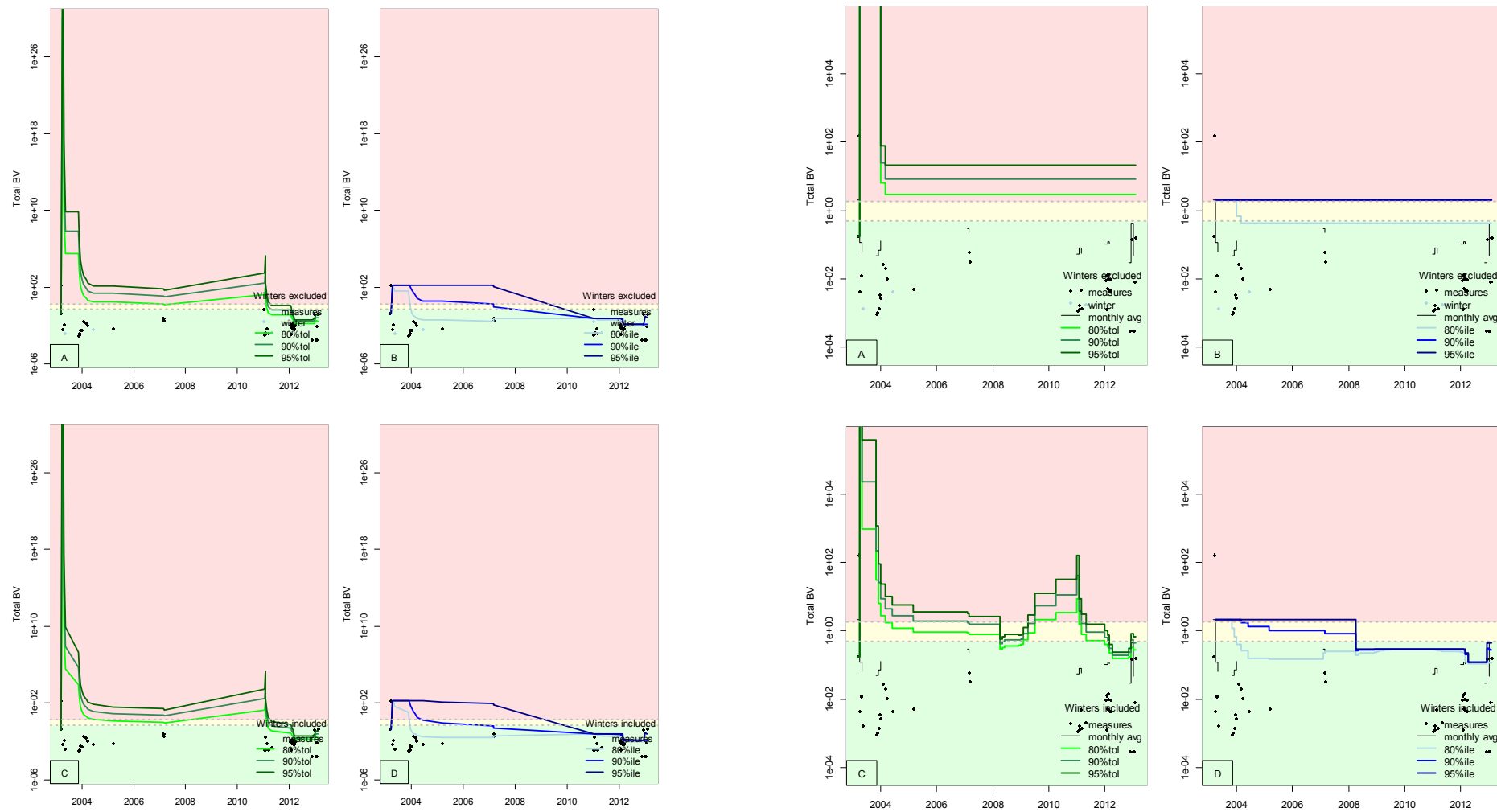


Figure 33. Total biovolumes (BV) in Lake Tarawera — Landing. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

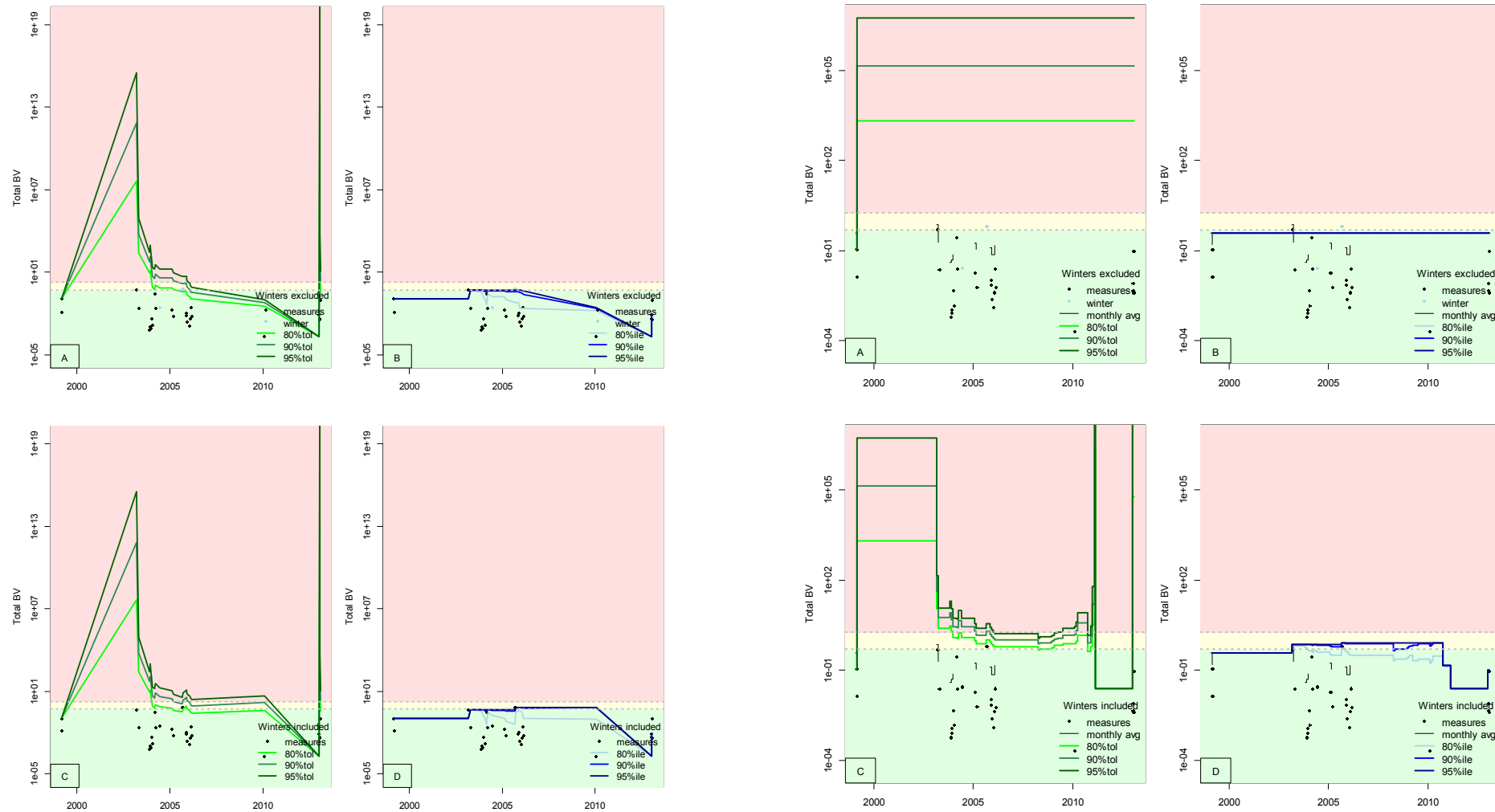


Figure 34. Total biovolumes (BV) in Lake Tarawera — Stoney. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

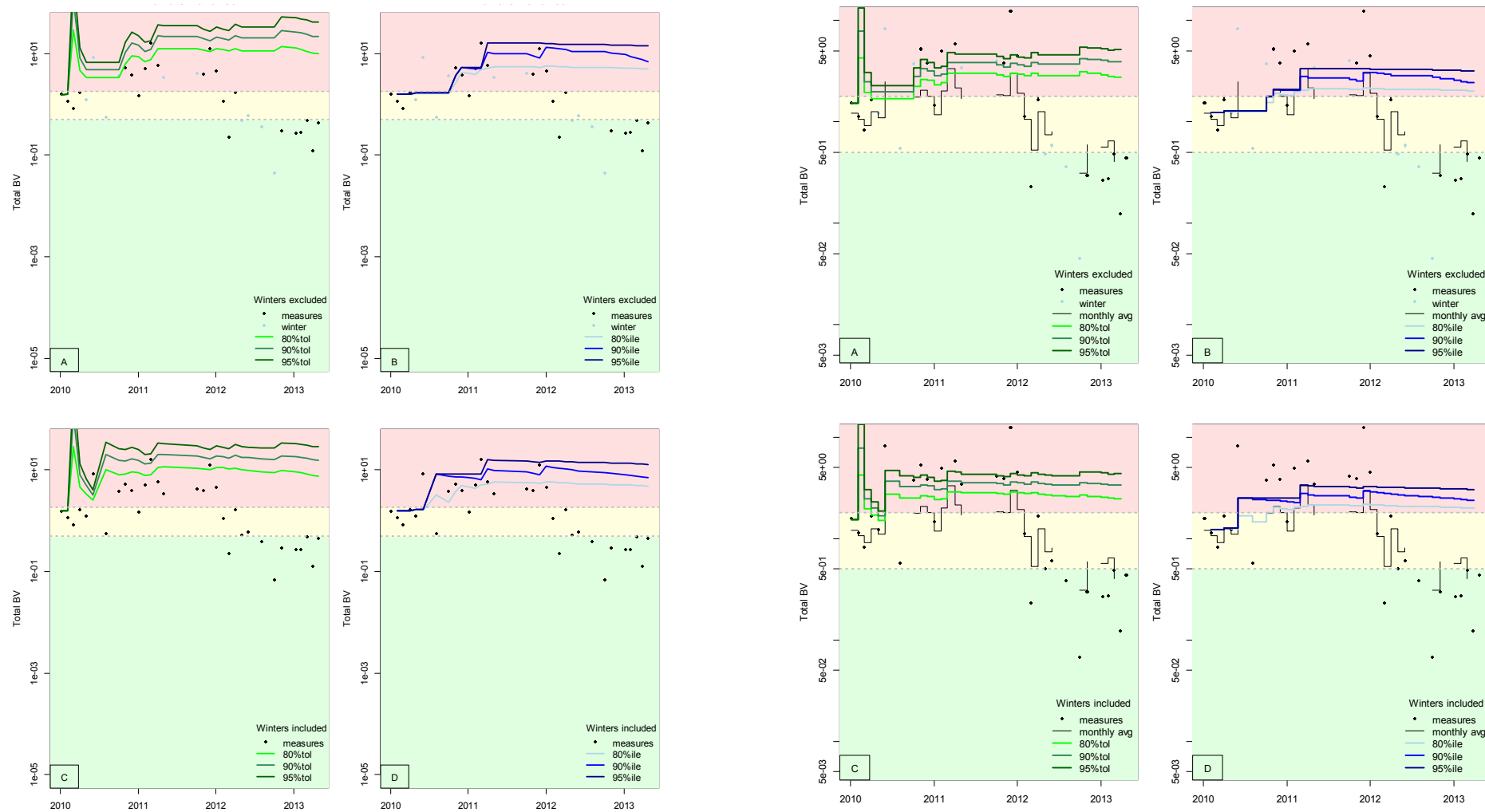


Figure 35. Total biovolumes (BV) in Lake Hakanoa — Landing. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band ‘D’, yellow ‘C’ and green ‘A.’

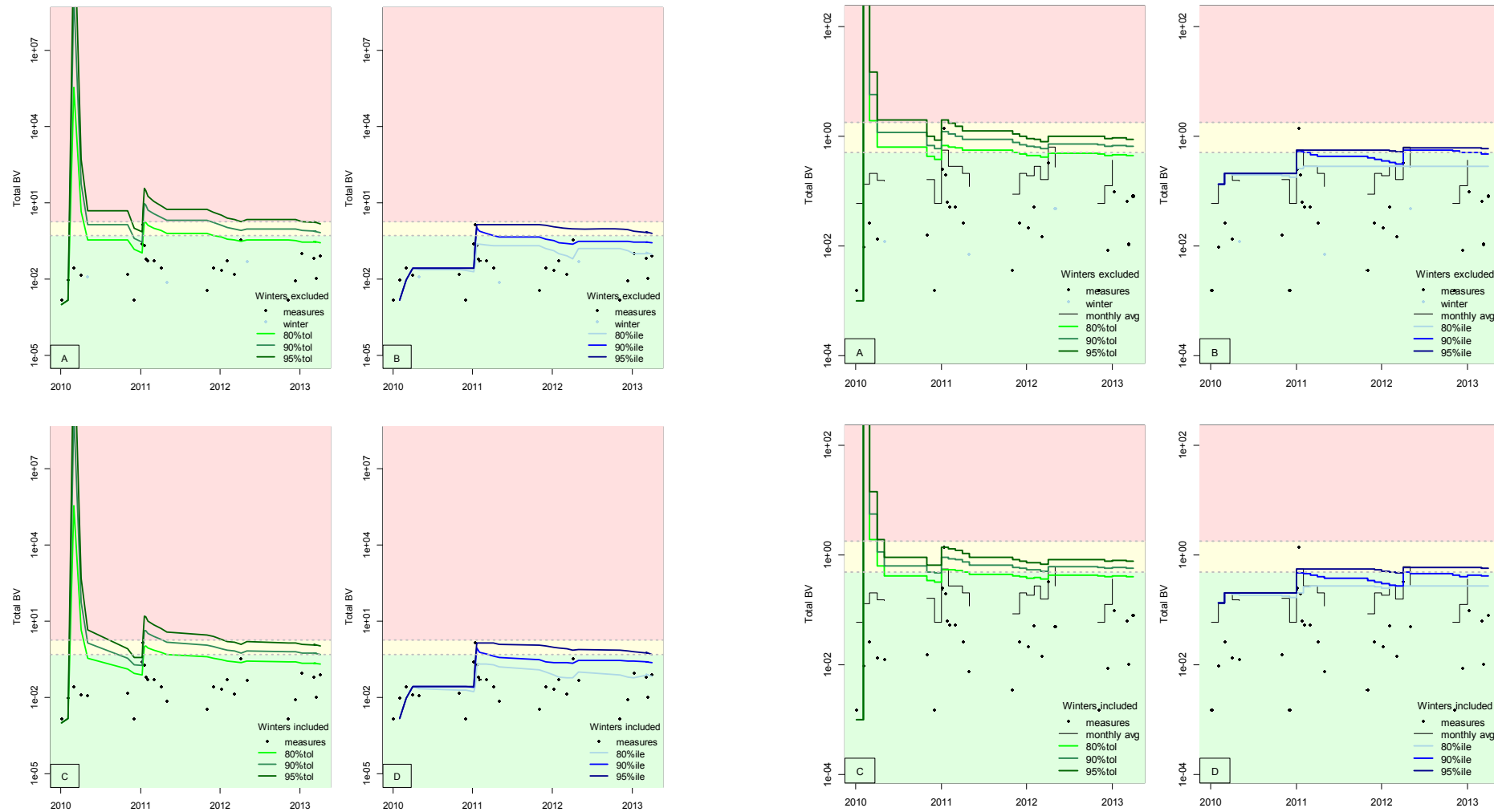


Figure 36. Total biovolumes (BV) in Lake Karapiro. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

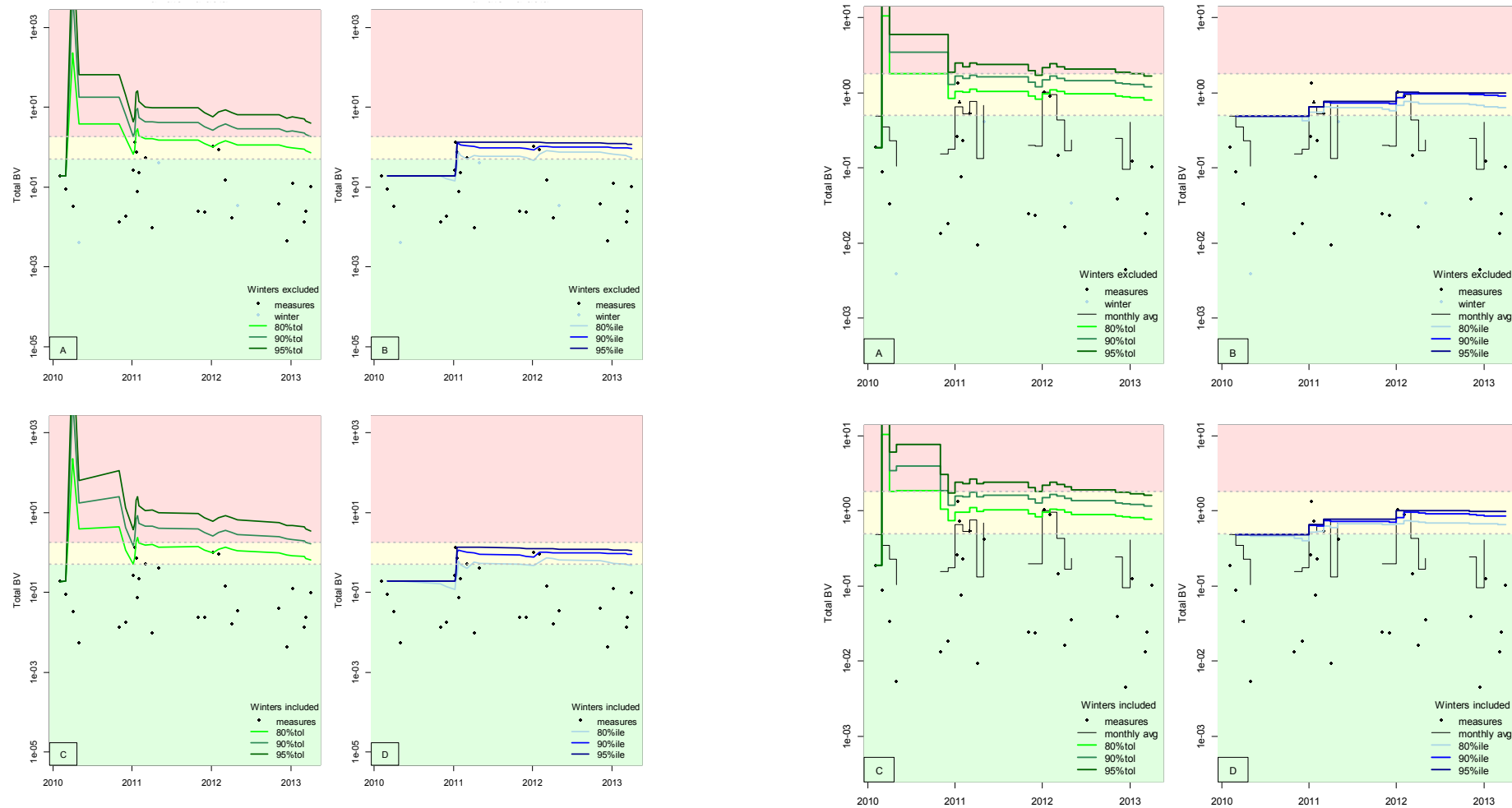


Figure 37. Total biovolumes (BV) in Lake Maraetai. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

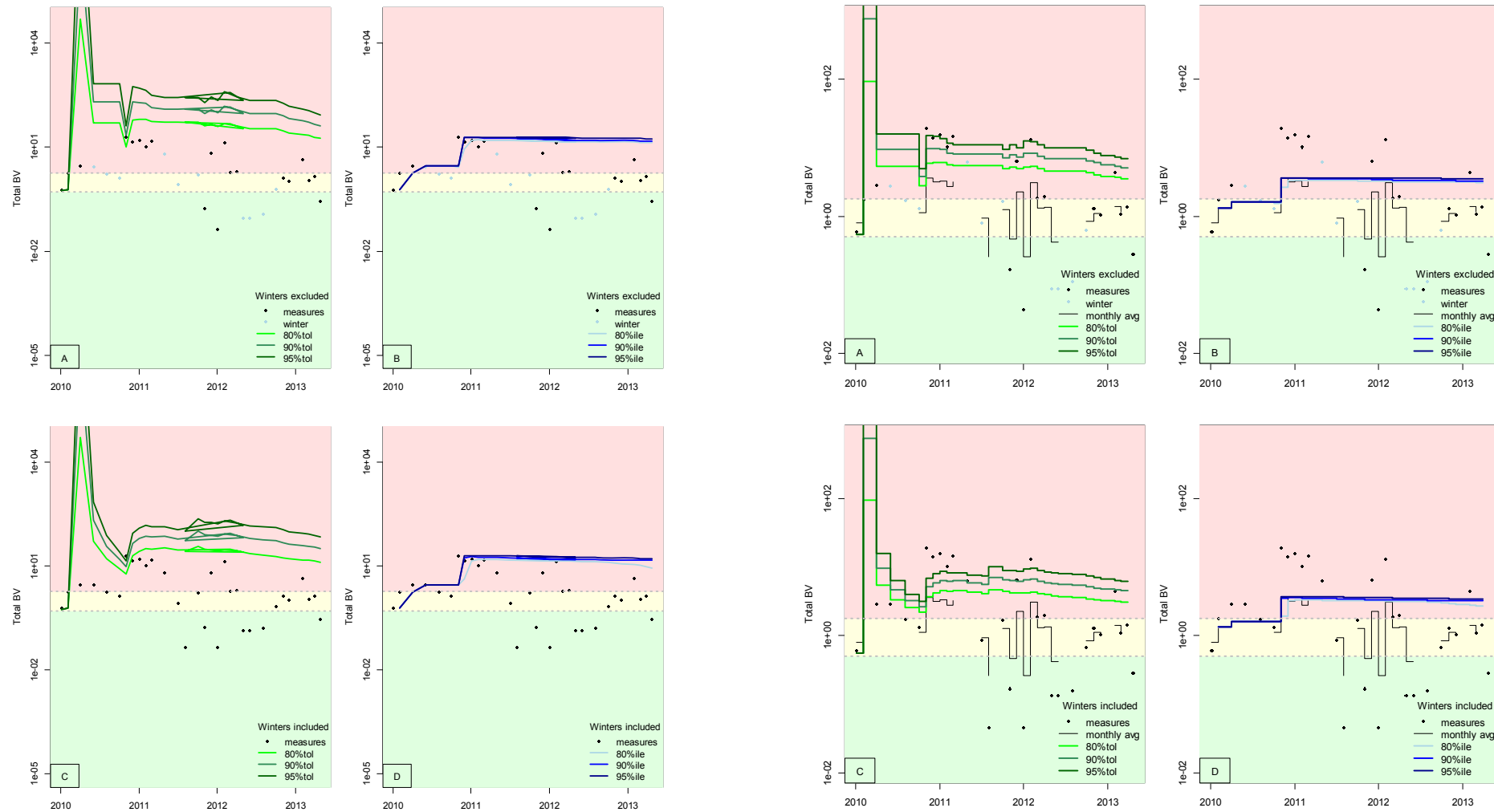


Figure 38. Total biovolumes (BV) in Lake Ngaroto. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'

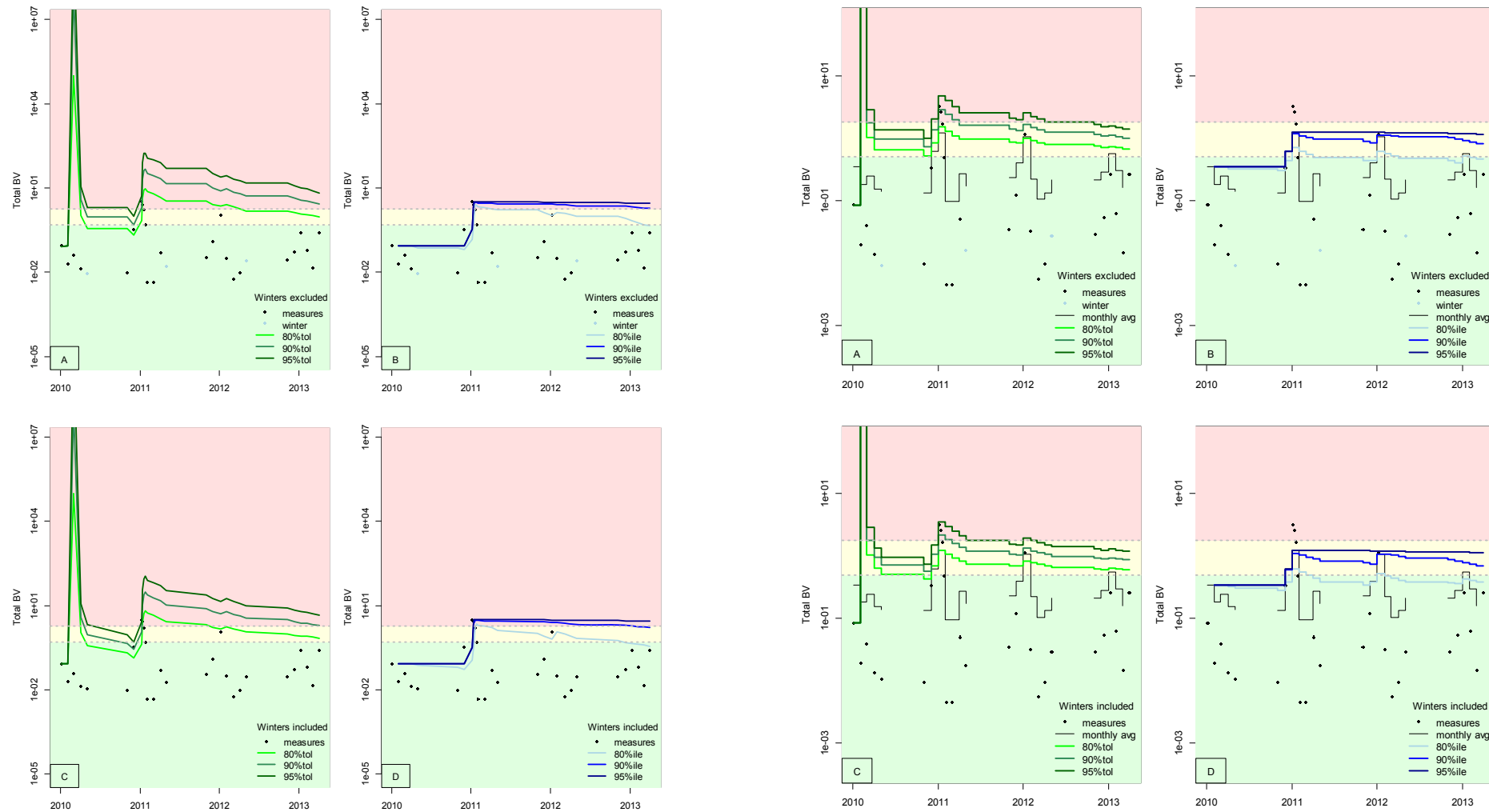


Figure 39. Total biovolumes (BV) in Lake Ohakuri. Left side of page: monthly averages pre-calculated (represented by the thin black discontinuous line) for (A) 80%, 90% and 95% tolerance intervals excluding winter (May to September inclusive) and, (D) including all data points, and (B) 80, 90 and 95 percentiles excluding winter and, (C) including all data points. Right side of page shows the same data with monthly averages pre-calculated (represented by the thin black discontinuous line). The red panel represents band 'D', yellow 'C' and green 'A.'