CHAPTER 4.

RESULTS

4.1 Experimental results from SALMO-OO and the simulation library for lakes with different environmental conditions

The aim of presenting results in this section is to show the ability of the SALMO-OO model to simulate a variety of trophic and mixing conditions for freshwater lakes using a generic approach and to demonstrate the improved validation results given by the simulation library. Results for phytoplankton biomass, zooplankton biomass, phosphate concentration and algal functional groups abundances are shown for each alternative phytoplankton growth and grazing model experiment utilising the SALMO-OO simulation library. Comparison between the simulation library experiments and the results produced by the original SALMO-OO growth and grazing functions are also given. Root-mean square error (RMSE) and r^2 values are given as a quantitative measure of fit between the measured data and the model outputs for each state variable.

4.1.1 Eutrophic and hypertrophic conditions

4.1.1.1 Bautzen reservoir, Germany

The simulation results for Bautzen reservoir by SALMO-OO (Figure 4.1a) describe the total phytoplankton biomass reasonably well, except for the time lag in the prediction of the spring peak, as reflected by the poor r^2 value ($r^2 = 0.0013$). Simulation of zooplankton biomass and phosphate concentration yielded moderately high r^2 values which gives confidence in the original structure of SALMO-OO for these state variables (Figure 4.1a). Predictions of phytoplankton functional groups is realistic of the eutrophic conditions of Bautzen reservoir with the spring peak being attributed to the dominance of green algae and the occurrence of blue-green algae in late spring and summer.

Phytoplankton growth model experiments

Comparisons between three alternative growth models and SALMO-OO are given in Figure 4.1a. Each alternative growth model improved the results for the prediction of phytoplankton biomass, both visually and quantitatively, compared to SALMO-OO. In particular, the growth models from Arhonditsis & Brett (2005) and CLEANER not only improved the r^2 and RMSE values but also improved the timing of the phytoplankton spring peak predictions. The predictions of zooplankton biomass given by growth models of Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) are visually similar to SALMO-OO, however, the statistical results have been improved. This is particularly seen from the lower RMSE values (3.45 and 4.24 respectively). However, despite the high r^2 value (0.7), the CLEANER growth model caused a large spike in the predictions of zooplankton biomass in early summer that was not reflected by the measured data and consequently gives a higher RMSE value (7.9 compared to SALMO-OO RMSE = 4.72). For phosphate predictions the growth model from CLEANER produced significantly better results then those produced by SALMO-OO. The simulation of phytoplankton functional groups by each alternative growth model is as expected for eutrophic conditions and gives a similar trend as shown by the SALMO-OO outputs.

Phytoplankton grazing model experiments

The grazing model from Arhonditsis & Brett (2005) produces results for phytoplankton biomass predictions similar to SALMO-OO (Figure 4.1b). The Arhonditsis & Brett (2005) grazing model gives the lowest RMSE value (9.72 compared to SALMO-OO RMSE of 10.32), but still gives a very low r^2 value (0.012). Conversely, The grazing model from Hongping & Jianyi (2002) gives the best r^2 value of all models tested (0.12) for phytoplankton predictions and describes the measured data more accurately than the grazing model from Arhonditsis & Brett (2005) (Figure 4.1b). The grazing model from CLEANER produces an improved result in regards to the r^2 value, but the RMSE value (10.87) is slightly higher then that produced by the SALMO-OO model (Figure 4.1b). Therefore, the Hongping & Jianyi (2002) grazing model results produce the best improvements to the simulation of each state variable, compared to the other grazing models and SALMO-OO. However, all alternative grazing models did not improve the timing of the phytoplankton spring peak.

For zooplankton biomass simulations the grazing model from Arhonditsis & Brett (2005) gave a slightly higher r^2 value compared to SALMO-OO ($r^2 = 0.66$ compared to $r^2 = 0.65$), however, all alternative grazing models did not perform any better then SALMO-OO according to the RMSE values, which were all higher then the SALMO-OO RMSE (Figure 4.1b). Nevertheless, each alternative grazing model still produced results that visually described the zooplankton measured data reasonably well, and in a similar fashion as given by the SALMO-OO model. Again, the grazing model from Arhonditsis & Brett (2005) produces the best results for phosphate, with a slightly higher r^2 value (0.32) and a significantly lower RMSE value (29.54), compared to SALMO-OO (Figure 4.1b). The simulations of phytoplankton functional groups is also still in accordance with expected conditions for eutrophic lakes, however, the grazing model from Arhonditsis & Brett (2005) indicates a greater abundance of diatoms during the summer period than other simulations.

Experiments of combined growth and grazing process models

According to the selection criteria outlined in section 3.6.3 it can be concluded that each alternative growth model and the grazing models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) have the ability to improve the results of phytoplankton biomass predictions. Therefore, combinations of these alternative models were tested to see if the results produced by SALMO-OO could be further improved.

Figure 4.1c illustrates the best four results from the combination experiments for Bautzen reservoir. Each combination of growth and grazing models presented in Figure 4.1a and 4.1b produced markedly improved results for phytoplankton biomass predictions, with the best statistical results given by growth AB & grazing HJ and growth CL & grazing HJ. The zooplankton RMSE results (Figure 4.1c) suggest that none of the combination models provided a better prediction then SALMO-OO, however, the combinations of growth CL & grazing AB did improve the r^2 value considerably (0.74). The best result for phosphate concentration was produced by the combination of growth CL & grazing AB, with an r^2 value of 0.48 and a significantly lower RMSE value (27.73) compared to SALMO-OO (r^2 = 0.31 and RMSE = 45.29). Phytoplankton functional group simulations still performed reasonably well and were realistic of eutrophic conditions. For all combinations shown in Figure 4.1c the succession between green algae and blue-green algae during the summer stratification is very clearly illustrated.

Therefore, taking into consideration the best performing phytoplankton results, with suitable outputs for zooplankton and phosphate predictions, the combination of the growth model from CLEANER and the grazing model from Hongping & Jianyi (2002) provides the best result that the simulation library can achieve for Bautzen Reservoir. This combination improves the quantitative results for phytoplankton biomass, with an r^2 value of 0.15 and RMSE of 8.89 compared to that calculated for the SALMO-OO phytoplankton results (r^2 = 0.0013 and RMSE = 10.32). The improvement in the timing of the phytoplankton spring peak predictions is more accurate compared to SALMO-OO and the phytoplankton functional groups are realistic and consistent with what is expected to occur in a dimictic, eutrophic lake, with a clear distinction in species succession during summer. Although the results for phytoplankton biomass are marginally better from the combination of growth AB & grazing HJ, it was considered that the combination of growth CL & grazing HJ was a more sound choice as the prediction of phosphate concentration was more accurate then the phosphate results from growth AB & grazing HJ. Similarly, Zooplankton predictions using the growth AB & grazing HJ combination more closely approximate the measured data, but the growth CL and grazing HJ combination do produce zooplankton results that are within acceptable ranges.

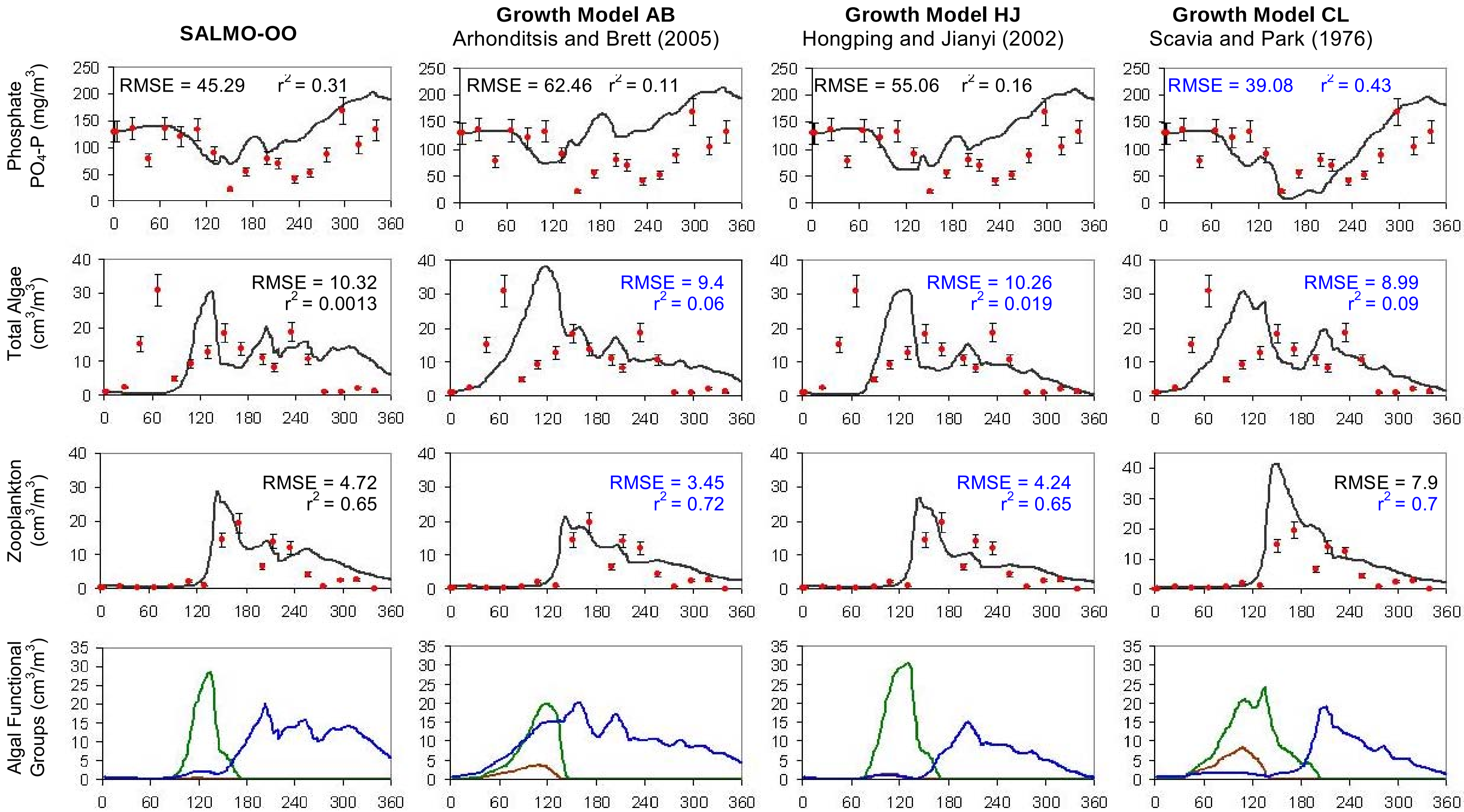

Figure 4.1a. Bautzen Reservoir (1978) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. — Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

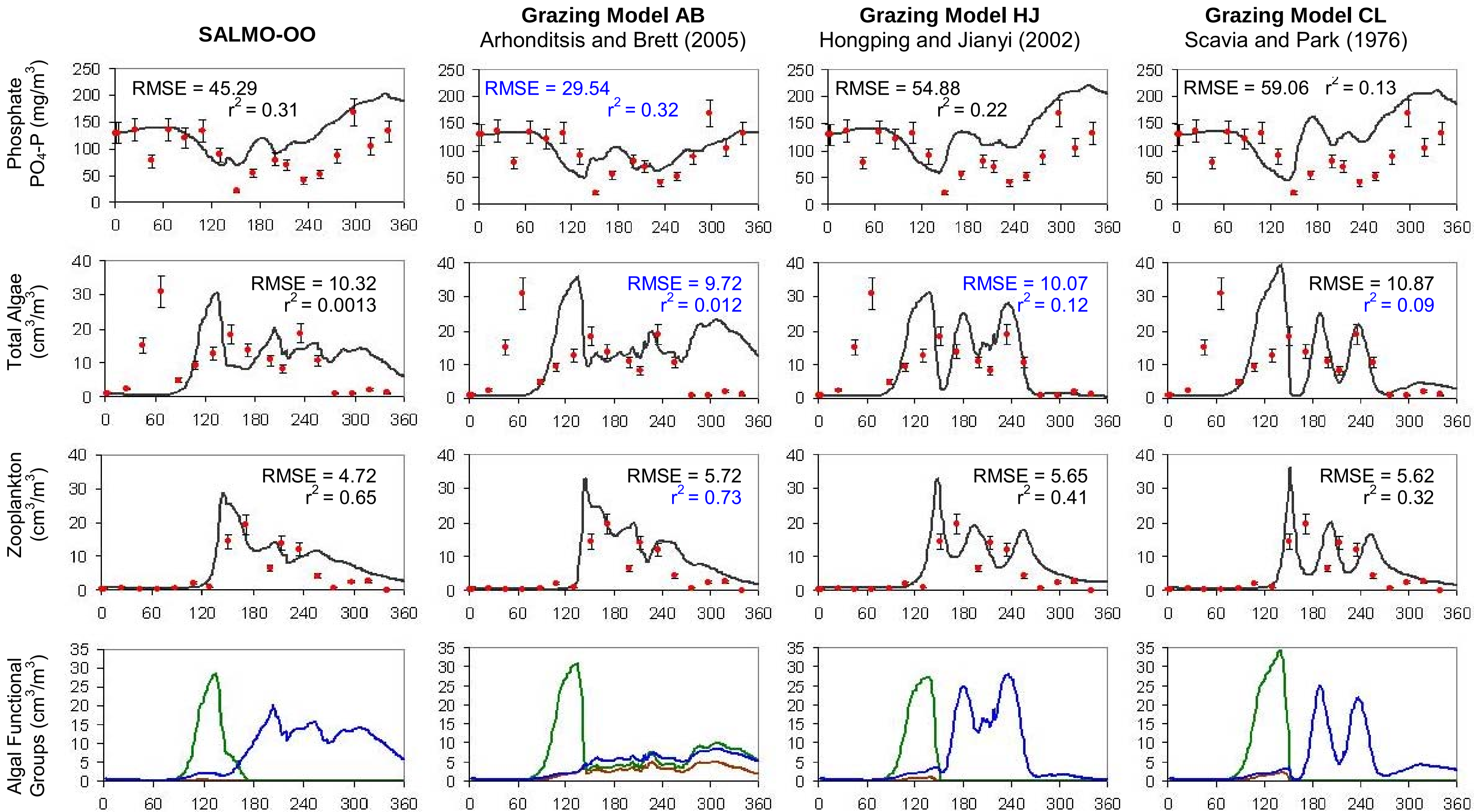

Figure 4.1b. Bautzen Reservoir (1978) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%.

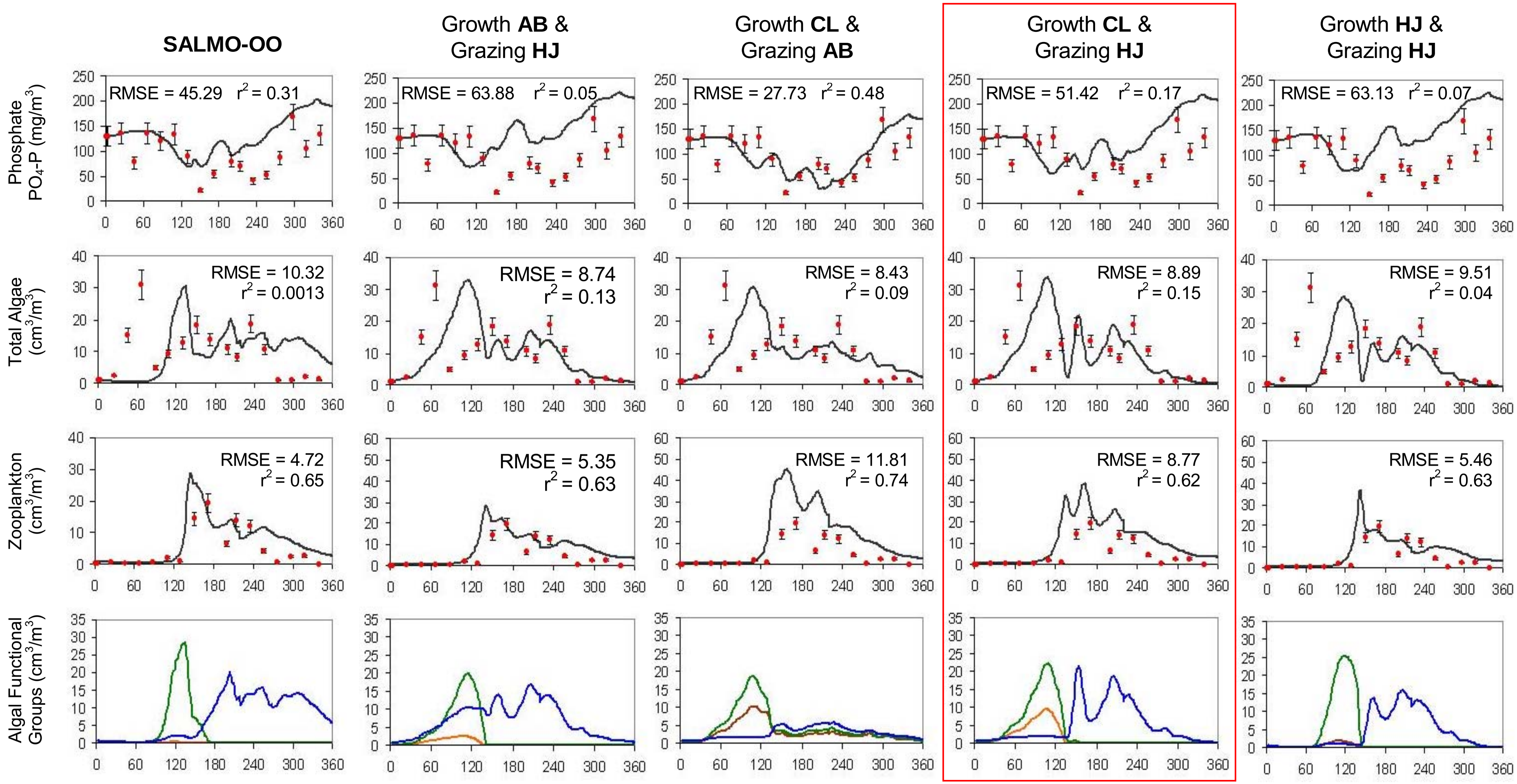

Figure 4.1c. Bautzen Reservoir (1978) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. — Blue-green Algae; — Green Algae; — Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis and Brett (2005); **HJ** - Hongping and Jianyi (2002); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976). Red box indicates the simulation that performs better all round compared to SALMO-OO.

4.1.1.2 Lake Arendsee, Germany

Lake Arendsee is a dimictic, eutrophic water body situated in a temperate climate and is an appropriate site to compare with Bautzen reservoir due to the similarities in trophic state, climate and mixing conditions. The simulation results for Lake Arendsee by SALMO-OO describe the total phytoplankton biomass reasonably well, which is reflected by the high r^2 value (0.65) However, the model does over predict the abundance of algae in early summer by about double the observed biomass (Figure 4.2a). Simulation of phosphate concentration yielded a very high r^2 value (0.86) and the visual analysis shows that the model can predict phosphate concentration very closely for the first half of the year, with a slight over prediction during late summer and into autumn. There are no measured data available for zooplankton biomass so no comparison between observed and simulated zooplankton can be confidently made. However, the general pattern in zooplankton dynamics is realistic with higher abundance when phytoplankton are beginning to decrease and lower abundances as the supply of algae diminishes towards the end of the year. Predictions of phytoplankton functional groups is realistic of eutrophic conditions with the dominance of blue-green algae during most of the year, but with green algae contributing significantly to the biomass levels during the spring peak. Similar results were predicted for phytoplankton functional group dynamics in Bautzen reservoir (Figure 4.1a).

Phytoplankton growth model experiments

Comparisons between three alternative growth models and SALMO-OO are given in Figure 4.2a. Growth models from Arhonditsis & Brett (2005) and CLEANER produced improved results for phytoplankton biomass predictions according to the statistical results, although these calculations are conflicting. The growth model from Arhonditsis & Brett (2005) gave a slightly improved r^2 value for phytoplankton (0.68), but produced the highest RMSE value (7.36) compared to SALMO-OO (RMSE = 5.16) and the other growth models. Conversely, the growth model from CLEANER reduced the RMSE value (4.69), indicating a greatly improved result, but produced a lower r^2 value (0.44) compared to SALMO-OO (r^2 = 0.65) and the other growth models. In this case, visual analysis determined the better result between the growth models from CLEANER and Arhonditsis & Brett (2005). The visual results given by the CLEANER growth model show a closer fit to the phytoplankton measured data compared to SALMO-OO and the growth model from Arhonditsis & Brett (2005), particularly during summer. Despite such discrepancies, each alternative growth model still over predicted phytoplankton abundances in early summer, similar to SALMO-OO (Figure 4.2a).

For phosphate predictions only the growth model from Hongping & Jianyi (2002) produced improved RMSE values (96.84) compared to SALMO-OO (102.43) and the other alternative models (Figure 4.2a). However, r^2 values were all lower (0.83) compared to SALMO-OO (0.86). Again, without zooplankton measured data a clear conclusion in prediction results is difficult to make. Nevertheless, zooplankton biomass responds in a logical manner dictated by phytoplankton dynamics, similar to those given by SALMO-OO. According to the predictions of phytoplankton functional groups, the growth model of Arhonditsis & Brett (2005) gives results that are typical of a hypertrophic system with the clear dominance of blue-green algae during the year. Growth models of Hongping & Jianyi (2002) and CLEANER produce a similar result as for Bautzen reservoir with the green algae contributing to the spring peak and then dominance of blue-green algae for the rest of the year.

Phytoplankton grazing model experiments

From the three alternative grazing models tested, only the growth model from Hongping & Jianyi (2002) produced a slightly better RMSE result (5.1) for phytoplankton biomass then the SALMO-OO model (Figure 4.2b). None of the other grazing models produced improved r^2 values or reduced RMSE values, and visually there was not much difference between each alternative model and SALMO-OO. A similar conclusion can be made for phosphate concentration predictions. The grazing models from Hongping & Jianyi (2002) and Arhonditsis & Brett (2005) produced lower RMSE values for phosphate predictions, with the Hongping & Jianyi (2002) model also producing a better r^2 value compared to SALMO-OO (Figure 4.2b). However, all three grazing model results look very similar to that produced by SALMO-OO. Zooplankton results were very similar for each alternative grazing model and SALMO-OO, with a distinct peak in summer after the decrease in phytoplankton biomass due to increased grazing pressure. The simulations of phytoplankton functional groups show typical eutrophic conditions, with the dominance of blue-green algae throughout the year and the dominant contribution of green algae and diatoms to the spring peak.

Experiments of combined growth and grazing process models

In keeping to the selection criteria outlined in section 3.6.3 it can be concluded that the growth models from Arhonditsis & Brett (2005) and CLEANER, and the grazing model from Hongping & Jianyi (2002) have the ability to improve the results of each of the state variables analysed. Therefore, combinations of these growth and grazing models were tested to see if the results produced by SALMO-OO could be further improved. In addition, the growth models from CLEANER and Arhonditsis & Brett (2005) were also tested with the grazing model from CLEANER and Arhonditsis & Brett (2005), as the results for these grazing models were very similar to those produced by the Hongping & Jianyi (2002) grazing model. Figure 4.2c illustrates the best four results from the combination experiments for Lake Arendsee. Each combination of growth and grazing models presented in Figure 4.2c produced markedly improved results for phytoplankton biomass predictions, with the best results all round given by growth CL & grazing AB and growth CL & grazing HJ.

In choosing the best combination to improve the simulation results for Lake Arendsee it is important to consider both visual results and statistical results collectively. The combination of models from CLEANER growth and either grazing AB, grazing HJ and grazing CL models, produced equally acceptable results for phytoplankton biomass predictions (Figure 4.2c). Visually, each combination produced trajectories that fit the measured data very well and even improved the duration of the main summer peak. Growth CL & grazing AB produced results with the lowest RMSE value (4.5), whereas growth CL & grazing CL produced the highest r^2 value of 0.63, although this was still slightly lower then the r^2 value for SALMO-OO (0.65). The r^2 values produced by growth CL & grazing AB and growth CL & grazing HJ were much lower compared to SALMO-OO and growth CL & grazing CL, but are still acceptable results.

The phosphate simulations produced by each alternative combination of CL growth and grazing models from AB, HJ and CL have produced excellent results, with higher r^2 values and lower RMSE values compared to SALMO-OO, with the best result produced by growth CL & grazing CL. Zooplankton biomass predictions are similar to those produced by the growth and grazing models experiments discussed earlier. However, zooplankton simulations from combination growth CL & grazing CL has produced marginally lower abundances of zooplankton biomass, compared to growth CL & grazing AB or grazing HJ. Simulation of phytoplankton functional groups by growth CL & grazing AB and growth CL & grazing CL are suggestive of mesotrophic conditions, with a balanced abundance of functional groups. The algal functional group predictions produced by growth CL & grazing HJ give results more realistic of eutrophic conditions. These algae functional group results are similar to those produced by Bautzen reservoir simulations, with a high abundance of green algae contributing to the spring peak and blue-green algae dominating throughout the rest of the year.

The combination of growth AB & grazing HJ statistically was the fourth best result produced by the combination experiments. However, phytoplankton and phosphate predictions using this combination were much poorer compared to the other combinations shown in Figure 4.2c and consequently do not significantly improve upon the predictions by SALMO-OO.

Therefore, as a major role of the model is to simulate algal functional groups as realistically as possible, it is my conclusion that the combination of growth CL & grazing HJ produces the most improved results for Lake Arendsee. Even though the phytoplankton predictions are statistically slightly better using the combinations of growth CL and grazing AB or grazing CL, the phytoplankton results from growth CL & grazing HJ are still very good and are better then that produced by SALMO-OO. Phosphate predictions are excellent and there is little visual difference between each combination. Thus, the deciding factor is the phytoplankton functional groups simulations, with growth CL & grazing HJ producing the most realistic results compared to the other grazing model combinations.

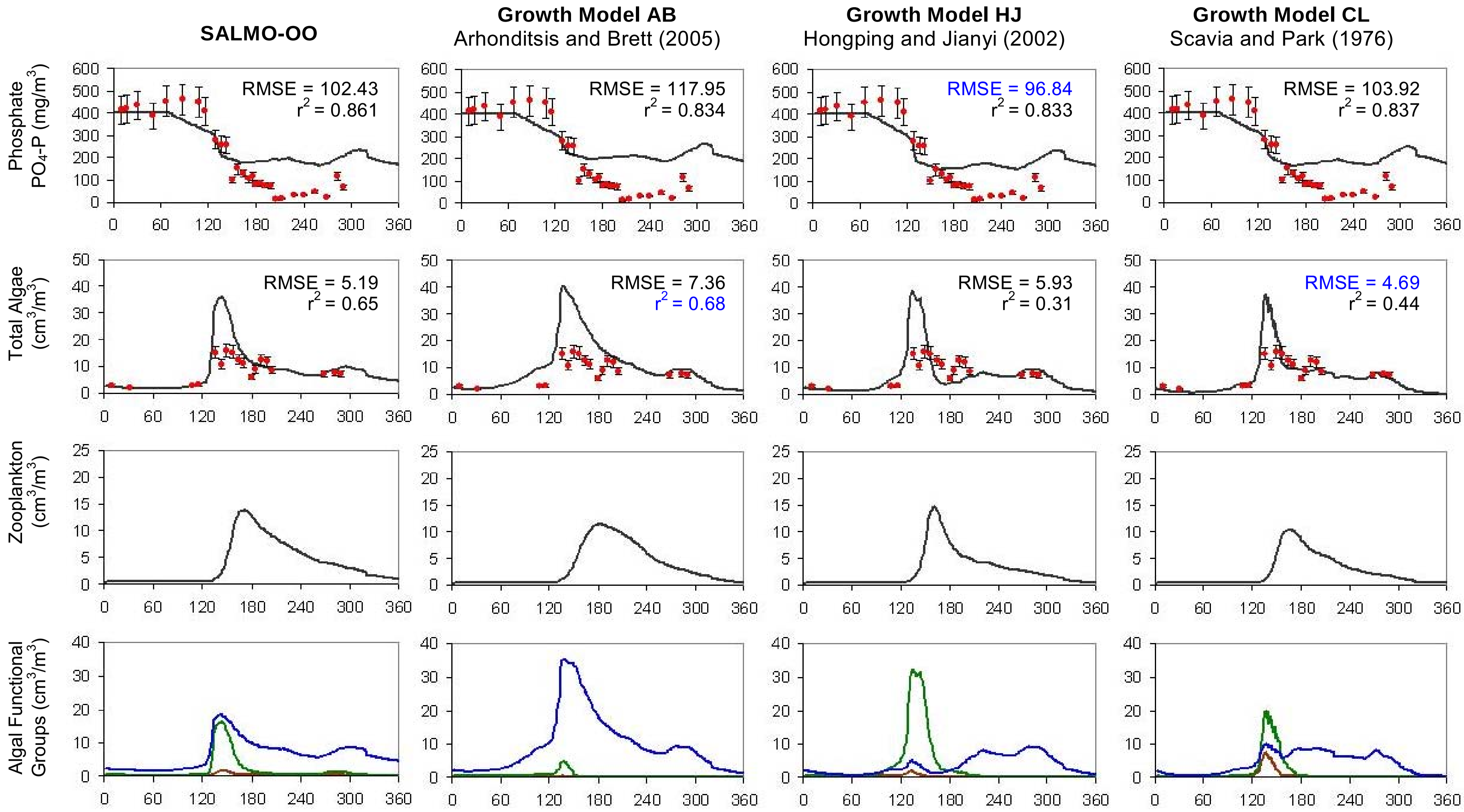

Figure 4.2a. Lake Arendsee (1979) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO.
— Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

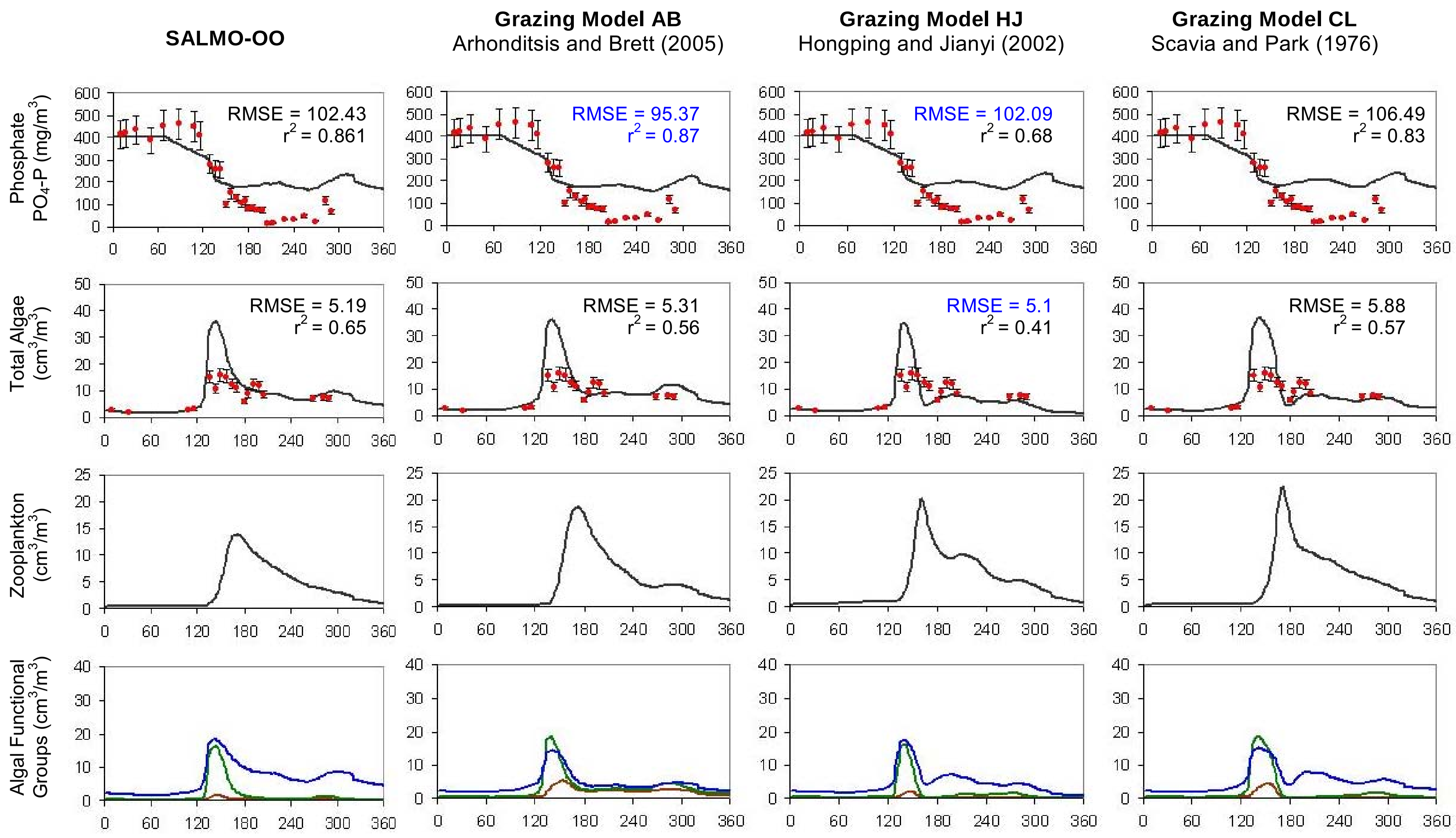

Figure 4.2b. Lake Arendsee (1979) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO.
— Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

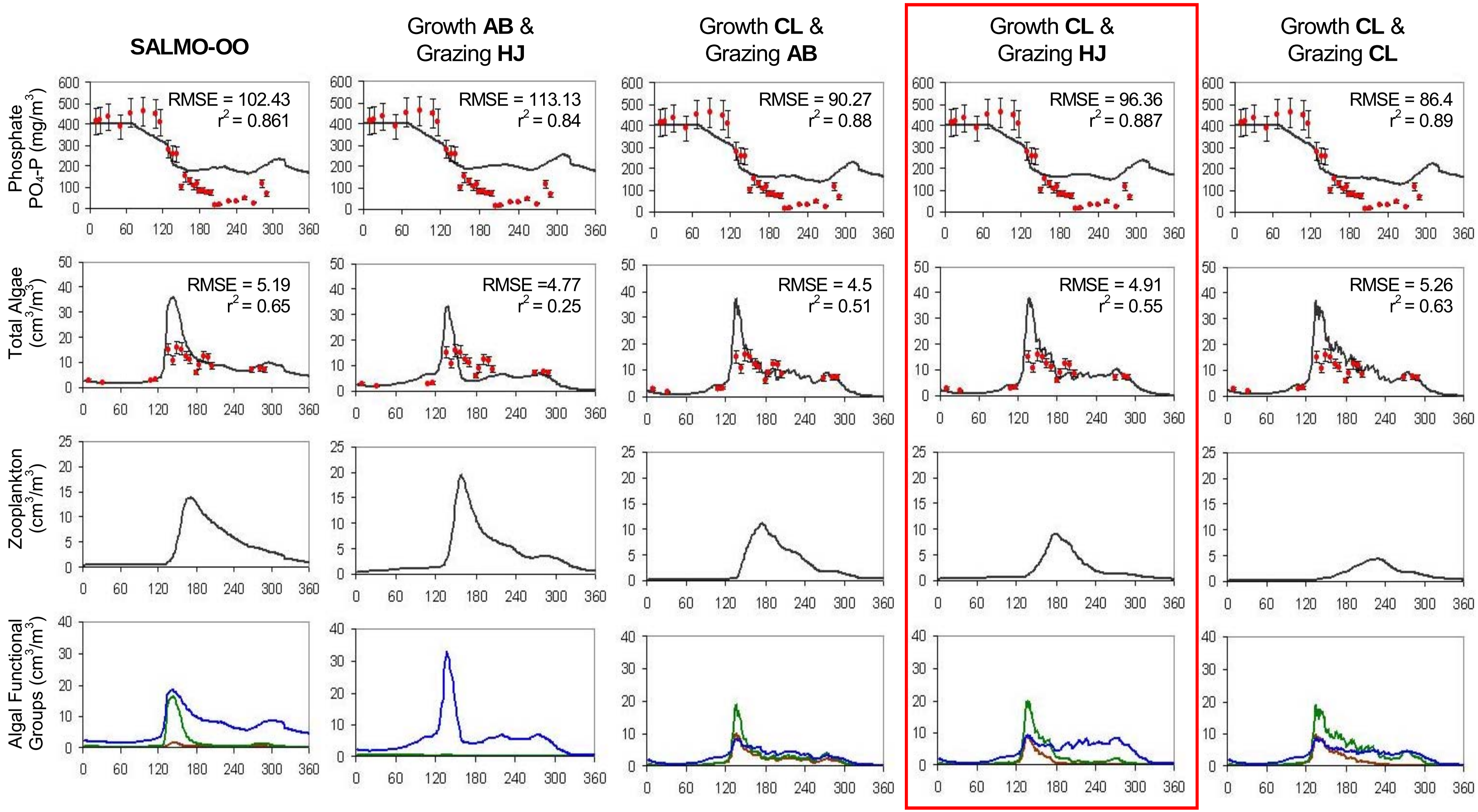

Figure 4.2c. Lake Arendsee (1979) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis and Brett (2005); **HJ** - Hongping and Jianyi (2002); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976). Red box indicates the simulation that performs better all round compared to SALMO-OO.

4.1.1.3 Lake Roodeplaat, South Africa

The Lake Roodeplaat, Lake Hartbeespoort and Lake Klipvoor experiments aim to show that the simulation library can be applied to other lakes with similar trophic conditions, but different mixing conditions. Bautzen Reservoir and Lake Arendsee are both cool temperate lakes with dimictic mixing conditions where ice cover is common during winter. Lakes Roodeplaat, Hartbeespoort and Klipvoor are located in areas of South Africa that have a warmer climate and exhibit warm monomictic conditions where stratification occurs once during summer.

The SALMO-OO model describes phytoplankton dynamics in Lake Roodeplaat reasonably well, although the magnitude of the summer phytoplankton peak is slightly over estimated (Figure 4.3a). General trends in phosphate concentrations are also reasonably well predicted by SALMO-OO, with a moderately high r^2 value (0.259). There are no Lake Roodeplaat measured data available for zooplankton biomass, but the trends seem realistic and follow the phytoplankton dynamics as expected. Algal functional group abundances simulated by the model reflect a typical hypertrophic system, with a high dominance of blue-green algae during the year (Figure 4.3a). However, according to the measured data the SALMO-OO model considerably over estimates blue-green algae abundances, particularly during summer, and predicts a virtual absence of the other functional groups, which the measured data shows are present albeit at low abundances.

Phytoplankton growth model experiments

Comparisons between three alternative growth models and SALMO-OO are given in Figure 4.3a. Each growth model improved the prediction of the phytoplankton peak in summer, resulting in a better fit to the measured data. This is reflected by the lower RMSE values and improved r^2 values. However, none of the alternative models was able to improve the timing of the summer peak predictions. Phosphate simulations produced very similar results for each growth model compared to SALMO-OO, with only the growth model from CLEANER improving the RMSE results. Generally, all models tested were able to simulate the trends in phosphate dynamics for Lake Roodeplaat, although there were some over predictions during late spring and late summer (Figure 4.3a). Zooplankton dynamics produced by each growth model are similar to those produced by SALMO-OO and behave as expected. The simulations of phytoplankton functional group dynamics by each alternative growth model are similar to the results produced by SALMO-OO, with the highest abundances attributed to blue-green algae biomass. However, the growth model from Hongping and Jianyi (2002) improves the magnitude of the blue-green algae peak during summer compared to SALMO-OO and the other growth models. Nevertheless, each alternative growth model fails to predict the occurrences of diatoms or green algae as observed by the measured data.

Phytoplankton grazing model experiments

The alternative grazing models all produced similar results to SALMO-OO for phytoplankton biomass predictions (Figure 4.3b), but over estimated the main summer peak to a much larger extent compared to the growth model simulations in Figure 4.3a. This is reflected in the poorer statistical results. However, the grazing model from Arhonditsis & Brett (2005) is the exception and produced the most accurate phytoplankton predictions, with the lowest RMSE value (9.1) and the highest r^2 values (0.17) compared to SALMO-OO (RMSE = 16.03 and r^2 = 0.12). The main summer phytoplankton peak was also reduced by the use of this grazing model. The Arhonditsis & Brett (2005) grazing model also produced the most improved phosphate concentration results, with the lowest RMSE value and highest r^2 value (Figure 4.3b). Zooplankton predictions behaved similarly as was seen for the growth model experiments in Figure 4.3a, however, the zooplankton biomass predictions produced by the Arhonditsis & Brett (2005) grazing model are higher presumably due to an increase in algal grazing (Figure 4.3b). The grazing model from Arhonditsis & Brett (2005) seems to be the best improvement to SALMO-OO performance, particularly the predictions of algal functional group dynamics, which describe the measured data more realistically then the other grazing models. The grazing models from CLEANER and Hongping and Jianyi (2002) simulate the dominance of blue-green algae, with a considerable over prediction of biomass during summer. In addition, no diatoms or green algae are predicted even at low levels.

Experiments of combined growth and grazing process models

In adherence with the selection criteria outlined in section 3.6.3 it can be concluded that each alternative growth model has the ability to improve the results of phytoplankton biomass predictions, and to a lesser extent phosphate dynamics. The grazing model from Arhonditsis & Brett (2005) produced the best results for each state variable examined, whereas, the grazing models from Hongping & Jianyi (2002) and CLEANER produced less realistic results for the phytoplankton functional group dynamics as observed by the measured data. Nevertheless, it would be prudent to examine each growth model with the grazing models from Hongping & Jianyi (2002) and CLEANER, to see if these combinations may enhance the models ability to predict phytoplankton and phosphate dynamics.

Figure 4.3c illustrates the best four results from the combination experiments for Lake Roodeplaat. Each combination of growth and grazing models presented in Figure 4.3c produced significantly improved results for phytoplankton biomass predictions, especially with a decrease in the main summer peak closer to the measured data. In all cases the RMSE values have been significantly reduced and higher r^2 values have been achieved. The best quantitative results were produced by the combinations of growth AB & grazing AB, which calculated the highest r^2 value of 0.27, and growth HJ & grazing AB, which gave the lowest RMSE value (8.93). Phosphate and zooplankton simulations are typical of the previous growth and grazing experiments for Lake Roodeplaat, although the phosphate predictions have improved, especially during late spring and early summer. This is reflected in the higher r^2 values, with the combination of growth CL & grazing AB producing the best result.

However, the use of the grazing model from CLEANER has resulted in unrealistic results for the algal functional group simulations, according to the measured data, with the dominance of blue-green algae predicted and virtually no diatoms or green algae described by the model. The addition of the grazing model from Arhonditsis & Brett (2005) has greatly improved the prediction of phytoplankton functional group dynamics for Lake Roodeplaat. The magnitude of the blue-green algal peak in summer has been reduced, and fits closer to the biomass levels observed in the measured data. Also, diatoms and green algae are more realistically simulated, however, there is a slight over prediction of green algae in late summer that is not observed in the measured data.

Therefore, the growth and grazing models from Arhonditsis & Brett (2005) are selected as the best combination that improves the SALMO-OO models results for Lake Roodeplaat. Phytoplankton and phosphate predictions are visually and quantitatively very good and describe the measured data very well, as given by the greatly improved r^2 and RMSE values. In addition, the combination of growth AB & grazing AB gives the most realistic results for blue-green algae predictions, closely predicting the summer peak, and gives excellent results for diatom biomass predictions.

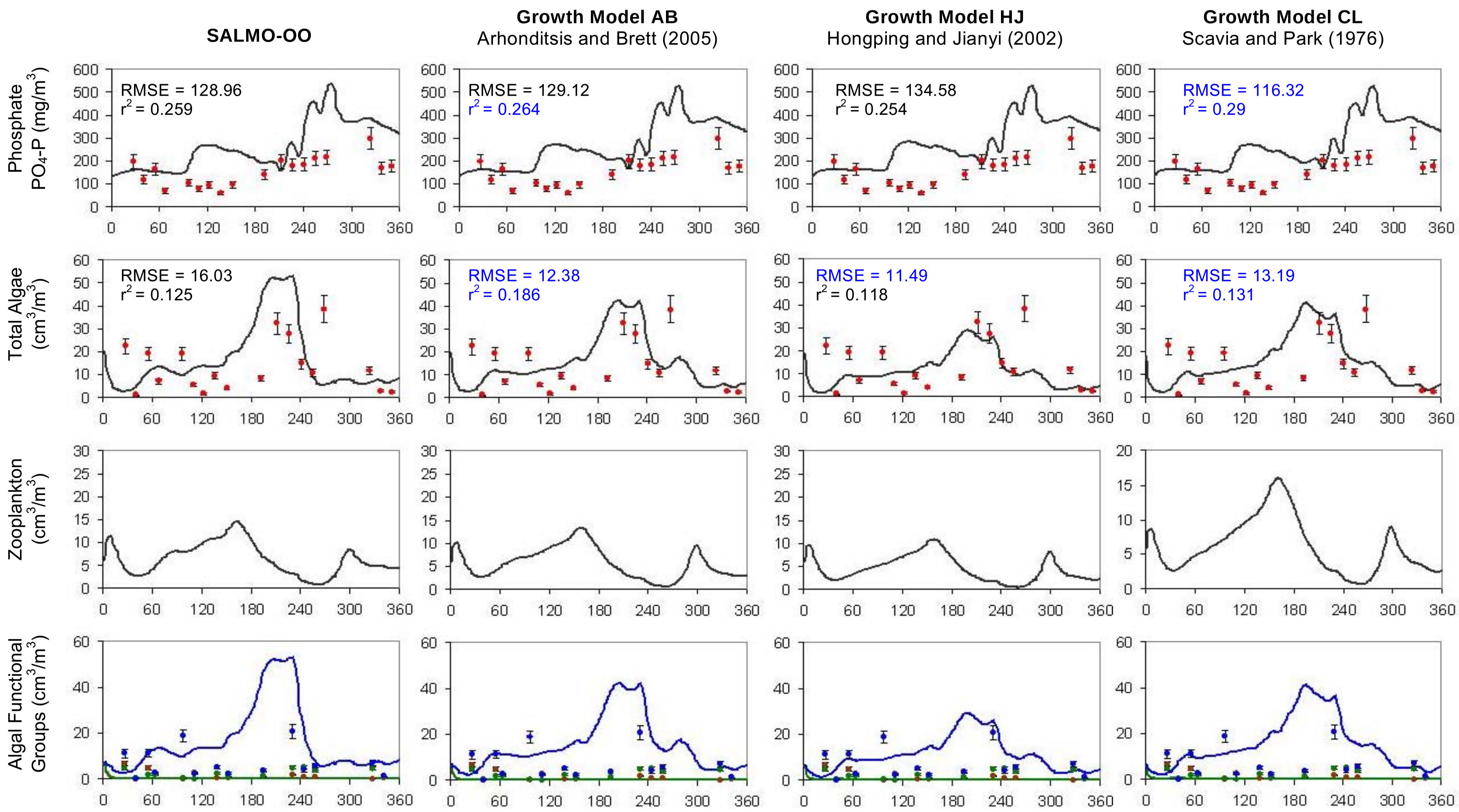

Figure 4.3a. Lake Roodeplaat (2003) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO.
— Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.• Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

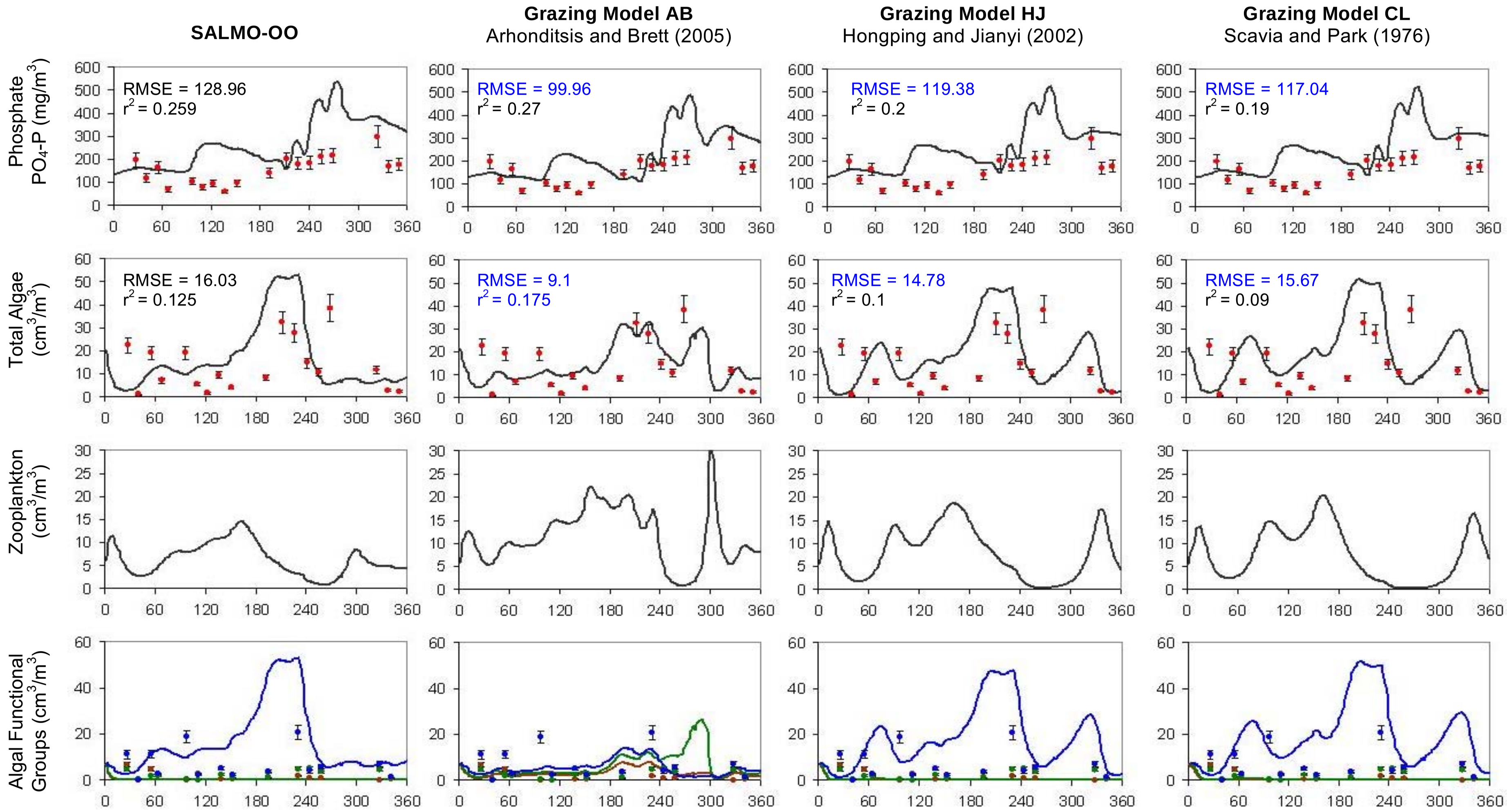

Figure 4.3b. Lake Roodeplaat (2003) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO.
— Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%. • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

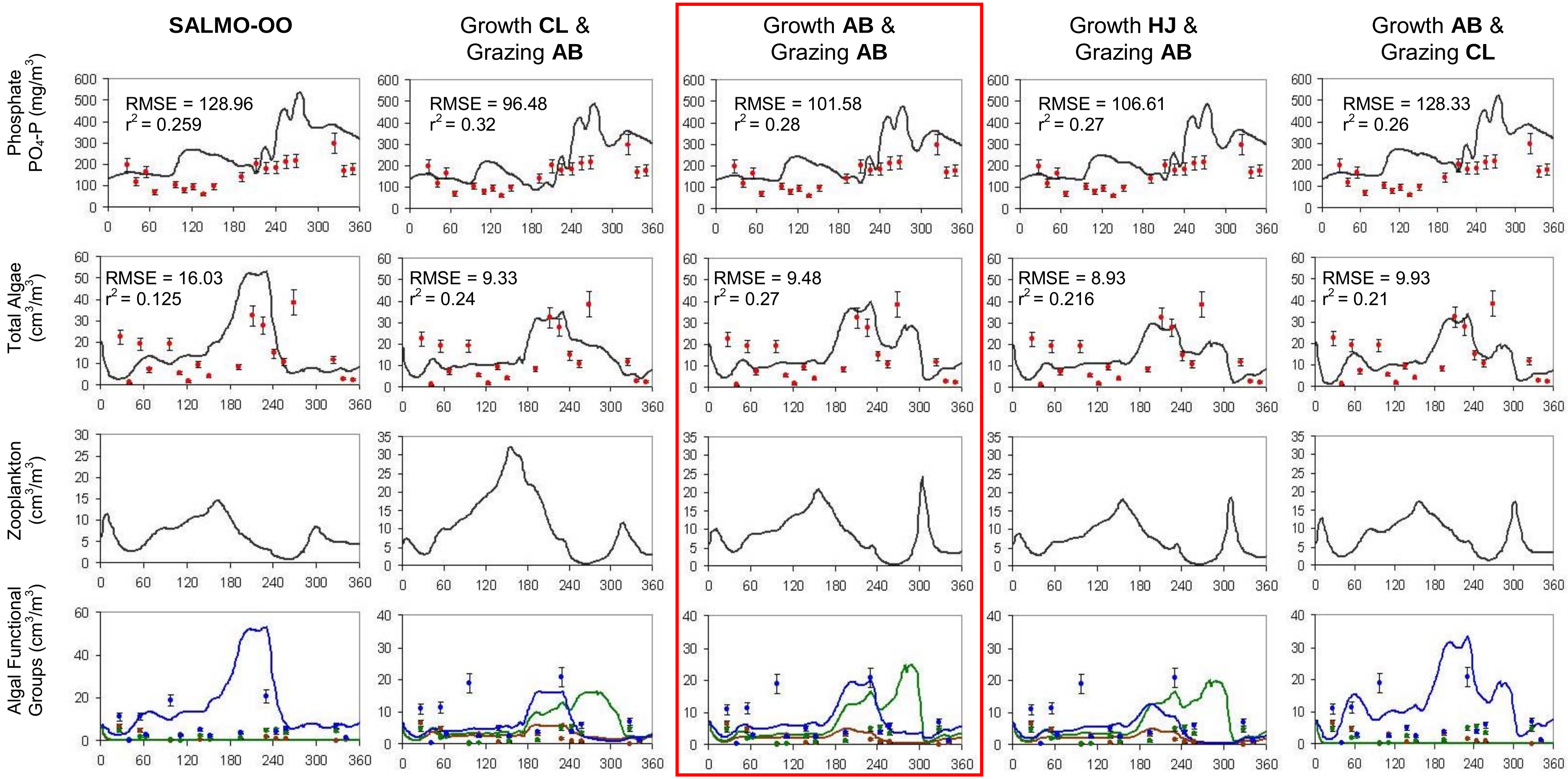

Figure 4.3c. Lake Roodeplaat (2003) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis and Brett (2005); **HJ** - Hongping and Jianyi (2002); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976). Red box indicates the simulation that performs better all round compared to SALMO-OO. ● Measured data for green algae; ● Measured data for diatoms; ● Measured data for blue-green algae.

4.1.1.4 Lake Hartbeespoort, South Africa

The simulation results for Lake Hartbeespoort by SALMO-OO describe the total phytoplankton biomass reasonably well (Figure 4.4a) except for the two extreme data points in spring and late summer, as reflected by the poor r^2 value (r^2 = 0.03). The simulation of phosphate concentration also yielded low r^2 values (0.02) with the model outputs illustrating the general trends in phosphate dynamics, but not accurately describing the phosphate measured data (Figure 4.4a). Zooplankton biomass predictions appear realistic, but no measured data is available for comparisons or statistical analysis. Predictions of phytoplankton functional groups are realistic of hypertrophic conditions with the complete dominance of blue-green algae during most of the year, and very little abundances of green algae and diatoms.

Phytoplankton growth model experiments

Comparisons between three alternative growth models and SALMO-OO are given in Figure 4.4a. The growth models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) produced slightly better predictions for phytoplankton biomass then SALMO-OO, particularly with lower RMSE values (23.18 and 22.46 respectively), but still failed to predict the two extreme values in spring and late summer. The growth model from CLEANER produced the lowest RMSE and highest r^2 value compared to SALMO-OO and the other growth models, albeit the r^2 value is very poor. However, visually the CLEANER growth model does not appear to describe the measured data very well, particularly the summer algal biomass values. The prediction of zooplankton biomass given by each alternative growth model seems to respond as expected following phytoplankton dynamics, with similar trajectories as those produced by SALMO-OO.

The phosphate results produced by the growth models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) are similar to the results produced by SALMO-OO, with a general trend in phosphate dynamics observed, but a poor fit to the measured data, as given by the very low r^2 values and high error values. The growth model from CLEANER produces a significantly lower RMSE value (51.05) and high r^2 value (0.22) for phosphate simulations compared to SALMO-OO (RMSE = 79.7 and r^2 = 0.02). However, the visual results are quite poor, with phosphate trajectories approaching zero during spring and early summer. The phosphate and phytoplankton results produced by the CLEANER growth model are dubious. The simulation of phytoplankton functional groups by each alternative growth model is as expected for hypertrophic conditions, with the dominance of blue-green algae throughout the year, as described by the measured data. Again the CLEANER growth model produces quite different results for algal functional group dynamics compared to the other growth models, with a high abundance of blue-green algae in late summer and green algae dominant in spring and early summer. These dynamics are not observed by the measured data.

Phytoplankton grazing model experiments

From the three alternative grazing models tested the grazing model from Arhonditsis & Brett (2005) produced the best predictions of phytoplankton biomass and phosphate concentrations both visually and quantitatively (Figure 4.4b). For phosphate simulations the grazing model from Arhonditsis & Brett (2005), produced a close fit to the measured data and a significantly lower RMSE (33.1) compared to SALMO-OO (79.67) (Figure 4.4b). The Arhonditsis & Brett (2005) grazing model also improved the phytoplankton biomass predictions, with less biomass predicted in early summer, thus a closer fit to the measured data as shown by the improved RMSE value (20.94). According to the RMSE values produced by the Hongping & Jianyi (2002) and CLEANER grazing models an improvement in the prediction in phytoplankton biomass was achieved. However, the model trajectories show the prediction of a phytoplankton peak during early summer/late spring that is not observed by the measured data. Phosphate predictions from these two grazing models were slightly improved compared to SALMO-OO, but still over predicted much of the phosphate measured data (Figure 4.4b). Each of the alternative grazing models still appears to produce realistic dynamics for zooplankton biomass.

The simulation of phytoplankton functional groups has somewhat changed compared to the results from the growth experiments in Figure 4.4a. All alternative grazing models still predict a dominance of blue-green algae during the year, with the grazing models from Hongping & Jianyi (2002) and CLEANER giving good descriptions of the blue-green algae measured data. However, green algae are simulated in greater abundances, particularly by the CLEANER and Arhonditsis & Brett (2005) grazing models, with much higher biomass values compared to the measured data. The Arhonditsis & Brett (2005) grazing model fails to predict accurately the abundances of blue-green algae, as observed by the measured data, but gives good estimates of green algae and diatom abundances.

Experiments of combined growth and grazing process models

According to the selection criteria outlined in section 3.6.3 it can be deduced that each alternative growth and grazing model has the ability to improve the results of either phytoplankton biomass and phosphate concentration predictions, as well as algal functional groups dynamics. Although the grazing model from Arhonditsis & Brett (2005) produced poor results for blue-green algae dynamics it is worthwhile to test this grazing model with combinations of other growth models as such good results were achieved for phosphate and phytoplankton simulations. Therefore, combinations of all three alternative growth and grazing models were tested in order to improve upon the results produced by the SALMO-OO model.

Figure 4.4c illustrates the best four results from the combination experiments for Lake Hartbeespoort. The top four results, based on quantitative measures, where composed of combinations of the growth and grazing models from CLEANER and Arhonditsis & Brett (2005). Phytoplankton biomass simulations are similar between the different combinations of models, and all have improved the results compared to the SALMO-OO model, particularly by decreasing the phytoplankton biomass values during early summer and late spring, as shown by the significantly reduced error values and the improved r^2 values. The best performing model for phytoplankton biomass predictions was produced by the combination of growth AB & grazing AB, with an RMSE of 19.87 and r^2 of 0.12 (Figure 4.4c). The best prediction of phosphate concentration is also given by the growth AB & grazing AB model combination, which calculates the lowest RMSE (37.7) value compared to the other models and SALMO-OO (Figure 4.4c). The combination of growth CL & grazing AB give a higher r^2 value (although still quite a poor result) for phosphate predictions, but visually it is clear that this model combination under estimated much of the phosphate dynamics as given by the measured data. The combinations of growth AB

& grazing CL and growth CL & grazing CL clearly over predict phosphate concentration for Lake Hartbeespoort. The simulation of phytoplankton functional groups by those combinations with grazing models from CLEANER predict a clear dominance of blue-green algae, describing the measured data well. Those combinations that utilise the grazing model from Arhonditsis & Brett (2005) predict slightly lower abundances of blue-green algae, but do simulate the occurrence of green algae and diatoms and fit the respective measured data well.

However, to choose the most suitable combinations of models for the description of Lake Hartbeespoort conditions a balanced approach must be taken. The combination of growth AB & grazing AB gives the best results for both phytoplankton biomass and phosphate conditions, however, this combinations does slightly over estimate the abundances of green algae and diatoms, and slightly under predicts the abundances of blue-green algae (Figure 4.4c). Conversely, the combination of growth CL & grazing CL gives a slightly less improved simulation of phytoplankton biomass and significantly over estimates phosphate concentrations, but does simulate the occurrence of blue-green algae quite well. However, growth CL & grazing CL predicts a sharp decrease in green algae and diatoms to values close to zero, which is unrealistic of Lake Hartbeespoort conditions as demonstrated by the measured data, which does show low numbers of these algal functional groups. Thus, I believe the combination of the growth and grazing models from Arhonditsis & Brett (2005) produces the best results for the Lake Hartbeespoort 2003 dataset. The simulations of phytoplankton biomass and phosphate concentrations are a great improvement from the results produced by SALMO-OO and the representation of the phytoplankton functional groups describes the measured data more realistically, even though blue-green algae are slightly under estimated.

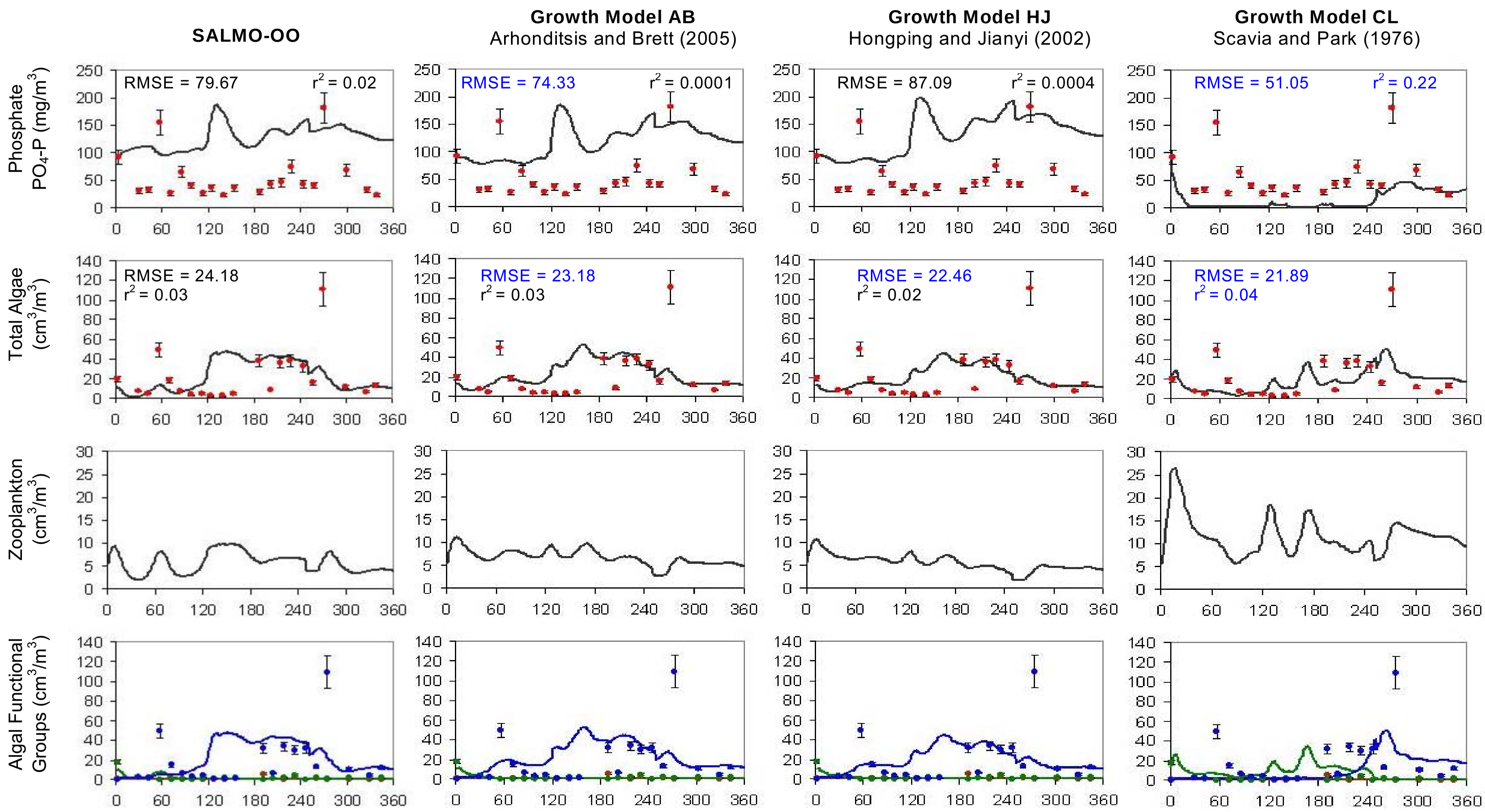

Figure 4.4a. Lake Hartbeespoort (2003) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%. • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

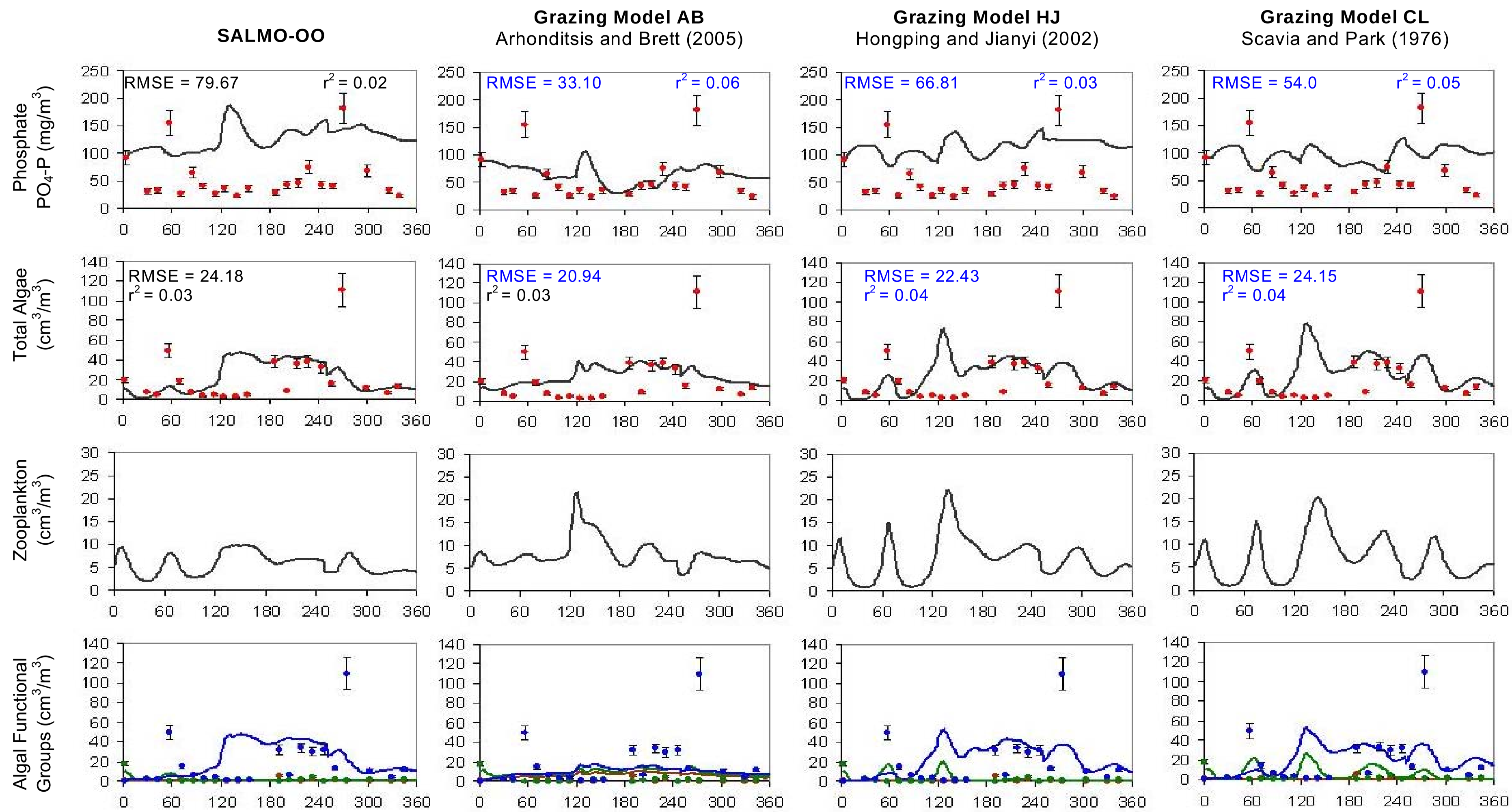

Figure 4.4b. Lake Hartbeespoort (2003) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%. • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

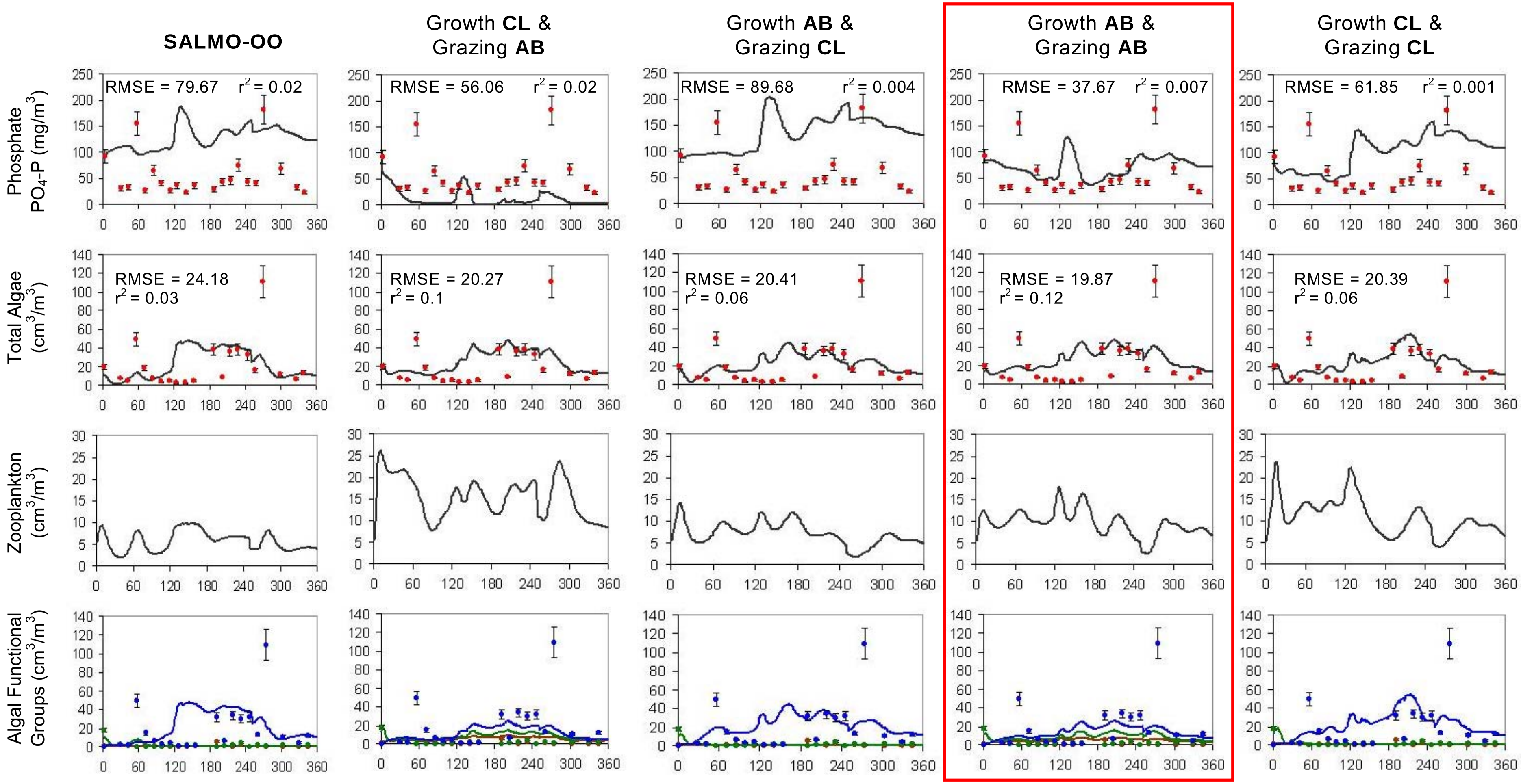

Figure 4.4c. Lake Hartbeespoort (2003) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis and Brett (2005); **HJ** - Hongping and Jianyi (2002); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976). Red box indicates the simulation that performs better all round compared to SALMO-OO. ● Measured data for green algae; ● Measured data for diatoms; ● Measured data for blue-green algae.

4.1.1.5 Lake Klipvoor, South Africa

The simulation results for Lake Klipvoor by SALMO-OO describe the total phytoplankton biomass very well (Figure 4.5a), with the successful prediction in timing and magnitude of the spring peak. Although the timing of the main summer peak is slightly early, which may account for the low r^2 value. The simulation of phosphate concentration yielded fairly good results with an r^2 value of 0.18, however, SALMO-OO over predicted the concentration of phosphorus during autumn/winter. Zooplankton biomass predictions appear realistic, but no measured data is available for comparisons or statistical analysis. Predictions of phytoplankton functional groups do illustrate a hypertrophic system, but do not match well with the measured data for each algal functional group.

Phytoplankton growth model experiments

Comparisons between three alternative growth models and SALMO-OO are given in Figure 4.5a. Statistically all alternative growth models improved the phytoplankton simulation results compared to SALMO-OO, significantly reducing the RMSE values and slightly improving the r^2 values. The growth models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) improved the timing and magnitude of the summer peak. However, each alternative growth model failed to predict the magnitude of the spring peak, which SALMO-OO describes well. The prediction of zooplankton biomass given by each alternative growth model seems to respond as expected following phytoplankton dynamics, with similar trajectories as those produced by SALMO-OO. The visual results for phosphate dynamics by each growth model are very similar to the phosphate results produced by SALMO-OO, however, statistically all growth models performed poorly (Figure 4.5a).

The simulation of phytoplankton functional groups by each alternative growth model is as expected for hypertrophic conditions, with the dominance of blue-green algae, as described by the measured data. However, each growth model over predicted the abundance of blue-green algae, but did improve the timing of the summer blue-green algal peaks. The measured data for Lake Klipvoor shows the presence of green algae at low abundances, with a peak in diatoms during spring. SALMO-OO was able to predict the occurrence of diatoms and green algae, even though the biomass levels were over estimated and the timing was incorrect, whereas, only the growth model from Hongping & Jianyi (2002) successfully generated the presence of high levels of green algae during summer (Figure 4.5a).

Phytoplankton grazing model experiments

Each alternative grazing model did not significantly improve upon the phytoplankton results produced by SALMO-OO. The grazing models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) gave higher RMSE values (Figure 4.5b) compared to SALMO-OO, although the Hongping & Jianyi (2002) grazing model did simulate the spring algal peak quite well, compared to the grazing model from Arhonditsis & Brett (2005). The phytoplankton simulations produced by the CLEANER grazing model produced results similar to SALMO-OO, with a slight improvement in the RMSE value. Phosphate predictions were largely unchanged, and in fact produced poorer results compared to the growth models results in Figure 4.5a. Again, zooplankton biomass predictions were generally as expected, however the grazing models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) produced very high zooplankton biomass levels during spring, which can be attributed to the low phytoplankton levels during spring.

The grazing models from Hongping & Jianyi (2002) and CLEANER produced similar results to SALMO-OO for the simulation of phytoplankton functional groups (Figure 4.5b), with the prediction of high levels of blue-green algae during spring and early summer and moderate abundances of green algae during summer, moderately higher than observed by the measured data. The grazing model from Arhonditsis & Brett (2005) produced lower levels of blue-green algae, but simulated blue-green alga dynamics similar to the trend exhibited by the measured data. Green algae and diatom abundances were again overestimated during summer, but the magnitude of the over estimation was smaller then those produced by SALMO-OO and the other grazing and growth models.

Experiments of combined growth and grazing process models

According to the selection criteria outlined in section 3.6.3 it can be deduced that each alternative growth and grazing model has the ability to improve the results of either phytoplankton biomass and phosphate concentration predictions, as well as algal functional groups dynamics. Figure 4.5c illustrates the best four results from the combination experiments for Lake Klipvoor. Quantitatively the best results produced for phytoplankton biomass simulations were performed by the combination of growth CL and grazing CL, with an RMSE of 58.3 and r^2 value of 0.15 (SALMO-OO RMSE = 62.3 and r^2 = 0.07). The main spring peak is simulated quite well by this combination, however the timing of the summer peak is too early even though the magnitude is similar. Phosphate concentration predictions were also quantitatively improved using this combination, although the over estimation during autumn and winter is still present (Figure 4.5c).

The simulation of the algal functional group dynamics was greatly improved by applying alternative growth and grazing models to the SALMO-OO structure. Both the combinations of growth CL & grazing CL and growth AB & grazing AB produced the best results (Figure 4.5c). Both simulated a more reasonable abundance of blue-green algae, although failing to reach the timing and magnitude of the summer peak, and simulated more realistic levels of green algae during summer. The significant difference between the two combinations is the ability of the growth and grazing models from Arhonditsis & Brett (2005) to simulate diatoms during spring that match the measured data very well. The growth and grazing models from CLEANER gave predictions of diatoms at very low levels close to zero. Therefore, the combination of the growth and grazing models from Arhonditsis & Brett (2005), which gave fairly similar predictions for phytoplankton biomass and phosphate concentration to growth CL & grazing CL, would be selected as the best combination to improve upon the results of SALMO-OO and describe the overall dynamics of Lake Klipvoor.

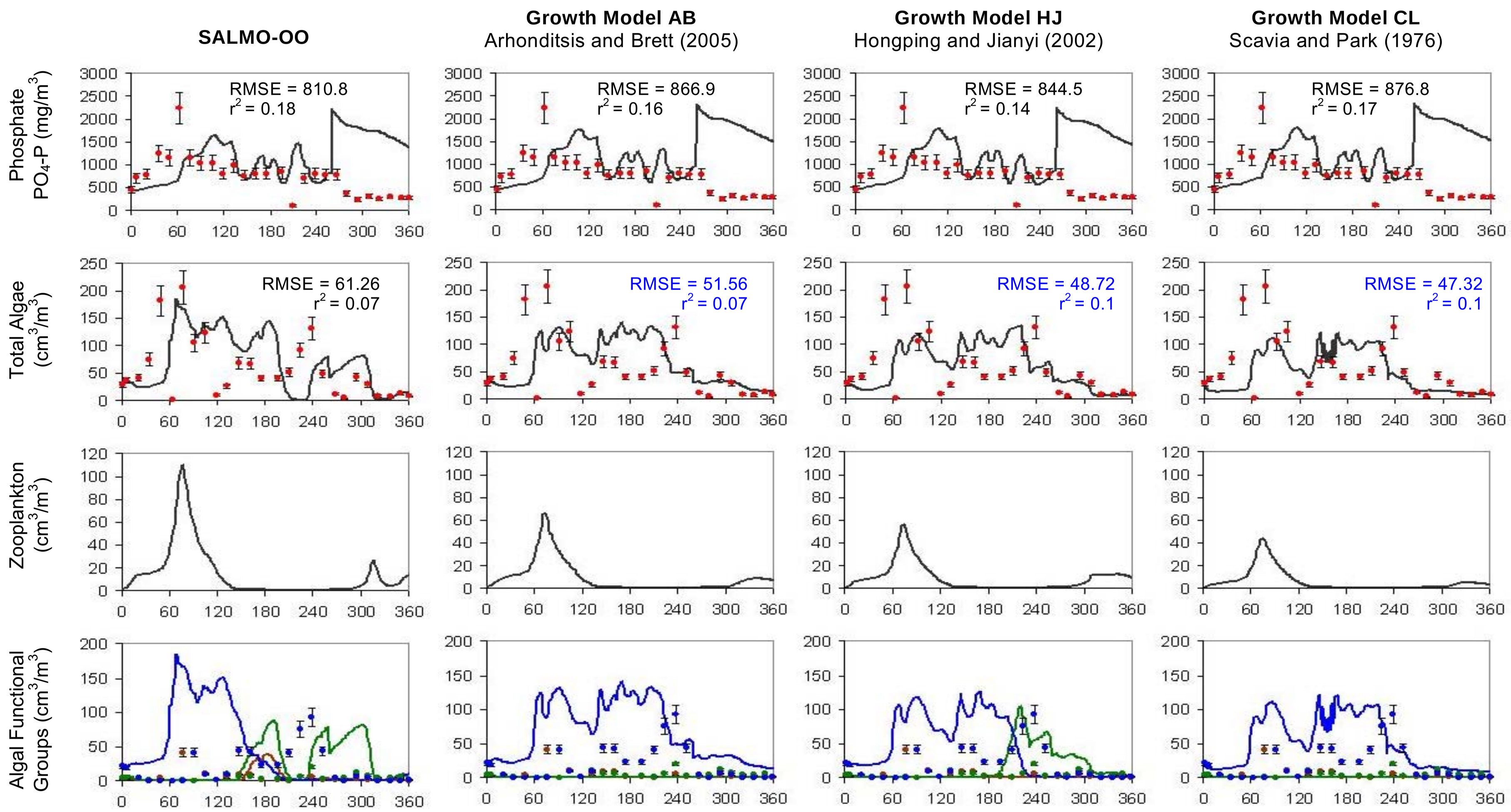

Figure 4.5a. Lake Klipvoor (2003) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%; • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

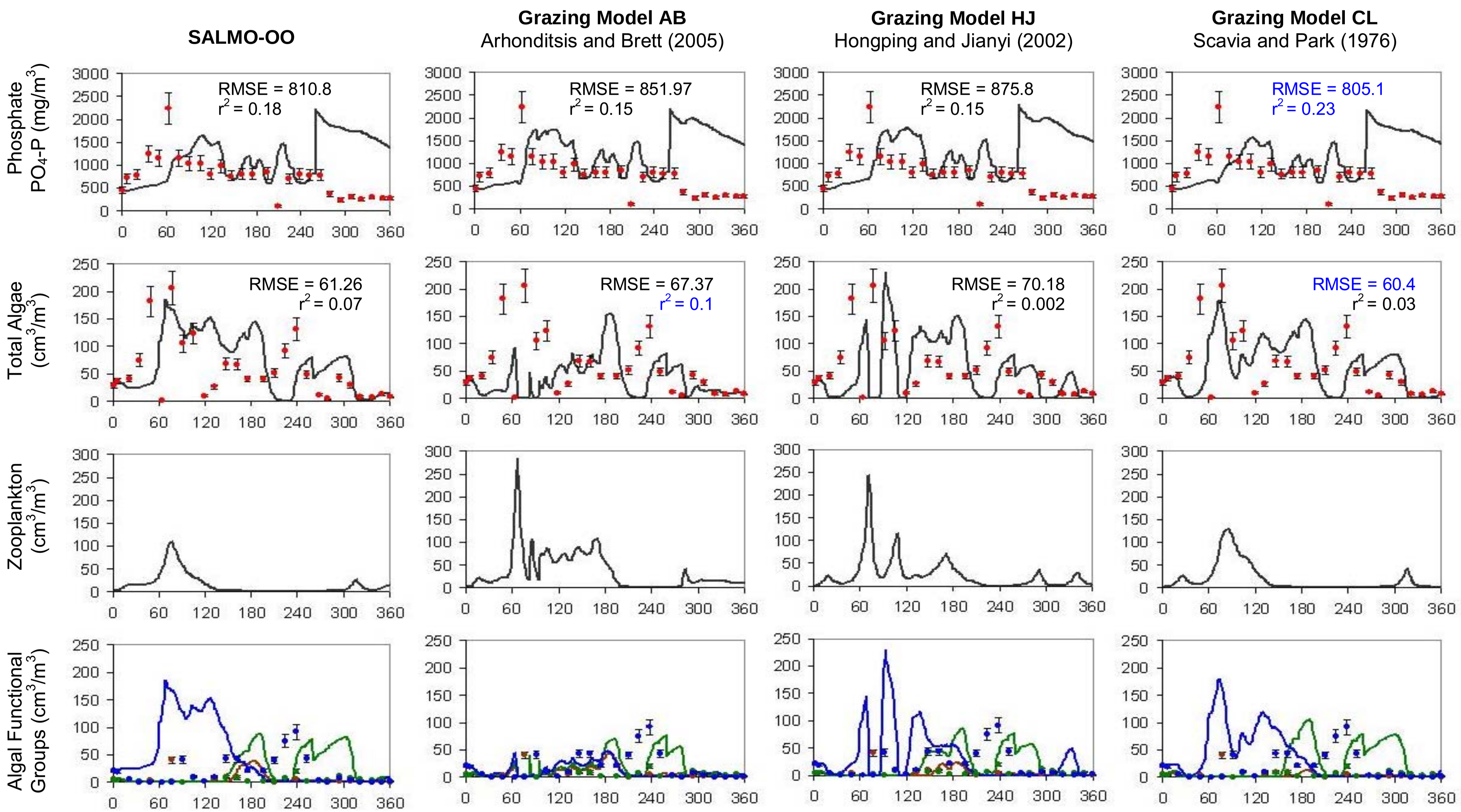

Figure 4.5b. Lake Klipvoor (2003) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%; • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

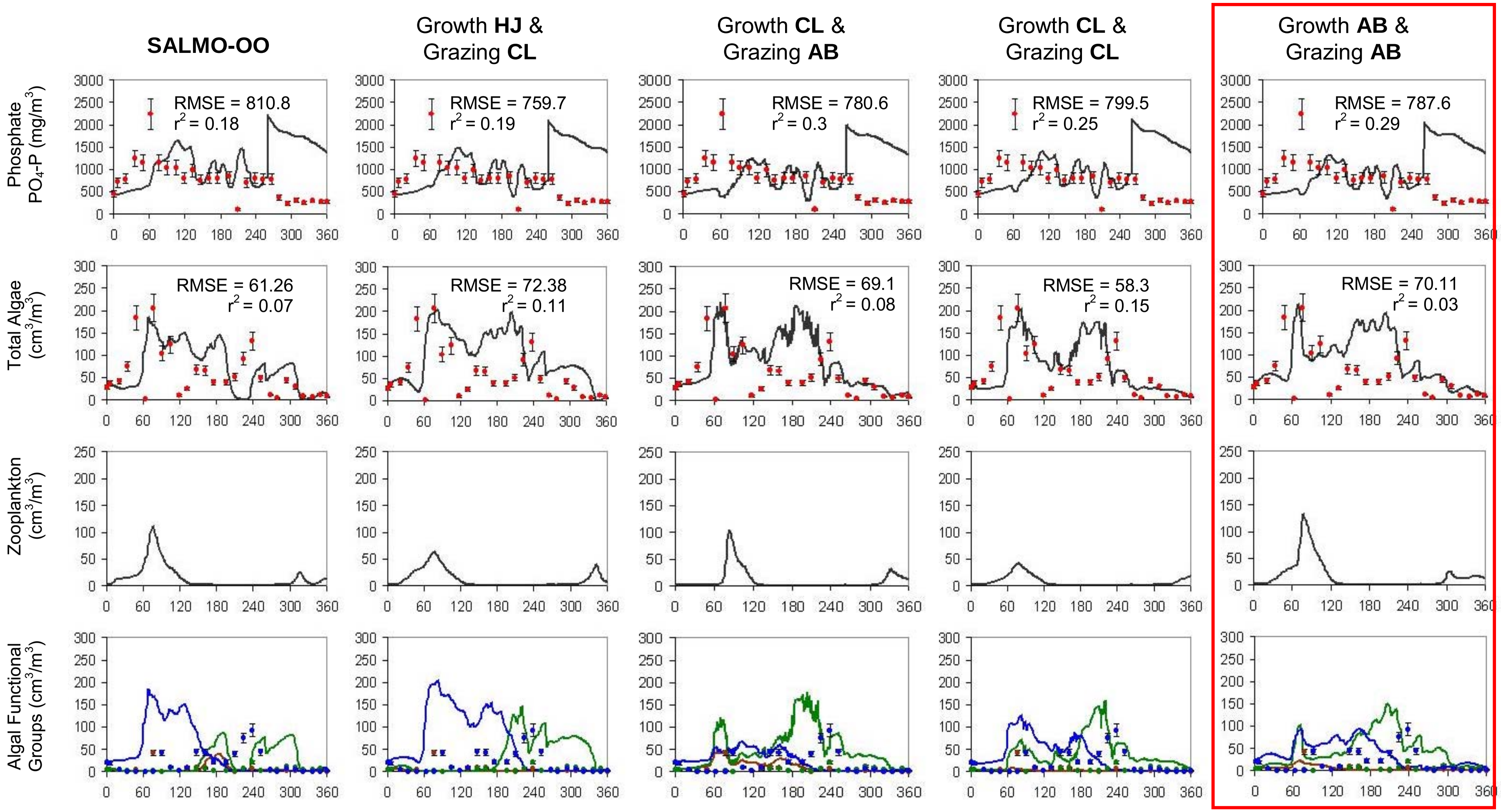

Figure 4.5c. Lake Klipvoor (2003) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%; • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae. **AB** - Arhonditsis and Brett (2005); **HJ** - Hongping and Jianyi (2002); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976). Red box indicates the simulation that performs better all round compared to SALMO-OO.