4.1.2 Mesotrophic conditions

In order to test the generality of the SALMO-OO model to describe different trophic states, two datasets representing mesotrophic lake conditions were used to further validate the model. Both lakes are also classed as dimictic and cool temperate.

4.1.2.1 Saidenbach Reservoir, Germany

The simulation results for Saidenbach Reservoir by SALMO-OO describe the total phytoplankton biomass reasonably well (Figure 4.6a), except the model under predicted the timing and magnitude of the spring peak, as reflected by the poor r^2 value ($r^2 = 0.04$). The model also does not adequately predict the two extreme data points during summer. Zooplankton biomass simulations are good, but a time lag is also observed coinciding with the dynamics of phytoplankton biomass (Figure 4.6a). The magnitude of the zooplankton main peak in summer is also not described adequately by SALMO-OO ($r^2 = 0.1$). Phosphate dynamics are reasonable for the first half of the year, but a grossly over predicted during summer and autumn, consequently a poor r^2 value is calculated (0.05) (Figure 4.6a). The prediction of phytoplankton functional group dynamics is consistent with mesotrophic conditions, with a balanced abundance of each functional group present.

Phytoplankton growth model experiments

Application of alternative phytoplankton growth models was applied to the Saidenbach Reservoir data in order to improve the SALMO-OO models predictions. The prediction of phytoplankton biomass was greatly improved by the application of all three alternative growth models (Figure 4.6a). The timing and magnitude of the spring peak fits more closely to the measured data and has improved the r^2 values considerably, particularly the growth models from Arhonditsis & Brett (2005) and CLEANER (0.11 and 0.13 respectively compared to SALMO-OO (r^2=0.04). The growth model from Hongping & Jianyi (2002) still gives a low r^2 value (0.05) possibly due to the over prediction of algae biomass towards the end of the year. None of the alternative growth models was able to predict the two very high biomass values during summer. Overall, the growth model from CLEANER produces the best visual result with the simulation fitting the measured data very well and producing the lowest RMSE value and highest r^2 value compared to SALMO-OO and the other growth models.

Prediction of phosphate concentration by the alternative growth models was best achieved by the CLEANER model, which produced an excellent visual result and greatly improved statistical results (RMSE = 3.63 compared to SALMO-OO RMSE = 7.12 and $r^2 = 0.18$ compared to SALMO-OO $r^2 = 0.05$) (Figure 4.6a). The simulation of zooplankton biomass by the alternative growth models has not greatly changed visually or quantitatively compared to SALMO-OO (Figure 4.6a). The statistical values have improved slightly, but visually the timing and magnitude of the summer peak is still under predicted. The simulation of algal functional group dynamics is as expected of mesotrophic conditions with a balanced abundance of each functional group contributing to the total biomass (Figure 4.6a). The simulations from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) growth model show a clear dominance of green algae during spring and early summer, with the succession of blue-green algae in late summer and autumn. However, the CLEANER growth model does not predict the high occurrence of blue-green algae during any time of year, which might be more common of oligotrophic conditions rather then mesotrophic. Also, all the alternative growth models show the occurrence of diatoms during the spring months, whereas SALMO-OO predicts the occurrence of diatoms during late summer.

Phytoplankton grazing model experiments

Very little improvement has been achieved by the application of the alternative phytoplankton grazing models to the simulation of total algae, phosphate and zooplankton state variables. However, there has been improvement in the models ability to predict the extreme algae values during summer (Figure 4.6b). Each alternative grazing model is able to improve the magnitude and timing of the high biomass values that were not described by the growth models. Zooplankton and phosphate simulations remain mostly unchanged, however, the simulation of the algal functional groups has been altered with a move towards green algae dominance during most of the year and a greater proportion of diatom biomass contributing to the total biomass of algae (Figure 4.6b). The CLEANER grazing model has predicted the occurrence of blue-green algae during late summer, unlike the simulations from the CLEANER growth model.

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 each alternative grazing model has the ability to improve the results of phosphate, phytoplankton and zooplankton biomass predictions. Although the grazing models did not improve the overall prediction of each state variable, it was deemed important to test combinations of each grazing and growth model to see if the prediction of the very high algal biomass values during summer could be achieved. Therefore, combinations of these alternative models were tested to see if the results produced by SALMO-OO could be further improved. Figure 4.6c illustrates the best five results from the combination experiments for Saidenbach Reservoir.

In all cases the combination models have improved the timing and magnitude of the phytoplankton spring peak and prediction of the decrease in biomass during the end of the simulation. Three combination models were able to describe the extreme algae biomass values during summer (combinations growth AB & grazing AB, growth HJ & grazing AB and growth AB & grazing CL) and were able to produce high r^2 values (0.34, 0.31 and 0.22 respectively) compared to SALMO-OO (r^2 = 0.04) and the other combinations (Figure 4.6c). However, the RMSE values were still higher than were desirable (above 1.7) and the simulation of phosphate dynamics was poor, with very large over predictions during the last half of the simulation (Figure 4.6c).

The best results produced for phytoplankton predictions, according to the RMSE values, was by the combination of growth CL & grazing HJ, which produced a significantly lower value compared to SALMO-OO (1.59 compared to SALMO-OO RMSE of 1.77). Visually this combination describes the measured data more closely than other combinations even though the two extreme values were not predicted. The combination of growth CL & grazing AB also produces a very good result for phytoplankton predictions, with a high and greatly improved r^2 value or 0.23, yet the RMSE value is still high (1.7). Also, these two combinations produced the best results for the prediction of phosphate concentration, with combination growth CL & grazing HJ producing a high r^2 value of 0.17 and a significantly lower RMSE of 4.07 (Figure 4.6c). The timing and magnitude of zooplankton biomass predictions have greatly improved visually and statistically in most cases, although the highest measured biomass was still not described in Figure 4.6c. The combination of growth CL & grazing HJ produces the best zooplankton results with the lowest RMSE value (2.04 compared to SALMO-OO RMSE of 2.4) and the highest r^2 value (0.34 compared to SALMO-OO r^2 of 0.1).

The simulation of phytoplankton functional groups is varied between models (Figure 4.6c). Some combinations show a moderate abundance of blue-green algae during summer and autumn, whereas others show very little blue-green algae present at all. The combination of growth CL & grazing HJ predicts the dominance of green algae for most of the year with a moderate abundance of diatoms during spring and early summer, with very little blue-green algae present. For mesotrophic conditions this can be typical in functional groups composition, however, it is more likely that there is some blue-green algae biomass available during summer, which is not given by this combination.

The choice of the model combination best suited to improve SALMO-OO predictions of the Saidenbach Reservoir data set basically came down to the phytoplankton functional group simulations. Each combination model can simulate phytoplankton and zooplankton biomass very well and although phosphate simulations were better using growth CL & grazing HJ, the results produced by growth CL & grazing AB are still satisfactory as the RMSE is well below that produced by SALMO-OO. However, the combination growth CL & grazing AB is able to simulate the phytoplankton functional groups dynamics more realistically then the combination growth CL & grazing HJ for this particular site. The simulation of accurate phytoplankton dynamics is very important, but if the functional group dynamics are not representative of a system's trophic state, then the overall confidence in the model is considerably reduced. Thus, the use of the growth model from CLEANER and the grazing model from Arhonditsis & Brett (2005) produced the best results for the Saidenbach data set.

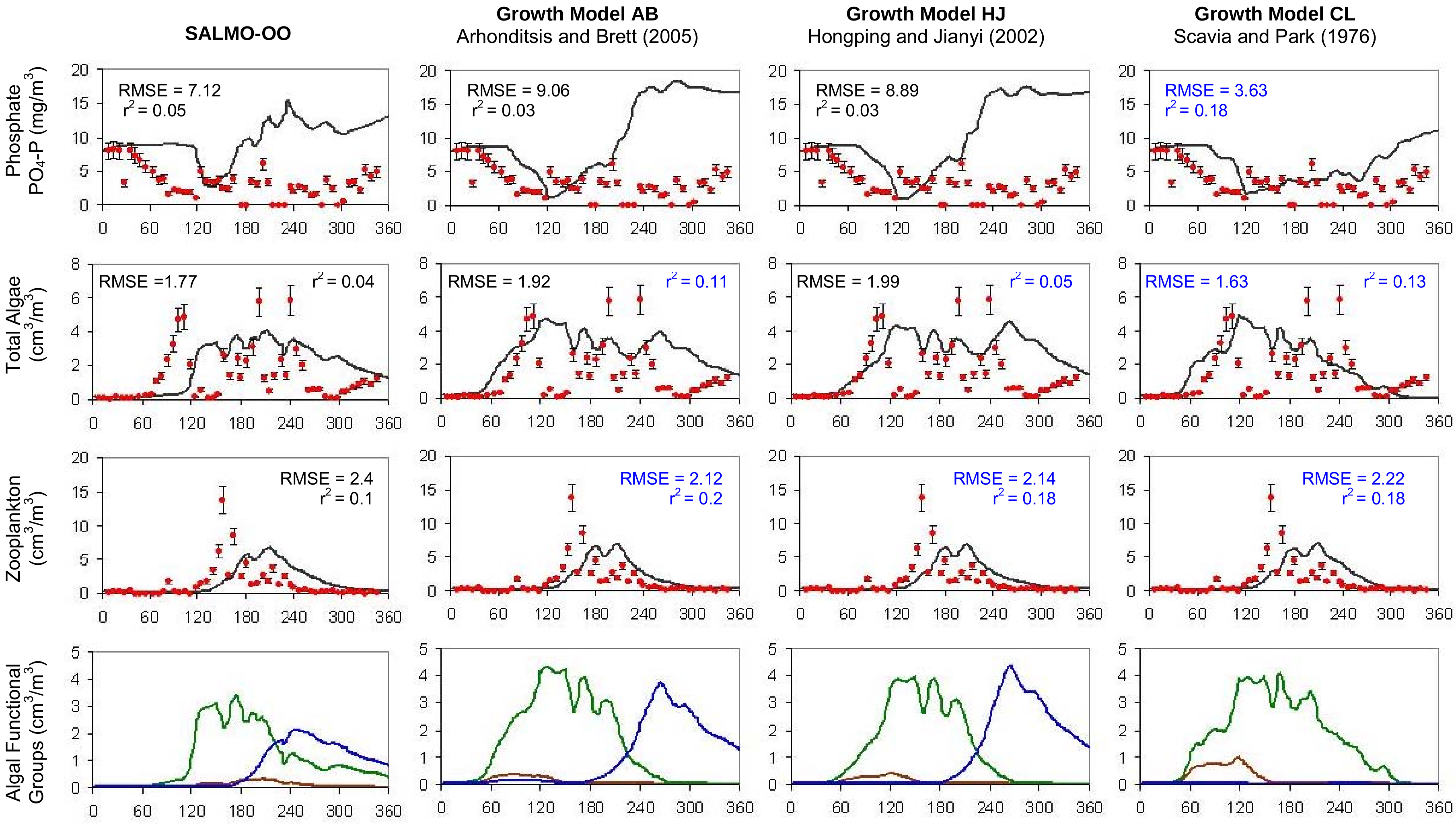

Figure 4.6a. Saidenbach reservoir (1975) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%.

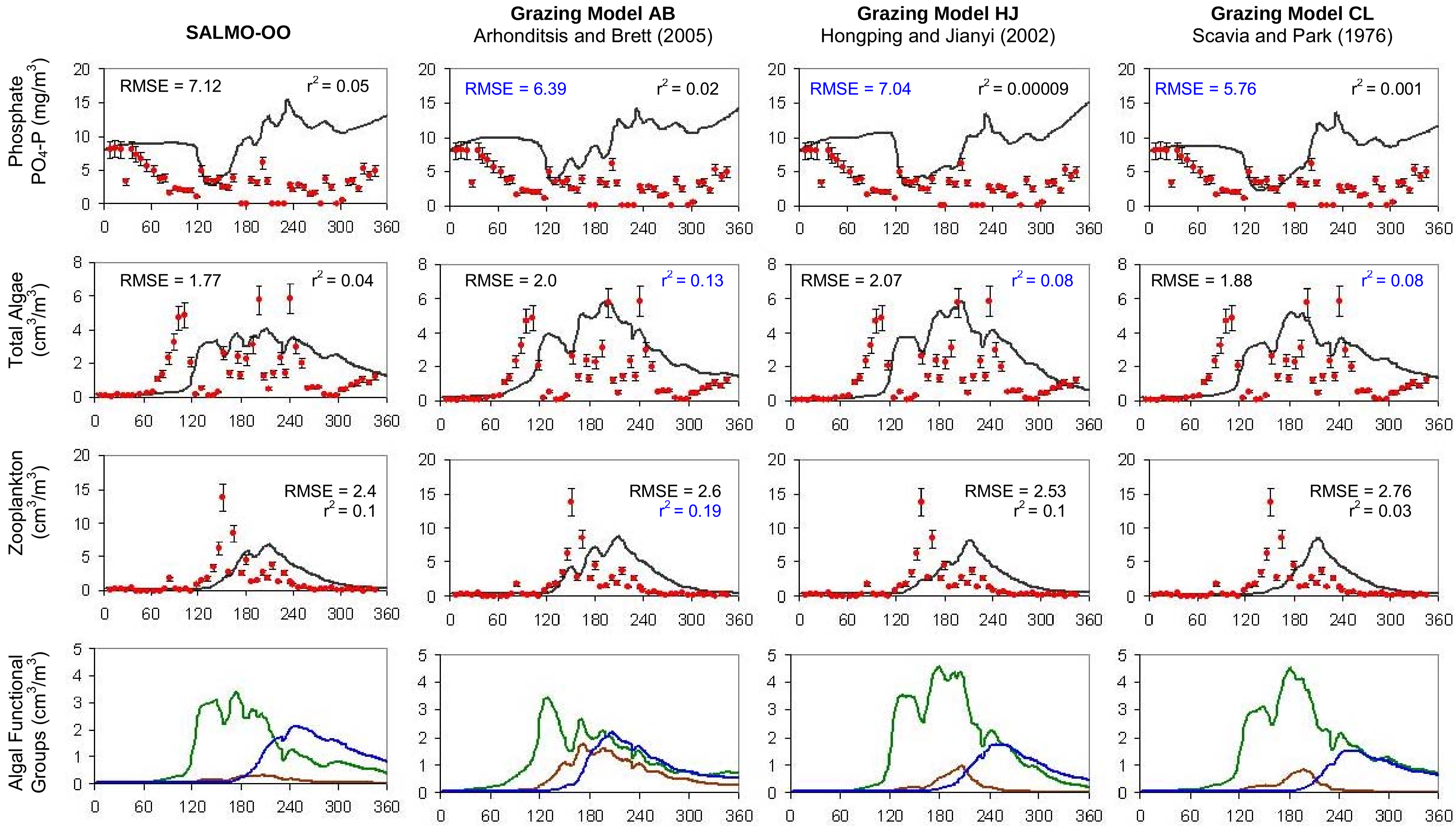

Figure 4.6b. Saidenbach reservoir (1975) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. — Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

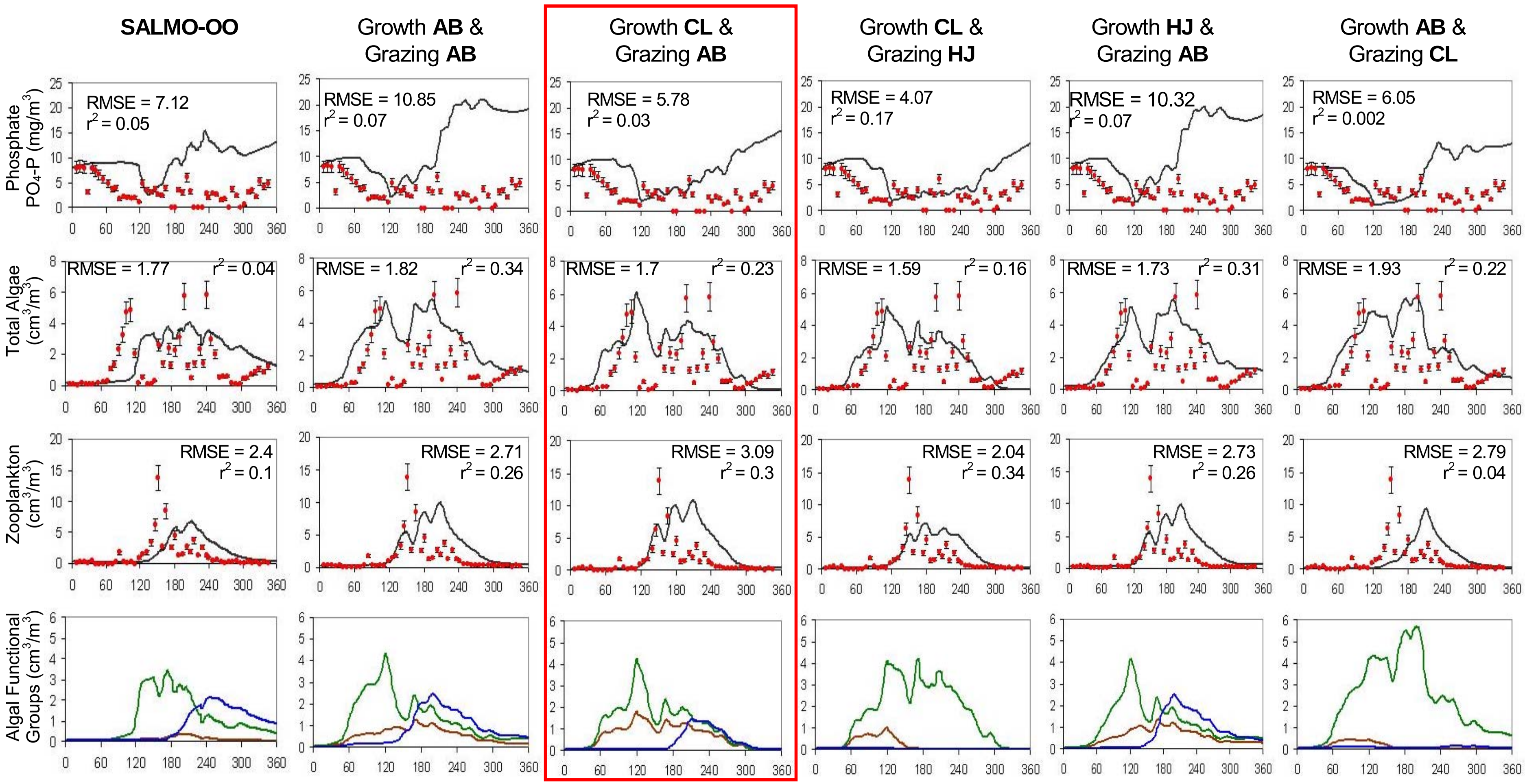

Figure 4.6c. Saidenbach reservoir (1975) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. — Blue-green Algae; — Green Algae; — Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis 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.

4.1.2.2 Lake Weida, Germany

The SALMO-OO model simulation results for Lake Weida produce (Figure 4.7a) a good fit of the measured data for phytoplankton biomass predictions ($r^2 = 0.22$). The simulation of phosphate and zooplankton dynamics produce output trajectories with a good fit to the measured data, especially for zooplankton predictions ($r^2 = 0.75$). The SALMO-OO model describes overall mesotrophic conditions as shown by the measured data reasonably well with the dominance of green algae and very low abundances of blue-green. However, the measured data indicates a peak in diatom abundances during early summer, which SALMO-OO does not adequately simulate.

Phytoplankton growth model experiments

Application of alternative growth models to the SALMO-OO model structure has given similar results for the simulation of phytoplankton biomass compared to SALMO-OO (Figure 4.7a). The main difference is the greater duration of the main algal peak in summer, particularly for growth models from Arhonditsis & Brett (2005) and CLEANER. Quantitatively these results are conflicting as the r^2 values are slightly improved (between 0.23 and 0.27) thea that produced by SALMO-OO (0.22), whereas the RMSE values are higher (between 1.77 and 1.86) indicating a less improved result compared to SALMO-OO (RMSE = 1.74). Phosphate simulations are in agreement with a slight improvement in statistical results (Figure 4.7a).

Zooplankton predictions are excellent in all cases and match the measured data very well as reflected by the high r^2 values (Figure 4.7a). Algal functional group simulations are similar to those produced by SALMO-OO, with the dominance of green algae during the year and low abundances of blue-green algae and diatoms. Again, the measured data show high abundances of diatoms during summer which none of the alternative growth models predicts (Figure 4.7a), although the CLEANER growth model does predict moderate abundance of diatoms during late spring, but this does not agree with the measured data.

Phytoplankton grazing model experiments

Alternative grazing models were also tested within the SALMO-OO model structure to see if improvements could be made to the simulation of the three key state variables (Figure 4.7b). The grazing models produced similar results to those of the alternative growth models in Figure 4.7a, but with a lesser degree of improvement quantitatively. Phytoplankton biomass simulations indicate that the growth model from Hongping & Jianyi (2002) was the most successful with a high r^2 value of 0.57 and a lower RMSE value (1.41) compared to the results produced by SALMO-OO. The grazing model from CLEANER produced similar results visually and quantitatively as SALMO-OO whereas the grazing model from Arhonditsis & Brett (2005) produced slightly poorer quantitative results and an over prediction in phytoplankton abundances during summer then observed by the measured data. The grazing model from Arhonditsis & Brett (2005) also produced less accurate zooplankton biomass predictions, failing to simulate the peak in zooplankton abundances during summer. The other two grazing models produced excellent results for zooplankton biomass although a slight delay in the timing of the summer peak is observed (Figure 4.7b).

Phosphate predictions are reasonable although the statistical values indicate a less accurate prediction compared to SALMO-OO (Figure 4.7b). The simulation of phytoplankton functional groups are similar to SALMO-OO and reflect the occurrence of mesotrophic conditions indicated by the measured data, but failed to simulate the occurrence of diatoms during summer. The exception is the grazing model from Arhonditsis & Brett (2005), which does predict moderate abundances of diatoms during summer, but fails to predict the higher abundances indicated by the measured data (Figure 4.7b).

Experiments of combined growth and grazing process models

In keeping with the selection criteria outlined in section 3.6.3 it can be deduced that each alternative growth model has the ability to improve the results of phytoplankton and phosphate predictions. The grazing models perform similarly to SALMO-OO but do not seem to improve the overall results, although the grazing model from Arhonditsis & Brett (2005) does improve the predictions of algal functional group seasonality. Nevertheless, each alternative growth and grazing model was tested to determine if any given combination of models could improve upon the results given by SALMO-OO. Figure 4.7c illustrates the best four results from the combination experiments for Lake Weida.

According to the phytoplankton biomass simulations, statistically, the combination of the growth and grazing models from Hongping & Jianyi (2002) produces the best results (Figure 4.7c) with an RMSE of 1.44 and an r^2 value of 0.67. The quantitative results given by the other combinations shown in Figure 4.7c are similar for both the RMSE and r^2 values (RMSE between 1.78 and 1.81, and r^2 between 0.23 and 0.25). However, the RMSE values suggest these alternative combinations do not improve the results for phytoplankton predictions. Phosphate predictions are also very similar, with simulations describing the measured data very well. The best result for phosphate predictions is given by the combination of growth CL & grazing AB with an RMSE value of 10.03 and an r^2 value of 0.24 (SALMO-OO RMSE = 10.14 and r^2 = 0.11). Zooplankton simulations are still excellent for all combinations shown, however, there is an over prediction in the magnitude of the main peak, which has resulted in less favourable RMSE values for each.

Generally, the best phytoplankton biomass prediction is used to determine which combination of growth and grazing models performs best for the simulation of each lake or reservoir data set, assuming that the phosphate and zooplankton biomass simulations are satisfactory. In this case the combination of the growth and grazing models from Hongping & Jianyi (2002) would be the best choice. However, as there is measured data for algal functional groups it can be seen that this combination, although indicating a mesotrophic state, does not represent the observations given by the measured data. In particular, no diatoms are predicted which is contrary to what the measured data indicates. This is the same for the other combination experiments for Lake Weida as well. The exception is the combination of growth CL & grazing AB, which simulate a greater abundance of diatoms during late spring and summer. Thus, the combination of growth CL & grazing AB, with agreeable results for phytoplankton, phosphate and zooplankton dynamics, and the more accurate representation of algal functional groups dynamics is the best choice to describe the conditions in Lake Weida.

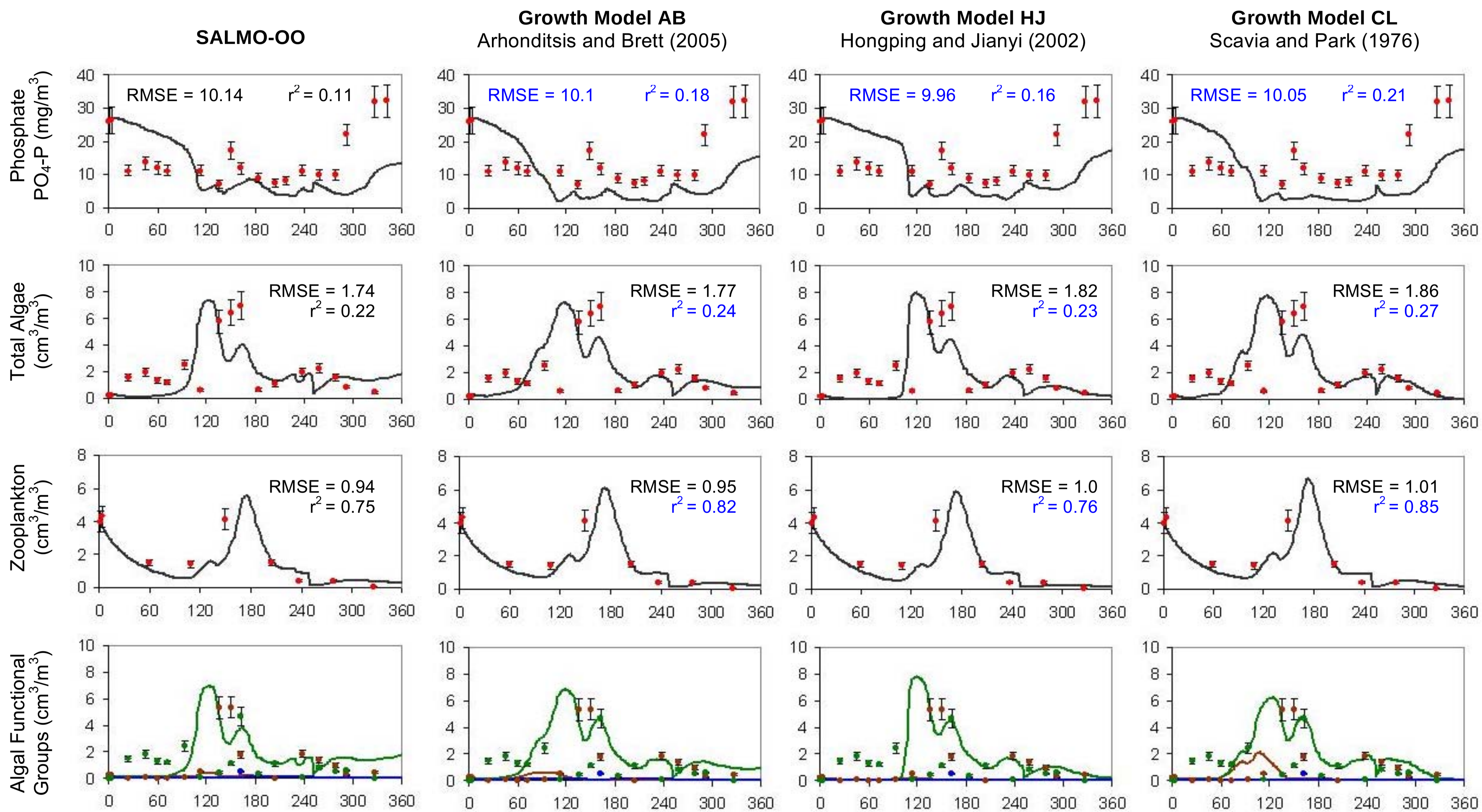

Figure 4.7a. Lake Weida (1984) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; • Measured data with standard deviation bars of 15%; • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

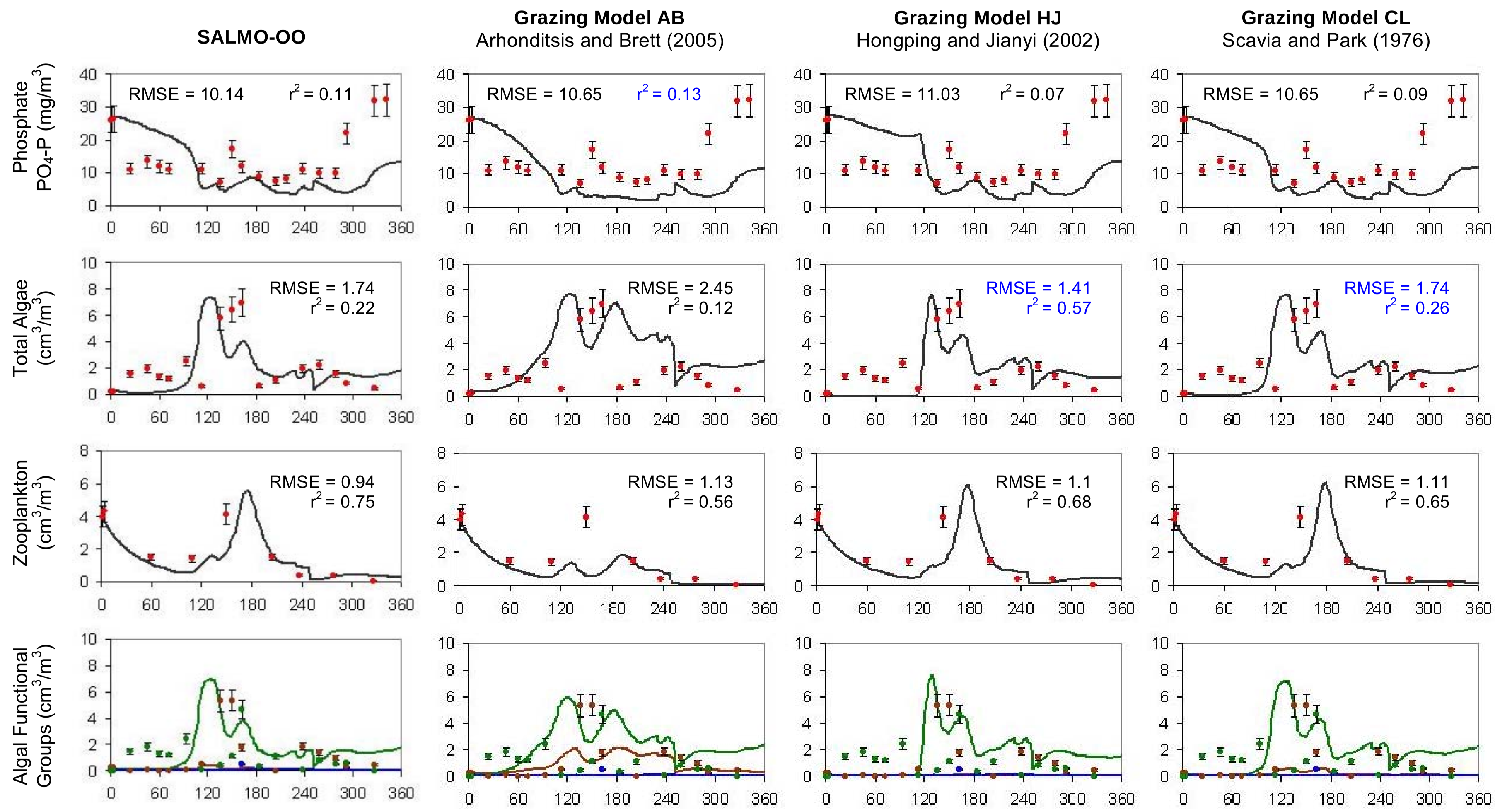

Figure 4.7b. Lake Weida (1984) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. — Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%; • Measured data for green algae; • Measured data for diatoms; • Measured data for blue-green algae.

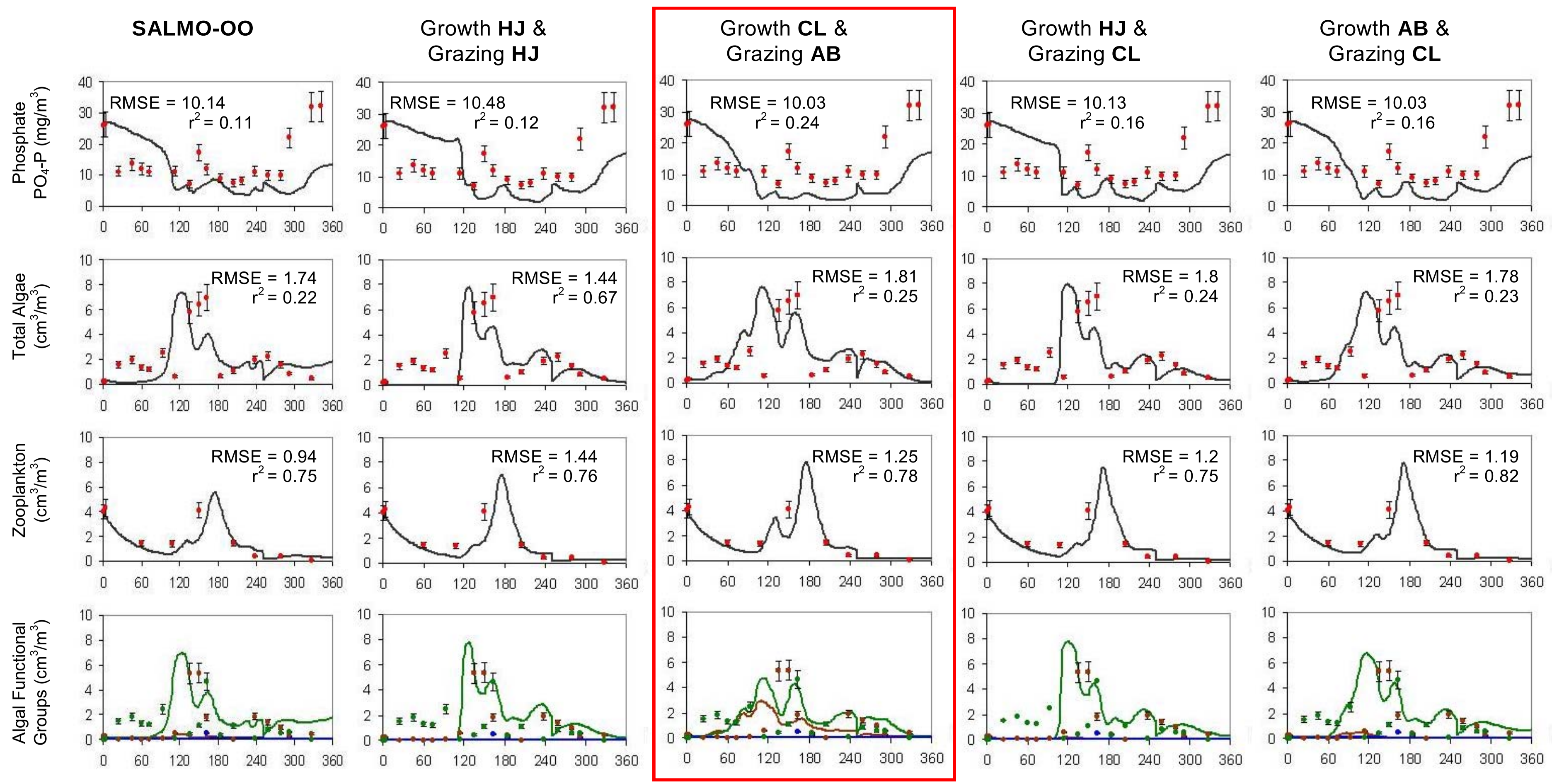

Figure 4.7c. Lake Weida (1984) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. — Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%; • Measured data for green algae; • 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.

4.1.3. Oligotrophic conditions

In order to further test the generality of the SALMO-OO model to describe different trophic states, two datasets representing oligotrophic lake conditions were used to validate the model. Lake Stechlin and Lake Soyang are both located in temperate climates, however, Lake Soyang is influenced by monsoonal rains, which have an effect on water quality and primary production. Both lakes also exhibit dimictic mixing patterns with ice cover in the coolest months.

4.1.3.1. Lake Stechlin, Germany

The predictions from the model SALMO-OO for the state variables phosphate, phytoplankton and zooplankton are presented in Figure 4.8a. The SALMO-OO model is unable to simulate the phytoplankton conditions of Lake Stechlin adequately with the timing of the algal peak predicted too late and the duration of the peak over predicted, as reflected by the low r^2 value (0.03). However, the magnitude of the main algal peak is predicted reasonably well. A similar trend occurs with phosphate predictions where the trends predicted by SALMO-OO are reasonable during the first part of the year, but a largely over predicted during the last part of the year. Zooplankton biomass is grossly over predicted compared to the measured data even though a high r^2 value is calculated. In spite of this, SALMO-OO is able to simulate oligotrophic conditions, with the dominance of green algae during the year and very little blue-green algae present (Figure 4.8a).

Phytoplankton growth model experiments

Application of alternative phytoplankton growth models was applied to the Lake Stechlin data in order to improve the SALMO-OO models predictions. In most cases the predictions of phytoplankton biomass were improved to various degrees. The growth model from Arhonditsis & Brett (2005) has slightly improved the timing and duration of the algal peak, but has predicted the magnitude of the peak to be more than that predicted by SALMO-OO (Figure 4.8a). This may be reflected in the slight improvement in the RMSE value (from SALMO-OO RMSE of 0.89 to 0.72) and the r^2 value (0.11 compared to 0.03 for SALMO-OO). The growth model from Hongping & Jianyi (2002) has also produced a better RMSE value (0.72), although the r^2 value is very poor (0.001). Visually, the growth model from Hongping & Jianyi (2002) has only improved the magnitude and duration of the algal peak, but has not affected the timing. The results given by the CLEANER growth model have greatly improved the simulations of phytoplankton biomass. The timing of the algal peak matches the measured data very well, which is reflected by the greatly improved r^2 value of 0.21. However, the magnitude and duration of the peak is still over predicted, as given by the still quite high RMSE value (0.78) compared to the RMSE values from the other growth models (0.72). Nevertheless, the use of the CLEANER model within the combination model experiments may help to improve the overall phytoplankton biomass predictions from those produced by SALMO-OO alone.

As far as the predictions for phosphate dynamics are concerned, only the growth model from CLEANER produced satisfactory results, despite the low r^2 value. The CLEANER model produced visual results that reflect the measured data more closely compared to the growth models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002), as shown by the lower RMSE value (3.16), which is also an improvement from the RMSE value produced by SALMO-OO (4.3) (Figure 4.8a). Zooplankton biomass predictions have not greatly improved using the alternative growth models and are visually similar to SALMO-OO (Figure 4.8a). The r^2 values are somewhat misleading as they are very high for a deterministic model, but this is not reflected by the visual comparisons between measured and simulated results. The RMSE values are more informative with a slight improvement given by growth models from Arhonditsis & Brett (2005) and Hongping & Jianyi (2002). The CLEANER growth model did not achieve a better RMSE value for zooplankton predictions compared to SALMO-OO. Nevertheless, regardless of improvements in statistical analysis neither SALMO-OO nor the alternative growth models were able to simulate zooplankton dynamics adequately. The simulations of algal functional group dynamics by each growth model are typical of oligotrophic conditions, with the dominance of green algae during the year and the absence of blue-green algae (Figure 4.8a).

Phytoplankton grazing model experiments

Three alternative grazing models were also tested on the Lake Stechlin data in order to enhance the results given by SALMO-OO (Figure 4.8b). The phytoplankton biomass predictions from the grazing model of Arhonditsis & Brett (2005) and Hongping & Jianyi (2002) give poor results compared to that of SALMO-OO. Visually both of these models over predict the timing, duration and magnitude of the algal peak, which is reflected by the higher RMSE value and low r^2 values. However, the grazing model from CLEANER produces a much-improved result with the magnitude and duration of predicted algal biomass fitting closer to the measured data, as shown by the lower RMSE value (0.67). This result is also an improvement on that produced by the CLEANER growth model, which calculated an RMSE value of 0.78. The simulation of phosphate concentrations is also disappointing, as neither grazing model was able to improve these results (Figure 4.8b). Zooplankton biomass simulations are similar to those produced by the growth models, with the grazing model producing poor visual results regardless of the r^2 values calculated (Figure 4.8b). The phytoplankton functional group predictions still illustrate oligotrophic conditions, however, the grazing model from Arhonditsis & Brett (2005) predicts the occurrence of blue-green algae during summer, which is not realistic (Figure 4.8b).

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 each alternative growth and grazing model has the ability to improve the results of each of the state variables analysed. Even though the visual and statistical results for each of the growth and grazing model experiments are conflicting there may be combinations of alternative models that may produce improved results. Therefore, combinations of these growth and grazing models were tested and the best four quantitative results are shown in Figure 4.8c.

The best overall results for Lake Stechlin were produced by the combination of the growth and grazing models from CLEANER. For phytoplankton biomass predictions the r^2 value is very good (0.61) and the RMSE value (0.28) is significantly lower then that produced by SALMO-OO and the other combination models (Figure 4.8c). This statistical result is compatible with the visual output as the combination of growth and grazing from CLEANER fits the measured data very well. Compared to the other combinations that produced good quantitative results the combination of the growth and grazing models from CLEANER successfully describe the main algal peak in timing, duration and magnitude, where as the other model combinations over predict the abundance of phytoplankton biomass during summer and autumn even though the prediction of the main peak is reasonable.

The combination of the growth and grazing model from CLEANER has produced a good result for phosphate dynamics compared to the other combination models, with the output trajectory fitting the measured data well, even though phosphate is over predicted during the last part of the simulation (Figure 4.8c). This seems to be a problem for the SALMO-OO model and all models tested in the library. However, the r^2 value produced by growth CL & grazing CL is very poor, compared to the RMSE value of 3.93 which is significantly lower then that produced by SALMO-OO (4.3). The r^2 analysis given by growth CL & grazing CL does not make sense when compared to the r^2 value produced by the combination of growth AB & grazing HJ (0.02), considering the visual results for this combination are obviously poor compared to growth CL & grazing CL (Figure 4.8c). In this case the visual results combined with the RMSE values are more conclusive in determining the best combination to simulate Lake Stechlin conditions for phosphate dynamics.

A similar conclusion can be made for the analysis of zooplankton predictions (Figure 4.8c). For all combinations tested the r^2 values are excellent (between 0.76 and 0.83) and suggest these models fit the measured data very closely. However, visually these combination models do not fit the measured data at all and significantly over predict zooplankton dynamics, even more so compared to SALMO-OO. However, the RMSE values give more convincing evidence of model performance, indicating none of the combined model produced better results (between 0.86 and 1.11) compared to those produced by the SALMO-OO model (0.61). Thus, in all cases zooplankton biomass predictions are poor and SALMO-OO produces the best results, albeit these results are inadequate also.

In spite of poor model performance in regards to zooplankton and phosphate predictions, it is the phytoplankton biomass and algal functional group predictions that are the focus of model improvements and consequently the combination of growth and grazing models from CLEANER produces very realistic algal functional group results for oligotrophic conditions, with the dominance of green algae during the year and very low abundances of blue-green algae. Therefore, the growth and grazing model from CLEANER produces the best overall results for Lake Stechlin, as this combination gives excellent results visually and quantitatively for phytoplankton dynamics, a reasonable phosphate simulation and simulates algal functional group dynamics as expected for oligotrophic conditions.

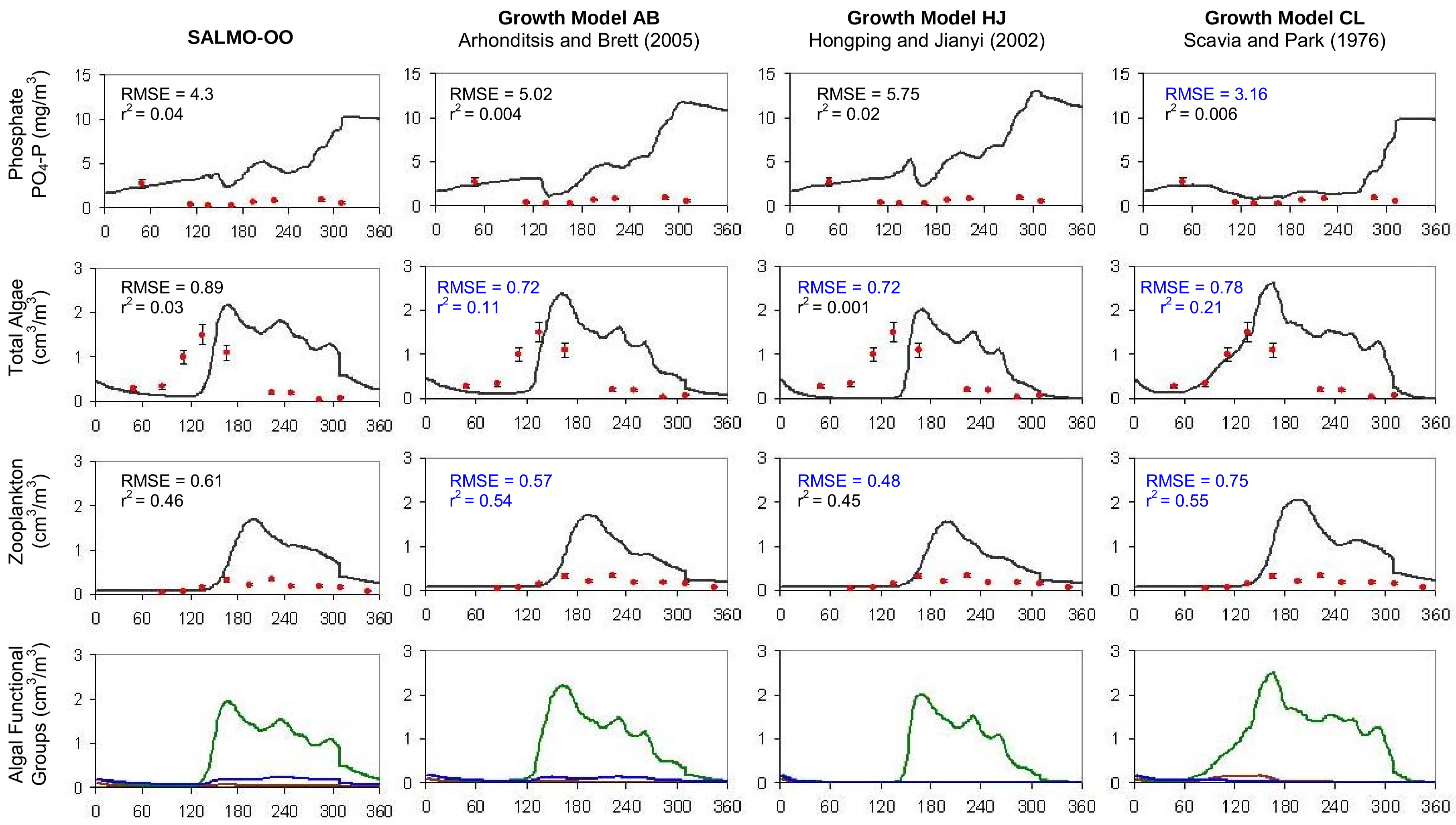

Figure 4.8a. Lake Stechlin (1975) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. — Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

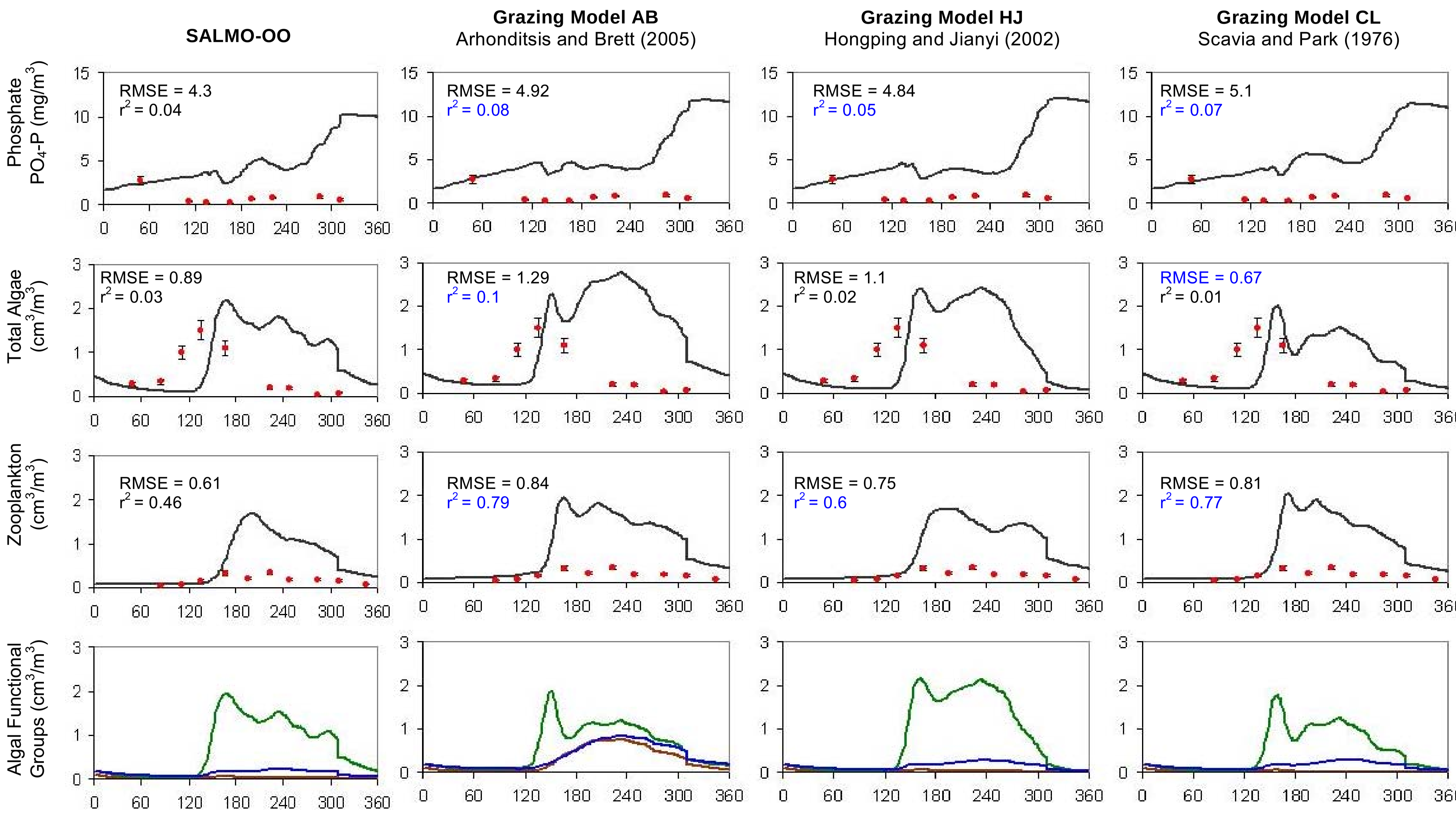

Figure 4.8b. Lake Stechlin (1975) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. — Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

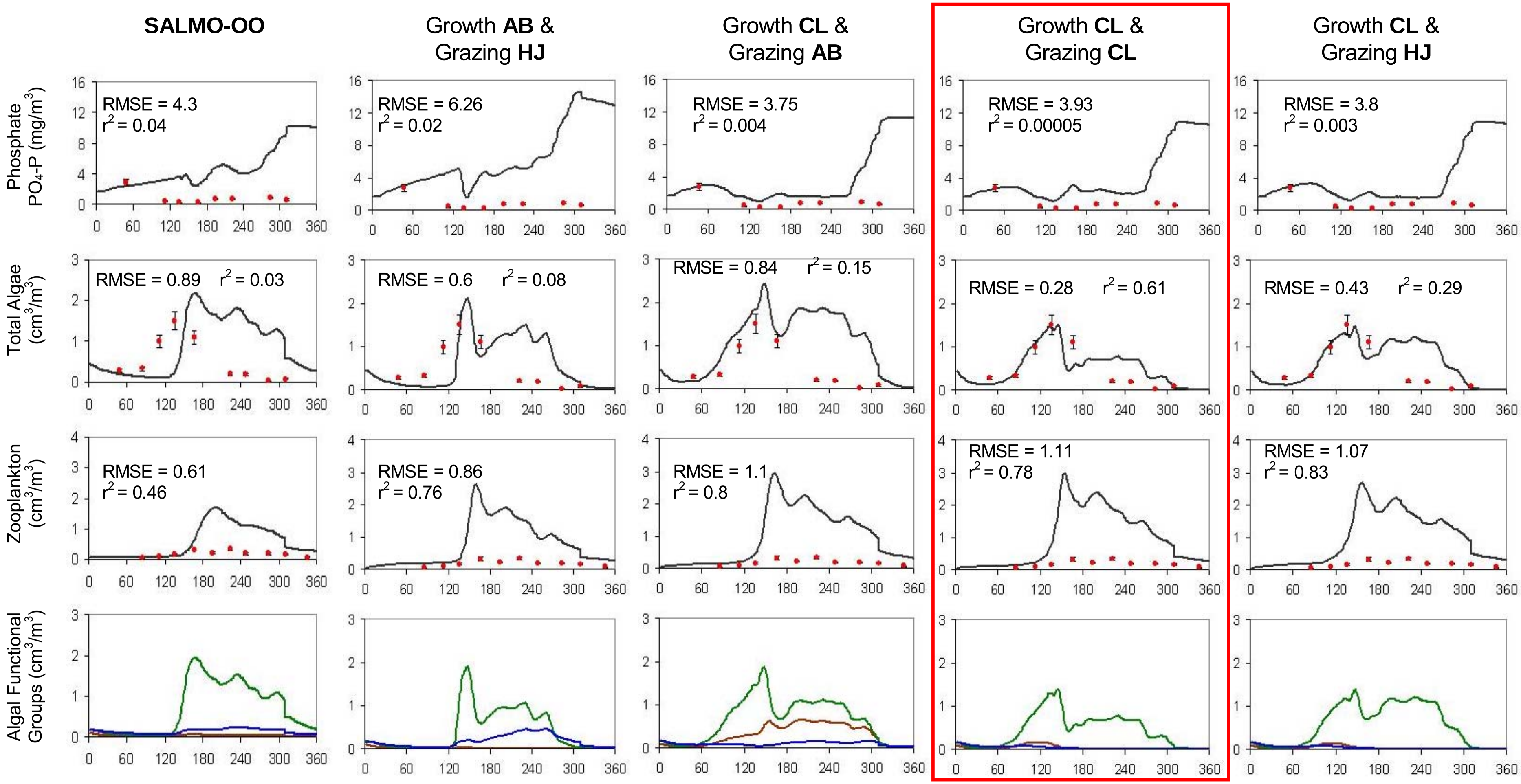

Figure 4.8c. Lake Stechlin (1975) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis and 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.

4.1.3.2 Lake Soyang, South Korea

The simulations of phytoplankton biomass in Lake Soyang gives satisfactory predictions (r^2 = 0.21) for most of the year (Figure 4.9a), except for the over prediction of the late summer peak which is not described by the model. This may be attributed to the occurrence of seasonal monsoons at the site that would affect the water inflow data that drives the model. A similar conclusion can be made for phosphate predictions as SALMO-OO is shown to describe phosphate dynamics reasonably well, but also over predicts the magnitude of phosphate concentrations during late summer, hence the low r^2 value (0.0085) (Figure 4.9a). There are no measured data available for comparisons of modelled zooplankton biomass results, but the model describes the expected seasonal dynamics, although a high abundance of zooplankton is predicted during late summer due to the over prediction in phytoplankton biomass during this time period. Lake Soyang is classified as oligotrophic and the SALMO-OO model predicts these conditions with the dominance of green algae, a small amount of diatoms and very low numbers of blue-green algae.

Phytoplankton growth model experiments

Three alternative growth models were applied to Lake Soyang to determine if improvements could be made to the predictions produced by the SALMO-OO model (Figure 4.9a). Each alternative growth model produced similar results for phytoplankton biomass predictions by adequately describing algal dynamics for most of the year, but over predicting the occurrence of a phytoplankton peak in late summer. This is similar to the results produced by SALMO-OO, however the growth models predict a lower magnitude of phytoplankton during this period, which can be considered as an improvement, which is reflected by the improvement in the r^2 and RMSE statistics. Phosphate predictions produced by each growth model are also similar to those produced by SALMO-OO, however a greater over estimation of phosphate concentrations is given during late summer (Figure 4.9a). Zooplankton biomass and algal functional group dynamics are realistically predicted by each alternative growth model, similar to the results for these state variables given by the SALMO-OO model.

Phytoplankton grazing model experiments

Application of three alternative grazing models to the structure of the SALMO-OO model has greatly improved the results for phytoplankton biomass predictions (Figure 4.9b). Each grazing model gives trajectories that more closely fit the measured data and significantly reduce the over prediction of the late summer algal peak produced by SALMO-OO and the alternative growth models (Figure 4.9a). This is reflected by the improvement in the RMSE values (SALMO-OO RMSE = 2.1 and the grazing models RMSE = 0.83 – 1.11). The simulation of phosphate dynamics is still much the same as those produced by the growth models and no significant improvements have been made. Due to the decrease in the predicted abundance of phytoplankton the zooplankton biomass simulations have produced much higher biomass values then those predicted by the growth models (Figure 4.9b), and the algal functional groups abundances have also decreased compared to those results produced by SALMO-OO. The grazing models from Hongping & Jianyi (2002) and CLEANER produce oligotrophic conditions with the clear dominance of green algae and very low occurrences of diatoms and blue-green algae. However, the grazing model from Arhonditsis & Brett (2005) simulates oligotrophic conditions with the dominance of green algae, but predicts moderate numbers of diatoms present during summer (Figure 4.9b).

Experiments of combined growth and grazing process models

In reference to the selection criteria outlined in section 3.6.3 it can be concluded that each alternative growth and grazing model has the ability to improve the results of the phytoplankton biomass predictions for Lake Soyang. It is unlikely that phosphate concentration predictions will improve, but the accurate representation of phytoplankton biomass and algal functional group dynamics is the main goal of the SALMO-OO simulation library. Combinations of each growth and grazing model were tested and the best four quantitative results are shown in Figure 4.9c. Visually, the results for phytoplankton biomass predictions are very similar with each combination predicting trajectories that fit very closely to the measured data during spring and summer, with a slight over prediction during late summer. This is illustrated by the RMSE values for phytoplankton (between 0.71 and 0.9), which are all significantly lower then the RMSE value produced by SALMO-OO (2.1), although the r^2 values (0.13 – 0.18) indicate less accuracy compared to the SALMO-OO model (0.21). Quantitatively the best results for the simulation of phytoplankton biomass are given by the combination of growth HJ & grazing AB with an RMSE value of 0.71.

Application of the simulation library has not improved phosphate predictions as indicated by the RMSE and r^2 values, but the general trends are similar to those produced by SALMO-OO but with a higher magnitude of phosphate predicted in late summer (Figure 4.9c). Even so, the best simulation out of each combination tested was produced by the combination of growth CL & grazing AB, yielding the lowest RMSE (4.67) and highest r^2 value (0.0033). Zooplankton biomass predictions by each combination of models are higher compared to SALMO-OO particularly during late summer, but are still representative of typical zooplankton – phytoplankton interactions (Figure 4.9c). Algal functional group dynamics are also similar between each combination of growth and grazing models shown in Figure 4.9c, with green algae dominating the total abundance of phytoplankton throughout the year as is expected of oligotrophic conditions.

A balanced approach is required in order to select the combination of growth and grazing models that best describe the overall dynamics of Lake Soyang. Considering each combination produces similar results for phytoplankton biomass predictions, the other state variables simulated need to be considered in order to make the right decision. Therefore, the combination of the growth model from CLEANER and the grazing model from Arhonditsis & Brett (2005) provides the combination that gives the best results for phosphate simulations, even though these results are not as good as those produced by SALMO-OO. The growth CL & grazing AB models are visually more accurate in describing the algal dynamics of Lake Soyang compared to SALMO-OO even though these do not give the best quantitative results. Nevertheless, the phytoplankton biomass predictions given by growth CL & grazing AB are very similar to those produced by growth HJ & grazing AB, which does give the best statistical results. Another positive attribute given by this combination is the simulation of phytoplankton functional groups, as growth CL & grazing AB not only predict the occurrence of green algae but also indicate the presence of diatoms during summer, which may be more representative of oligotrophic conditions for this system.

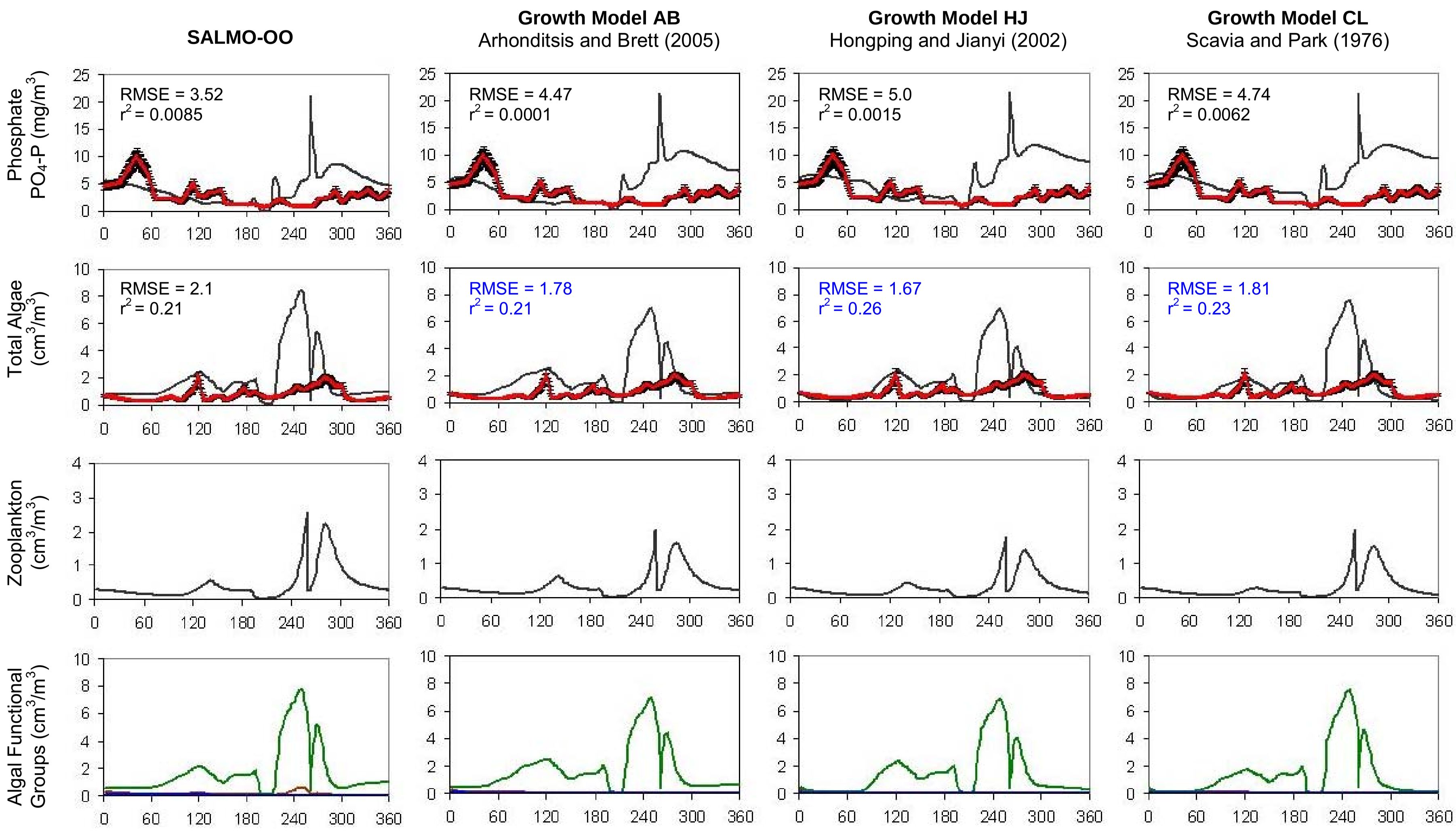

Figure 4.9a. Lake Soyang (1998) simulation results from the SALMO-OO model and alternative phytoplankton growth process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO.
— Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

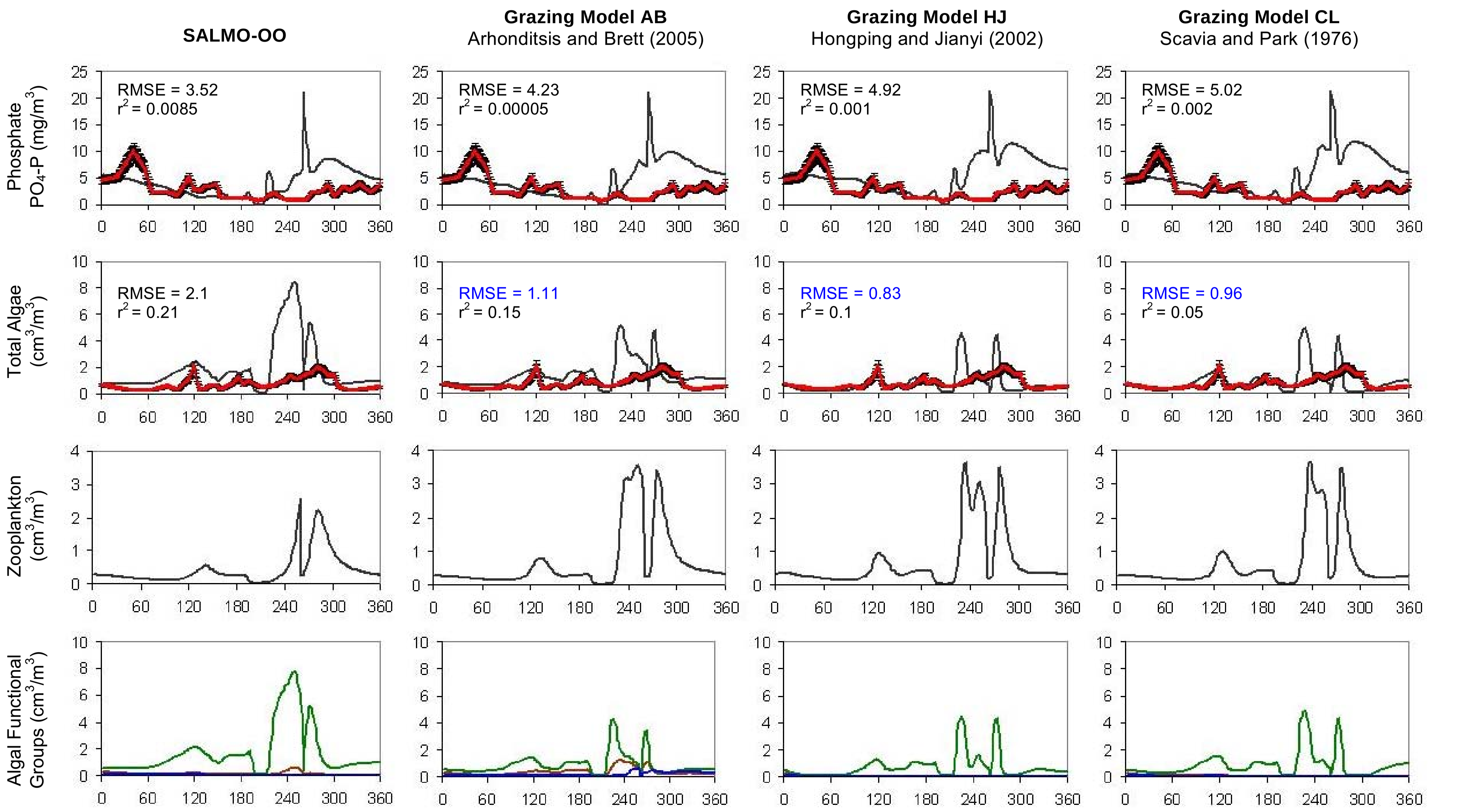

Figure 4.9b. Lake Soyang (1998) simulation results from the SALMO-OO model and alternative phytoplankton grazing process models from the simulation library. X-axis is in days. Blue text indicates those simulations that perform quantitatively better then SALMO-OO. — Blue-green Algae; — Green Algae; — Diatoms; • Measured data with standard deviation bars of 15%.

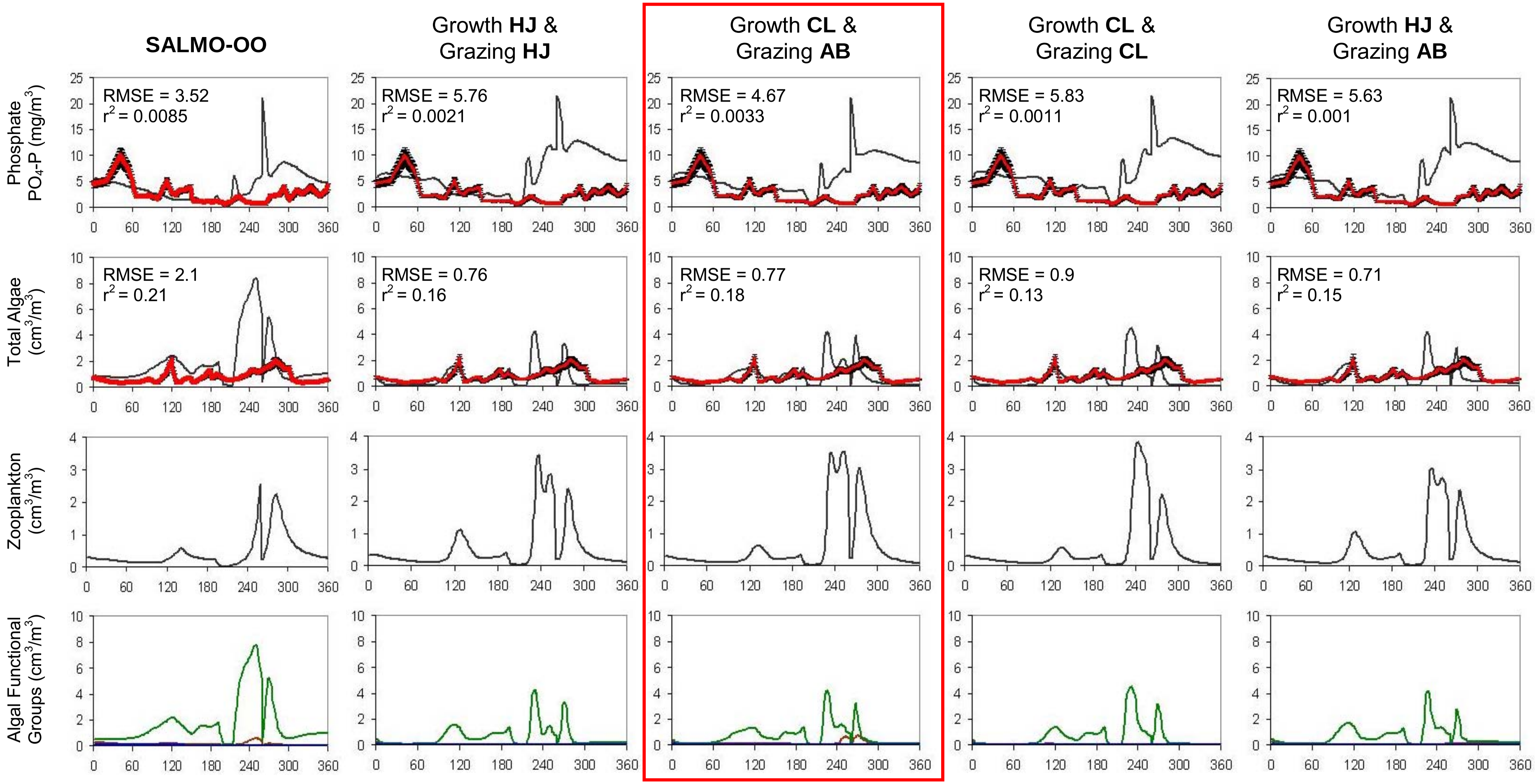

Figure 4.9c. Lake Soyang (1998) simulation results from combinations of alternative growth and grazing process models from the SALMO-OO simulation library. X-axis is in days. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis and Brett (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.

4.2. Generic model structures for lakes with different environmental conditions

A key goal of this project is the identification of generic model structure for lakes with similar physical, chemical or biological conditions. Nine lake and reservoir data sets covering a wide range of environmental conditions have been investigated to determine if generic model structures can be found, for lake categories defined by trophic states that reflect community structures and habitat properties, and circulation types that reflect climate and morphometry. Three different trophic states (eutrophic (including hypertrophic), mesotrophic and oligotrophic) and two different mixing conditions (warm monomictic and dimictic) have been tested. In many cases a common model structure has been found for a particular category.

A key factor that has determined a particular generic model structure has been the simulation of phytoplankton functional groups dynamics. Often a certain model structure has been found which best simulates phytoplankton biomass dynamics, but fails to realistically predict algal functional groups for a particular trophic state. Thus, the combination of growth and grazing models which best describes the seasonality of algal functional groups and still gives satisfactory simulations, both visually and quantitatively, for phytoplankton biomass has been chosen. Table 4.1 summarises the generic model structures provided by the SALMO-OO simulation library.

Table 4.1. Summary of generic model structures found by the SALMO-OO simulation library for different categories of lakes and reservoirs based on trophic state and mixing conditions.

Trophic State	Mixing Conditions	Best combination from SALMO-OO simulation library	Validation data sets
Eutrophic and Hypertrophic	Dimictic	Growth CL and Grazing HJ	Bautzen reservoir, Germany Lake Arendsee, Germany
	Warm monomictic	Growth AB and Grazing AB	Lake Hartbeespoort, South Africa Lake Roodeplaat, South Africa Lake Klipvoor, South Africa
Mesotrophic	Dimictic	Growth CL and Grazing AB	Saidenbach reservoir, Germany Weida reservoir, Germany
Oligotrophic	Dimictic	Growth CL and Grazing CL	Lake Stechlin, Germany Lake Soyang, South Korea

Category 1: Eutrophic/hypertrophic state and dimictic conditions

Bautzen Reservoir and Lake Arendsee were tested for this category. Both lakes are located in temperate climates and have similar ecological conditions, particularly for algal dynamics. The best combination for both data sets was the growth model from CLEANER and the grazing model from Hongping & Jianyi (2002). This particular combination of growth and grazing models produces fairly accurate predictions for phytoplankton and zooplankton biomass and also for phosphate concentration, but was found to be best suited for the realistic prediction of phytoplankton functional group dynamics (Figure 4.10).

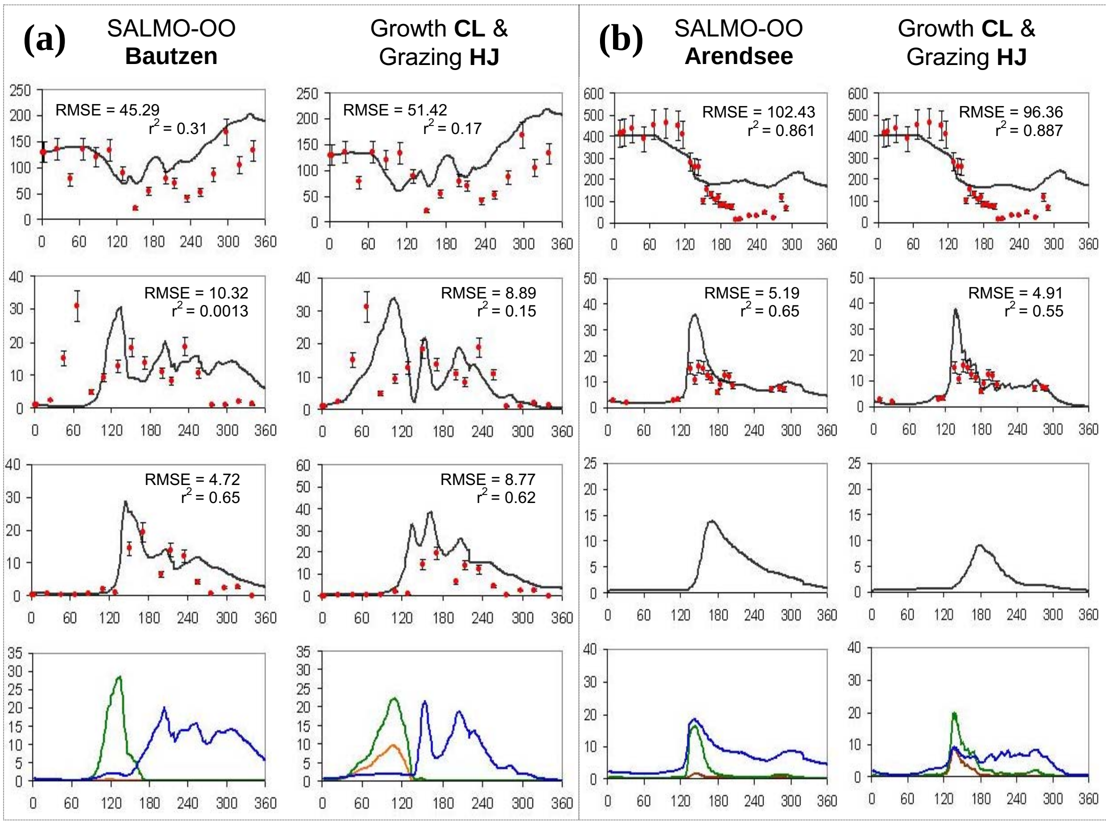

Figure 4.10. The best combination model results for (a) Bautzen Reservoir and (b) Lake Arendsee produced by the SALMO-OO simulation library for eutrophic/hypertrophic, dimictic water bodies. Comparisons are made with the simulations from the SALMO-OO model without any changes to the growth or grazing process equations. X-axis is in days. — Blue-green Algae; — Green Algae; — Diatoms; ● Measured data with standard deviation bars of 15%. **HJ** - Hongping and Jianyi (2002); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976).

Category 2: Eutrophic/hypertrophic state and warm monomictic

Lakes Roodeplaat, Hartbeespoort and Klipvoor are all located within the same catchment area in South Africa and are highly eutrophic, exhibiting very large concentrations of phosphate and chlorophyll *a*. Measured data for the phytoplankton functional groups was available for all three lakes, which dictated the selection of growth and grazing model combinations to best simulate each site. Replacement of SALMO-OO's growth and grazing process models with the growth and grazing process models from Arhonditsis & Brett (2005) gave the best results, particularly of each functional group for all three lakes (Figure 4.11). Other combinations of growth and grazing models gave better predictions for phytoplankton or phosphate dynamics, however, the use of the grazing model from

Arhonditsis & Brett (2005) produced the most realistic simulations of phytoplankton functional group dynamics.

For Lake Roodeplaat, application of the growth AB & grazing AB model combination resulted in significant improvements to the prediction of phosphate and phytoplankton dynamics, particularly during summer (Figure 4.11a). This model combination also gives a more realistic representation of phytoplankton functional group dynamics for Lake Roodeplaat. SALMO-OO simulates a clear dominance of blue-green algae, which is not uncommon of a hypertrophic system. However, the measured data for diatoms and green algae suggests occurrences at low values, rather than absence from the system. The inclusion of the Arhonditsis & Brett (2005) grazing model allows the overall SALMO-OO model to simulate the presence of diatoms and green algae at comparable levels that are observed by the measured data, although a slight over prediction of green algae is produced in late summer that is not reflected by the measured data (Figure 4.11a).

The simulation of Lake Hartbeespoort by the growth and grazing models from Arhonditsis & Brett (2005) has particularly improved the simulation of phosphate dynamics (Figure 4.11b), which describes the measured data well despite the poor r^2 value. Phytoplankton dynamics have improved slightly, with reductions in the biomass values during late spring and early summer. The simulation of phytoplankton functional group dynamics by SALMO-OO shows a clear dominance in blue-green algae, with virtually no occurrences of diatoms and green algae. The measured data indicates that diatoms and green algae are present in low abundances, and the application of the growth and grazing models from Arhonditsis & Brett (2005) does predict low abundances of green algae and diatoms (Figure 4.11b). However, this model combination does under estimate the abundances of blue-green algae, whereas SALMO-OO simulated blue-green algae biomass levels, particularly during summer, very well. It is difficult to assess which models are the most suited to simulate conditions in Lake Hartbeespoort. SALMO-OO gives good predictions of phytoplankton biomass and blue-green algae abundances, however the growth and grazing models from Arhonditsis & Brett (2005) give slightly better phytoplankton predictions and greatly improve phosphate simulations, although with slightly poorer blue-green algae predictions. However, this may be compensated by a better representation of overall algal functional groups dynamics, with the improved description of green algae and diatoms.

For Lake Klipvoor the application of the growth and grazing model from Arhonditsis & Brett (2005) produced reasonably good results for phytoplankton biomass and phosphate predictions, although phytoplankton biomass predictions were more accurately simulated by SALMO-OO, particularly during summer (Figure 4.11c). However, the growth and grazing models from Arhonditsis & Brett (2005) produced more realistic results for algal functional groups dynamics then the SALMO-OO model. SALMO-OO over estimated the biomass of blue-green algae and did not accurately simulate the timing of the main blue-green algal bloom during summer. The Arhonditsis & Brett (2005) growth and grazing model combination simulated a more reasonable abundance of blue-green algae, although this model combination also failed to reach the timing and magnitude of the summer peak. In addition, the Arhonditsis & Brett (2005) growth and grazing models were able to simulate diatoms during spring that match the measured data very well, whereas SALMO-OO produced a diatom peak during summer that was not described by the measured data (Figure 4.11c).

Therefore, the Arhonditsis & Brett (2005) growth and grazing models made clear improvements on the simulation of phytoplankton functional group dynamics, as observed by the measured data for each lake site. Despite some discrepancies between improvement on the simulation of phytoplankton or phosphate dynamics, the Arhonditsis & Brett (2005) growth and grazing model combination did produce reasonable and realistic results for these state variables. Therefore, this combination of growth and grazing models seems to be the most suitable for hypertrophic, warm monomictic lakes.

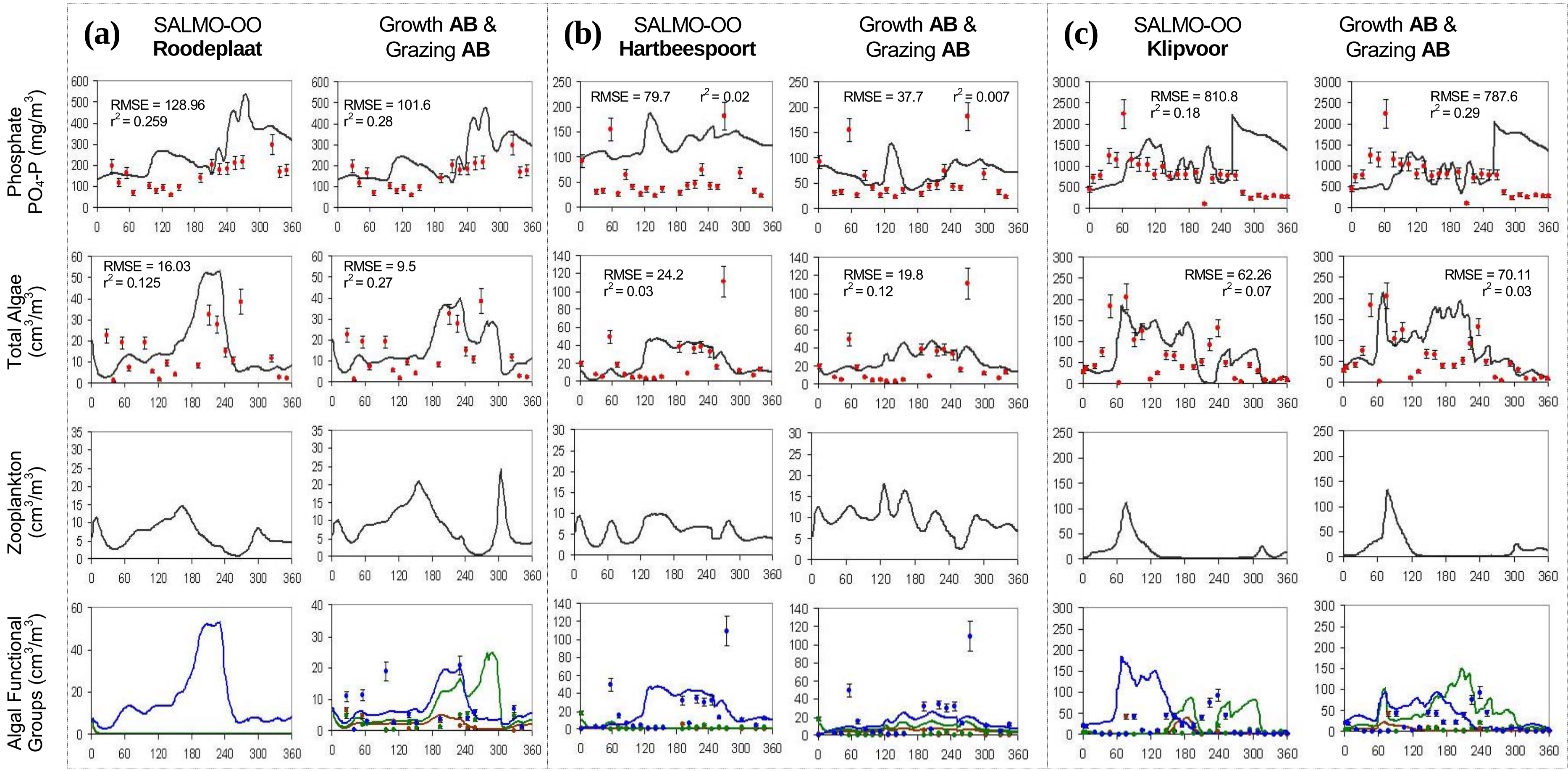

Figure 4.11. The best combination model results for (a) Lake Roodeplaat, (b) Lake Hartbeespoort and (c) Lake Klipvoor produced by the SALMO-OO simulation library for eutrophic/hypereutrophicmonomictic water bodies. Comparisons are made with the simulations from the SALMO-OO model without any changes to the growth or grazing process equations. 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); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976).

Category 3: Mesotrophic state and dimictic conditions

Saidenbach Reservoir and Lake Weida were tested in this category. Both lakes are located in Germany and have similar ecological conditions, particularly for phytoplankton dynamics. For Saidenbach reservoir the combination of the growth model from CLEANER and the grazing model from Arhonditsis & Brett (2005) produced the best results, particularly for phytoplankton functional group dynamics, and gives excellent results for phytoplankton and zooplankton biomass simulations (Figure 4.12). Again the accurate simulation of phytoplankton functional group seasonality is the deciding factor for the best model combinations for Lake Weida. As there is measured data for each algal functional group available for Lake Weida the combination of the growth model from CLEANER and the grazing model from Arhonditsis & Brett (2005) can be selected with confidence, even though there are model combinations that produce better quantitative results for phytoplankton biomass predictions. This particular combination is shown to give a more accurate representation of algal functional groups dynamics, as well as satisfactory results for phytoplankton, phosphate and zooplankton dynamics (Figure 4.12).

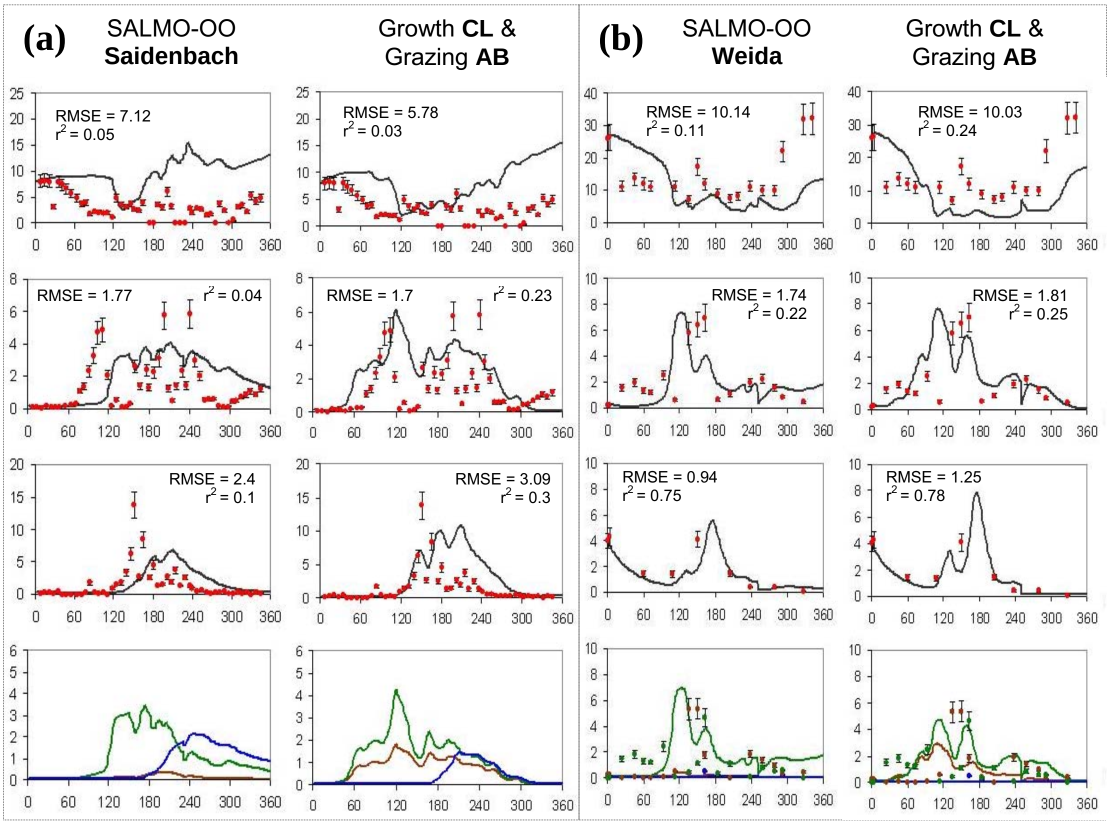

Figure 4.12. The best combination model results for (a) Saidenbach reservoir and (b) Lake Weida produced by the SALMO-OO simulation library for mesotrophic, dimictic water bodies. Comparisons are made with the simulations from the SALMO-OO model without any changes to the growth or grazing process equations. 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); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976).

Category 4: Oligotrophic state and dimictic conditions

Data from Lake Stechlin and Lake Soyang were used to test this category. Both lakes are classed as dimictic with temperate climates even though Lake Soyang is influenced by monsoons during summer. For Lake Stechlin a clear result was found with the use of growth and grazing models from CLEANER producing the best overall results, particularly for phytoplankton biomass predictions (Figure 4.13). However, a different combination was found to be best suited to the simulation of Lake Soyang. The growth model from CLEANER and the grazing model from Arhonditsis & Brett (2005) produced the best results. However, the growth and grazing models from CLEANER, which would allow a generic model structure to be used for dimictic, oligotrophic systems, still gives very good simulations with marginally different statistical results for phytoplankton and phosphate state variables (Figure 4.13). Thus, it was found to be an acceptable result to use the growth and grazing models from CLEANER to simulate dimictic, oligotrophic systems.

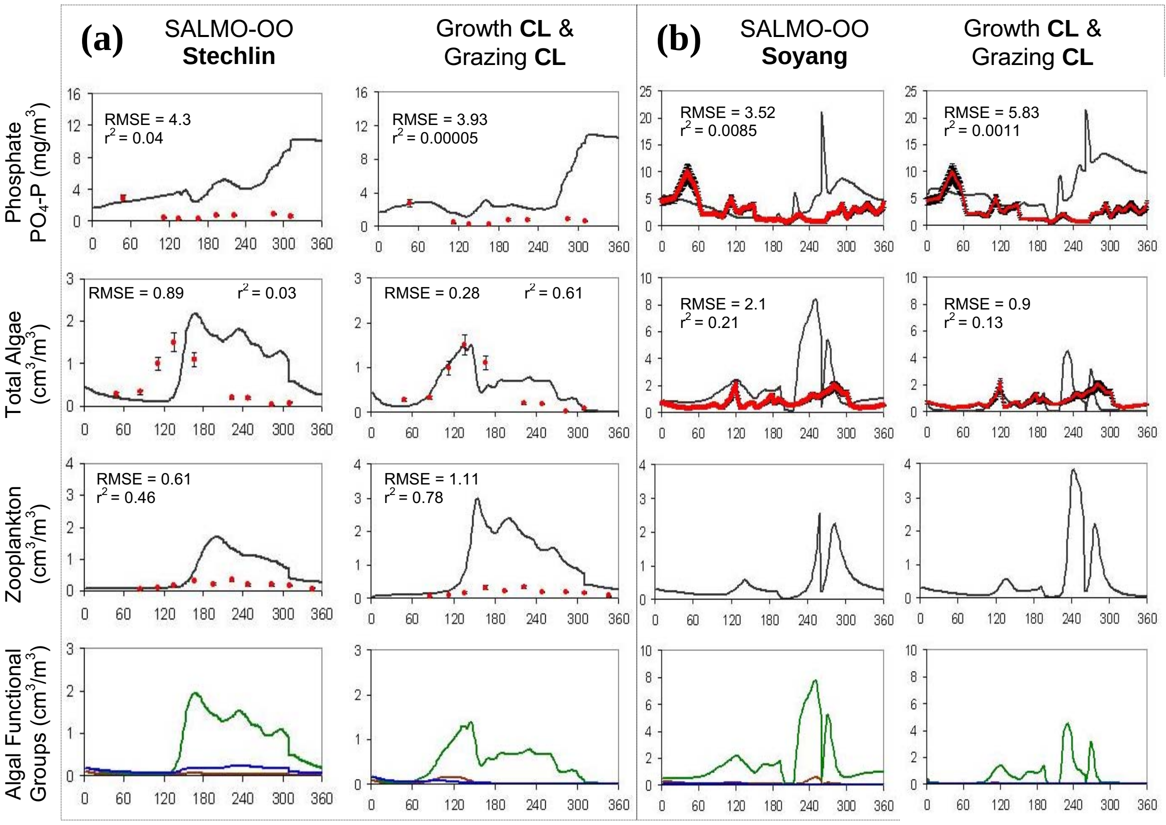

Figure 4.13. The best combination model results for (a) Lake Stechlin and (b) Lake Soyang produced by the SALMO-OO simulation library for oligotrophic, dimictic water bodies. Comparisons are made with the simulations from the SALMO-OO model without any changes to the growth or grazing process equations. X-axis is in days. ▬ Blue-green Algae; ▬ Green Algae; ▬ Diatoms; ● Measured data with standard deviation bars of 15%. **AB** - Arhonditsis and Brett (2005); **CL** - CLEANER Model - (Park *et al*, 1974; Scavia & Park, 1976).