**SUPPLEMENTARY MATERIALS**

**APPENDIX A: Figures**

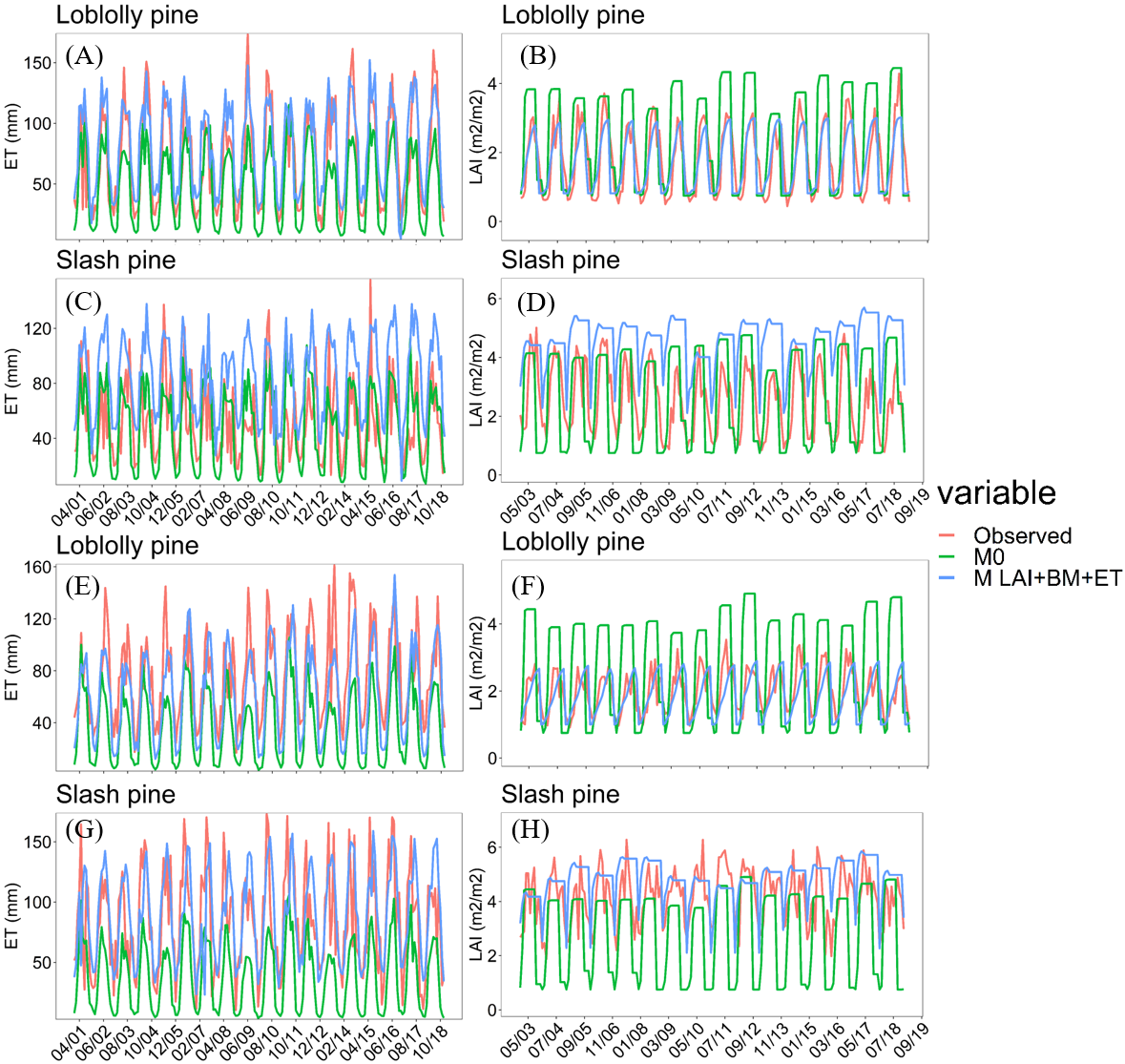


Figure S1. Simulated ET and LAI for loblolly and slash pine versus MODIS estimates at Upatoi Creek watershed (Figures A to D) and Upper Santa Fe River watershed (Figures E to H) under M0 and MLAI+BM+ET model configurations.

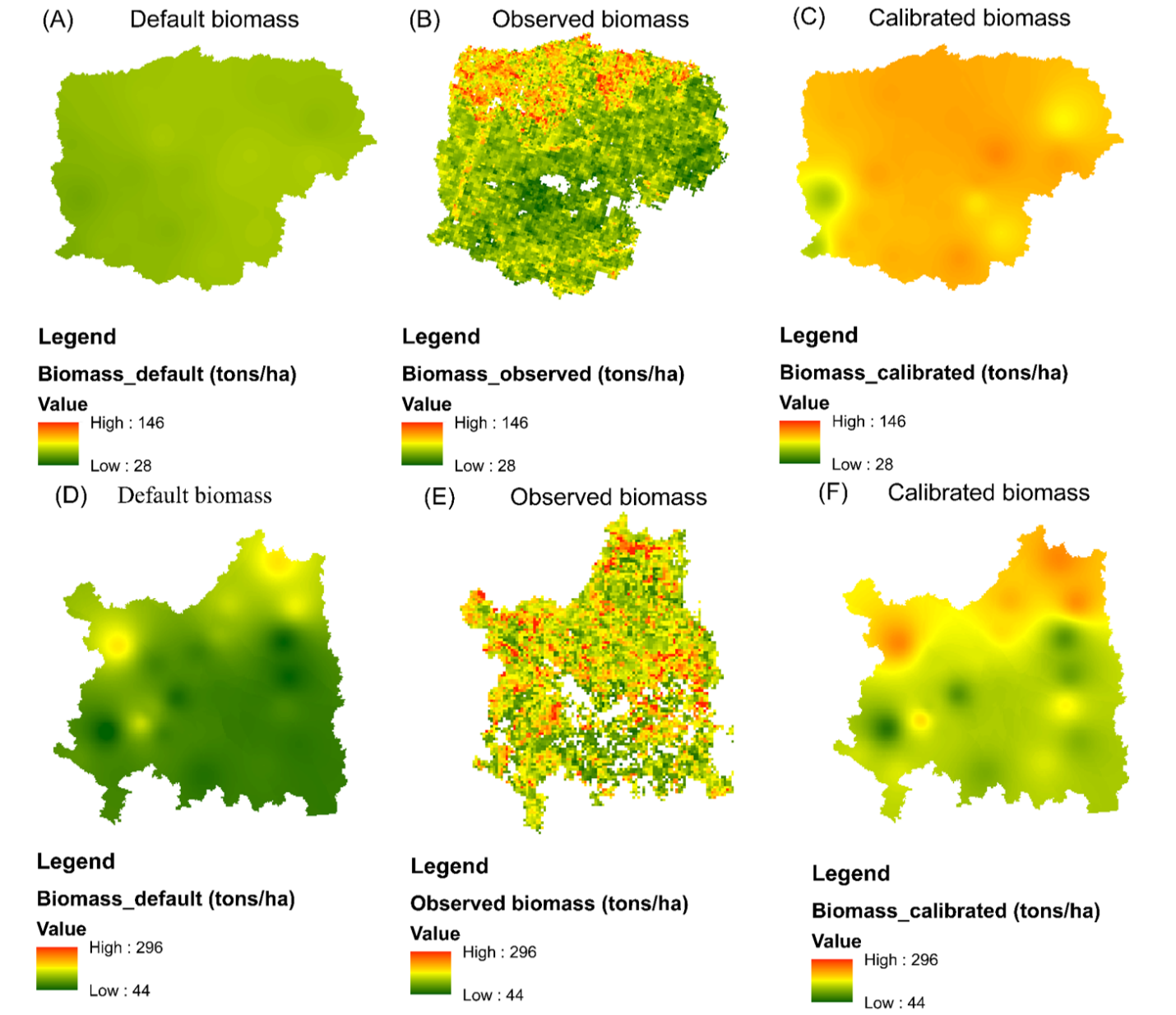


Figure S2. Simulated total forest biomass versus USDA Forest Service forest biomass product estimates at Upatoi Creek (Figures A to C) and Upper Santa Fe River watershed (Figures D to F) under M0 and MLAI+BM+ET model configurations. (A-D) Biomass simulated by SWAT using default parameters in the plant database, (B-E) Observed biomass for the Upatoi Creek watershed derived from USDA Forest Service forest biomass, (C-F) Biomass simulated by SWAT using calibrated plant-related parameters.

Figure S3. Comparison of simulated mean annual baseflow and ET under different model setup configurations against estimated baseflow and ET at Upatoi Creek and Upper Santa Fe River watersheds. Observed baseflow and watershed-wide ET are estimated via baseflow separation tool and MODIS ET data, respectively

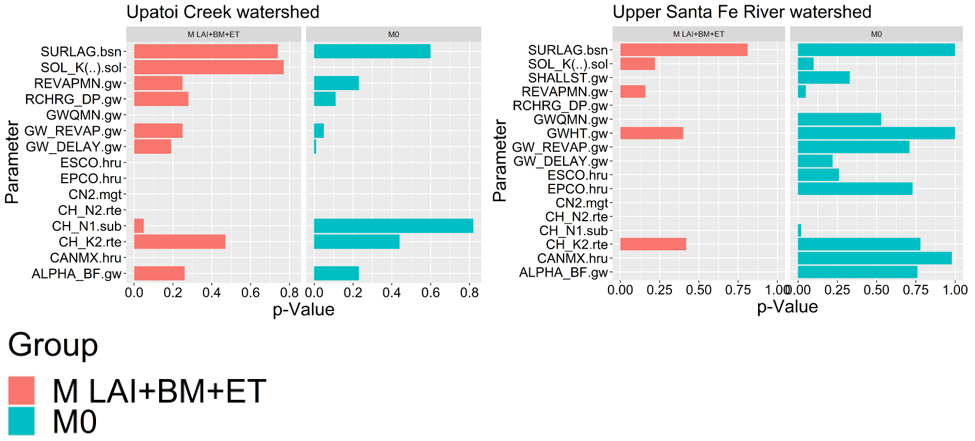


Figure S4. Sensitivity of streamflow parameters under traditional and multi-facet calibration schemes at Upatoi Creek and Upper Santa Fe River watersheds. P-values < 0.05 denote parameters with high sensitivity.

**APPENDIX B: Tables**

Table S1. Summary of the selected IHA and EFC parameters and their respective ecosystem influences.

|  |  |  |
| --- | --- | --- |
| IHA Parameter Group | Hydrologic Parameters | Ecosystem Influences |
| 1. Magnitude and duration of annual extreme water conditions  ***(10 parameters)*** | Annual minima, 1-day mean; Annual minima, 3-day means; Annual minima, 7-day means; Annual minima, 30-day means; Annual minima, 90-day means; Annual maxima, 1-day mean; Annual maxima, 3-day means; Annual maxima, 7-day means; Annual maxima, 30-day means; Annual maxima, 90-day means | * Balance of competitive, ruderal, and stress- tolerant organisms * Creation of sites for plant colonization * Structuring of aquatic ecosystems by abiotic vs. biotic factors * Structuring of river channel morphology and physical habitat conditions * Soil moisture stress in plants Dehydration in animals * Anaerobic stress in plants * Volume of nutrient exchanges between rivers and floodplains * Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments * Distribution of plant communities in lakes, ponds, floodplains * Duration of high flows for waste disposal, aeration of spawning beds in channel sediments |
| 2. Environmental Flow Components (EFCs) Parameters – Monthly low flows  ***(12 parameters)*** | Mean values of low flows during each calendar month | * Provide adequate habitat for aquatic organisms * Maintain suitable water temperatures, dissolved oxygen, and water chemistry * Maintain water table levels in floodplain, soil moisture for plants * Provide drinking water for terrestrial animals * Keep fish and amphibian eggs suspended * Enable fish to move to feeding and spawning areas * Support hyporheic organisms (living in saturated sediments) |

Table S2. Model performance before and after calibration of monthly LAI and ET in SWAT. Values between parenthesis () represent model’s performance under its default settings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Upper Santa Fe | | Upatoi Creek | |
|  | Loblolly pine | Slash pine | Loblolly pine | Slash pine |
| Monthly LAI |  |  |  |  |
| R2 | 0.48 (0.29) | 0.21 (0.25) | 0.66 (0.42) | 0.2 (0.27) |
| NSE | 0.32 (-5) | -0.37 (-3) | 0.65 (-0.74) | -3.1 (-0.56) |
| PBIAS % | 7 (-38) | -16 (33) | 3.9 (-38) | -82.4 (-8.2) |
| RMSE | 0.52 (1.55) | 1.15 (2) | 0.58 (1.3) | 2.3 (1.4) |
|  |  |  |  |  |
| Monthly ET |  |  |  |  |
| R2 | 0.65 (0.57) | 0.45 (0.6) | 0.75 (0.68) | 0.34 (0.33) |
| NSE | 0.46 (-0.66) | 0.38 (-0.60) | 0.65 (0.43) | -1.5 (0) |
| PBIAS | 17.5 (50) | -6.5 (55) | -17.8 (29.3) | -66 (3.9) |
| RMSE | 24.9 (43.55) | 31.90 (52.2) | 23.36 (29.9) | 42 (26.4) |

Table S3. Calibrated model parameters, their respective initial range and best fitted values under traditional and multivariable calibration approaches at Upatoi Creek and Upper Santa Fe River watersheds.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Initial range | Best parameter value | | | |
|  |  | Upatoi Creek | | Upper Santa Fe | |
|  |  | M0 | MLAI+BM+ET | M0 | MLAI+BM+ET |
| *r\_\_CN2.mgt* | -0.3-0.1 | -0.166963 | -0.028276 | -0.087033 | 0.001072 |
| *V\_\_ALPHA\_BF.gw* | 0.01-0.2 | 0.141159 | 0.176099 | 0.105335 | 0.112806 |
| *r\_\_GW\_DELAY.gw* | -0.3-0.3 | 0.000271 | -0.306779 | 0.039278 | -0.119104 |
| *r\_\_GW\_REVAP.gw* | -0.3-0.3 | 0.336196 | 0.400228 | 1.329347 | 6.278326 |
| *r\_\_SOL\_K().sol* | -0.3-0.3 | 0.545236 | 0.446698 | -0.094449 | 0.124502 |
| *v\_\_RCHRG\_DP.gw* | 0-1 | 0.462241 | 0.373301 | 0.403537 | 0.145733 |
| *V\_\_SURLAG.bsn* | 1-24 | 3.822869 | 15.131299 | 18.912979 | 12.507653 |
| *R\_\_CH\_N1.sub* | 0.1-1 | 0.58338 | 0.539291 | 1.017428 | 1.216417 |
| *v\_\_CH\_N2.rte* | -0.01-0.3 | 0.293692 | 0.403082 | 0.171482 | 0.365554 |
| *r\_\_CH\_K2.rte* | 0.1-0.5 | 0.356586 | 0.076447 | 0.392475 | 0.246932 |
| *r\_\_GWQMN.gw* | -0.5-4 | 0.819083 | 0.475702 | 5.067966 | 0.549191 |
| *r\_\_REVAPMN.gw* | -0.5-0.5 | -0.290221 | 0.012907 | -0.823312 | -0.676632 |
| *v\_\_ESCO.hru* | 0-1 | 0.18564 | 0.815-0.82\* | 0.070324 | 0.82-0.86\* |
| *v\_\_EPCO.hru* | 0-1 | 0.475542 | 0.38-0.48\* | 0.972392 | 0.38-0.48\* |
| *v\_\_CANMX.hru* | 0-5 | 3.768076 | 0.596-0.94\* | 4.944259 | 0.52-0.94\* |

**Appendix C: Supporting materials**

* 1. Improvements in forest dynamics
  2. Upatoi Creek watershed (UCW)

Although SWAT was run for the 1998-2018 period, the analysis of simulated forest processes discussed here is limited to the period 2001-2018 for ET and 2003-2018 for LAI, because of MODIS data availability.

As shown in Fig. 3, both LAI and ET predictions for loblolly pine improved significantly under MLAI+BM+ET. The default SWAT parameterization largely overestimated the annual maximum LAI in comparison to MODIS. According to MODIS estimates, the average monthly LAI from 2003 to 2018 at UCW was 1.78 m2/m2. In the simulation with M0, the predicted average monthly LAI was 2.45 m2/m2, while MLAI+BM+ET simulated an average monthly LAI of 1.71 m2/m2. The superior model performance under MLAI+BM+ET is supported by the statistical measures shown in Table 4. As can be seen in Fig. 3, M0 missed most of MODIS ET peaks, which were captured in the MLAI+BM+ET model configuration. The better goodness of fit between MLAI+BM+ET and MODIS ET is demonstrated in Table 4 by higher *NSE* and *R2* values. The model’s inability to capture ET peaks with the M0 model configuration translated into 30% underestimation of ET. On the other hand, MLAI+BM+ET overestimated ET by 18% during 2001-2018. Although significant, this overestimation is within the uncertainty margin of 20% associated with the MODIS ET product, as reported by Mu et al. (2013).

Simulated LAI and ET for slash pine failed to accurately match MODIS estimates (Fig. 3 and Table 4). These results are not alarming since slash pine cover less than 0.1% of the UCW, representing an area of only 70 hectares. Furthermore, this may indicate that the slash pine parameterization developed in FL is not suited for slash pine trees growing in GA. This finding should not come as a surprise given the substantial geographic distance between the plantation field where slash pine was calibrated and the UCW. The significant model overestimation of ET with the MLAI+BM+ET model configuration is most probably a consequence of the LAI overestimation, given the role played by LAI in ET estimation. Another likely cause of the poor model performance of ET in MLAI+BM+ET is the value of maximum stomatal conductance (GSI) calibrated at the field-scale site in FL, which may be too high for slash pine trees occurring in GA.

We compared simulated forest biomass with USDA’s Forest Service forest biomass product. To that end, we averaged simulated forest biomass in M0 and MLAI+BM+ET for each subbasin. The subbasin level averaged biomass values were interpolated to the watershed area using Inverse Distance Weighting (IDW) interpolation method in ArcMap to allow for a more spatially discretized comparison against the gridded 250 meters resolution biomass product. The results are shown in Fig. 4. Under M0, the average annual simulated biomass during 1998-2018 was 64 ± 4 (average ± one standard deviation) tons/ha, while MLAI+BM+ET predicted an average of 104 ± 13 tons/ha during the same period. USDA reported average biomass of 64 ± 15 tons/ha. Although the average biomass predicted by M0 matched USDA’s values, M0 failed to reach biomass values larger than 70 tons/ha. In contrast, the maximum biomass predicted by MLAI+BM+ET reached values up to 121 tons/ha, closer to 146 tons/ha of maximum biomass from USDA forest biomass data. The spatial distribution pattern of simulated biomass is similar in M0 and MLAI+BM+ET, although MLAI+BM+ET showed better agreement with USDA biomass data in the northwestern portion of the watershed. In this area, which is heavily covered by loblolly pine (Fig. 2A), M0 tended to underestimate biomass.

* 1. Upper Santa Fe River watershed

It is visually clear that MLAI+BM+ET outperformed M0 in capturing LAI seasonality for loblolly pine (Fig. 3). The goodness of fit measured by *R2* and *NSE* and shown in Table 4 demonstrates the benefits of MLAI+BM+ET in comparison to M0. The evident model overestimation in M0 is evidenced by *PBIAS* values of 38%, which has improved to 7% in MLAI+BM+ET. Monthly ET for loblolly pine was significantly underestimated in M0 compared with MODIS reference time-series (Fig. 3). With the default parameterization, the average annual ET was 448 ± 58 mm during 2001-2018, which was significantly lower than MODIS estimates of 897 ± 88 mm. In the simulation with the improved model parameterization, the average annual ET increased to 740 ± mm, representing a 40% increase compared with the default model. Monthly ET simulated by MLAI+BM+ET was underestimated by 17.5%, which is lower than the 50% of underestimation with M0. The good agreement between simulated monthly ET in MLAI+BM+ET and MODIS ET is statistically supported by the higher *NSE* and *R2* and lower *RMSE* values, as shown in Table 4.

Slash pine also had the LAI dynamics largely improved in MLAI+BM+ET. This can be visually seen in Fig. 3, where MLAI+BM+ET reproduces the annual growth cycle captured by MODIS reasonably well. Moreover, the annual LAI peaks estimated by MODIS are better represented in MLAI+BM+ET than in M0, although even with the MLAI+BM+ET model configuration SWAT could not accurately capture the bimodal LAI seasonality shown in MODIS data. This issue was also reported by Zhang et al. (2020) and is most probably attributable to SWAT’s impossibility of simulating more than one growth cycle per year under the Heat Unit theory. The average annual ET estimated by M0 in the period 2001-2018 was 453 ± 57 mm, much lower than the average MODIS ET for the same period (999 ± 86 mm). The improved parameterization increased ET estimates by 58% compared with M0, resulting in an annual average ET of 1,060 ± 65 mm (7% higher than MODIS). The average annual ET simulated by the improved model was in good accordance with the ET range of 754-1168 mm/year at slash pine plantations in Florida reported by McLaughlin et al. (2013). Although the *R2* value deteriorated in MLAI+BM+ET compared to M0 for slash pine, other statistical measures improved for MLAI+BM+ET in comparison to M0 (Table 4).

Finally, the simulated biomass also improved in MLAI+BM+ET compared to M0, based on USDA reported biomass reference data (Fig. 4). The average annual forest biomass simulated in M0 was 92 ± 45 tons/ha, which is significantly lower than the USDA reported average of 120 ± 37 tons/ha. The MLAI+BM+ET model configuration increased annual average biomass estimates by 40% compared with M0, resulting in 153 ± 50 tons/ha of biomass during 1998-2018. The improved model parameterization also ameliorated the spatial pattern of forest biomass, especially in the central portion of the watershed, where M0 substantially underestimated biomass accumulation. Previous studies reported similar findings (Yang et al., 2018; Yang and Zhang, 2016), revealing that the default SWAT model presents some shortcomings in simulating tree biomass.