Appendix B. Additional simulation results

Figure B1. Selected simulation results under the 2-state ("foraging" in black and "transit" in gray) scenarios with no spatial covariate on transition probabilities. Each panel presents the true and estimated probability densities for turning angle based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates (Rate $\in$ 2,1,0.5). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

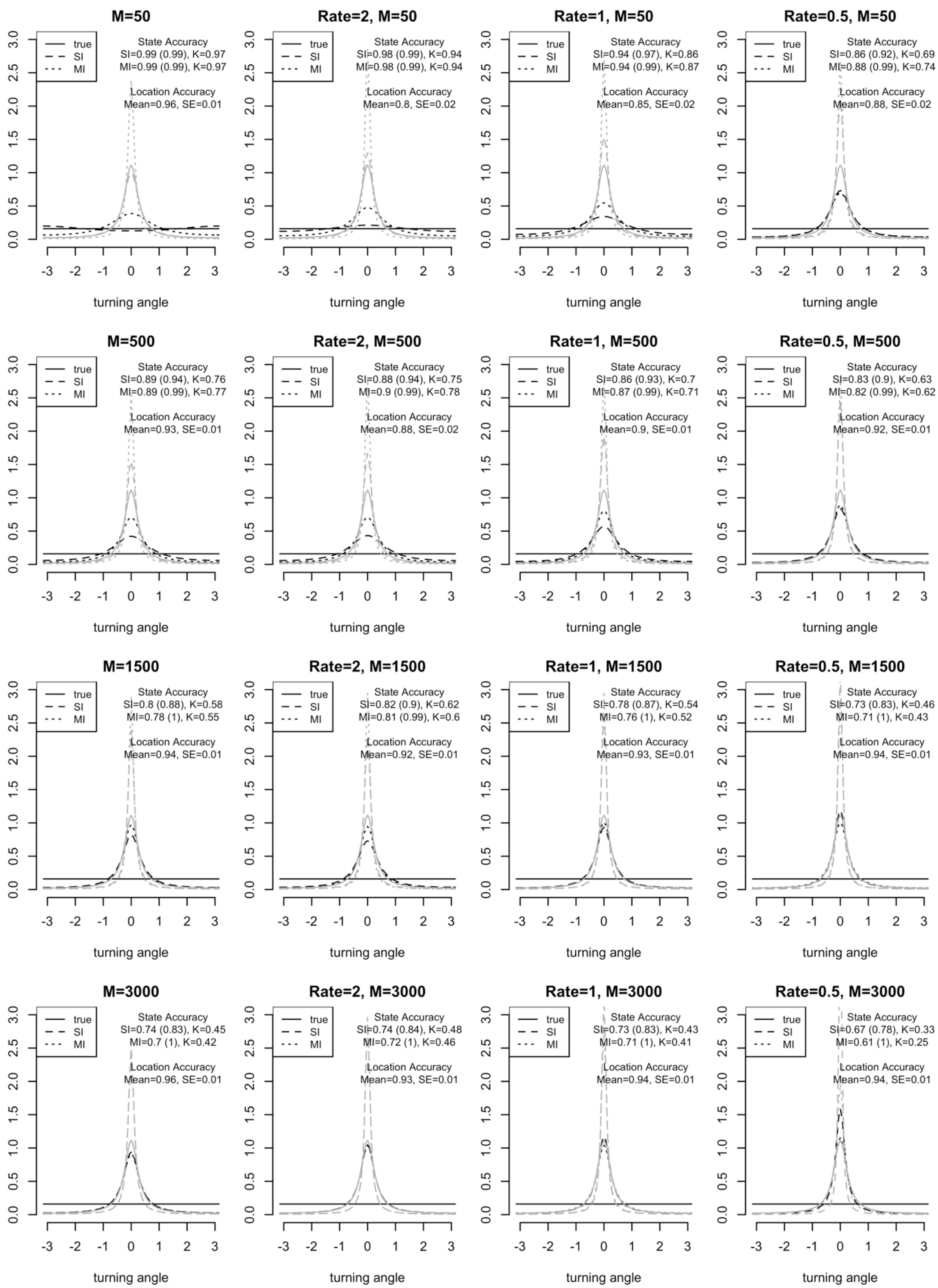

M=50
true
SI
MI
State Accuracy
SI=0.99 (0.99), K=0.97
MI=0.99 (0.99), K=0.97
Location Accuracy
Mean=0.96, SE=0.01
turning angle
Rate=2, M=50
State Accuracy
SI=0.98 (0.99), K=0.94
MI=0.98 (0.99), K=0.94
Location Accuracy
Mean=0.8, SE=0.02
turning angle
Rate=1, M=50
State Accuracy
SI=0.94 (0.97), K=0.86
MI=0.94 (0.99), K=0.87
Location Accuracy
Mean=0.85, SE=0.02
turning angle
Rate=0.5, M=50
State Accuracy
SI=0.86 (0.92), K=0.69
MI=0.88 (0.99), K=0.74
Location Accuracy
Mean=0.88, SE=0.02
turning angle
M=500
State Accuracy
SI=0.89 (0.94), K=0.76
MI=0.89 (0.99), K=0.77
Location Accuracy
Mean=0.93, SE=0.01
turning angle
Rate=2, M=500
State Accuracy
SI=0.88 (0.94), K=0.75
MI=0.9 (0.99), K=0.78
Location Accuracy
Mean=0.88, SE=0.02
turning angle
Rate=1, M=500
State Accuracy
SI=0.86 (0.93), K=0.7
MI=0.87 (0.99), K=0.71
Location Accuracy
Mean=0.9, SE=0.01
turning angle
Rate=0.5, M=500
State Accuracy
SI=0.83 (0.9), K=0.63
MI=0.82 (0.99), K=0.62
Location Accuracy
Mean=0.92, SE=0.01
turning angle
M=1500
State Accuracy
SI=0.8 (0.88), K=0.58
MI=0.78 (1), K=0.55
Location Accuracy
Mean=0.94, SE=0.01
turning angle
Rate=2, M=1500
State Accuracy
SI=0.82 (0.9), K=0.62
MI=0.81 (0.99), K=0.6
Location Accuracy
Mean=0.92, SE=0.01
turning angle
Rate=1, M=1500
State Accuracy
SI=0.78 (0.87), K=0.54
MI=0.76 (1), K=0.52
Location Accuracy
Mean=0.93, SE=0.01
turning angle
Rate=0.5, M=1500
State Accuracy
SI=0.73 (0.83), K=0.46
MI=0.71 (1), K=0.43
Location Accuracy
Mean=0.94, SE=0.01
turning angle
M=3000
State Accuracy
SI=0.74 (0.83), K=0.45
MI=0.7 (1), K=0.42
Location Accuracy
Mean=0.96, SE=0.01
turning angle
Rate=2, M=3000
State Accuracy
SI=0.74 (0.84), K=0.48
MI=0.72 (1), K=0.46
Location Accuracy
Mean=0.93, SE=0.01
turning angle
Rate=1, M=3000
State Accuracy
SI=0.73 (0.83), K=0.43
MI=0.71 (1), K=0.41
Location Accuracy
Mean=0.94, SE=0.01
turning angle
Rate=0.5, M=3000
State Accuracy
SI=0.67 (0.78), K=0.33
MI=0.61 (1), K=0.25
Location Accuracy
Mean=0.94, SE=0.01
turning angle

Figure B2. Selected simulation results under the 2-state (“foraging” and “transit”) scenarios with no spatial covariate on state transition probabilities. Each panel presents the estimated tracks for $N = 7$ individuals under varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. Black lines indicate the tracks using the single imputation (SI) approach while gray lines indicate each realization of the position process using the multiple imputation (MI) approach. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance).

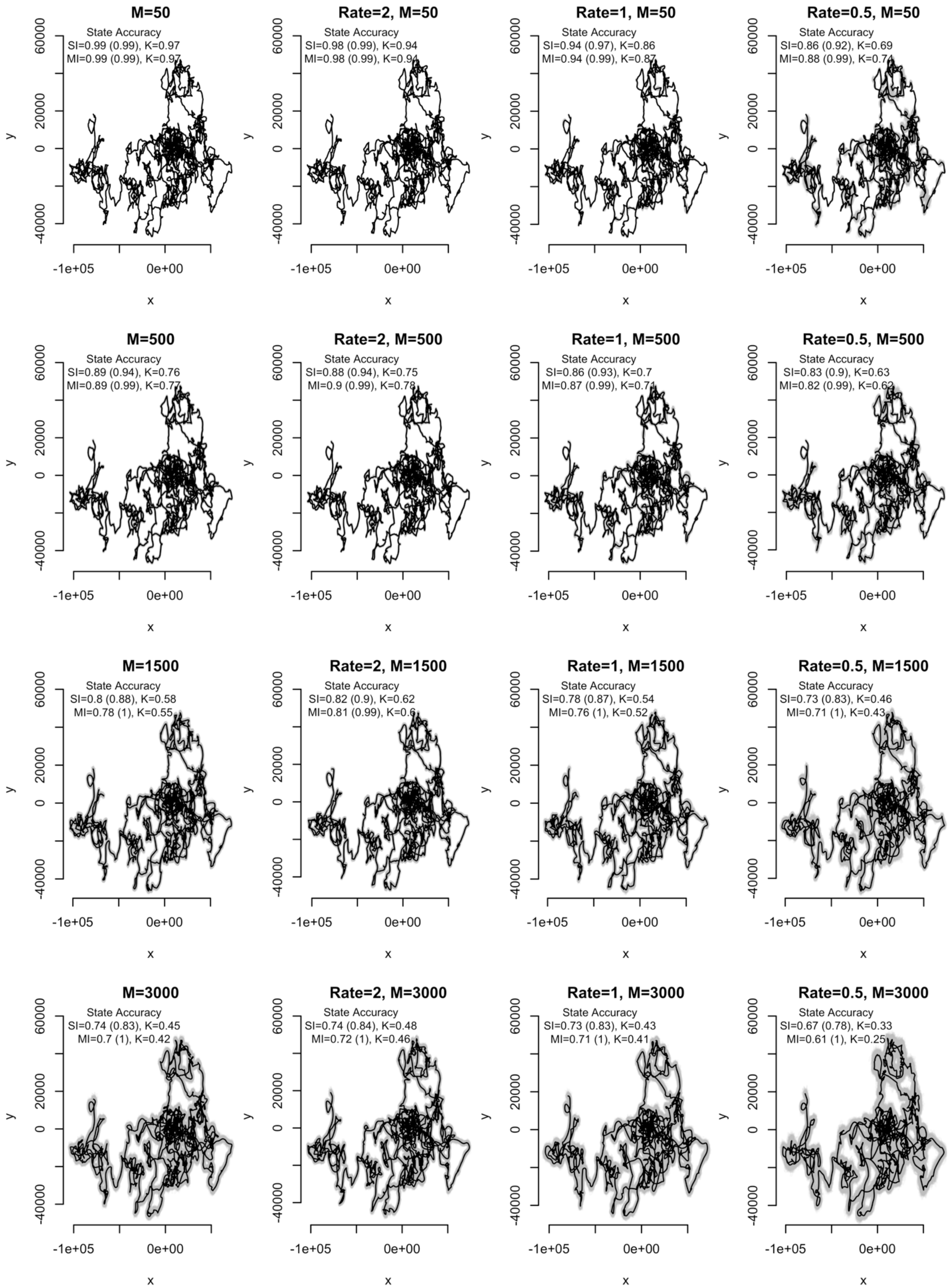

M=50
State Accuracy
SI=0.99 (0.99), K=0.97
MI=0.99 (0.99), K=0.97
Rate=2, M=50
State Accuracy
SI=0.98 (0.99), K=0.94
MI=0.98 (0.99), K=0.94
Rate=1, M=50
State Accuracy
SI=0.94 (0.97), K=0.86
MI=0.94 (0.99), K=0.87
Rate=0.5, M=50
State Accuracy
SI=0.86 (0.92), K=0.69
MI=0.88 (0.99), K=0.74
M=500
State Accuracy
SI=0.89 (0.94), K=0.76
MI=0.89 (0.99), K=0.77
Rate=2, M=500
State Accuracy
SI=0.88 (0.94), K=0.75
MI=0.9 (0.99), K=0.78
Rate=1, M=500
State Accuracy
SI=0.86 (0.93), K=0.7
MI=0.87 (0.99), K=0.71
Rate=0.5, M=500
State Accuracy
SI=0.83 (0.9), K=0.63
MI=0.82 (0.99), K=0.62
M=1500
State Accuracy
SI=0.8 (0.88), K=0.58
MI=0.78 (1), K=0.55
Rate=2, M=1500
State Accuracy
SI=0.82 (0.9), K=0.62
MI=0.81 (0.99), K=0.6
Rate=1, M=1500
State Accuracy
SI=0.78 (0.87), K=0.54
MI=0.76 (1), K=0.52
Rate=0.5, M=1500
State Accuracy
SI=0.73 (0.83), K=0.46
MI=0.71 (1), K=0.43
M=3000
State Accuracy
SI=0.74 (0.83), K=0.45
MI=0.7 (1), K=0.42
Rate=2, M=3000
State Accuracy
SI=0.74 (0.84), K=0.48
MI=0.72 (1), K=0.46
Rate=1, M=3000
State Accuracy
SI=0.73 (0.83), K=0.43
MI=0.71 (1), K=0.41
Rate=0.5, M=3000
State Accuracy
SI=0.67 (0.78), K=0.33
MI=0.61 (1), K=0.25
y
x
60000
20000
0
-40000
-1e+05
0e+00

Figure B3. Comparison of state accuracy for the single imputation ("SI") and multiple imputation approaches based on $n = 400$ ("MI400"), $n = 30$ ("MI30"), and $n = 5$ ("MI5") imputations of the position process in the 2-state simulation scenarios with no spatial covariate on state transition probabilities with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates (Rate $\in 2,1,0.5$). State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state (×), the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (•), and a measure of agreement between the true and estimated states ($+$) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks.

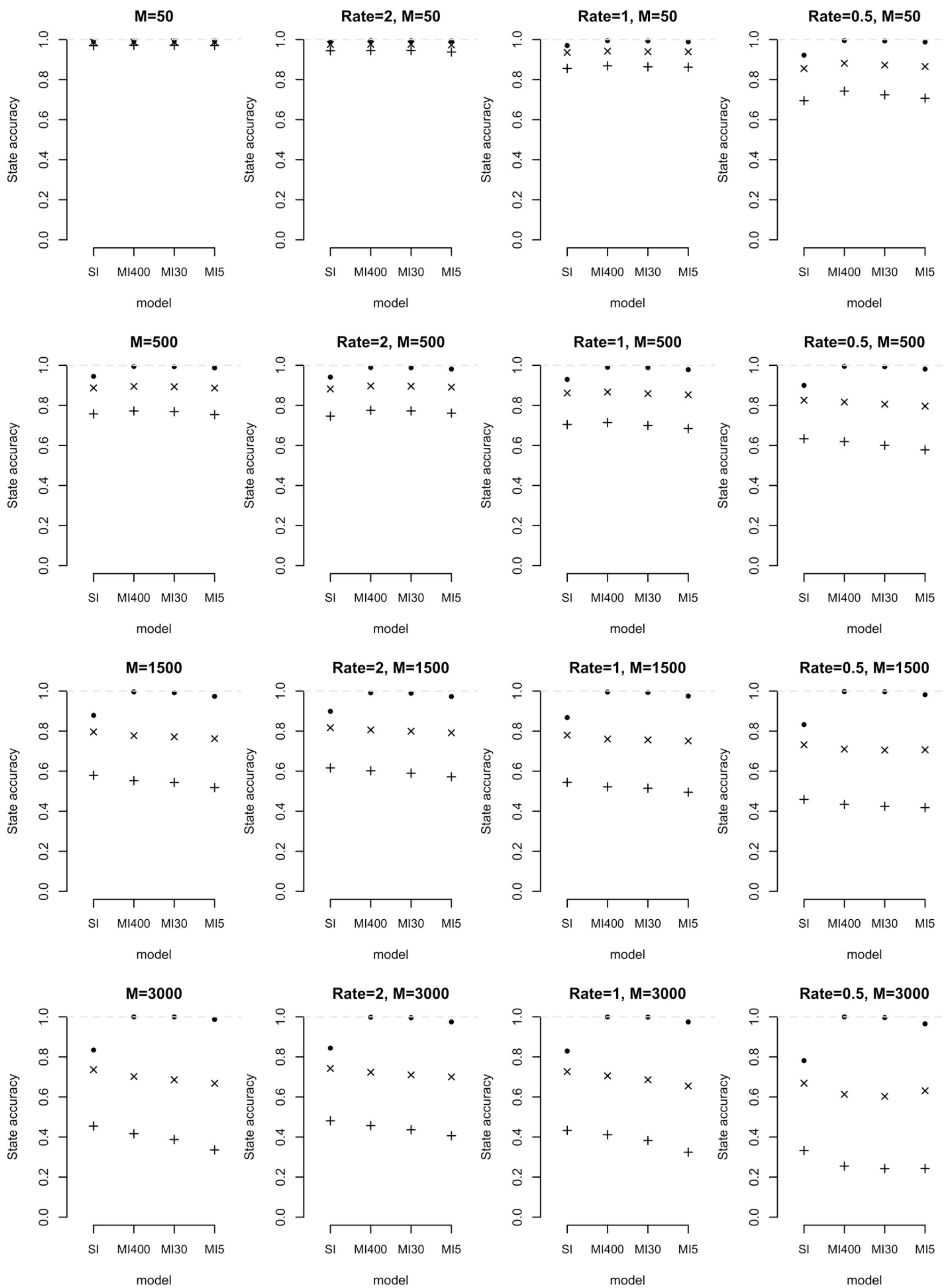

M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
M=3000
Rate=2, M=3000
Rate=1, M=3000
Rate=0.5, M=3000
State accuracy
0.0
0.2
0.4
0.6
0.8
1.0
SI
MI400
MI30
MI5
model

Figure B4. Comparison of location accuracy for the multiple imputation approaches based on $n = 400$, $n = 30$, and $n = 5$ imputations of the position process in the 2-state simulation scenarios with no spatial covariate on state transition probabilities with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach. The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks.

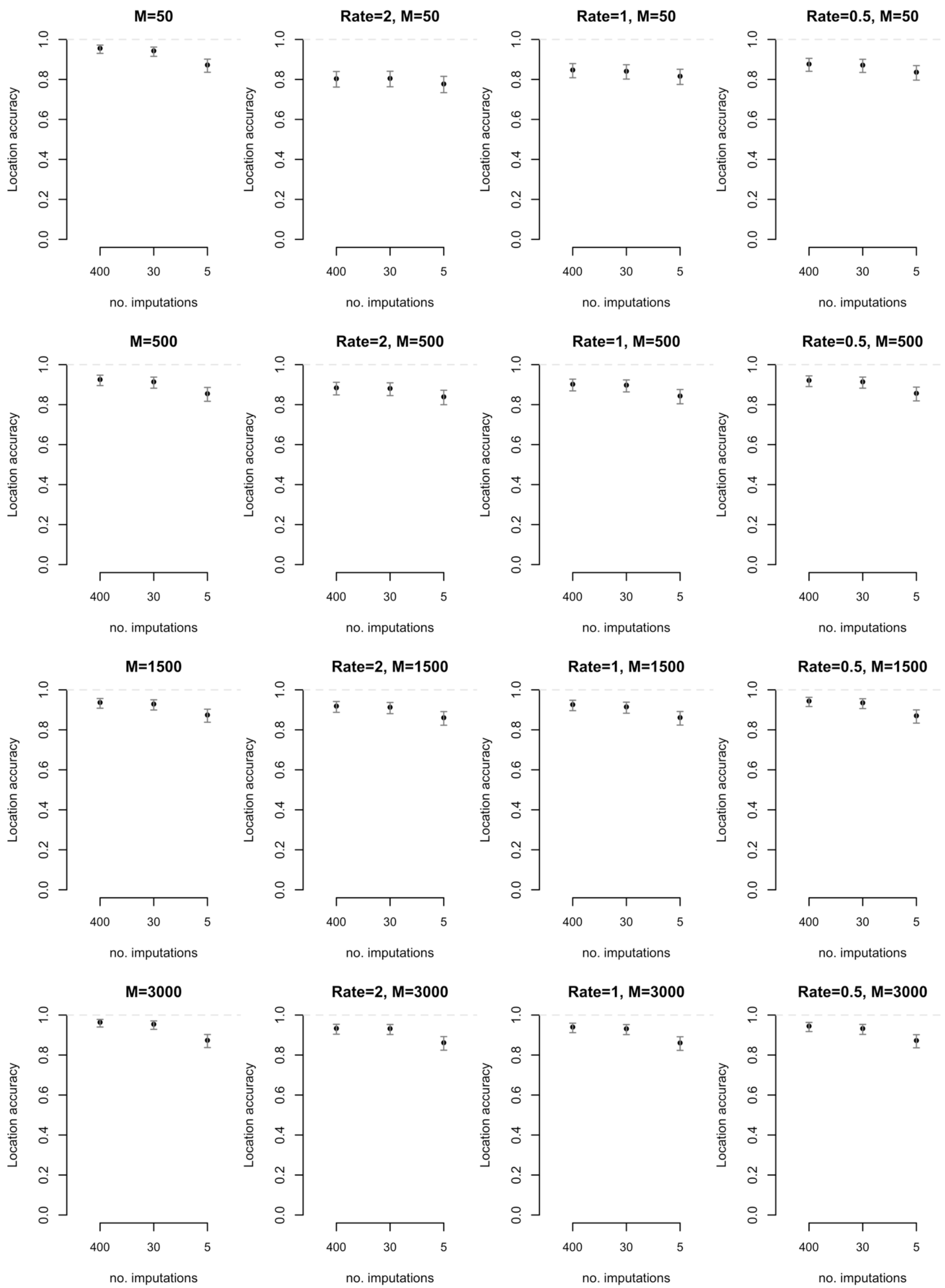

M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
M=3000
Rate=2, M=3000
Rate=1, M=3000
Rate=0.5, M=3000
Location accuracy
0.0
0.2
0.4
0.6
0.8
1.0
400
30
5
no. imputations

Figure B5. Selected simulation results under the 2-state ("foraging" in black and "transit" in gray) scenarios including a spatial covariate on state transition probabilities. Each panel presents the true and estimated probability densities for step length based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

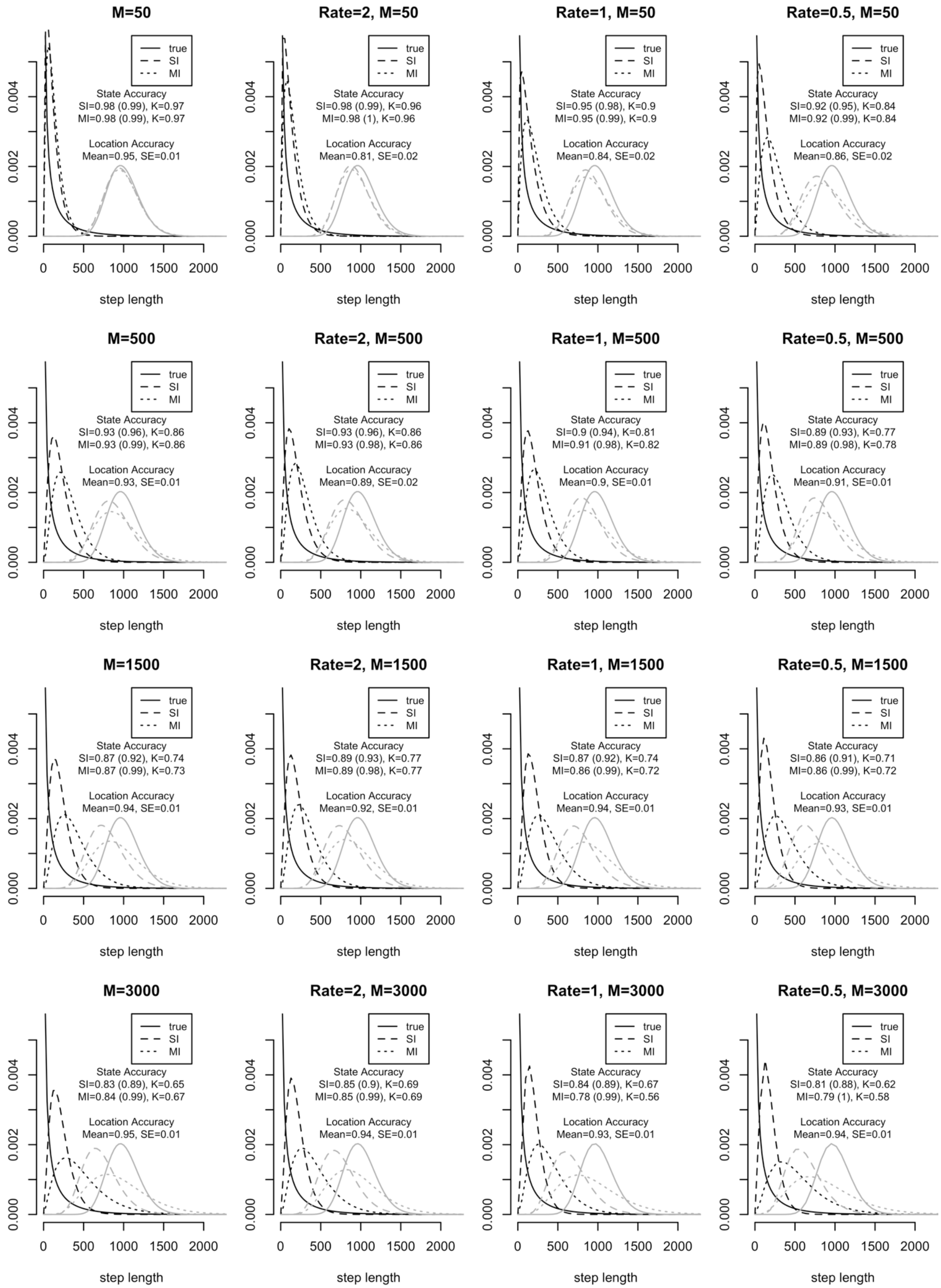

M=50
true
SI
MI
State Accuracy
SI=0.98 (0.99), K=0.97
MI=0.98 (0.99), K=0.97
Location Accuracy
Mean=0.95, SE=0.01
Rate=2, M=50
State Accuracy
SI=0.98 (0.99), K=0.96
MI=0.98 (1), K=0.96
Location Accuracy
Mean=0.81, SE=0.02
Rate=1, M=50
State Accuracy
SI=0.95 (0.98), K=0.9
MI=0.95 (0.99), K=0.9
Location Accuracy
Mean=0.84, SE=0.02
Rate=0.5, M=50
State Accuracy
SI=0.92 (0.95), K=0.84
MI=0.92 (0.99), K=0.84
Location Accuracy
Mean=0.86, SE=0.02
M=500
State Accuracy
SI=0.93 (0.96), K=0.86
MI=0.93 (0.99), K=0.86
Location Accuracy
Mean=0.93, SE=0.01
Rate=2, M=500
State Accuracy
SI=0.93 (0.96), K=0.86
MI=0.93 (0.98), K=0.86
Location Accuracy
Mean=0.89, SE=0.02
Rate=1, M=500
State Accuracy
SI=0.9 (0.94), K=0.81
MI=0.91 (0.98), K=0.82
Location Accuracy
Mean=0.9, SE=0.01
Rate=0.5, M=500
State Accuracy
SI=0.89 (0.93), K=0.77
MI=0.89 (0.98), K=0.78
Location Accuracy
Mean=0.91, SE=0.01
M=1500
State Accuracy
SI=0.87 (0.92), K=0.74
MI=0.87 (0.99), K=0.73
Location Accuracy
Mean=0.94, SE=0.01
Rate=2, M=1500
State Accuracy
SI=0.89 (0.93), K=0.77
MI=0.89 (0.98), K=0.77
Location Accuracy
Mean=0.92, SE=0.01
Rate=1, M=1500
State Accuracy
SI=0.87 (0.92), K=0.74
MI=0.86 (0.99), K=0.72
Location Accuracy
Mean=0.94, SE=0.01
Rate=0.5, M=1500
State Accuracy
SI=0.86 (0.91), K=0.71
MI=0.86 (0.99), K=0.72
Location Accuracy
Mean=0.93, SE=0.01
M=3000
State Accuracy
SI=0.83 (0.89), K=0.65
MI=0.84 (0.99), K=0.67
Location Accuracy
Mean=0.95, SE=0.01
Rate=2, M=3000
State Accuracy
SI=0.85 (0.9), K=0.69
MI=0.85 (0.99), K=0.69
Location Accuracy
Mean=0.94, SE=0.01
Rate=1, M=3000
State Accuracy
SI=0.84 (0.89), K=0.67
MI=0.78 (0.99), K=0.56
Location Accuracy
Mean=0.93, SE=0.01
Rate=0.5, M=3000
State Accuracy
SI=0.81 (0.88), K=0.62
MI=0.79 (1), K=0.58
Location Accuracy
Mean=0.94, SE=0.01
step length
0 500 1000 1500 2000
0.000 0.002 0.004

Figure B6. Selected simulation results under the 2-state ("foraging" in black and "transit" in gray) scenarios including a spatial covariate on state transition probabilities. Each panel presents the true and estimated probability densities for turning angle based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

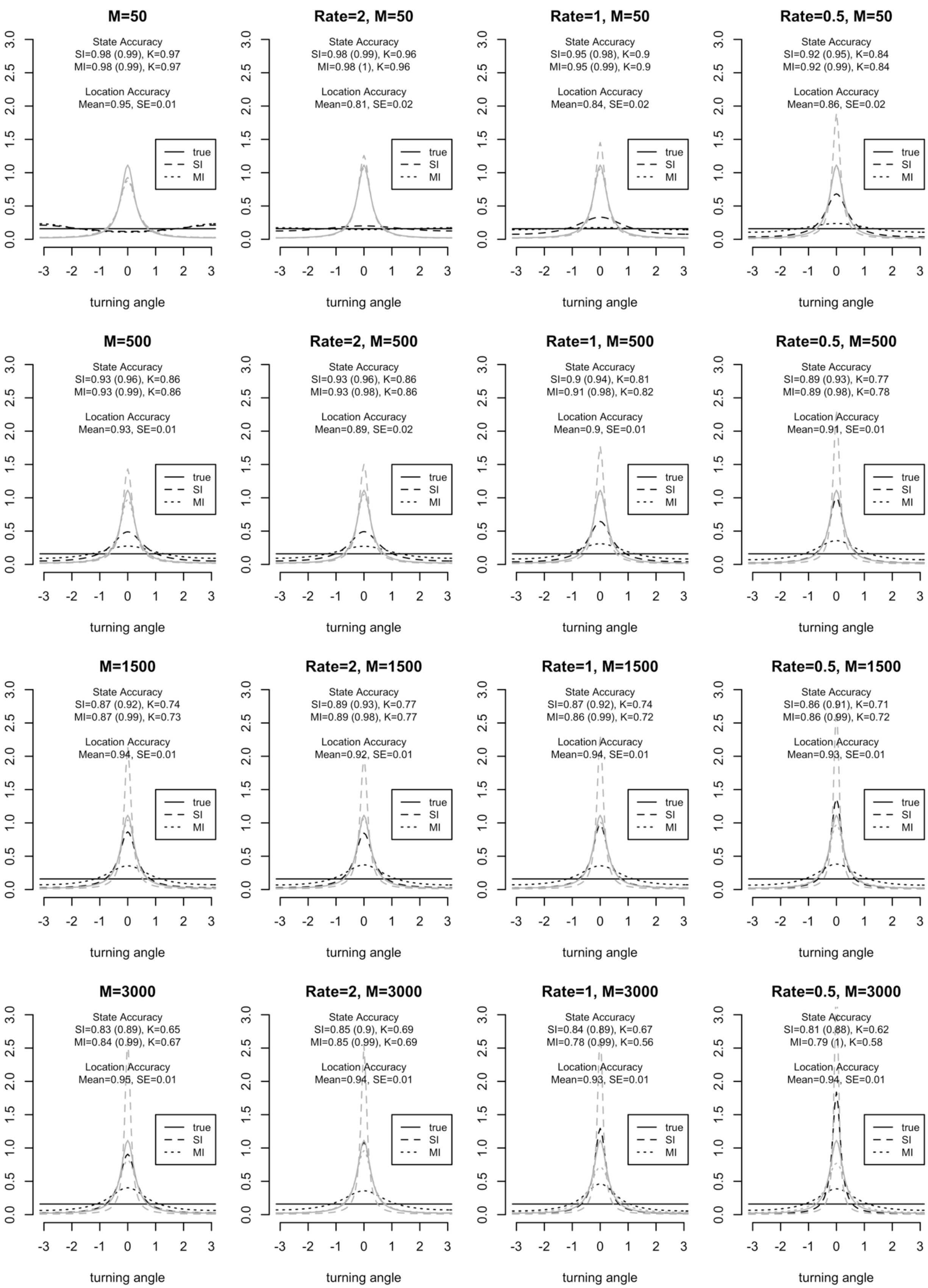

M=50
State Accuracy
SI=0.98 (0.99), K=0.97
MI=0.98 (0.99), K=0.97
Location Accuracy
Mean=0.95, SE=0.01
Rate=2, M=50
State Accuracy
SI=0.98 (0.99), K=0.96
MI=0.98 (1), K=0.96
Location Accuracy
Mean=0.81, SE=0.02
Rate=1, M=50
State Accuracy
SI=0.95 (0.98), K=0.9
MI=0.95 (0.99), K=0.9
Location Accuracy
Mean=0.84, SE=0.02
Rate=0.5, M=50
State Accuracy
SI=0.92 (0.95), K=0.84
MI=0.92 (0.99), K=0.84
Location Accuracy
Mean=0.86, SE=0.02
M=500
State Accuracy
SI=0.93 (0.96), K=0.86
MI=0.93 (0.99), K=0.86
Location Accuracy
Mean=0.93, SE=0.01
Rate=2, M=500
State Accuracy
SI=0.93 (0.96), K=0.86
MI=0.93 (0.98), K=0.86
Location Accuracy
Mean=0.89, SE=0.02
Rate=1, M=500
State Accuracy
SI=0.9 (0.94), K=0.81
MI=0.91 (0.98), K=0.82
Location Accuracy
Mean=0.9, SE=0.01
Rate=0.5, M=500
State Accuracy
SI=0.89 (0.93), K=0.77
MI=0.89 (0.98), K=0.78
Location Accuracy
Mean=0.91, SE=0.01
M=1500
State Accuracy
SI=0.87 (0.92), K=0.74
MI=0.87 (0.99), K=0.73
Location Accuracy
Mean=0.94, SE=0.01
Rate=2, M=1500
State Accuracy
SI=0.89 (0.93), K=0.77
MI=0.89 (0.98), K=0.77
Location Accuracy
Mean=0.92, SE=0.01
Rate=1, M=1500
State Accuracy
SI=0.87 (0.92), K=0.74
MI=0.86 (0.99), K=0.72
Location Accuracy
Mean=0.94, SE=0.01
Rate=0.5, M=1500
State Accuracy
SI=0.86 (0.91), K=0.71
MI=0.86 (0.99), K=0.72
Location Accuracy
Mean=0.93, SE=0.01
M=3000
State Accuracy
SI=0.83 (0.89), K=0.65
MI=0.84 (0.99), K=0.67
Location Accuracy
Mean=0.95, SE=0.01
Rate=2, M=3000
State Accuracy
SI=0.85 (0.9), K=0.69
MI=0.85 (0.99), K=0.69
Location Accuracy
Mean=0.94, SE=0.01
Rate=1, M=3000
State Accuracy
SI=0.84 (0.89), K=0.67
MI=0.78 (0.99), K=0.56
Location Accuracy
Mean=0.93, SE=0.01
Rate=0.5, M=3000
State Accuracy
SI=0.81 (0.88), K=0.62
MI=0.79 (1), K=0.58
Location Accuracy
Mean=0.94, SE=0.01
true
SI
MI
turning angle

Figure B7. Selected simulation results under the 2-state scenarios including a spatial covariate on state transition probabilities. Each panel presents the true and estimated transition probabilities as a function of the spatial covariate based on the single and multiple imputation (MI) approaches with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. Solid lines indicate the transition probability from the "foraging" state to "transit" states, while dashed lines indicate the transition probability from "transit" to "foraging". For comparison, estimates from the same hidden Markov model using the "true" data (i.e., no measurement error or temporal irregularity) are also included ("HMM"). 95% normal confidence intervals were calculated using the delta method and finite-difference approximations of the first derivative.

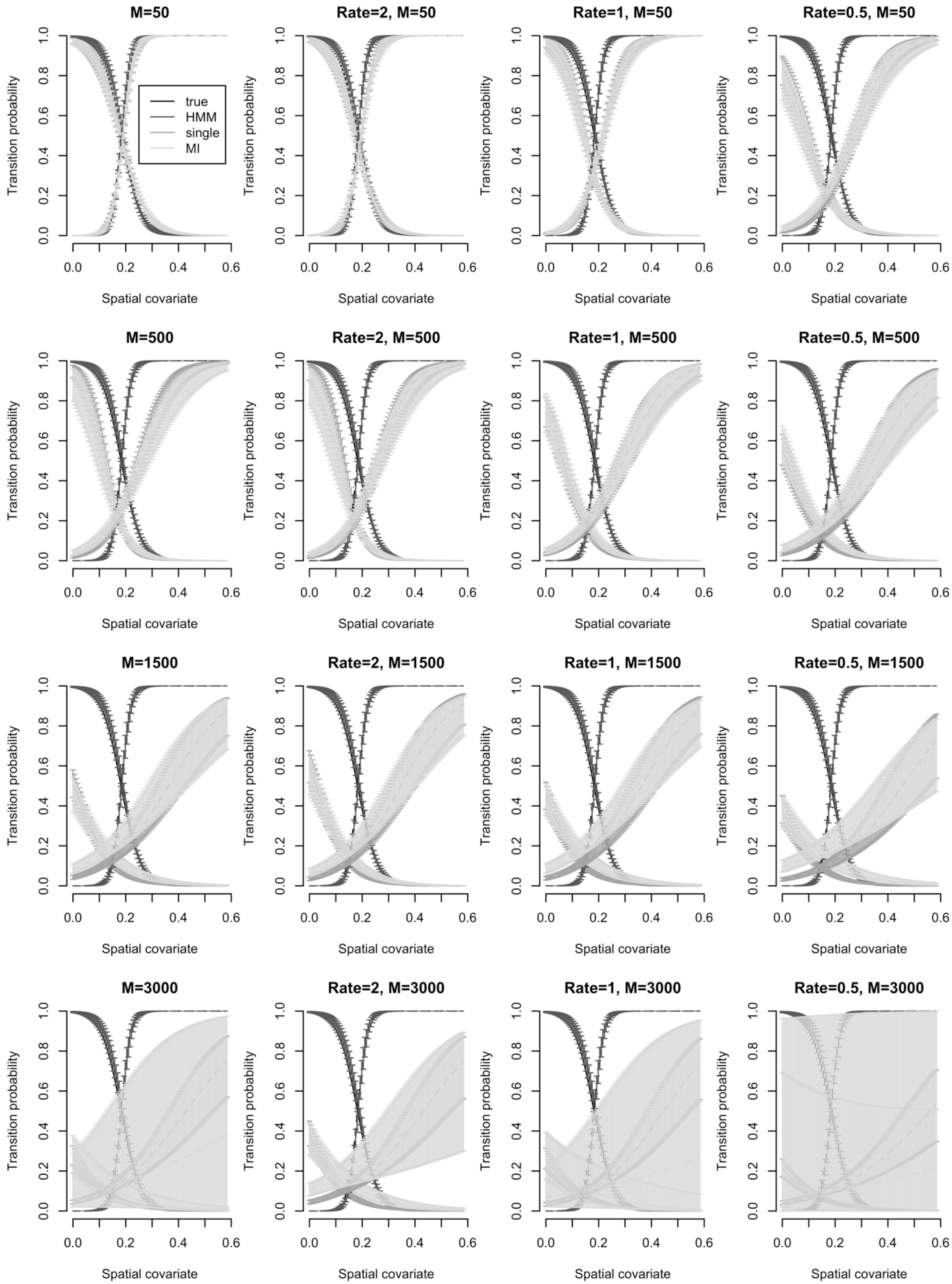
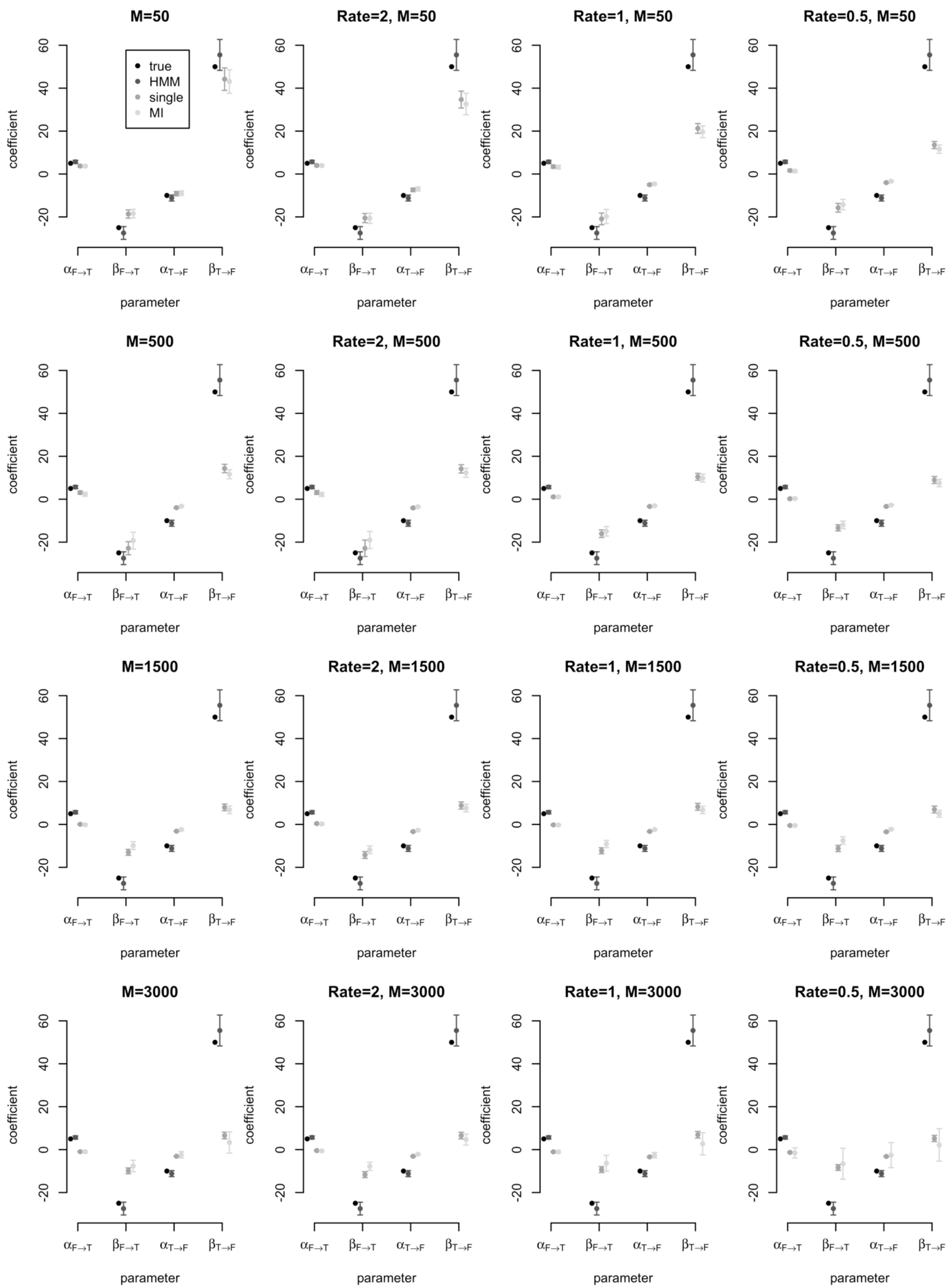

M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
M=3000
Rate=2, M=3000
Rate=1, M=3000
Rate=0.5, M=3000
true
HMM
single
MI
Transition probability
Spatial covariate

Figure B8. Selected simulation results under the 2-state scenarios including a spatial covariate on state transition probabilities. Each panel presents the true and estimated transition probability coefficients (on the logit scale) based on the single and multiple imputation (MI) approaches with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$), where the transition probabilities $\gamma_{F,T}^{(t)} = \text{logit}^{-1}(\alpha_{F\rightarrow T} + c_t\beta_{F\rightarrow T})$ and $\gamma_{T,F}^{(t)} = \text{logit}^{-1}(\alpha_{T\rightarrow F} + c_t\beta_{T\rightarrow F})$ for the "foraging" (*F*) and "transit" (*T*) states. The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. For comparison, estimates from the same hidden Markov model using the "true" data (i.e., no measurement error or temporal irregularity) are also included ("HMM"). Confidence intervals are 95% normal ("single" and "HMM") or *t*-distributed based on standard multiple imputation formulae ("MI").



M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
M=3000
Rate=2, M=3000
Rate=1, M=3000
Rate=0.5, M=3000
true
HMM
single
MI
coefficient
parameter
$\alpha_{F\to T}$
$\beta_{F\to T}$
$\alpha_{T\to F}$
$\beta_{T\to F}$

Figure B9. Comparison of state accuracy for the single imputation ("SI") and multiple imputation approaches based on $n = 400$ ("MI400"), $n = 30$ ("MI30"), and $n = 5$ ("MI5") imputations of the position process in the 2-state simulation scenarios including a spatial covariate on state transition probabilities with varying levels of location measurement error ($M \in \{50,500,1500,3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state (×), the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (•), and a measure of agreement between the true and estimated states ($+$) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks.

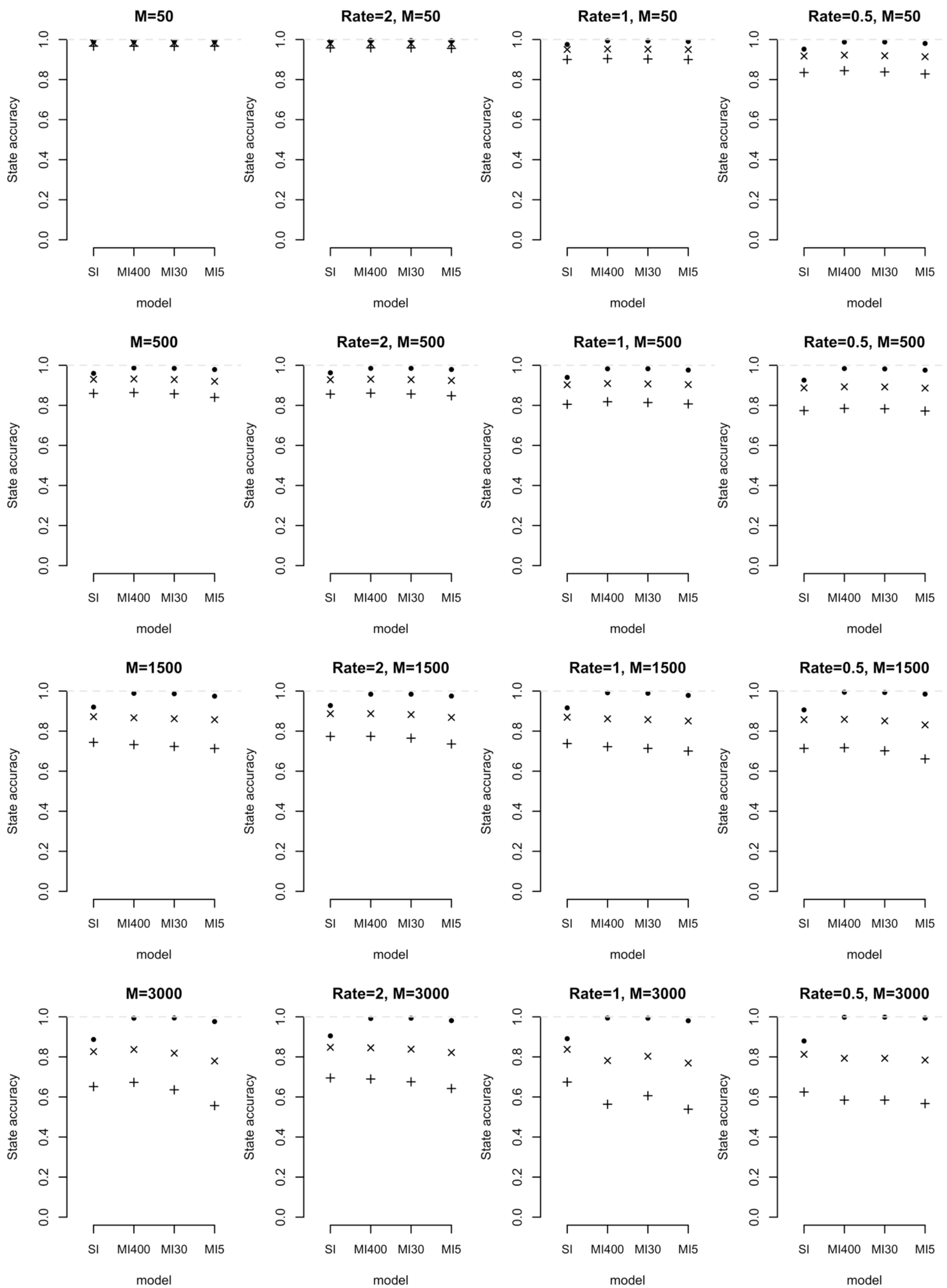

M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
M=3000
Rate=2, M=3000
Rate=1, M=3000
Rate=0.5, M=3000
State accuracy
model
SI
MI400
MI30
MI5
0.0
0.2
0.4
0.6
0.8
1.0

Figure B10. Comparison of location accuracy for the multiple imputation approaches based on $n = 400$, $n = 30$, and $n = 5$ imputations of the position process in the 2-state simulation scenarios including a spatial covariate on state transition probabilities with varying levels of location measurement error ($M \in \{50{,}500{,}1500{,}3000\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2{,}1{,}0.5$). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach. The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks.

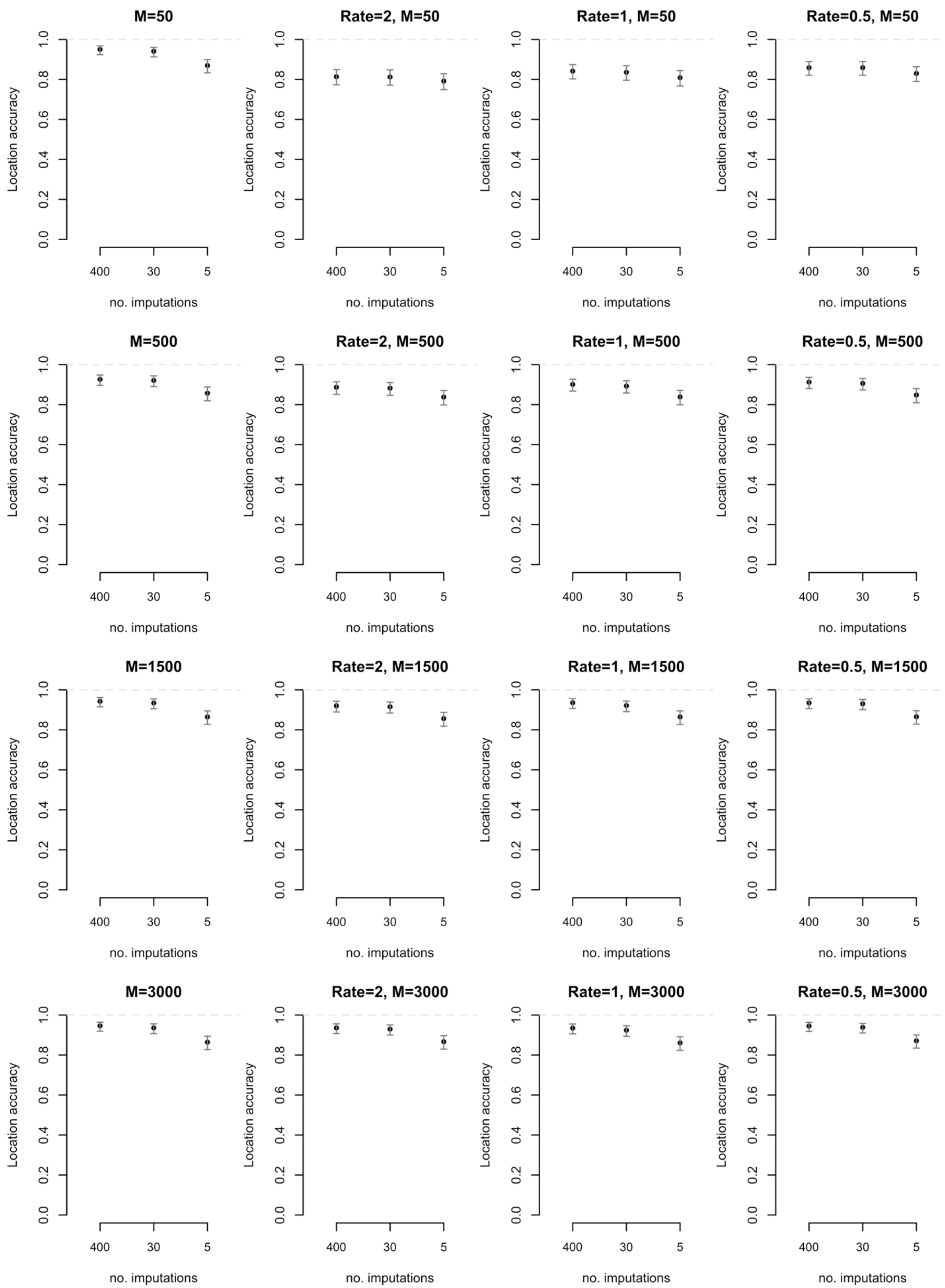

M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
M=3000
Rate=2, M=3000
Rate=1, M=3000
Rate=0.5, M=3000
Location accuracy
0.0
0.2
0.4
0.6
0.8
1.0
400
30
5
no. imputations

Figure B11. Selected simulation results under the 4-state ("hauled out on ice" = black, "resting at sea" = dark gray, "foraging" = gray, and "transit" = light gray) scenarios. Each panel presents the true and estimated probability densities for step length based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500\}$) and missing location data arising from temporally-irregular sampling rates ($\mathrm{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

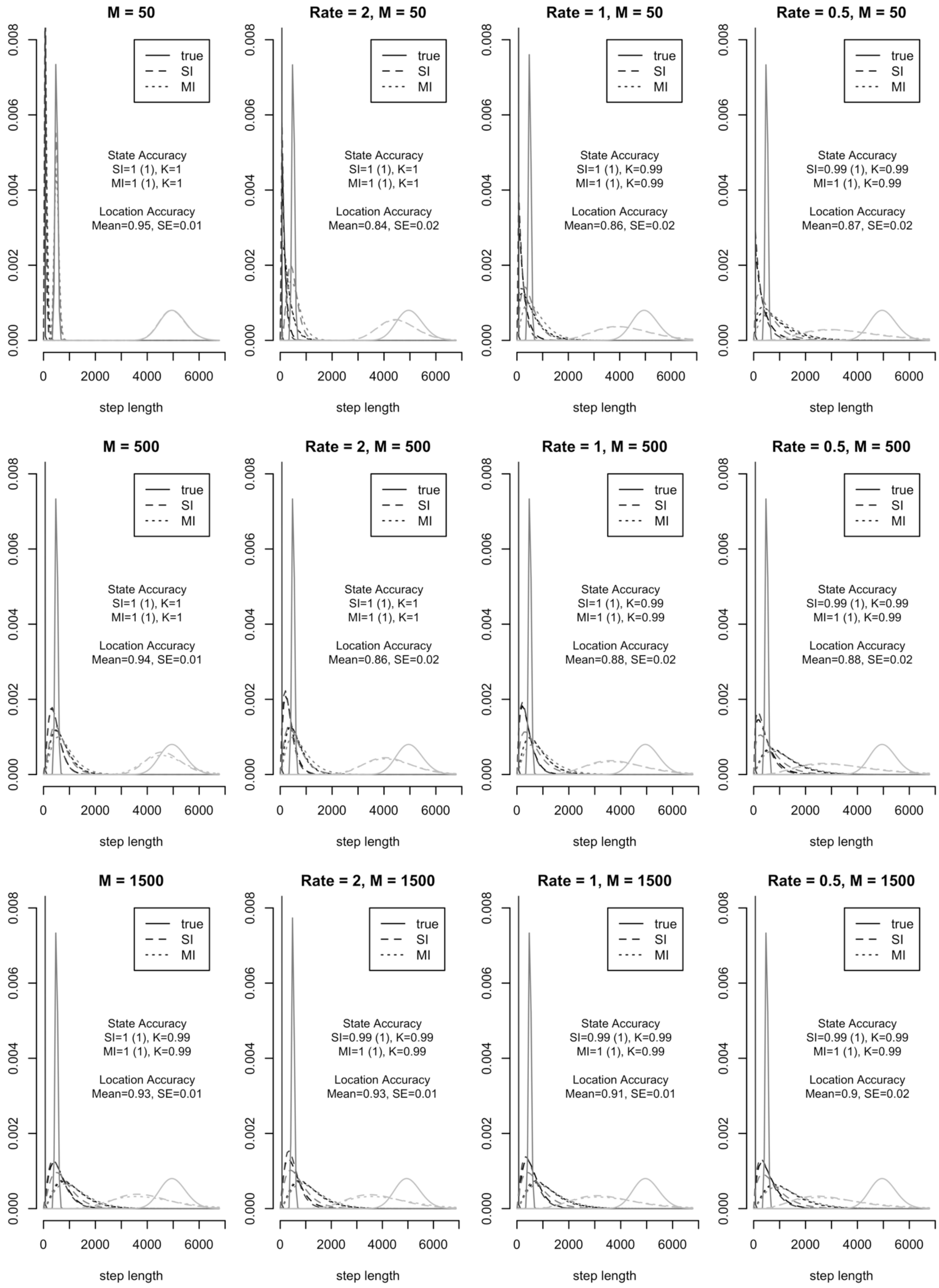

M = 50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.95, SE=0.01
step length
Rate = 2, M = 50
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.84, SE=0.02
Rate = 1, M = 50
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.86, SE=0.02
Rate = 0.5, M = 50
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.87, SE=0.02
M = 500
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.94, SE=0.01
Rate = 2, M = 500
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.86, SE=0.02
Rate = 1, M = 500
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
Rate = 0.5, M = 500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
M = 1500
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
Rate = 2, M = 1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
Rate = 1, M = 1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.91, SE=0.01
Rate = 0.5, M = 1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.9, SE=0.02
0.000
0.002
0.004
0.006
0.008
0
2000
4000
6000

Figure B12. Selected simulation results under the 4-state ("hauled out on ice" = black, "resting at sea" = dark gray, "foraging" = gray, and "transit" = light gray) scenarios. Each panel presents the true and estimated probability densities for turning angle based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

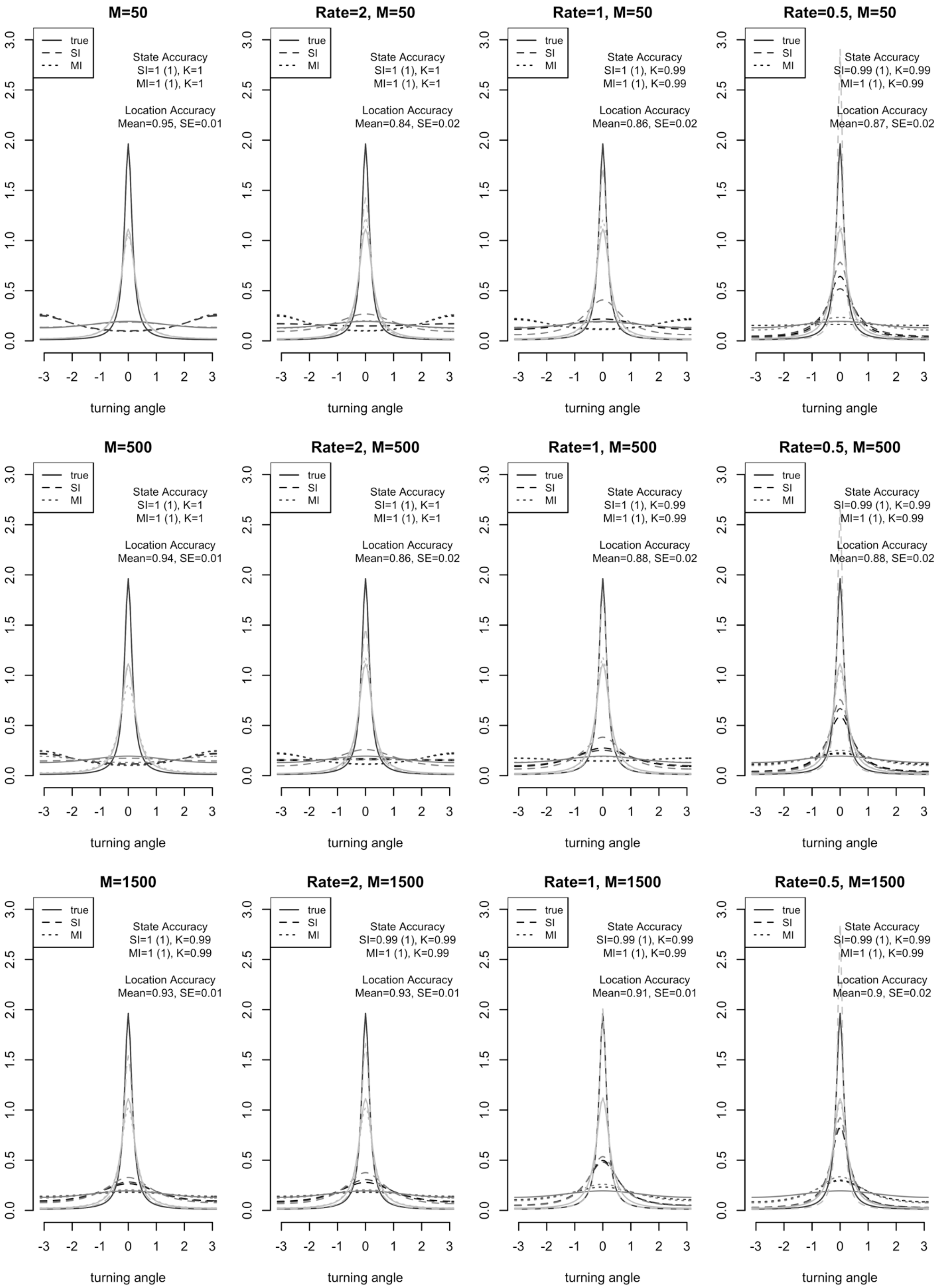

M=50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.95, SE=0.01
turning angle
Rate=2, M=50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.84, SE=0.02
turning angle
Rate=1, M=50
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.86, SE=0.02
turning angle
Rate=0.5, M=50
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.87, SE=0.02
turning angle
M=500
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.94, SE=0.01
turning angle
Rate=2, M=500
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.86, SE=0.02
turning angle
Rate=1, M=500
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
turning angle
Rate=0.5, M=500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
turning angle
M=1500
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
turning angle
Rate=2, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
turning angle
Rate=1, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.91, SE=0.01
turning angle
Rate=0.5, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.9, SE=0.02
turning angle

Figure B13. Selected simulation results under the 4-state ("hauled out on ice" = black, "resting at sea" = dark gray, "foraging" = gray, and "transit" = light gray) scenarios. Each panel presents the true and estimated probability densities for dive time based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

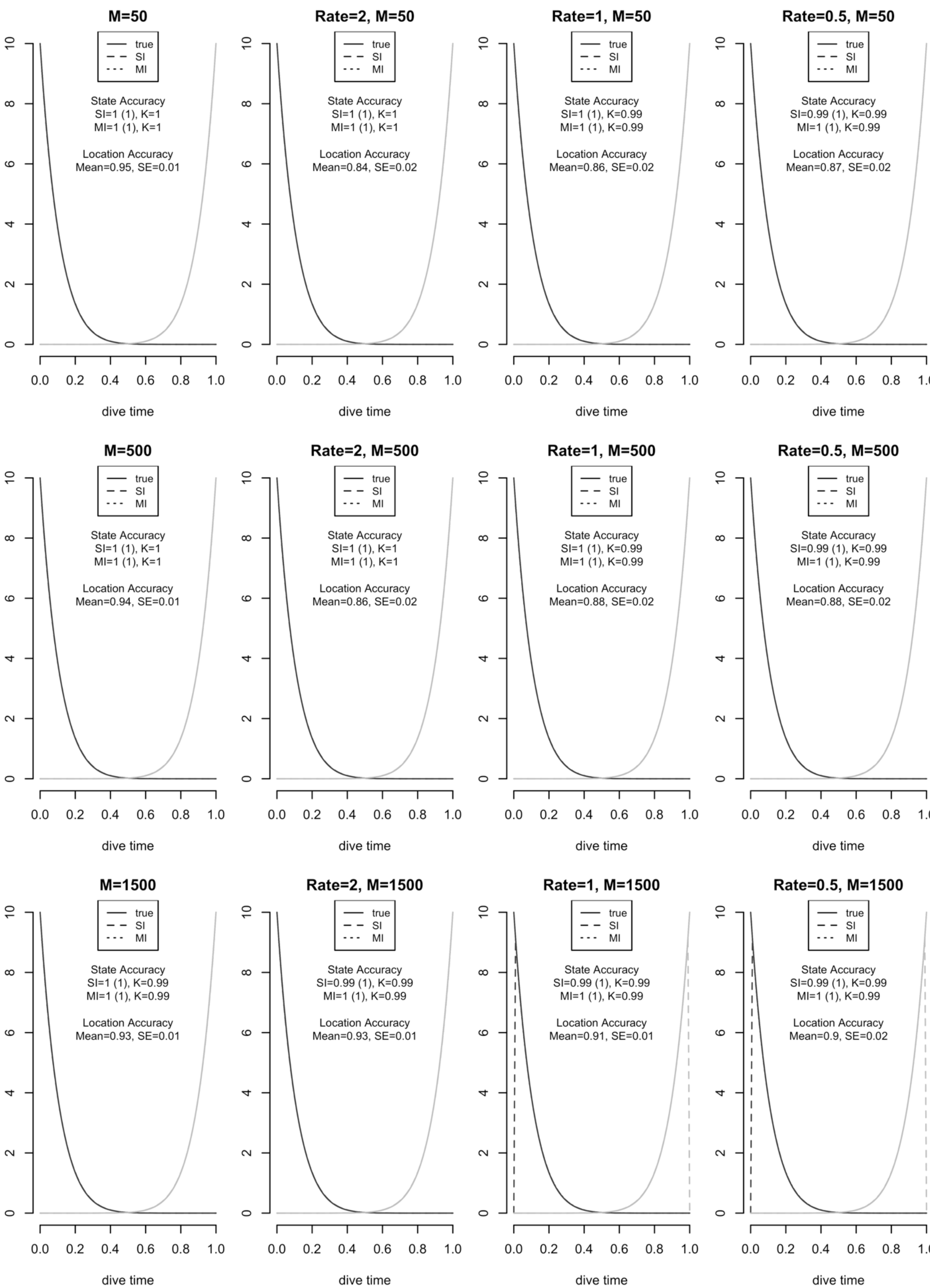

M=50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.95, SE=0.01
dive time
Rate=2, M=50
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.84, SE=0.02
Rate=1, M=50
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.86, SE=0.02
Rate=0.5, M=50
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.87, SE=0.02
M=500
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.94, SE=0.01
Rate=2, M=500
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.86, SE=0.02
Rate=1, M=500
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
Rate=0.5, M=500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
M=1500
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
Rate=2, M=1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
Rate=1, M=1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.91, SE=0.01
Rate=0.5, M=1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.9, SE=0.02

Figure B14. Selected simulation results under the 4-state ("hauled out on ice" = black, "resting at sea" = dark gray, "foraging" = gray, and "transit" = light gray) scenarios. Each panel presents the true and estimated probability densities for dry time based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50{,}500{,}1500\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2{,}1{,}0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

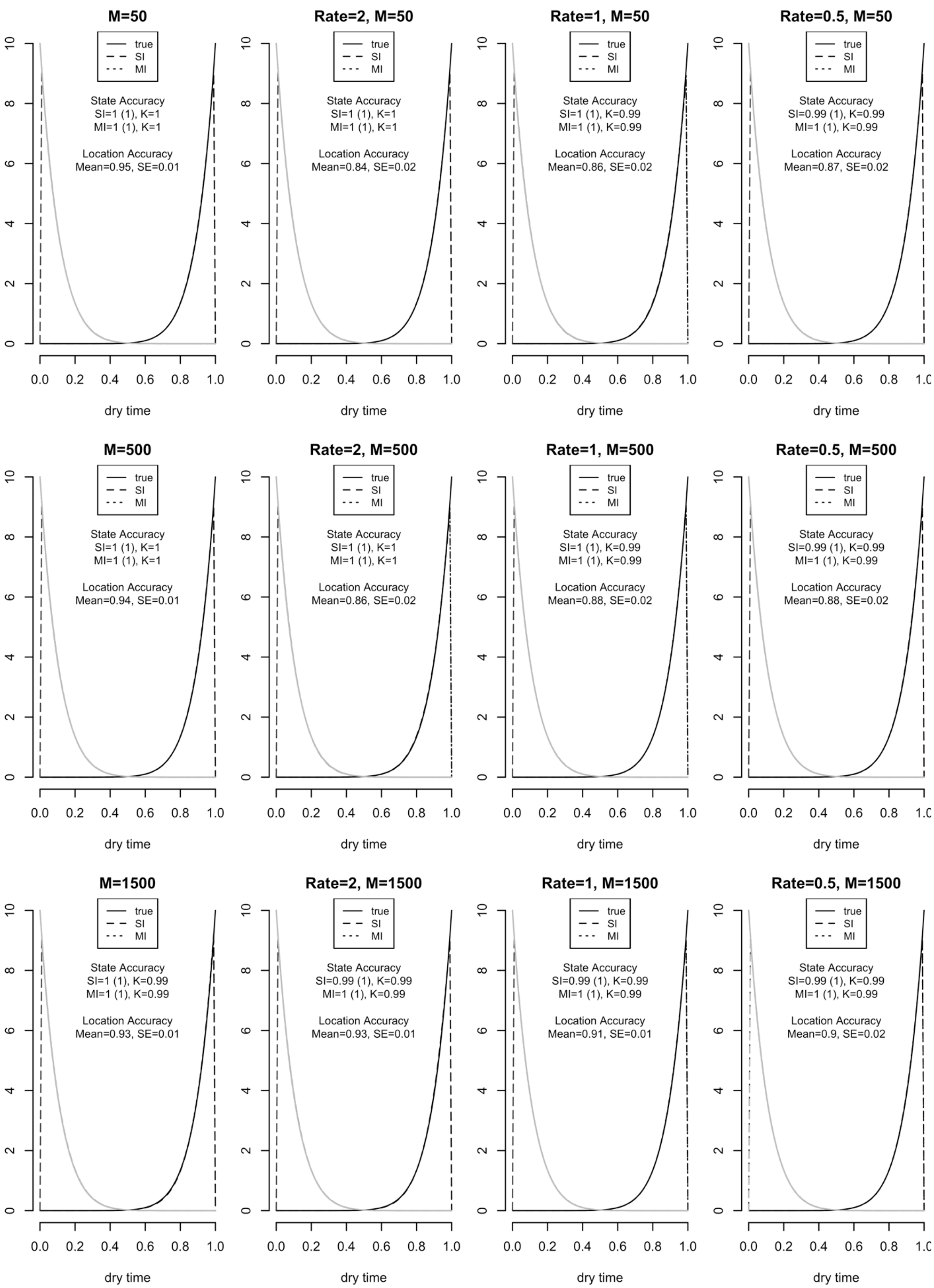

M=50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.95, SE=0.01
dry time
Rate=2, M=50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.84, SE=0.02
dry time
Rate=1, M=50
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.86, SE=0.02
dry time
Rate=0.5, M=50
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.87, SE=0.02
dry time
M=500
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.94, SE=0.01
dry time
Rate=2, M=500
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.86, SE=0.02
dry time
Rate=1, M=500
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
dry time
Rate=0.5, M=500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
dry time
M=1500
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
dry time
Rate=2, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
dry time
Rate=1, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.91, SE=0.01
dry time
Rate=0.5, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.9, SE=0.02
dry time

Figure B15. Selected simulation results under the 4-state (“hauled out on ice” = black, “resting at sea” = dark gray, “foraging” = gray, and “transit” = light gray) scenarios. Each panel presents the true and estimated probability densities for number of dives based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

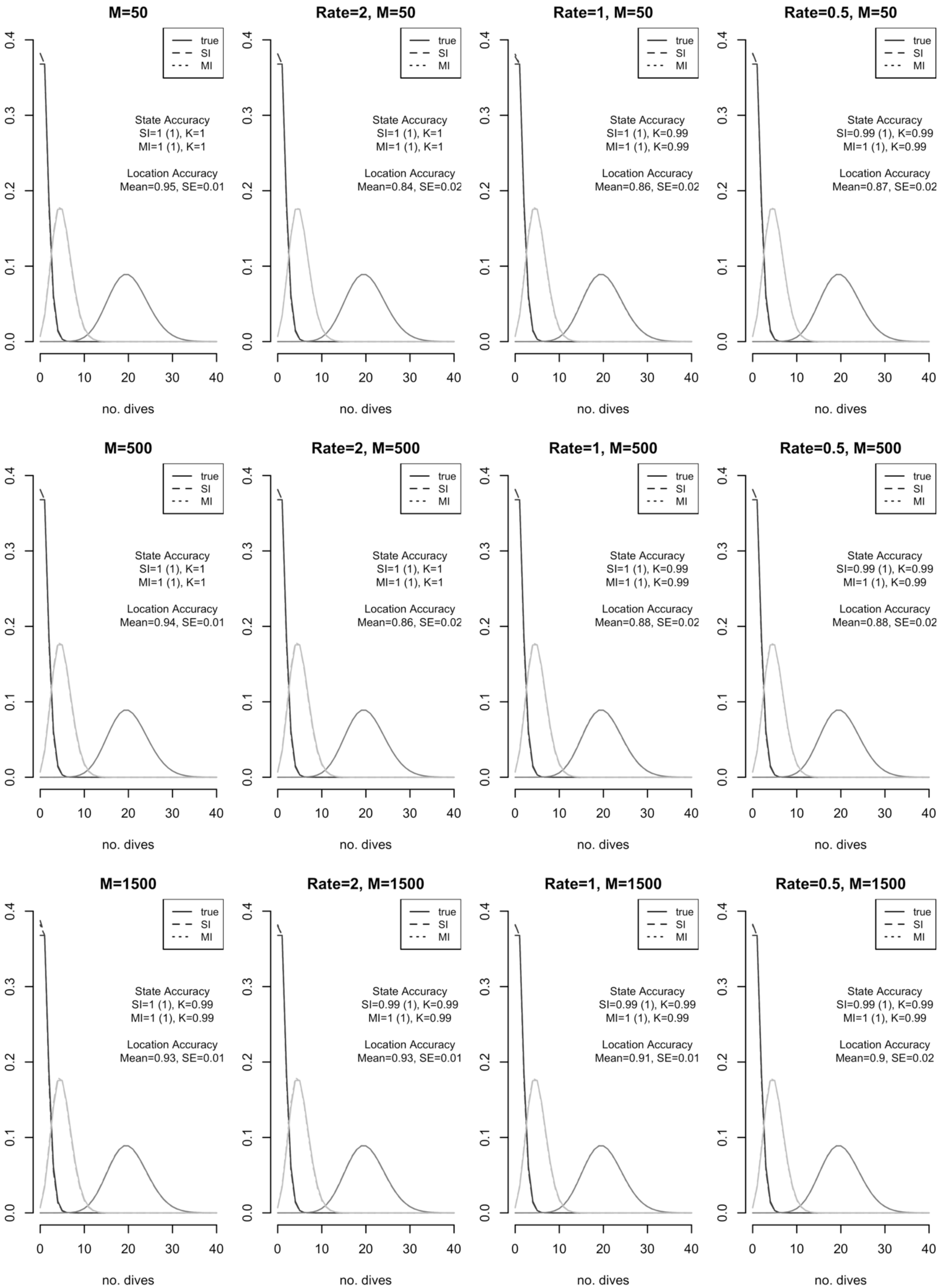

M=50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.95, SE=0.01
no. dives
Rate=2, M=50
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.84, SE=0.02
no. dives
Rate=1, M=50
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.86, SE=0.02
no. dives
Rate=0.5, M=50
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.87, SE=0.02
no. dives
M=500
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.94, SE=0.01
no. dives
Rate=2, M=500
true
SI
MI
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.86, SE=0.02
no. dives
Rate=1, M=500
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
no. dives
Rate=0.5, M=500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
no. dives
M=1500
true
SI
MI
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
no. dives
Rate=2, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
no. dives
Rate=1, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.91, SE=0.01
no. dives
Rate=0.5, M=1500
true
SI
MI
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.9, SE=0.02
no. dives

Figure B16. Selected simulation results under the 4-state ("hauled out on ice" = black, "resting at sea" = dark gray, "foraging" = gray, and "transit" = light gray) scenarios. Each panel presents the estimated probability densities for sea ice concentration based on the single (SI) and multiple (MI) imputation approaches with varying levels of location measurement error ($M \in \{50,500,1500\}$) and missing location data arising from temporally-irregular sampling rates ($\text{Rate} \in 2,1,0.5$). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks. State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state, the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (in parentheses), and a measure of agreement between the true and estimated states (K) that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach.

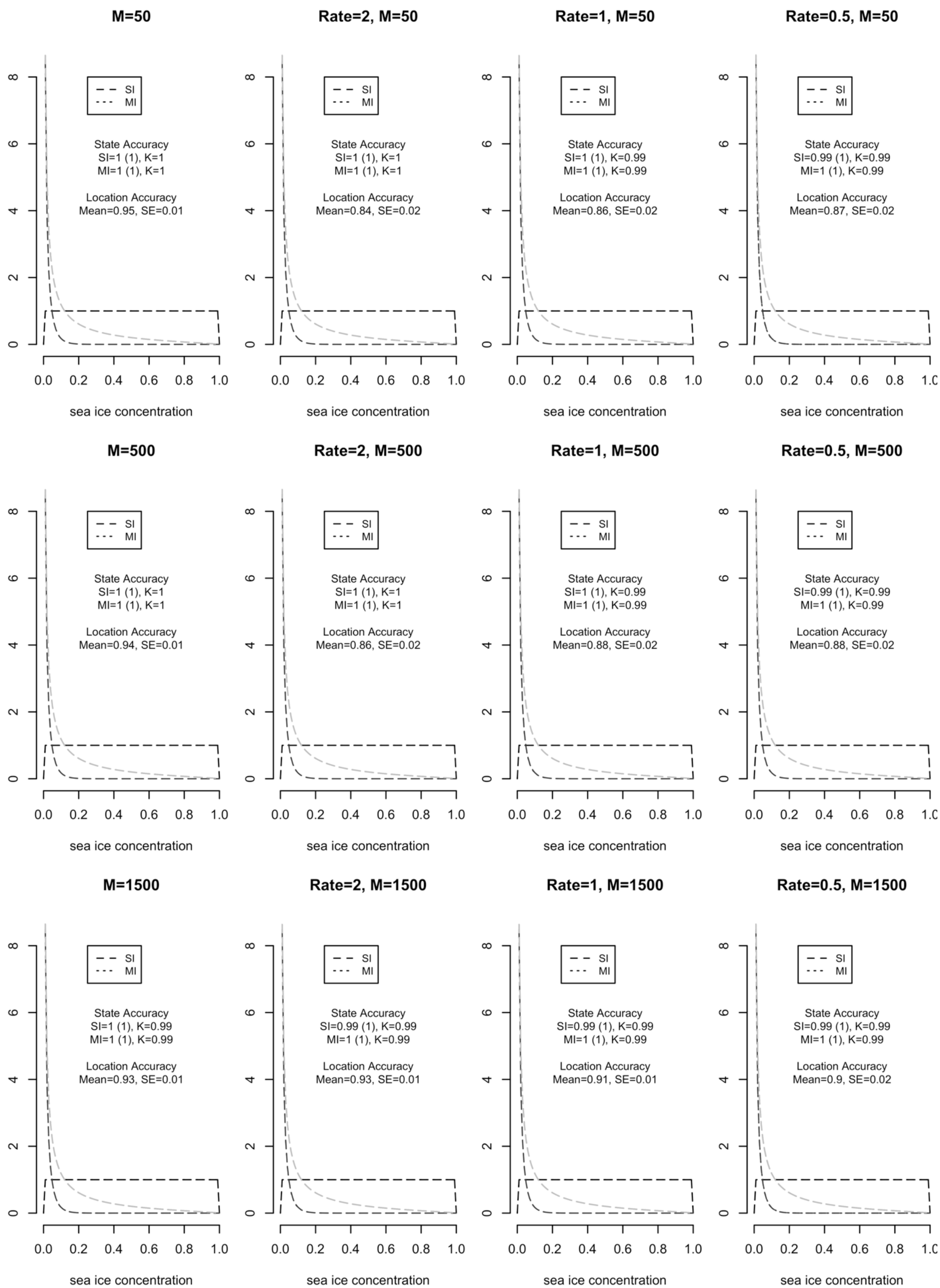
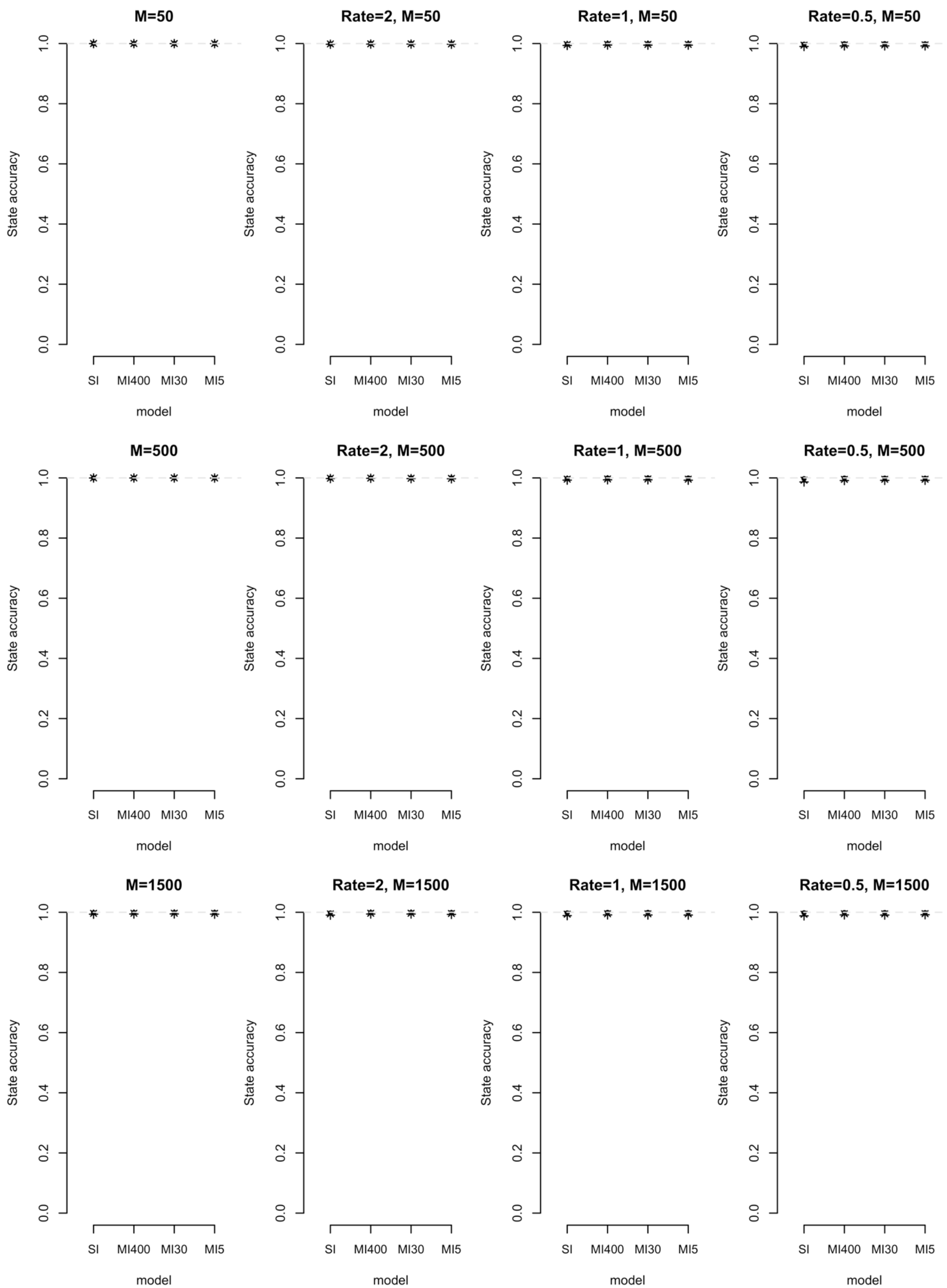
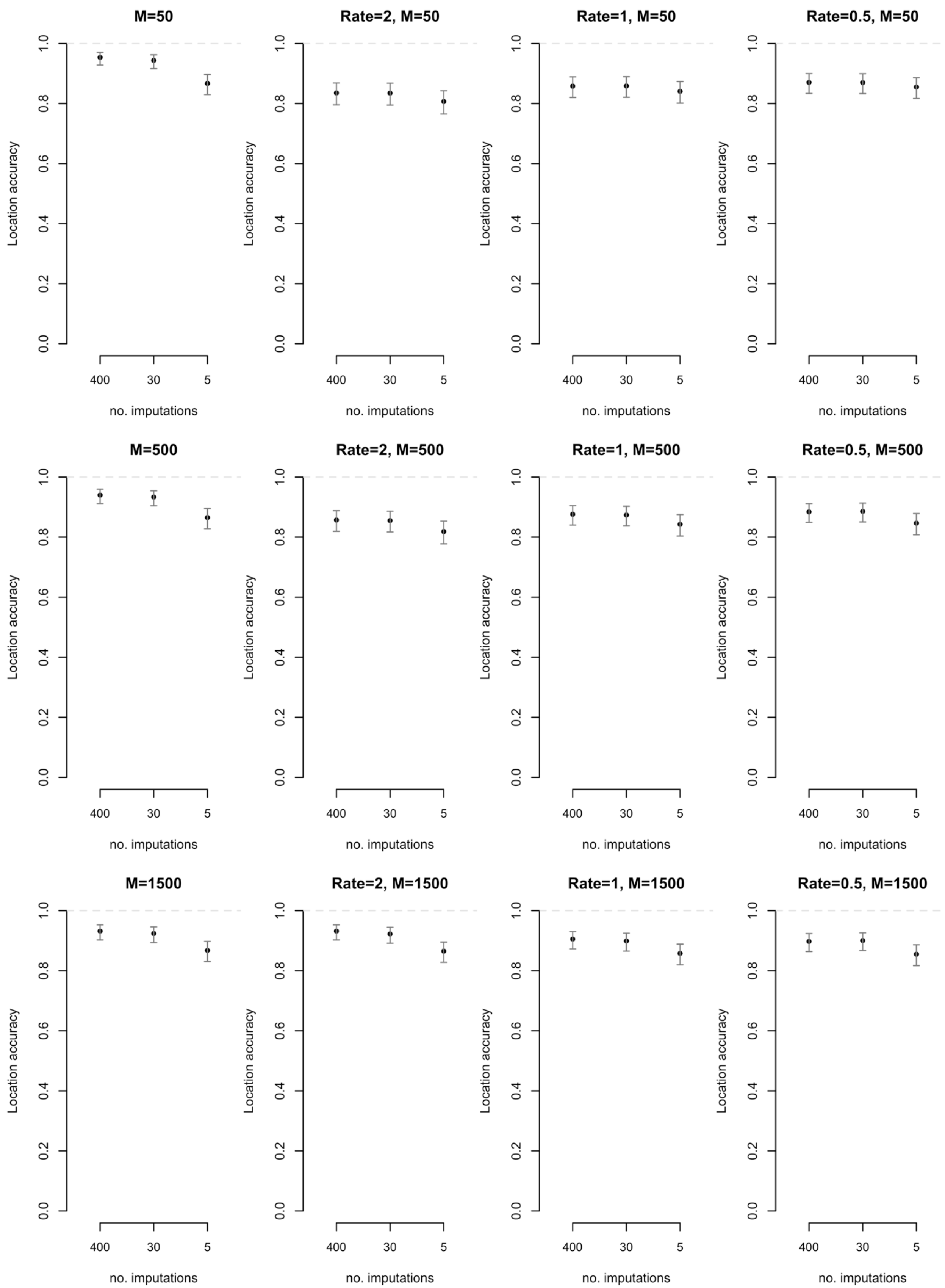

M=50
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.95, SE=0.01
Rate=2, M=50
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.84, SE=0.02
Rate=1, M=50
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.86, SE=0.02
Rate=0.5, M=50
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.87, SE=0.02
M=500
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.94, SE=0.01
Rate=2, M=500
State Accuracy
SI=1 (1), K=1
MI=1 (1), K=1
Location Accuracy
Mean=0.86, SE=0.02
Rate=1, M=500
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
Rate=0.5, M=500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.88, SE=0.02
M=1500
State Accuracy
SI=1 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
Rate=2, M=1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.93, SE=0.01
Rate=1, M=1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.91, SE=0.01
Rate=0.5, M=1500
State Accuracy
SI=0.99 (1), K=0.99
MI=1 (1), K=0.99
Location Accuracy
Mean=0.9, SE=0.02
SI
MI
sea ice concentration
0.0
0.2
0.4
0.6
0.8
1.0
0
2
4
6
8

Figure B17. Comparison of state accuracy for the single imputation ("SI") and multiple imputation approaches based on $n = 400$ ("MI400"), $n = 30$ ("MI30"), and $n = 5$ ("MI5") imputations of the position process in the 4-state simulations with varying levels of location measurement error ($M \in \{50,500,1500\}$) and missing location data arising from temporally-irregular sampling rates (Rate $\in 2,1,0.5$). State classification accuracy for each scenario is based on the proportion of time steps for the estimated most likely state sequence that match the true state (×), the proportion of estimated state probabilities with at least 0.05 probability assigned to the true state (•), and a measure of agreement between the true and estimated states $(+)$ that takes chance agreement into account and ranges from 0 (no better than chance) to 1 (perfect agreement not attributable to chance). The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks.



M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
State accuracy
model
SI
MI400
MI30
MI5
0.0
0.2
0.4
0.6
0.8
1.0

Figure B18. Comparison of location accuracy for the multiple imputation approaches based on $n = 400$, $n = 30$, and $n = 5$ imputations of the position process in the 4-state simulations with varying levels of location measurement error ($M \in \{50{,}500{,}1500\}$) and missing location data arising from temporally-irregular sampling rates (Rate $\in 2{,}1{,}0.5$). Location accuracy for each scenario is based on the proportion of true locations that fall within their respective estimated 95% confidence bands using the multiple imputation approach. The first column pertains to scenarios with temporally-regular sampling that exactly matches the time steps of the simulated tracks.


M=50
Rate=2, M=50
Rate=1, M=50
Rate=0.5, M=50
M=500
Rate=2, M=500
Rate=1, M=500
Rate=0.5, M=500
M=1500
Rate=2, M=1500
Rate=1, M=1500
Rate=0.5, M=1500
Location accuracy
no. imputations
400
30
5
0.0
0.2
0.4
0.6
0.8
1.0