**Supplementary table 1:** Municipalities with cocoa production in the states of Bahia and Pará, from 1985 to 2021, according to Municipal Agricultural Production (PAM) data provided by the Brazilian Institute of Geography and Statistics (IBGE). Geographical coordinates (Longitude and Latitude) presented in decimal degrees according to IBGE.

|  |  |  |  |
| --- | --- | --- | --- |
| State | Municipality | Longitude | Latitude |
| Bahia | Aiquara  | -39.89058 | -14.12602 |
|  | Alcobaça  | -39.19241 | -17.52825 |
|  | Almadina  | -39.64218 | -14.70983 |
|  | Amargosa  | -39.60240 | -13.03020 |
|  | Amélia Rodrigues | -38.75202 | -12.40199 |
|  | Apuarema  | -39.74474 | -13.85593 |
|  | Arataca  | -39.41971 | -15.26601 |
|  | Aratuípe  | -39.00122 | -13.07830 |
|  | Aurelino Leal  | -39.32971 | -14.32181 |
|  | Barra do Rocha  | -39.60387 | -14.20703 |
|  | Barro Preto  | -39.47340 | -14.80905 |
|  | Belmonte  | -38.88015 | -15.86170 |
|  | Boa Nova  | -40.20664 | -14.36636 |
|  | Buerarema  | -39.30113 | -14.95758 |
|  | Caatiba  | -40.40957 | -14.97873 |
|  | Cachoeira  | -38.96691 | -12.60027 |
|  | Camacan  | -39.49334 | -15.41712 |
|  | Camamu  | -39.10642 | -13.94427 |
|  | Canavieiras  | -38.94529 | -15.67948 |
|  | Coaraci  | -39.55001 | -14.64126 |
|  | Cravolândia  | -39.81573 | -13.35808 |
|  | Dário Meira  | -39.90320 | -14.43367 |
|  | Elísio Medrado  | -39.52076 | -12.94743 |
|  | Eunápolis  | -39.57604 | -16.37271 |
|  | Firmino Alves  | -39.92455 | -14.98756 |
|  | Floresta Azul  | -39.65647 | -14.86068 |
|  | Gandu  | -39.48480 | -13.74527 |
|  | Gongogi  | -39.46684 | -14.32448 |
|  | Guaratinga  | -39.78114 | -16.58072 |
|  | Ibicaraí  | -39.58942 | -14.86299 |
|  | Ibicuí  | -39.98825 | -14.84542 |
|  | Ibirapitanga  | -39.36985 | -14.16202 |
|  | Ibirataia  | -39.63973 | -14.06936 |
|  | Igrapiúna  | -39.14231 | -13.82317 |
|  | Iguaí  | -40.08975 | -14.75321 |
|  | Ilhéus  | -39.04571 | -14.79306 |
|  | Ipiaú  | -39.73765 | -14.13228 |
|  | Itabela  | -39.56229 | -16.57481 |
|  | Itabuna  | -39.27465 | -14.79398 |
|  | Itacaré  | -38.99547 | -14.27859 |
|  | Itagi  | -40.00727 | -14.16324 |
|  | Itagibá  | -39.84559 | -14.28961 |
|  | Itagimirim  | -39.61512 | -16.08572 |
|  | Itaju do Colônia  | -39.72334 | -15.14197 |
|  | Itajuípe  | -39.37627 | -14.67490 |
|  | Itamaraju  | -39.52833 | -17.03678 |
|  | Itamari  | -39.68329 | -13.77865 |
|  | Itambé  | -40.62729 | -15.24398 |
|  | Itanhém  | -40.32944 | -17.16705 |
|  | Itapé  | -39.42499 | -14.89754 |
|  | Itapebi  | -39.53239 | -15.96965 |
|  | Itapetinga | -40.24634 | -15.24591 |
|  | Itapitanga  | -39.56680 | -14.42184 |
|  | Itororó  | -40.06420 | -15.11601 |
|  | Ituberá  | -39.14843 | -13.73653 |
|  | Jaguaquara  | -39.96964 | -13.52995 |
|  | Jequié  | -40.07230 | -13.86086 |
|  | Jiquiriçá  | -39.56963 | -13.25580 |
|  | Jitaúna  | -39.88933 | -14.01747 |
|  | Jucuruçu  | -40.16003 | -16.84390 |
|  | Jussari  | -39.49393 | -15.18871 |
|  | Laje  | -39.42262 | -13.18145 |
|  | Maraú  | -39.01476 | -14.10348 |
|  | Mascote  | -39.30300 | -15.56501 |
|  | Mata de São João  | -38.30122 | -12.53113 |
|  | Mucuri  | -39.54739 | -18.07922 |
|  | Muniz Ferreira  | -39.11054 | -13.00171 |
|  | Mutuípe  | -39.50634 | -13.22868 |
|  | Nazaré  | -39.00658 | -13.03501 |
|  | Nilo Peçanha  | -39.10466 | -13.60202 |
|  | Nova Canaã  | -40.14572 | -14.79414 |
|  | Nova Ibiá  | -39.62511 | -13.81071 |
|  | Nova Viçosa  | -39.37288 | -17.89124 |
|  | Pau Brasil  | -39.65217 | -15.46504 |
|  | Piraí do Norte  | -39.37463 | -13.76178 |
|  | Porto Seguro  | -39.06458 | -16.44394 |
|  | Potiraguá  | -39.87175 | -15.59398 |
|  | Prado  | -39.22305 | -17.33683 |
|  | Presidente Tancredo Neves  | -39.42155 | -13.45611 |
|  | Santa Cruz da Vitória  | -39.81087 | -14.96339 |
|  | Santa Luzia  | -39.33066 | -15.43125 |
|  | Santo Antônio de Jesus  | -39.26124 | -12.96939 |
|  | São Francisco do Conde  | -39.09453 | -12.84179 |
|  | São José da Vitória  | -38.68145 | -12.62856 |
|  | São Miguel das Matas  | -39.33687 | -15.07953 |
|  | São Sebastião do Passe | -39.45579 | -13.04820 |
|  | Simões Filoh | -38.49248 | -12.51824 |
|  | Taperoá  | -38.40336 | -12.78723 |
|  | Teixeira de Freitas  | -39.09897 | -13.53779 |
|  | Teolândia  | -39.74615 | -17.53814 |
|  | Terra Nova | -39.49304 | -13.60403 |
|  | Ubaíra  | -39.66162 | -13.26212 |
|  | Ubaitaba  | -39.32299 | -14.31223 |
|  | Ubatã  | -39.52492 | -14.21246 |
|  | Una  | -39.07479 | -15.29263 |
|  | Uruçuca  | -39.28654 | -14.59177 |
|  | Valença  | -39.06975 | -13.37281 |
|  | Varzedo  | -39.39469 | -12.97601 |
|  | Vereda  | -40.08595 | -17.22522 |
|  | Wenceslau Guimarães  | -39.47945 | -13.68709 |
| Pará | Abaetetuba  | -48.87922 | -1.72221 |
|  | Acará  | -48.19908 | -1.96177 |
|  | Alenquer  | -54.73877 | -1.94661 |
|  | Almeirim  | -52.57921 | -1.52942 |
|  | Altamira  | -52.21036 | -3.20445 |
|  | Anapu  | -51.20610 | -3.46722 |
|  | Aveiro  | -55.31298 | -3.61505 |
|  | Baião  | -49.67067 | -2.79073 |
|  | Bannach | -50.40685 | -7.35126 |
|  | Barcarena  | -48.61945 | -1.51117 |
|  | Brasil Novo  | -47.56697 | -0.83019 |
|  | Breu Branco  | -49.56886 | -3.77890 |
|  | Bujaru  | -50.47947 | -1.68074 |
|  | Cametá  | -49.49827 | -2.24333 |
|  | Castanhal  | -47.92276 | -1.29308 |
|  | Concórdia do Pará  | -47.94542 | -1.99279 |
|  | Cumaru do Norte\_ | -47.94542 | -1.99279 |
|  | Eldorado do Carajás  | -49.35763 | -6.10333 |
|  | Gurupá  | -51.64314 | -1.40670 |
|  | Igarapé-Açu | -47.62027 | -1.12862 |
|  | Igarapé-Miri  | -48.96386 | -1.97890 |
|  | Inhangapi  | -47.91123 | -1.42875 |
|  | Itaituba  | -55.98823 | -4.26291 |
|  | Itupiranga  | -49.33258 | -5.13412 |
|  | Jacareacanga | -57.75906 | -6.22005 |
|  | Limoeiro do Ajuru  | -49.38323 | -1.89626 |
|  | Marabá  | -49.10112 | -5.34668 |
|  | Medicilândia  | -52.88933 | -3.44423 |
|  | Mocajuba  | -49.50461 | -2.58348 |
|  | Moju  | -48.76714 | -1.89031 |
|  | Monte Alegre  | -54.07318 | -1.99929 |
|  | Novo Progresso | -55.41901 | -7.03789 |
|  | Novo Repartimento  | -49.95281 | -4.25231 |
|  | Óbidos  | -55.52123 | -1.90145 |
|  | Oeiras do Pará  | -49.85999 | -2.00446 |
|  | Ourilândia do Norte  | -51.07924 | -6.74938 |
|  | Pacajá  | -50.64032 | -3.83581 |
|  | Parauapebas  | -49.89072 | -6.07009 |
|  | Placas  | -54.21585 | -3.86934 |
|  | Porto de Moz | -50.82443 | -1.93909 |
|  | Prainha | -52.23596 | -1.75059 |
|  | Rio Maria | -50.04693 | -7.31414 |
|  | Rurópolis  | -54.90910 | -4.10182 |
|  | Santa Izabel do Pará  | -48.16093 | -1.29723 |
|  | Santa Maria do Pará | -49.71752 | -8.87143 |
|  | Santarém  | -54.70002 | -2.43887 |
|  | São Domingos do Araguaia  | -48.72948 | -5.54204 |
|  | São Félix do Xingu  | -51.97916 | -6.63910 |
|  | São Francisco do Pará | -47.79763 | -1.16978 |
|  | São Geraldo do Araguaia  | -48.55955 | -6.39512 |
|  | Sapucaia | -49.69978 | -6.94176 |
|  | Senador José Porfírio  | -51.94861 | -2.59393 |
|  | Terra Santa | -47.90953 | -1.04017 |
|  | Tomé-Açu  | -48.15267 | -2.41702 |
|  | Trairão  | -55.99764 | -4.70094 |
|  | Tucumã  | -51.15119 | -6.75213 |
|  | Tucuruí  | -49.67121 | -3.77424 |
|  | Uruará  | -52.01189 | -2.88369 |
|  | Vitória do Xingu  | -52.01189 | -2.88369 |
|   | Xinguara | -49.94205 | -7.10026 |

**Supplementary table 2.** Statistical details of the most parsimonious models obtained for historical cocoa productivity patterns in Bahia (a) and Pará (b). Model selection was based on the Akaike Information Criterion (AIC). The models selected were those with AIC values similar (ΔAIC < 4) to the AIC value of the best model. *w*: model weight; df: degrees of freedom of each model. Blanks indicate that the term was not included in the model. (\*): interaction between variables. *Acronyms*: FCC: forest cover change, TCC: total cropland change on a logarithmic scale, FFC: forest fragmentation change on a logarithmic scale (change in forest edge density), RF: recent forest cover and SA: spatial autocorrelation.

|  |
| --- |
| (a) Bahia |
| Model | RFC ± SE | FFC ± SE | TCC ± SE | FCC ± SE | RFC \* FFC ± SE | RFC \* TCC ± SE | RFC \* FCC ± SE | SA ± SE | df | AIC | ∆AIC | W |
| 1 |  -0.002 ± 0.001 |   |  -0.347 ± 0.161 |   |   |   |   | 1.277 ± 0.214 | 5 | -85.2 | 0.0 | 0.12 |
| 2 |  -0.002 ± 0.001 |   |   | 0.161 ± 0.075 |   |   |   | 1.363 ± 0.214 | 5 | -85.2 | 0.0 | 0.11 |
| 3 |  -0.003 ± 0.001 | -0.096 ± 0.084 |   | 0.193 ± 0.080 |   |   |   | 1.311 ± 0.218 | 6 | -84.5 | 0.6 | 0.08 |
| 4 |  -0.003 ± 0.001 | -0.193 ± 0.080 |   | -0.019 ± 0.016 |   |   |   | 1.311 ± 0.218 | 6 | -84.1 | 1.0 | 0.07 |
| 5 |  -0.006 ± 0.005 |   |   | 0.040 ± 0.173 |   |   | 0.004 ± 0.005 | 1.328 ± 0.219 | 6 | -83.8 | 1.3 | 0.05 |
| 6 |  -0.002 ± 0.001 |   |  -0.368 ± 0.165 |   |   |   |   | 1.293 ± 0.291 | 6 | -83.7 | 1.5 | 0.05 |
| 7 |  -0.002 ± 0.001 |   |   | 0.171 ± 0.074 |   |   |   | 1.384 ± 0.217 | 6 | -83.6 | 1.5 | 0.05 |
| 8 |  -0.002 ± 0.001 | -0.110 ± 0.086 |   | 0.210 ± 0.080 |   |   |   | 1.331 ± 0.220 | 7 | -83.3 | 1.8 | 0.04 |
| 9 |  -0.002 ± 0.001 |   |  -0.319 ± 0.569 |   |   |  -0.001 ± 0.001 |   | 1.278 ± 0.215 | 6 | -83.2 | 2.0 | 0.04 |
| 10 |  -0.002 ± 0.001 | 0.002 ± 0.081 |  -0.348 ± 0.165 |   |   |   |   | 1.279 ± 0.220 | 6 | -83.2 | 2.0 | 0.04 |
| 11 |  -0.002 ± 0.001 |   | 0.504 ± 0.863 | 0.169 ± 0.133 |   |  -0.010 ± 0.012 |   | 1.336 ± 0.220 | 7 | -82.9 | 2.3 | 0.03 |
| 12 |  -0.002 ± 0.001 |   |  -0.222 ± 0.224 | 0.102 ± 0.221 |   |   |   | 1.341 ± 0.221 | 7 | -82.7 | 2.5 | 0.03 |
| 13 |  -0.002 ± 0.001 | -0.074 ± 0.104 |  -0.098 ± 0.268 | 0.154 ± 0.131 |   |   |   | 1.303 ± 0.221 | 7 | -82.7 | 2.6 | 0.03 |
| 14 |  -0.001 ± 0.004 | -0.040 ± 0.207 |   | 0.177 ± 0.096 |  -0.001 ± 0.004 |   |   | 1.329 ± 0.228 | 7 | -82.6 | 2.7 | 0.03 |
| 15 |  -0.002 ± 0.001 |  |  |  |  |  |   | 1.317 ± 0.217 | 4 | -82.5 | 2.7 | 0.03 |
| 16 |  -0.006 ± 0.005 |  |   | 0.487 ± 0.173 |   |   | 0.004 ± 0.005 | 1.348 ± 0.222 | 7 | -82.5 | 2.7 | 0.03 |
| 17 |  -0.001 ± 0.010 |   |  -0.242 ± 0.442 | 0.112 ± 0.218 |   |   |  -0.001 ± 0.010 | 1.322 ± 0.220 | 7 | -82.3 | 3.0 | 0.02 |
| (b) Pará |
| 1 |   |  -0.119 ± 0.051 |  0.205 ± 0.083 | 0.328 ± 0.127 |   |   |   |   | 6 | 1.18 | 0.00 | 0.16 |
| 2 |  -0.013 ± 0.005 |   | 0.139 ± 0.072 | 0.233 ± 0.274 |   |   | 0.011 ± 0.005 |   | 7 | 1.83 | 0.65 | 0.12 |
| 3 |   |  -0.012 ± 0.052 | 0.175 ± 0.083 | 0.257 ± 0.122 |   |   |   |   | 5 | 2.23 | 1.06 | 0.09 |
| 4 |  -0.002 ± 0.002 |  -0.104 ± 0.054 | 0.202 ± 0.083 | 0.494 ± 0.219 |   |   |   |   | 7 | 2.23 | 1.06 | 0.09 |
| 5 |  -0.002 ± 0.002 |  -0.108 ± 0.054 | 0.174 ± 0.083 | 0.447 ± 0.220 |   |   |   |   | 6 | 3.08 | 1.90 | 0.06 |
| 6 |  -0.011 ± 0.005 |   |   | 0.200 ± 0.280 |   |   | 0.010 ± 0.005 |   | 6 | 3.80 | 2.62 | 0.04 |
| 7 |  -0.003 ± 0.002 |   | 0.121 ± 0.073 | 0.578 ± 0.220 |   |   |   |   | 6 | 4.19 | 3.01 | 0.03 |
| 8 |  -0.005 ± 0.004 |  -0.235 ± 0.160 | 0.170 ± 0.083 | 0.539 ± 0.246 | 0.001 ± 0.002 |   |   |   | 7 | 4.30 | 3.12 | 0.03 |
| 9 |  -0.010 ± 0.005 |   |   | 0.221 ± 0.283 |   |   | 0.008 ± 0.005 |   | 5 | 4.39 | 3.21 | 0.03 |
| 10 |  -0.011 ± 0.005 |   | 0.095 ± 0.071 | 0.248 ± 0.282 |   |   | 0.009 ± 0.005 |   | 6 | 4.48 | 3.30 | 0.03 |
| 11 |  -0.006 ± 0.006 |  -0.085 ± 0.063 | 0.159 ± 0.085 | 0.317 ± 0.284 |   |   | 0.004 ± 0.006 |   | 7 | 4.49 | 3.31 | 0.03 |
| 12 |  -0.001 ± 0.003 |  -0.109 ± 0.055 | 0.337 ± 0.262 | 0.448 ± 0.222 |   |  -0.002 ± 0.003 |   |   | 7 | 4.61 | 3.43 | 0.03 |

|  |
| --- |
| (a) Bahia |
| Model | SC ± SE | FC ± SE | FF ± SE | LD ± SE | CCI ± SE | MA ± SE | SA ± SE | SC \* CCI ± SE | SC \* FF ± SE | SC \* FC ± SE | SC \* LD ± SE | CCI \* FC ± SE | df | AIC | ∆AIC | W |
| 1 |  1.581 ± 0.003 |  -0.005 ± 0.001 |  -0.126 ± 0.247 | 0.630 ± 0.181 |  |  |  |  |  |  |  |  | 8 | 279.8 | 0.0 | 0.16 |
| 2 |  |  |  -0.115 ± 0.245 |  -0.083 ± 0.306 |  -0.727 ± 0.348 |  |  |  |  |  |  |  | 8 | 280.8 | 0.9 | 0.10 |
| 3 |  -0.162 ± 0.060 |  |  -0.109 ± 0.025 | 0.323 ± 0.173 |  -0.278 ± 0.85 |  |  | 0.229 ± 0.106 |  |  |  |  | 8 | 280.8 | 1.0 | 0.10 |
| 4 | 0.151 ± 0.065 |  |  -0.113 ± 0.025 | 0.507 ± |  -0.156 ± 0.059 |  -1.480 ± 0.062 |  |  |  |  |  |  | 8 | 281.2 | 1.3 | 0.08 |
| 5 | 0.150 ± 0.065 |  |  -0.117 ± 0.025 | 0.596 ± 0.185 |  |  -1.326 ± 0.085 |  -0.007 ± 0.002 |  |  |  |  |  | 8 | 281.7 | 1.8 | 0.06 |
| 6 | 0.151 ± 0.065 |  |  -0.112 ± 0.025 |  -0.154 ± 0.310 |  -0.595 ± 0.240 |   |  |  |  |  |  |  | 8 | 281.8 | 1.9 | 0.06 |
| 7 | 0.050 ± 0.215 |  |  -0.055 ± 0.028 |  |  -0.306 ± 0.084 |   |  | 0.236 ± 0.104 |  -0.056 ± 0.037 |  |  |  | 7 | 281.9 | 2.0 | 0.05 |
| 8 | 0.174 ± 0.159 |  |  -0.084 ± 0.022 |  |  -0.308 ± 0.085 |  -0.934 ± 0.055 |  |  0.238 ± 0.105 |  |  |  |  | 8 | 282.1 | 2.2 | 0.05 |
| 9 |  |  -0.003 ± 0.001 |  -0.123 ± 0.907 | 0.636 ± 0.181 |  |   |  -0.004 ± 0.003 |  |  |  |  |  | 8 | 282.3 | 2.4 | 0.04 |
| 10 |  |  -0.005 ± 0.001 |  -0.126 ± 0.024 | 0.642 ± 0.181 |  |  -0.819 ± 0.050 |  |  |  |  |  |  | 8 | 282.6 | 2.8 | 0.04 |
| 11 | 0.397 ± 0.161 |  -0.004 ± 0.001 |  -0.091 ± 0.031 | 0.429 ± 0.170 |  |   |  |  |  |  |  |  | 7 | 283.4 | 3.5 | 0.02 |
| 12 |  |  |  -0.113 ± 0.867 | 0.543 ± 0.185 |  -0.120 ± 0.062 |   |  -0.005 ± 0.003 |  |  |  |  |  | 8 | 283.4 | 3.5 | 0.02 |
| 13 |  -0.184 ± 0.159 |  |  -0.078 ± 0.024 |  |  -0.322 ± 0.084 |  -0.802 ± 0.050 |  |  0.245 ± 0.010 |  |  -0.003 ± 0.003 |  |  | 8 | 283.5 | 3.7 | 0.02 |
| 14 |  |  -0.003 ± 0.024 |  -0.121 ± 0.024 | 0.423 ± 0.186 |  |   |  |  |  |  |  |  -0.007 ± 0.004 | 8 | 283.7 | 3.8 | 0.02 |
| (b) Pará |
| 1 |  -1.144 ± 0.515 |  |  |  -0.608 ± 0.393 | 0.009 ± 0.097 |  |  |  0.524 ± 0.152 |  |  |  1.430 ± 0.573 |  | 8 | 208.3 | 0.0 | 0.26 |
| 2 |  -0.842 ± 0.317 |  |  -0.069 ± 0.061 |  | 0.055 ± 0.090 |  |  |  0.336 ± 0.136 |  0.213 ± 0.095 |  |  |  | 8 | 209.8 | 1.5 | 0.12 |
| 3 |  0.815 ± 0.516 | 0.006 ± 0.004 |  |  | 0.047 ± 0.092 |  |  | 0.369 ± 0.132 |  |  -0.167 ± 0.007 |  |  | 6 | 210.2 | 1.8 | 0.10 |
| 4 |  -0.224 ± 0.162 |  |  |  | 0.064 ± 0.093 |  |  | 0.340 ± 0.139 |  |  |  |  | 8 | 211.1 | 2.7 | 0.06 |
| 5 |  -0.219 ± 0.163 |  |  |  | 0.051 ± 0.094 | 0.008 ± 0.001 |  |  3.346 ± 0.139 |  |  |  |  | 7 | 211.6 | 3.2 | 0.05 |
| 6 |  -0.229 ± 0.162 | 0.002 ± 0.004 |  |  | 0.059 ± 0.093 |  |  |  0.340 ± 0.139 |  |  |  |  | 7 | 212.0 | 3.6 | 0.04 |
| 7 |  |  |  |  | 0.182 ± 0.078 |  |  |  |  |  |  |  | 4 | 212.1 | 3.7 | 0.04 |
| 8 |  -0.219 ± 0.165 |  |  |  -0.107 ± 0.339 | 0.054 ± 0.097 |  |  |  0.335 ± 0.140 |  |  |  |  | 7 | 212.1 | 3.7 | 0.04 |
| 9 |  |  |  |  |  |  |  |  |  |  |  |  | 7 | 212.2 | 3.8 | 0.03 |

**Supplementary table 3.** Most parsimonious models obtained for the analyses of small and large-scale cocoa farming with recent cocoa productivity data. Model selection was based on the Akaike Information Criterion (AIC). The best models (i.e. those with ΔAIC < 4) are presented, where ΔAIC = AIC difference between the model and the model with the smallest AIC (Model 1). W: model weight according to the ΔAIC; df: degrees of freedom of each model. Blanks indicate that the variable was not included in the model. + = inclusion of categorical variable, \* = interaction between variables. *Acronyms*: SC: scale of farming (small vs. large, the last being the reference level), FC: forest cover percentage, FF: forest fragmentation (edge density of natural forest), LD: landscape diversity, CCI: cocoa cropland importance on a logarithmic scale, MA: municipality area and SA: spatial autocorrelation.



**Supplementary figure 1:** Spatial correlograms showing the degree of spatial autocorrelation (Moran’s I) among municipalities for each response variable (a, c, e and g) and the residuals of the final global GLM or GLMM model appropriate to each response (b, d, f and h).