14 Terrestrial biodiversity

The following protocol describes the contribution of global terrestrial biodiversity models to ISIMIP2b. Biodiversity is influenced by both climate and land-use change, as well as the biome changes resulting from these drivers. All of these drivers will be considered in terrestrial biodiversity simulations.

Different model types may be used to simulate terrestrial biodiversity, such as correlative species distribution models (SDMs), macroecological species-richness models (MEMs), process-based biodiversity models, and others. There are no restrictions regarding the model type, as long as the methodology has been documented in previous peer-reviewed publications.

In its initial stage, this protocol focuses on correlative SDMs and MEMs; it will be amended with the needs and requirements of other model types as required.

Species distribution models are used to identify the potential climatic niche of a species and so allow to predict a species' probability of occurrence under present and future climatic conditions. Running these models for multiple species, one can aggregate the individual occurrence probabilities to a summed probability of occurrence (a proxy of species richness).

Species distribution data, in combination with the observed climate dataset "EWEMBI" provided by ISIMIP, are used for the initial model construction (i.e., model calibration). Biodiversity projections are then calculated using the ISIMIP2b bias-corrected GCM data.

The effects of biome and land-use changes on biodiversity are currently not considered. In the future, biome and land-use changes may be directly used as predictor variables during model construction.

14.1 Scenarios

Climate scenarios	
picontrol	Pre-industrial climate (year specific for the entire period 1661-2299).
historical	Historical climate.
rcp26	Future climate from RCP2.6.
rcp60	Future climate from RCP6.0.
rcp85	Future climate from RCP8.5.
Human influences scenarios	
nosoc	No human influences considered.

Table 50 ISIMIP2b scenarios for global (and potentially regional) terrestrial biodiversity simulations.

	Experiment	Input	Pre-industrial 1660-1860	Historical 1861-2005[1]	Future 2006-2099[2]2	Extended future 2101-2299[3]
I	pre-industrial climate	Climate	**picontrol**	**picontrol**	**picontrol**	**picontrol**
	no other human influences	Human & LU	**nosoc**	**nosoc**	**nosoc**	**nosoc**
II	RCP2.6 climate	Climate	Experiment I	**historical**	**rcp26**	**rcp26**
	no other human influences	Human & LU		**nosoc**	**nosoc**	**nosoc**
III	RCP6.0 climate	Climate	Experiment I	Experiment II	**rcp60**	not simulated
	no other human influences	Human & LU			**nosoc**	
IV-VII	not simulated					
VIII	RCP8.5 climate	Climate	Experiment I	Experiment II	**rcp85**	not simulated
	no other human influences	Human & LU			**nosoc**	

* For now, only correlative species distribution models are considered. Additional scenario combinations will be contributed from other model types in due time.

[1] For the Terrestrial biodiversity sector, “historical” refers to a 30-year period of current conditions (i.e., 1976-2005).

[2] Within these long-term time periods, biodiversity models will be run for average conditions of selected 30-year periods (2006-2035, 2036-2065, 2066-2095)and the 30-year periods centered around the 1.5°C GCM-specific Global Mean Temperature (GMT) thresholds (1996-2025, 2012-2041, 2018-2047, 2034-2063, 2038-2067, 2042-2071) provided by ISIMIP (https://www.isimip.org/protocol/temperature-thresholds-and-time-slices/) are considered.

[3] Within this extended-future time period, biodiversity models will be run for average conditions of selected 30-year periods (2086-2115, 2136-2165, 2186-2215, 2236-2265).

14.2 Output data

Table 51 Output variables to be reported by terrestrial biodiversity sector models.

Variable (long name)	Variable name	Unit (NetCDF format)	Resolution	Comments
Amphibian species probability of occurrence	**amphibianprob**	Probability of occurrence per cell[2]	30-year averages of selected time periods[1] (0.5°x0.5°)	Results from individual SDMs assuming full dispersal[3]
Terrestrial bird species probability of occurrence	**birdprob**			
Terrestrial mammal species probability of occurrence	**mammalprob**			
Amphibian summed probability of occurrence	**amphibiansumprob**	Summed probability of occurrence per cell[2]	30-year averages of selected time periods[1] (0.5°x0.5°)	Aggregated results from individual SDMs with different dispersal scenarios[4]
Terrestrial bird summed probability of occurrence	**birdsumprob**			
Terrestrial mammal summed probability of occurrence	**mammalsumprob**			
Summed probability of endemic amphibian species[5]	**endamphibiansumprob**			
Summed probability of endemic terrestrial bird species[5]	**endbirdsumprob**			
Summed probability of endemic terrestrial mammal species[5]	**endmammalsumprob**			
Summed probability of threatened amphibian species[6]	**thramphibiansumprob**			
Summed probability of threatened terrestrial bird species[6]	**thrbirdsumprob**			
Summed probability of threatened terrestrial mammal species[6]	**thrmammalsumprob**			
Amphibian species richness	**amphibiansr**	Estimated number of species (species richness) per cell	30-year averages of selected time periods[1] (0.5°x0.5°)	Results from macroecological richness models
Terrestrial bird species richness	**birdsr**			

Terrestrial mammal species richness	**mammalsr**			

[1] Currently the following 30-year periods (2006-2035, 2036-2065, 2066-2095, 2086-2115, 2136-2165) and the 30-year periods centered around the 1.5°C GCM-specific Global Mean Temperature (GMT) thresholds (1996-2025, 2012-2041, 2018-2047, 2034-2063, 2038-2067, 2042-2071) provided by ISIMIP (https://www.isimip.org/protocol/temperature-thresholds-and-time-slices/) are considered.

[2] For the Maximum Entropy (MaxEnt) model algorithm the output is not probability, but habitat suitability/relative occurrence probability. Values also range between 0 and 1.

[3] Probability of occurrence is projected to the currently present and all neighbouring realms of a species and so sort of represents the unlimited dispersal of a species into the future.

[4] Summed probability of occurrence is calculated for different dispersal scenarios (no dispersal, 0.5*d, 1*d, 2*d, full dispersal). Full dispersal represents the sum of the probability of occurrence output files. No dispersal assumes that species can only be present where they are actually present according to the IUCN and BirdLife range maps. The other three dispersal scenarios consider species-specific dispersal buffers added to the present range, where **d** is the largest diameter of the original range of the species.

[5] Endemic (range-restricted) species are the smallest ranging 15% of all species.

[6] Threatened species are all species that are (i) either critically endangered, (ii) endangered or (iii) vulnerable according to their IUCN red list status.

15 References

Bolt, J. and van Zanden, J. L.: The Maddison Project: collaborative research on historical national accounts, Econ. Hist. Rev., 67(3), 627–651, 2014.

Choulga, M., Kourzeneva, E., Zakharova, E. and Doganovsky, A.: Estimation of the mean depth of boreal lakes for use in numerical weather prediction and climate modelling, Tellus A Dyn. Meteorol. Oceanogr., 66(1), 21295, doi:10.3402/tellusa.v66.21295, 2014.

Dellink, R., Chateau, J., Lanzi, E. and Magné, B.: Long-term economic growth projections in the Shared Socioeconomic Pathways, Glob. Environ. Chang., doi:10.1016/j.gloenvcha.2015.06.004, 2015.¶

Elliott, J. and Müller, C. and Deryng, D. and Chryssanthacopoulos, J. and Boote, K. J. and Büuchner, M. and Foster, I. and Glotter, M. and Heinke, J. and Iizumi, T. and Izaurralde, R. C. and Mueller, N. D. and Ray, D. K. and Rosenzweig, C. and Ruane, A. C. and Sheffield, J.: The Global Gridded Crop Model Intercomparison: data and modeling protocols for Phase 1 (v1.0), Geosci. Model Dev., 8, 261–277, https://doi.org/10.5194/gmd-8-261-2015, 2015.

Frieler, K., Lange, S., Piontek, F., Reyer, C. P. O., Schewe, J., Warszawski, L., Zhao, F., Chini, L., Denvil, S., Emanuel, K., Geiger, T., Halladay, K., Hurtt, G., Mengel, M., Murakami, D., Ostberg, S., Popp, A., Riva, R., Stevanovic, M., Suzuki, T., Volkholz, J., Burke, E., Ciais, P., Ebi, K., Eddy, T. D., Elliott, J., Galbraith, E., Gosling, S. N., Hattermann, F., Hickler, T., Hinkel, J., Hof, C., Huber, V., Jägermeyr, J., Krysanova, V., Marcé, R., Müller Schmied, H., Mouratiadou, I., Pierson, D., Tittensor, D. P., Vautard, R., van Vliet, M., Biber, M. F., Betts, R. A., Bodirsky, B. L., Deryng, D., Frolking, S., Jones, C. D., Lotze, H. K., Lotze-Campen, H., Sahajpal, R., Thonicke, K., Tian, H., and Yamagata, Y.: Assessing the impacts of 1.5 °C global warming – simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b), Geosci. Model Dev., 10, 4321-4345, https://doi.org/10.5194/gmd-10-4321-2017, 2017.

Gasparrini A, Leone M. Attributable risk from distributed lag models. BMC Med Res Methodol. 2014 Apr 23;14:55. doi: 10.1186/1471-2288-14-55. PMID: 24758509; PMCID: PMC4021419.¶

Haith, D. A. and Shoemaker., L. L.: Generalized Watershed Loading Functions for stream flow nutrients, Water Resour. Bull., 23, 471–478, 1987.

Håkanson, L. Models to predict Secchi depth in small glacial lakes. *Aquatic Science* **57,** 31–53 (1995). https://doi.org/10.1007/BF00878025¶

Hinkel, Jochen and Lincke, Daniel and Vafeidis, Athanasios T. and Perrette, Mahé and Nicholls, Robert James and Tol, Richard S. J. and Marzeion, Ben and Fettweis, Xavier and Ionescu, Cezar and Levermann, Anders: Coastal flood damage and adaptation costs under 21st century sea-level rise, Proceedings of the National Academy of Sciences, 111 (9): 3292-3297; DOI: 10.1073/pnas.1222469111, 2014.¶

Hurtt, G. C., L. Chini, R. Sahajpal, S. Frolking, B. L. Bodirsky, K. Calvin, J. C. Doelman, J. Fisk, S. Fujimori, K. K. Goldewijk, T. Hasegawa, P. Havlik, A. Heinimann, F. Humpenöder, J. Jungclaus, Jed Kaplan, J. Kennedy, T. Kristzin, D. Lawrence, P. Lawrence, L. Ma, O. Mertz, J. Pongratz, A. Popp, B. Poulter, K. Riahi, E. Shevliakova, E. Stehfest, P. Thornton, F. N. Tubiello, D. P. van Vuuren, X. Zhang (2020). Harmonization of Global Land-Use Change and Management for the Period 850-2100 (LUH2) for CMIP6.Geoscientifc Model Development Discussions. https://doi.org/10.5194/gmd-2019-360

Klein Goldewijk, K., Beusen, A., Doelman, J., and Stehfest, E.: Anthropogenic land use estimates for the Holocene – HYDE 3.2, Earth Syst. Sci. Data, 9, 927-953, https://doi.org/10.5194/essd-9-927-2017, 2017. ¶

Kopp, Robert E. and Horton, Radley M. and Little, Christopher M. and Mitrovica, Jerry X. and Oppenheimer, Michael and Rasmussen, D. J. and Strauss, Benjamin H. and Tebaldi, Claudia: Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites, Earth's Future, 2 (8): 383-406, https://doi.org/10.1002/2014EF000239, 2014.¶

Kopp, Robert E. and Kemp, Andrew C. and Bittermann, Klaus and Horton, Benjamin P. and Donnelly, Jeffrey P. and Gehrels, W. Roland and Hay, Carling C. and Mitrovica, Jerry X. and Morrow, Eric D. and Rahmstorf, Stefan: Temperature-driven global sea-level variability in the Common Era, Proceedings of the National Academy of Sciences, 113 (11): E1434--E1441, doi:10.1073/pnas.1517056113, 2016.¶

Kourzeneva, E. 2009. Global dataset for the parameterization of lakes in numerical weather prediction and climate modelling. ALADIN Newsletter. 37, July_December, (eds. F. Bouttier and C. Fischer), Meteo-France, Toulouse, France, 46_53.

Kourzeneva, E.: External data for lake parameterization in Numerical Weather Prediction and climate modeling, Boreal Environ. Res., 15(2), 165–177, 2010.

Lange, S.: Bias correction of surface downwelling longwave and shortwave radiation for the EWEMBI dataset, Earth Syst. Dynam., 9, 627–645, https://doi.org/10.5194/esd-9-627-2018, 2018.¶

Lamarque, J. F., Dentener, F., McConnell, J., Ro, C. U., Shaw, M., Vet, R., Bergmann, D., Cameron-Smith, P., Dalsoren, S., Doherty, R., Faluvegi, G., Ghan, S. J., Josse, B., Lee, Y. H., Mackenzie, I. a., Plummer, D., Shindell, D. T., Skeie, R. B., Stevenson, D. S., Strode, S., Zeng, G., Curran, M., Dahl-Jensen, D., Das, S., Fritzsche, D. and Nolan, M.: Multi-model mean nitrogen and sulfur deposition from the atmospheric chemistry and climate model intercomparison project (ACCMIP): Evaluation of historical and projected future changes, Atmos. Chem. Phys., 13(16), 7997–8018, doi:10.5194/acp-13-7997-2013, 2013a.

Lamarque, J. F., Shindell, D. T., Josse, B., Young, P. J., Cionni, I., Eyring, V., Bergmann, D., Cameron-Smith, P., Collins, W. J., Doherty, R., Dalsoren, S., Faluvegi, G., Folberth, G., Ghan, S. J., Horowitz, L. W., Lee, Y. H., MacKenzie, I. a., Nagashima, T., Naik, V., Plummer, D., Righi, M., Rumbold, S. T., Schulz, M., Skeie, R. B., Stevenson, D. S., Strode, S., Sudo, K., Szopa, S., Voulgarakis, a. and Zeng, G.: The atmospheric chemistry and climate model intercomparison Project (ACCMIP): Overview and description of models, simulations and climate diagnostics, Geosci. Model Dev., 6(1), 179–206, doi:10.5194/gmd-6-179-2013, 2013b.

De Lary, R.: Massif des Landes de Gascogne. II – ETAT DES CONNAISSANCES TECHNIQUES, Bourdeaux., 2015.

Lehner, B. and Döll, P.: Development and validation of a global database of lakes, reservoirs and wetlands, J. Hydrol., 296(1–4), 1–22, doi:10.1016/J.JHYDROL.2004.03.028, 2004.

Millero FJ & Poisson A: International one-atmosphere equation of state of seawater. Deep-Sea Research, 28, 625–629, 1981.

Monfreda, C., Ramankutty, N. and Foley, J. A.: Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000, Glob. Biogeochem. Cycles, 22(GB1022), doi:10.1029/2007GB002947., 2008.

Müller Schmied, H., Adam, L., Eisner, S., Fink, G., Flörke, M., Kim, H., Oki, T., Portmann, F. T., Reinecke, R., Riedel, C., Song, Q., Zhang, J. and Döll, P.: Impact of climate forcing uncertainty and human water use on global and continental water balance components, Proc. Int. Assoc. Hydrol. Sci., 93, doi:10.5194/piahs-93-1-2016, 2016.

Murakami, D. and Yamagata, Y.: Estimation of gridded population and GDP scenarios with spatially explicit statistical downscaling, [online] Available from: http://arxiv.org/abs/1610.09041 (Accessed 29 May 2017), 2016.

Popp, A., Humpenöder, F., Weindl, I., Bodirsky, B. L., Bonsch, M., Lotze-Campen, H., Müller, C., Biewald, A., Rolinski, S., Stevanovic, M. and Dietrich, J. P.: Land-use protection for climate change mitigation, Nat. Clim. Chang., 4(December), 2–5, doi:10.1038/nclimate2444, 2014.

Reyer, C. P. O., Silveyra Gonzalez, R., Dolos, K., Hartig, F., Hauf, Y., Noack, M., Lasch-Born, P., Rötzer, T., Pretzsch, H., Meesenburg, H., Fleck, S., Wagner, M., Bolte, A., Sanders, T. G. M., Kolari, P., Mäkelä, A., Vesala, T., Mammarella, I., Pumpanen, J., Collalti, A., Trotta, C., Matteucci, G., D'Andrea, E., Foltýnová, L., Krejza, J., Ibrom, A., Pilegaard, K., Loustau, D., Bonnefond, J.-M., Berbigier, P., Picart, D., Lafont, S., Dietze, M., Cameron, D., Vieno, M., Tian, H., Palacios-Orueta, A., Cicuendez, V., Recuero, L., Wiese, K., Büchner, M., Lange, S., Volkholz, J., Kim, H., Horemans, J. A., Bohn, F., Steinkamp, J., Chikalanov, A., Weedon, G. P., Sheffield, J., Babst, F., Vega del Valle, I., Suckow, F., Martel, S., Mahnken, M., Gutsch, M., and Frieler, K.: The PROFOUND Database for evaluating vegetation models and simulating climate impacts on European forests, Earth Syst. Sci. Data, 12, 1295–1320, https://doi.org/10.5194/essd-12-1295-2020, 2020. ¶

Samir, C. and Lutz, W.: The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100, Glob. Environ. Chang., doi:10.1016/j.gloenvcha.2014.06.004, 2014.

Schneiderman, E. M., Pierson, D. C., Lounsbury, D. G. and Zion, M. S.: Modeling the hydrochemistry of the Cannonsville watershed with Generalized Watershed Loading Functions (GWLF), J. Am. Water Resour. Assoc., 38, 1323–1347, 2002.¶

Shatwell (unpubl.)

Stevanović, M., Popp, A., Lotze-Campen, H., Dietrich, J. P., Müller, C., Bonsch, M., Schmitz, C., Bodirsky, B., Humpenöder, F. and Weindl, I.: High-end climate change impacts on agricultural welfare, Sci. Adv., 2016.

Subin, Z. M., Riley, W. J. and Mironov, D.: An improved lake model for climate simulations: Model structure, evaluation, and sensitivity analyses in CESM1, J. Adv. Model. Earth Syst., 4(1), M02001, doi:10.1029/2011MS000072, 2012.

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., Tramberend, S., Satoh, Y., Van Vliet, M. T. H., Yillia, P., Ringler, C., Burek, P. and Wiberg, D.: Modeling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches, Geosci. Model Dev., 9(1), 175–222, doi:10.5194/gmd-9-175-2016, 2016.¶