

WildMAPS: A Global repository and visualisation tool for habitat suitability predictions

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Abstract

1 The Global Biodiversity Framework outlines a consensus of global targets for reversing the
2 decline of biodiversity. A core theme that underpins the framework is the identification of areas
3 that hold the most potential for realising positive outcomes for biodiversity. Identifying these
4 areas is a complex process involving large scientific datasets and stakeholders from a range of
5 background and disciplines. Habitat suitability models are a class of ecological models that
6 identifies the habitat preferences of a species as a function of their observed distribution. Despite
7 the central importance of these predictions to meeting global biodiversity targets, its use outside
8 academia has been limited by academic journal paywalls, inconsistent reporting formats and
9 technical statistical language. Overcoming these limitations presents an invaluable opportunity
10 to increase the accessibility and usability of species predictions conservation decision-making.
11 To that end, we developed WildMAPS- an open-source lightweight web platform that stores and
12 visualises habitat suitability model predictions published in academic journals. To date, the
13 platform hosts predictions of 52 taxa from three regions of biodiversity significance on an
14 interactive GIS application. The published application marks the first step towards the
15 harmonisation of published species predictions on a single platform that will facilitate the use of
16 predictions in optimising resources for achieving local and global biodiversity targets.

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19 Keywords: biodiversity, habitat suitability modelling, web-based platform;

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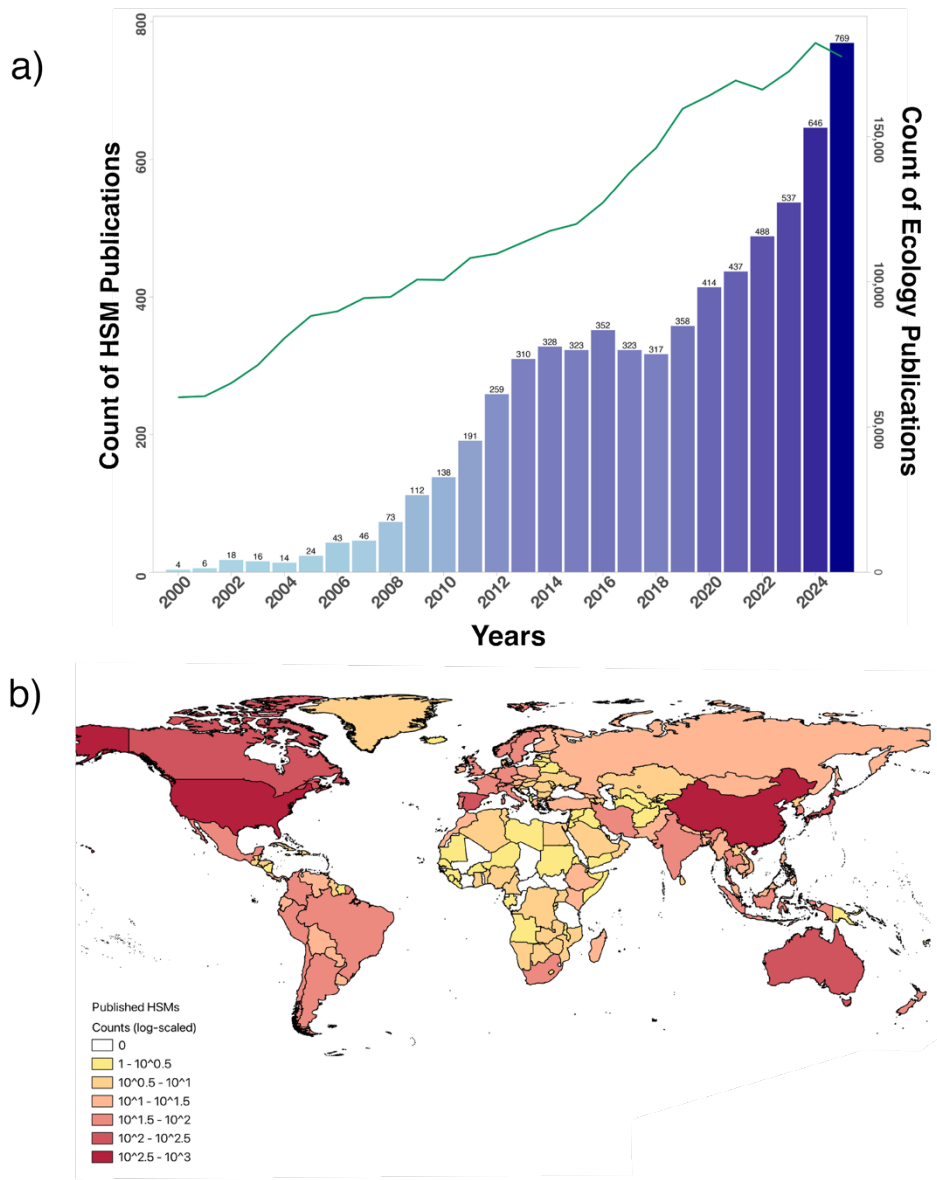
21 Introduction

22 Human activities have transformed most of the global terrestrial surface (Ellis et al. 2021), placing
23 unprecedented pressure on Earth's ecosystems and biodiversity (Semenchuk et al. 2022). For
24 ecosystems, these pressures have impaired nature's capacity to self-regulate, reducing key
25 ecosystem functions and services, including air and water quality regulation, carbon
26 sequestration, soil formation, and pollination (Díaz et al. 2019). An indicator frequently used to
27 measure overall impact on ecosystems is biodiversity. Approximately 21% of the species
28 assessed to date are threatened with extinction (IUCN, 2025). Global wild vertebrate biomass has
29 declined by over 80%, and substantial contractions in species' geographic ranges have been
30 documented across taxa (Díaz et al. 2019).

31 How species select and respond to their environment is a central question in ecology (Sutherland
32 et al., 2009). This question has inspired the proliferation of statistical modelling frameworks that
33 use empirical data on species occurrences to understand the specific environmental drivers that
34 defines suitable habitat for a species (Fletcher and Fortin, 2018). , For ease, we adopt the term
35 habitat suitability model (HSM) as terminology that more accurately encapsules a majority of
36 modelling cases that empirically predicts the suitability of habitat in a landscape based on
37 statistically parameterised relationships between a set of environmental predictors and species
38 occurrence.

39 Owing to its utility for mapping ecological patterns, habitat suitability modelling has been applied
40 to explore a wide range of questions central to conservation (Guisan et al., 2013). This trend has
41 accelerated recently due to developments in computation, remote sensing, and availability of
42 species occurrence data in global data repositories (Figure 1a and 1b) (Araújo et al., 2019).

43



44

45 Figure 1: (a) The growth of publications on habitat suitability modelling in the last 20 years has accelerated
 46 beyond the rate of increase in the field ecology representing a significant interest and attention paid to
 47 species modelling over two decades. (b) Publications were unevenly distributed across the planet with the
 48 continent of Africa recording the lowest average number of habitat suitability publications.

49 HSMs provide a foundation for diverse conservation applications, including identifying priority
 50 areas (e.g. Penjor *et al.*, 2021), evaluating protected areas effectiveness (e.g. Chiaverini *et al.*,
 51 2025), detecting biodiversity hotspots (e.g. Sartor *et al.*, 2024), assessing the spread of diseases
 52 or alien species (e.g. Burch *et al.*, 2020; Chen *et al.*, 2015), investigating landscape connectivity

53 (e.g. Youngquist and Boone, 2021, Kaszta et al., 2020), and forecasting the effects of climate
54 change (e.g Macdonald et al., 2020 and infrastructure development (e.g. Kazta et al 2019a and
55 b). Critically, these models are now being used to develop scientific consensus in major global
56 assessments on the impact of human activities on the living world. For example, IPBES
57 (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) (Ferrier et
58 al., 2016) and IUCN (International Union for Conservation of Nature) use species predictive models
59 to simulate impacts of land use change and climate scenarios (Foden and Young, 2016; Kim et
60 al., 2018)

61 Despite its growing use, the predictive outputs of HSMs remain largely inaccessible outside of
62 academia, for a variety of reasons. First, many predictive models are published in journals
63 without open access. A search on the OpenAlex research database found only 57.5% of articles
64 on habitat suitability models were open access (<https://openalex.org>, search implemented in
65 April 2026). While Open Access (OA) initiatives have been instrumental in overcoming journal
66 paywalls, these efforts do not address the second issue; data harmonisation and accessibility.
67 Modelling results and predictions, if available, are stored as raw raster files in third-party data
68 repositories or supplementary files, accessible only through technical GIS software (REF). Most
69 critically, because scientific papers are written by and for academics, their technical nature often
70 remains a barrier to non-specialist stakeholders (Cook et al., 2010). For instance, the
71 performance and accuracy of predictions are often reported using a variety of statistical metrics
72 without clear standards or benchmarks (Zurell et al., 2020).

73

74 Here, we introduce WildMAPS, an open-access digital platform designed specifically to
75 democratise the use of and increase access to published habitat suitability models of taxa from
76 across the globe. WildMAPS leverages the substantial progress in modelling ecological systems
77 and robust habitat predictions which can be deployed in an array of land use decision
78 optimisation exercises. The platform standardises, stores, and visualises published habitat

79 suitability models on a lightweight GIS interface. As an additional feature, the platform enables
80 users to view HSM predictions, whilst overlaying open-source spatial layers of relevance to land-
81 use planning with key statistics relevant to land use planners. Therefore, the broad objectives of
82 the platform are (1) to increase visibility and usability of published habitat suitability models for
83 non-scientists, (2) enable users to interact with predictions visually and compare summary
84 statistics for taxa of interest, and (3) provide a user-friendly access point to download rasters of
85 predictive maps that can be used for downstream analysis and modelling.

86 Introducing WildMAPS

87 WildMAPS is hosted on a public domain (<https://wildcru.org/map-app/>) and source-codes for all
88 raster processing and visualisation area available on Github repository
89 (<https://github.com/hkuril/WildMaps-processing>).

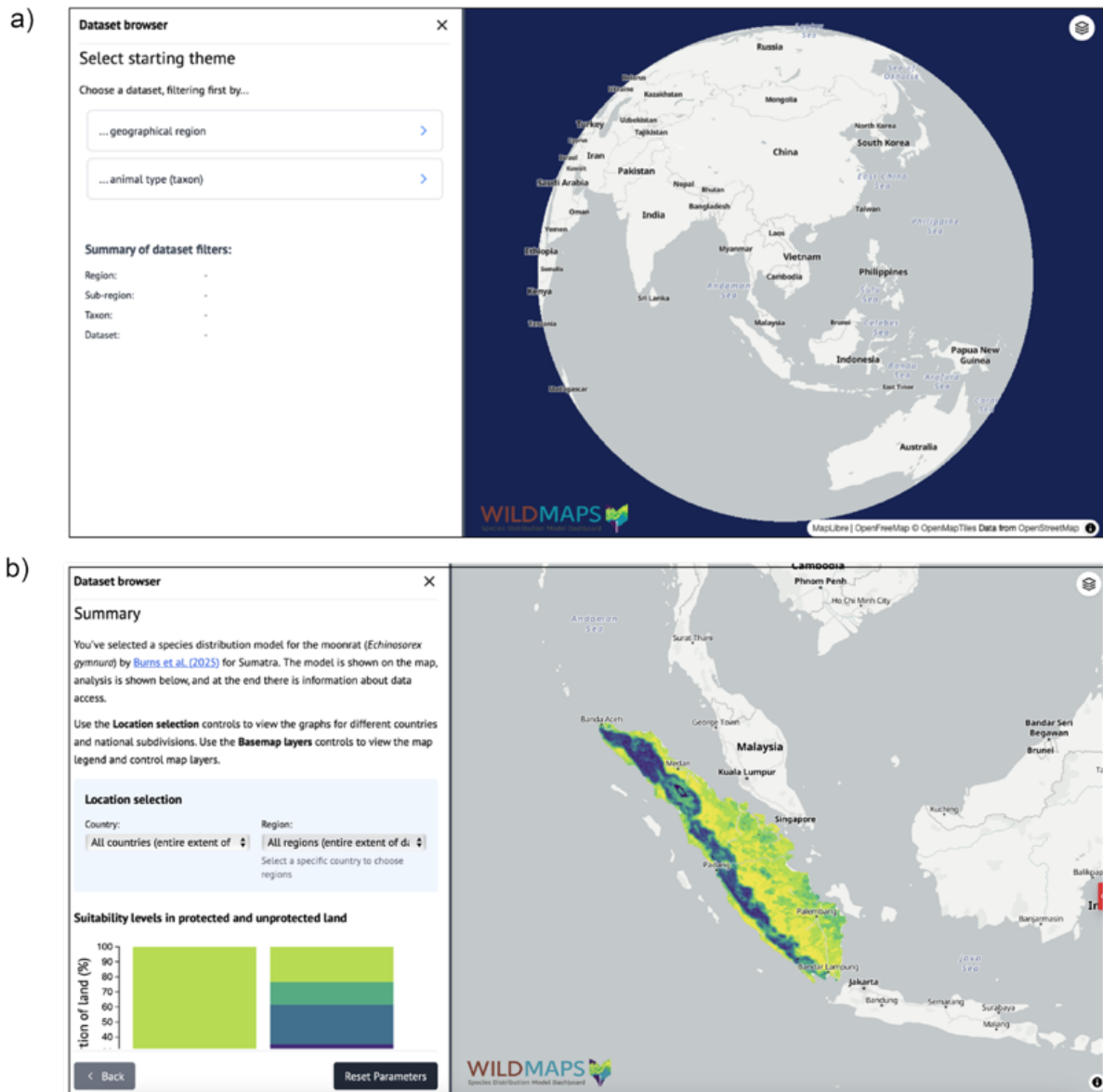
90 As a visualisation platform, WildMAPS (Figure 2a and 2b) enables scientists to systematically
91 manage and convey their modelling predictions to a wider audience of stakeholders who may
92 benefit from their use as both static maps and for downstream analysis and land use planning.

93 WildMAPS is deliberately designed as a light-weight starting point to complement existing spatial
94 analytical software such as Marxan (Watts et al., 2009) and CoLa (Jantz et al., 2025), which by
95 contrast require significant computation to run algorithms that optimise land prioritisation (Watts
96 et al., 2009), measure habitat connectivity (Hall et al., 2021; Landguth et al., 2012) , and design
97 optimal biodiversity corridors (Jantz et al., 2025).

98 In WildMAPS, we define a habitat suitability (HS) map as a raster of cells (or pixels), where each
99 cell is assigned a probability value between 0 to 1 representing the likelihood of suitable habitat
100 being present at that cell. Each published HSM uses species-environment relationships to map
101 potential distributions of a species in a specific time and place (Araújo et al., 2019). The choice
102 of where and when to map these predictions are most often a function of the question
103 investigated, and should therefore, be used within the appropriate context. The predictions of

104 habitat suitability for a given species in an area can be easily tested using an independent dataset
105 arising from new systematic surveys or opportunistic citizen science records.

106



107 Figure 2: (a) The open-access platform WildMAPS includes a dashboard that enables users to
108 easily navigate the existing database by taxa or geography. (b) The prediction map is displayed
109 using standard scales and colour ramps, while all metadata and summary statistics for the
110 chosen model is displayed on the main panel of platform.

111 Versioning

112 WildMAPS currently hosts predictions for a total of 54 taxa from three global regions, South
113 America, Southeast Asia and South Asia (as of April 2026). These are collections of models
114 developed and published by the team of co-authors in this publication. The predictions are
115 collectively visualised by taxa or region. Predictions were downloaded directly from the
116 publication and visualised in a standardised colour scheme, and scale for ease of interpretation
117 on the platform. It is however important to highlight that each prediction was derived from distinct
118 models, and therefore parameterised differently. Predictions derived from separate models are
119 therefore, not comparable. Through the online submission form, future versions of WildMAPS will
120 include predictions from HSMs developed by the large and growing international community of
121 species ecological modellers.

122 Submission process

123 Habitat suitability predictions are most usually mapped as pixel-based data files (rasters), which
124 are usually stored in the GeoTIFF format. To store and visualise predictions on WildMAPS,
125 researchers need only submit a request using an online form available on the platform (Figure 3).
126 The form requests essential pieces of metadata on authorship, publication and details on taxa
127 and geography which is used to index the platform's database. Authors also upload a technical
128 file that outlines modelling methodology and performance as a means of making the quality and
129 reliability of a prediction transparent to the users without needing access to the full publication.
130 We also ask that rasters are stored in a public data repository such as Zenodo, FigShare or DRYAD
131 to enable downstream use of the habitat predictions.

132 Reporting standards

133 The usability of predictions from HSMs are strongly dependent on the attributes of the dataset
134 and modelling parameters. Due to a wide variety of factors, quality of published HSMs vary widely
135 (Araújo et al., 2019; Fourcade, 2016; Fourcade et al., 2018), with an alarming proportion of

136 published models lacking sufficient rigour to be used in real-world scenario planning (Araujo et
 137 al. 2019). To this end, we have incorporated a standardised reporting framework (Table 1) around
 138 the four aspects that are imperative to the quality of a model: (i) quality of the response variable,
 139 (ii) quality of the predictor variables, (iii) model building and (iv) model evaluation (Table 1). These
 140 reports are viewable as a ‘technical report’ for all rasters available in WildMAPS. For users without
 141 sufficient experience to discern the standards reported, the platform includes a summary of
 142 specific issues to consider within each of the four aspects of modelling quality as described by a
 143 consortium of leading experts in modelling (Araujo et al. 2019). Metadata will also include contact
 144 information of corresponding author and reference to original paper (Figure 3). Users are
 145 encouraged to contact authors before deploying predictions of a model in real-world
 146 conservation scenarios.

147

148 Table 1: Examples of metrics used to report metadata on the habitat suitability model (HSM)
 149 hosted in WildMAPS. The framework categorises model quality into four critical dimensions
 150 (response variables, predictor variables, model building, and evaluation) following the quality
 151 standards proposed by Araújo et al. (2019).

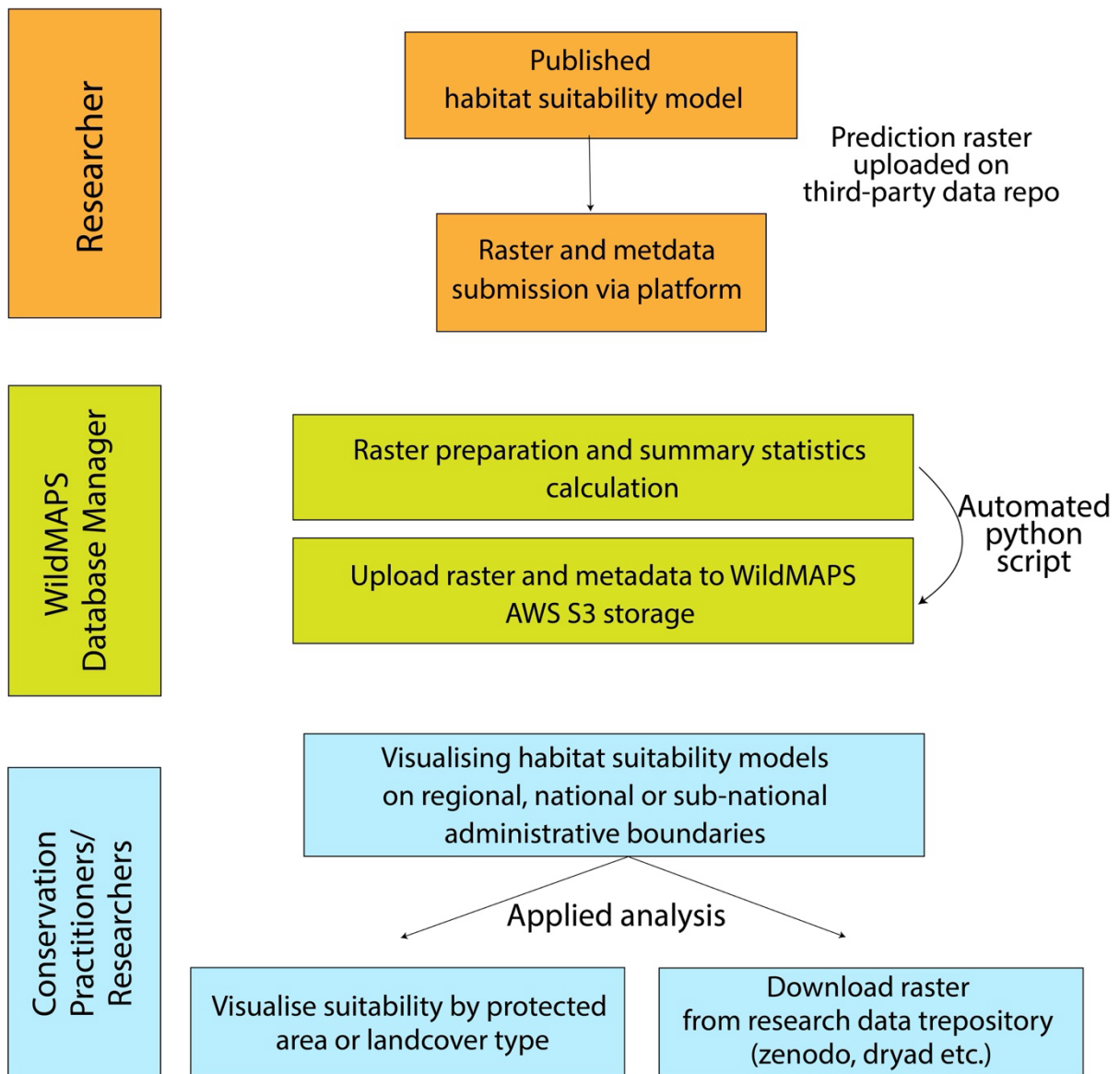
Factors	Standard	Measure/Metric
Response variable	Study design (systematic: even distribution across environmental gradient; non-systematic: biased or opportunistic)	Systematic or non-systematic
	Data source and sample size	Camera-trap, GPS collar, DNA
Predictor variables	Predictor selection	Expert-informed, statistical, correlational (distal), or causal (proximal)
	Predictors used	List of predictors and resolution used in final model
Model building	Train/Test partitioning ratio	80:20, 70:30, 60:40 etc.
	Functional form	LM, GLM, GLMM, GAM, GAMM, Occupancy, Random Forest

	Treatment of uncertainty	Data bootstrapping, multiple model-averaging, Monte-Carlo simulations of parameter estimates
Model evaluation	Evaluation data source	Independent or test data
	Model performance	R ² , Boyce Index, AUC, Cohen's kappa

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153 Summary statistics and landcover visualisation

154 To increase the utility of these maps, WildMAPS calculates summary statistics (Figure 3)
155 representing the proportion of suitable habitat within distinct spatial units, allowing stakeholders
156 to easily visualize the suitability of an area of interest for a given taxon. For convenience of
157 summary, the range of continuous probabilities for each raster are divided into four categorical
158 bins of equal width (*low suitability, medium low suitability, medium high suitability and high*
159 *suitability*), with the thresholds between each category set at 25%, 50% and 75% of the 99th
160 percentile of the highest suitability value. WildMAPS calculates the proportion of area covered by
161 each of these categories within protected areas (IUCN and UNEP-WCMC, 2025), within distinct
162 land cover categories (European Union's Copernicus Land Monitoring Service Information, 2025),
163 and within each country and first-level country subdivision (e.g. state) (Runfola et al., 2020). To
164 enable optimised discrimination between suitable and unsuitable habitat, for each given map,
165 colour scales are relative to minimum and maximum habitat suitability. An advantage of this pre-
166 calculation approach is that the resulting website app does not perform real-time calculations,
167 resulting in quicker loading times and reducing overall cloud-server costs.



170 Figure 3: Workflow designed to democratise current standards for peer-review published habitat
 171 suitability models, which include open sharing of prediction rasters and transparent reporting of
 172 metadata such as model performance, evaluation and design. Submission form available on
 173 platform collates information from paper into central database that automatically updates on the
 174 WildMAPS platform.

175 Technical Specifications

176 To ensure the longevity of the app as a resource, we designed a fast, user-friendly, intuitive
177 application, with minimal running costs. To do this, the platform's pipeline converts HSM raster
178 outputs into PNG tiles and retrieves them from Amazon Web Services S3 cloud storage. Inbuilt
179 vector layers, such as the World Database on Protected Areas (IUCN and UNEP-WCMC, 2025),
180 which can be overlaid on user-selected HSM predictive maps.

181 The WildMAPS upload pipeline utilises common raster and vector processing tools, such as data
182 reproduction, transformation and calculation of statistics via logical operations (Figure 3). We
183 used *Python v3.11.13*, with *rasterio v1.4.3* (<https://github.com/rasterio>), *shapely v2.1.1* (shapely,
184 2025), *geopandas v1.0.1* (Geopandas, 2025), and GDAL bindings to preprocess rasters and
185 automate calculation of summary statistics before upload to the platform
186 (<https://github.com/hkuril/WildMaps-processing>)

187

188 Case study of use

189 On Borneo, WildMAPS hosts habitat suitability predictions for 48 distinct species (Burns et al.,
190 2025; Gomez et al., 2025). Visualising all data available for a geography in a single platform
191 presents considerable advantages for conservation planning. Species predictions can be
192 stacked to answer macroecological questions using metrics of habitat suitability, For state
193 governments on Borneo, WildMAPS has already been used to increase accessibility to species
194 predictions, which, as an immediate result, is being used in tandem with spatial optimisation
195 algorithms such as Marxan (Watts et al., 2009) and Ebrel (Unnithan Kumar et al., 2025) for solving
196 complex land use optimisation challenges on upcoming state land use structural plans.

197 The Bornean case study demonstrates an initial but powerful example of the benefits of
198 standardising and consolidating species habitat suitability predictions in a single platform can
199 vastly improve its accessibility and use to relevant stakeholders.

200 Conclusion and vision for the future

201 Mapping the predicted available habitat for life on Earth is a key task for ecologist in the wake of
202 planetary poly-crisis. The vast number of habitat predictions that have already been published
203 presents a powerful tool for tackling these challenges, with WildMAPS solving the basic problem
204 of accessibility. In the spirit of dynamic exchange between science and practise, we encourage
205 users of WildMAPS to contact corresponding authors associated with each dataset before
206 deploying predictions in real-world scenarios.

207 For ecologist, WildMAPS can and should be used as a tool for communicating evidence-based
208 predictions on species use of habitat. At present, WildMAPS relies on researchers to proactively
209 submit their published models onto the platform. The development and growth of large language
210 models for aiding systematic reviews (Moorthy et al 2025) will support the automation,
211 consolidation and summarising of the growing body of published habitat suitability models.
212 WildMAPS is currently limited in its use to areas with existing data coverage and a legacy of
213 research interest. Therefore, the distribution of data on WildMAPS will reflect similar gaps as has
214 been identified in global biodiversity datasets to date (Amano et al., 2016; Chapman et al., 2024;
215 Faxon and Chapman, 2025)

216 We envisage that WildMAPS will help under-represented taxa and regions in the world where
217 more attention is needed. Integration with open-source biological occurrence datasets (GBIF)
218 and effective partnerships with local biologists will be crucial for filling in the gaps. These
219 combined steps will bring be necessary to making WildMAPS a truly global platform with multi-
220 taxa raster stacks of parametrised habitat suitability models for every pixel on the planet.

221

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225 References

- 226 Amano, T., Lamming, J.D., Sutherland, W.J., 2016. Spatial gaps in global biodiversity information
227 and the role of citizen science. *Bioscience* 66, 393–400.
- 228 Araújo, M.B., Anderson, R.P., Márcia Barbosa, A., Beale, C.M., Dormann, C.F., Early, R., Garcia,
229 R.A., Guisan, A., Maiorano, L., Naimi, B., O'Hara, R.B., Zimmermann, N.E., Rahbek, C.,
230 2019. Standards for distribution models in biodiversity assessments. *Science Advances*
231 5, eaat4858. <https://doi.org/10.1126/sciadv.aat4858>
- 232 Burch, C., Loraamm, R., Unnasch, T., Downs, J., 2020. Utilizing ecological niche modelling to
233 predict habitat suitability of eastern equine encephalitis in Florida. *Annals of GIS* 26,
234 133–147.
- 235 Burns, P., Kaszta, Z., Cushman, S.A., Brodie, J.F., Hakkenberg, C.R., Jantz, P., Deith, M., Luskin,
236 M.S., Ball, J.G., Mohd-Azlan, J., 2025. The utility of dynamic forest structure from GEDI
237 lidar fusion in tropical mammal species distribution models. *Frontiers in Remote*
238 *Sensing* 6, 1563430.
- 239 Chapman, M., Goldstein, B.R., Schell, C.J., Brashares, J.S., Carter, N.H., Ellis-Soto, D., Faxon,
240 H.O., Goldstein, J.E., Halpern, B.S., Longdon, J., 2024. Biodiversity monitoring for a just
241 planetary future. *Science* 383, 34–36.
- 242 Chen, D., Wong, H., Belanger, P., Moore, K., Peterson, M., Cunningham, J., 2015. Analyzing the
243 correlation between deer habitat and the component of the risk for Lyme disease in
244 Eastern Ontario, Canada: a GIS-based approach. *ISPRS International Journal of Geo-*
245 *Information* 4, 105–123.
- 246 Cook, C.N., Hockings, M., Carter, R., 2010. Conservation in the dark? The information used to
247 support management decisions. *Frontiers in Ecology and the Environment* 8, 181–186.
- 248 Delisle, Z.J., Flaherty, E.A., Nobbe, M.R., Wzientek, C.M., Swihart, R.K., 2021. Next-generation
249 camera trapping: systematic review of historic trends suggests keys to expanded
250 research applications in ecology and conservation. *Frontiers in Ecology and Evolution* 9,
251 617996.
- 252 Faxon, H., Chapman, M., 2025. Beyond spatial bias: understanding the colonial legacies and
253 contemporary social forces shaping biodiversity data. *Environmental Research Letters*
254 20, 064053.
- 255 Ferrier, S., Ninan, K., Leadley, P., Alkemade, R., Acosta, L., Akçakaya, H., Brotons, L., Cheung,
256 W., Christensen, V., Harhash, K., 2016. The methodological assessment report on
257 scenarios and models of biodiversity and ecosystem services-summary for
258 policymakers, in: *The Methodological Assessment Report on Scenarios and Models of*
259 *Biodiversity and Ecosystem Services-Summary for Policymakers*. Secretariat of the
260 Intergovernmental Science-Policy Platform on Biodiversity ..., pp. 1–32.
- 261 Foden, W.B., Young, B.E., 2016. IUCN SSC guidelines for assessing species' vulnerability to
262 climate change.
- 263 Fourcade, Y., 2016. Comparing species distributions modelled from occurrence data and from
264 expert-based range maps. Implication for predicting range shifts with climate change.
265 *Ecological Informatics* 36, 8–14. <https://doi.org/10.1016/j.ecoinf.2016.09.002>

266 Fourcade, Y., Besnard, A.G., Secondi, J., 2018. Paintings predict the distribution of species, or
267 the challenge of selecting environmental predictors and evaluation statistics. *Global*
268 *Ecology and Biogeography* 27, 245–256. <https://doi.org/10.1111/geb.12684>
269 Geopandas, 2025. geopandas.
270 Gomez, C.R., Kitchener, A.C., Hearn, A.J., Maryanto, I., Johnson, P.J., Macdonald, D.W.,
271 Yamaguchi, N., 2025. A web-based tool for rapid and accurate craniometric
272 differentiation of clouded leopard species. *Scientific Reports* 15, 11240.
273 Guisan, A., Tingley, R., Baumgartner, J.B., Naujokaitis-Lewis, I., Sutcliffe, P.R., Tulloch, A.I.T.,
274 Regan, T.J., Brotons, L., McDonald-Madden, E., Mantyka-Pringle, C., Martin, T.G.,
275 Rhodes, J.R., Maggini, R., Setterfield, S.A., Elith, J., Schwartz, M.W., Wintle, B.A.,
276 Broennimann, O., Austin, M., Ferrier, S., Kearney, M.R., Possingham, H.P., Buckley, Y.M.,
277 2013. Predicting species distributions for conservation decisions. *Ecology Letters* 16,
278 1424–1435. <https://doi.org/10.1111/ele.12189>
279 Hall, K.R., Anantharaman, R., Landau, V.A., Clark, M., Dickson, B.G., Jones, A., Platt, J.,
280 Edelman, A., Shah, V.B., 2021. Circuitscape in Julia: empowering dynamic approaches
281 to connectivity assessment. *Land* 10, 301.
282 Hill, A.P., Prince, P., Piña Covarrubias, E., Doncaster, C.P., Snaddon, J.L., Rogers, A., 2018.
283 AudioMoth: Evaluation of a smart open acoustic device for monitoring biodiversity and
284 the environment. *Methods in Ecology and Evolution* 9, 1199–1211.
285 IUCN, 2025. The IUCN Red List of Threatened Species. Version 2025-2. IUCN.
286 IUCN, UNEP-WCMC, 2025. The World Database on Protected Areas (WDPA).
287 Jantz, P., Macdonald, D.W., Gonzales, I., Hearn, A.J., Kaszta, Z., Landguth, E.L., Burnham, D.,
288 Goetz, S.J., Zeller, K.A., Loveridge, A.J., 2025. Connecting Landscapes: A decision
289 support system to facilitate conservation led development. *Environmental Modelling &*
290 *Software* 106576–106576.
291 Kaszta, Ž., Cushman, S.A., Macdonald, D.W., 2020. Prioritizing habitat core areas and corridors
292 for a large carnivore across its range. *Animal Conservation* 23, 607–616.
293 Kim, H., Rosa, I.M., Alkemade, R., Leadley, P., Hurtt, G., Popp, A., Van Vuuren, D.P., Anthoni, P.,
294 Arneth, A., Baisero, D., 2018. A protocol for an intercomparison of biodiversity and
295 ecosystem services models using harmonized land-use and climate scenarios.
296 *Geoscientific Model Development* 11, 4537–4562.
297 King, N., Rajvanshi, A., Willoughby, S., Roberts, R., Mathur, V.B., Cadman, M., Chavan, V., 2012.
298 Improving access to biodiversity data for, and from, EIAs—a data publishing framework
299 built to global standards. *Impact Assessment and Project Appraisal* 30, 148–156.
300 Landguth, E., Hand, B., Glassy, J., Cushman, S., Sawaya, M., 2012. UNICOR: a species
301 connectivity and corridor network simulator. *Ecography* 35, 9–14.
302 Macdonald, D.W., Chiaverini, L., Bothwell, H.M., Kaszta, Ž., Ash, E., Bolongon, G., Can, Ö.E.,
303 Campos-Arceiz, A., Channa, P., Clements, G.R., 2020. Predicting biodiversity richness in
304 rapidly changing landscapes: climate, low human pressure or protection as salvation?
305 *Biodiversity and Conservation* 29, 4035–4057.
306 Penjor, U., Kaszta, Ž., Macdonald, D.W., Cushman, S.A., 2021. Prioritizing areas for conservation
307 outside the existing protected area network in Bhutan: the use of multi-species, multi-
308 scale habitat suitability models. *Landscape Ecology* 36, 1281–1309.
309 <https://doi.org/10.1007/s10980-021-01225-7>
310 Phillips, S.J., Dudík, M., Schapire, R.E., 2004. A maximum entropy approach to species
311 distribution modeling. Presented at the Proceedings of the twenty-first international
312 conference on Machine learning, p. 83.
313 shapely, 2025. shapely.
314 Sutherland, W.J., Adams, W.M., Aronson, R.B., Aveling, R., Blackburn, T.M., Broad, S., Ceballos,
315 G., Côté, I.M., Cowling, R.M., Da Fonseca, G.A.B., 2009. One hundred questions of

316 importance to the conservation of global biological diversity. *Conservation biology* 23,
317 557–567.

318 Unnithan Kumar, S., Baker, D.J., Maclean, I.M., Gaston, K.J., 2025. Spatial prioritisation for
319 nature recovery with multiple options for habitat creation. *Journal of Applied Ecology* 62,
320 2688–2700.

321 Watts, M.E., Ball, I.R., Stewart, R.S., Klein, C.J., Wilson, K., Steinback, C., Lourival, R., Kircher, L.,
322 Possingham, H.P., 2009. Marxan with Zones: Software for optimal conservation based
323 land-and sea-use zoning. *Environmental Modelling & Software* 24, 1513–1521.

324 Zurell, D., Franklin, J., König, C., Bouchet, P.J., Dormann, C.F., Elith, J., Fandos, G., Feng, X.,
325 Guillera-Arroita, G., Guisan, A., Lahoz-Monfort, J.J., Leitão, P.J., Park, D.S., Peterson, A.T.,
326 Rapacciuolo, G., Schmatz, D.R., Schröder, B., Serra-Diaz, J.M., Thuiller, W., Yates, K.L.,
327 Zimmermann, N.E., Merow, C., 2020. A standard protocol for reporting species
328 distribution models. *Ecography* 43, 1261–1277. <https://doi.org/10.1111/ecog.04960>
329