Bioclimatic and physical characterization of the world's islands

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Edited by Daniel S. Simberloff, The University of Tennessee, Knoxville, TN, and approved July 24, 2013 (received for review April 12, 2013)

The Earth's islands harbor a distinct, yet highly threatened, biological and cultural diversity that has been shaped by geographic isolation and unique environments. Island systems are key natural laboratories for testing theory in ecology and evolution. However, despite their potential usefulness for research, a quantitative description of island environments and an environmental classification are still lacking. Here, we prepare a standardized dataset and perform a comprehensive global environmental characterization for 17,883 of the world's marine islands >1 km² (~98% of total island area). We consider area, temperature, precipitation, seasonality in temperature and precipitation, past climate change velocity, elevation, isolation, and past connectivity-key island characteristics and drivers of ecosystem processes. We find that islands are significantly cooler, wetter, and less seasonal than mainlands. Constrained by their limited area, they show less elevational heterogeneity. Wet temperate climates are more prevalent on islands, whereas desert climates are comparatively rare. We use ordination and clustering to characterize islands in multidimensional environmental space and to delimit island ecoregions, which provides unique insights into the environmental configuration and diversity of the world's islands. Combining ordination and classification together with global environmental data in a common framework opens up avenues for a more integrative use of islands in biogeography, macroecology, and conservation. To showcase possible applications of the presented data, we predict vascular plant species richness for all 17,883 islands based on statistically derived environment-richness relationships.

environmental regionalization | island biogeography | vascular plant diversity

M arine islands harbor a great part of our planet's biological and cultural diversity and provide ecosystem services to more than 500 million people (1). Existing estimates assign 3– 3.6% of the Earth's land area to islands (2, 3) and their number exceeds 100,000, depending on threshold size (4). Islands vary greatly in geologic history, area, isolation, elevation, and climatic conditions (2, 5, 6). The complex interplay between islands' past and present environments and their isolated nature has produced biota that differ greatly among islands and between islands and mainlands (7). Islands are characterized by a high proportion of endemic species (3) and their unique biota are particularly susceptible to anthropogenic threats (1, 8, 9). Island research and conservation could make great progress with truly global analyses, but standardized data on key island biogeographic characteristics are currently lacking.

Biogeographic and macroecological research, and conservation planning, rely on spatially explicit data on both biodiversity and abiotic conditions (10). For instance, knowledge on environmental and compositional representativeness and irreplaceability is necessary for conservation prioritization (11, 12) and requires standardized data for all locations worldwide. Global data on climatic and other environmental drivers of ecosystem processes, and ecosystem responses like productivity and vegetation structure, are becoming increasingly available at increasing resolution (13), and knowledge on the biotic constituents of ecosystems has improved greatly (13, 14). The advent of such large environmental and biodiversity datasets has opened up opportunities for global-scale analyses and, especially for mainlands, has facilitated significant progress in research over the past decade.

Although initially restricted to model archipelagos, such as Galapagos, Hawaii, and the Canaries, island research has inspired some of the most influential theories in ecology and evolution (5, 15–17). Recently, quantitative global analyses have also appeared (8, 18, 19) but have been restricted to a nonrandom subset of islands with available data. A synthesis of the macroecology of the world's islands is still missing. Although the large number, small size, and discrete boundaries of islands provide exciting research opportunities (17), the same qualities have hampered the compilation of standardized data. The United Nations Environment Programme Island Directory (20) was a first step toward a global overview, providing information on ~2,000 islands. More recently, scientific knowledge on physical and biological aspects of select islands and archipelagoes was summa-rized (6) and the "Global Island Database" made available information for conservation and policy making (gid.unep-wcmc. org). Despite such first steps toward a global island dataset, a rigorous, standardized, and quantitative characterization of the world's islands is still lacking.

From a biological perspective, islands are inherently different from continental areas and drivers of these differences are key to understanding processes and patterns on islands (1). In island biogeographic theory, isolation and area are considered the most important drivers of island biodiversity (2, 15). Speciation predominantly occurs on large and isolated islands and large islands are more likely to maintain viable populations of many species (21–24). Isolation affects island biota in complex ways (22). For instance, the amount of surrounding landmass may determine the number of arriving propagules and the overwater distance may act as a dispersal filter causing compositional disharmonyan underrepresentation of certain taxonomic or ecological groups (25). However, a comprehensive framework for global island research requires going beyond classical island biogeographic determinants (26). Age and time-area dynamics are key predictors of the diversity of evolutionary arenas (27), and consequently island age and geology (e.g., volcanic vs. continental) represent core factors for understanding island biodiversity (23, 28). In addition, macroclimate, heterogeneity, and climate stability are known to influence endemism, assembly, and phylogenetic structure of island communities (19, 29-31).

Areas within which ecosystems share certain characteristics may be defined as "ecoregions" (32). Delineations may be based on biotic composition, evolutionary legacy, drivers of ecosystem

The authors declare no conflict of interest.

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Author contributions: P.W., W.J., and H.K. designed research; P.W. and H.K. performed research; P.W. analyzed data; and P.W., W.J., and H.K. wrote the paper.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

Data deposition: The data in Dataset S1 have been deposited in the Dryad Repository, datadryad.org (dx.doi.org/10.5061/dryad.fv94v).

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10. 1073/pnas.1306309110/-/DCSupplemental.

processes (e.g., temperature), or measures of ecosystem responses (e.g., productivity; ref. 33). Biomes, e.g., describe regions of similar vegetation structure determined by temperature and precipitation (34–36). Often, criteria for delineations are not well defined. For instance, the widely used World Wildlife Fund ecoregion classification represents an expert-based assessment of both the distinctiveness of biotic assemblages and proxies such as vegetation structure (37). More quantitative classifications, made possible by the increasing availability of information, efficient algorithms, and computational power, have appeared recently (33, 38–40), but islands are often underrepresented or altogether excluded, due to their small size.

Here, we aim to provide a comprehensive environmental synopsis and classification of the world's islands. We (*i*) provide a comprehensive multivariate characterization and a standardized dataset of island bioclimatic and physical conditions; (*ii*) compare island and mainland environments; (*iii*) explore multivariate approaches for delineating environmental island ecoregions; (*iv*) provide general perspectives how this unique multivariate characterization may be used in island research and management; and (*v*) implement an example application by making environment-based predictions of vascular plant species richness on islands worldwide.

Results and Discussion

Island Environments. Our bioclimatic and physical characterization of the world's islands considered 85,122 marine islands smaller than Greenland. These islands comprise $\sim 7.84 \times 10^6$ km², or 5.3% of the Earth's land area, significantly exceeding previous estimates of 3–3.6% (2, 3). In total, 65,730 islands in the dataset are smaller than 1 km², but they make up only 0.17% of overall island area. Hence, island sizes show a strongly rightskewed distribution (17 islands >100,000 km²; Fig. S1). How many islands exist in total cannot be straightforwardly estimated. Fractal theory predicts island number to increase with decreasing minimum considered island area, up to millions of smallest islets and rocks (4). We focused on islands >1 km², which is biologically justifiable because on small islands speciation events and endemism are rare (21, 22) and stochastic forces drive diversity patterns (41). Of 19,392 islands >1 km², 17,883 had sufficient environmental information for a detailed assessment of bioclimatic and physical conditions (Fig. 1 and Table S1). Together, they comprise ~ 7.67×10^6 km², i.e., 5.2% of the Earth's land area and 97.8% of total island area, and serve as a solid baseline for an abiotic characterization of the world's islands.

Contrary to what some map projections suggest, Hawaii is not the most remote archipelago. The most remote islands belong to the Society and Austral Islands and Western Tuamotu (French Polynesia; Fig. 1B). Tahiti, ~5,900 km from the nearest mainland, is the largest of these islands. In terms of surrounding landmass (42), the most isolated islands lie east of Australia (from Macquarie Island to Fiji; Fig. 1C), including New Zealand and New Caledonia, islands of outstandingly high endemism richness (3). Assuming a decrease in sea levels of 122 m (43), about 75% of all islands were probably connected to a continent during the last glacial maximum (LGM) (Fig. 1D). Such land bridges could have allowed biotic exchange between and homogenization of the respective island and mainland assemblages. Isolated evolution on unconnected islands, in contrast, may have preserved unique assemblages, including relict endemics on old continental fragments and iconic adaptive radiations on volcanic archipelagos (17, 44).

Sixty-five percent of all islands are tropical. Annual mean temperature and temperature seasonality follow typical latitudinal trends (Fig. 1 F and G). Past climate change velocity, i.e., the speed needed to track the mean annual change in temperature since the LGM [21,000 years before the present (y BP)], while accounting for variation in topographic complexity, is highest on North Atlantic islands (Fig. 1H), which is consistent with ref. 31. Precipitation is highest on tropical and highly elevated islands (Fig. 11), with high intraarchipelago variation. For instance, within the Marquesas, only islands higher than 800 m receive rainfall exceeding 3,000 mm/y. Consequently, they harbor cloud and rain forests and differ from lower islands in composition and richness (45). In contrast, flat islands can be extremely dry. Precipitation seasonality is highest on tropical islands at western continental coasts (e.g., Isla Lobos de Tierra, Peru, and Cape Verde; Fig. 1J).



Fig. 1. Global patterns of key physical and bioclimatic variables on 17,883 marine islands >1 km². (A) Island area (*Area*), (*B*) distance to mainland (*Dist*), (*C*) surrounding landmass proportion (*SLMP*), (*D*) glacial maximum mainland connection (*GMMC*), (*E*) elevational range (*Elev*), (*F*) annual mean temperature (*Temp*), (*G*) temperature seasonality (*varT*), (*H*) climate change velocity in temperature (*CCVT*), (*I*) annual precipitation (*Prec*), (*J*) precipitation seasonality (*varP*). Points are plotted in order of decreasing frequency, i.e., islands with rare environments are plotted on top of islands with common characteristics if points overlap.

Some island characteristics are strongly correlated (Fig. S2 and Table S2). We found highest correlations between isolation metrics and mainland connection, among climatic variables, and between area and elevation. Some of these correlations are underlain by simple geometric constraints. For instance, high mountains require a minimum area and remote islands are unlikely to have had past mainland connections. For a subset of 102 volcanic islands for which we obtained estimates of geologic age since emergence, island age was not related to area (as raw variable, P = 0.62; \log_{10} -transformed, P = 0.96; as quadratic term, P = 0.77). In theory, the area of a volcanic island increases after its emergence and decreases after volcanic activity has stopped (28), but the expected hump-shaped relationship between age and area may only be noticeable within geologically homogeneous systems like single archipelagos. However, we found a significant negative correlation between island age and elevational range (r = -0.25, P < 0.05), possibly reflecting the effect of erosion on island height.

We performed principal component analysis (PCA) to reduce correlated variables to independent components and visualize island characteristics in fewer dimensions (Fig. 2 A-C and Fig. S3). The first three axes of a PCA including all 10 bioclimatic and physical variables accounted for 72.4% of the variance, with the most important axis (39%) representing primarily bioclimatic variables (Fig. 2 A and B, and Table S3). Isolation and mainland connection metrics varied mainly along the second axis, almost separating the islands into two groups (Fig. 24). The third axis separated small, flat islands from large, high islands, with most islands falling on the small, flat end (Fig. 2B). Visualized on a world map (Fig. 2D), the PCA results allow identification of groups of islands with similar characteristics. An abrupt change occurred at the transition from continental to oceanic islands. Within these groups, we detected more gradual changes along physical and bioclimatic axes. These gradients were even more pronounced when PCA was applied to current bioclimatic (Fig. 2F) or physical variables separately (Fig. 2G).

Island–Mainland Comparisons. Island and mainland characteristics differed markedly. Elevational range was significantly lower on islands than in mainland grid cells (Fig. 3*A*). Although this is partly due to the small size of most islands compared with the coarse mainland grain, limited area is also an intrinsic island feature that precludes elevational ranges comparable to mainland mountain regions. Significantly lower seasonality and higher

precipitation on islands indicate lower climatic continentality than on mainlands (Fig. 3A). Due to a large number of Arctic islands, annual mean temperatures were lower on islands, whereas past climate change velocity was significantly higher, with especially high values in the Canadian Arctic Archipelago. In a common PCA space, islands and mainland regions occupied different areas (Fig. 3 D and E). The first two axes explained 68.6% of the variation and uncovered the most striking differences, as kernel densities were uncorrelated among islands and mainlands (r =0.07, P > 0.05). For other axis combinations, kernel density correlations were significant (PC1/PC3: r = 0.72; PC2/PC3: r = 0.16; both P < 0.001). Kernel densities of islands connected to the mainland during the LGM and unconnected islands were significantly correlated, indicating that they occupy a similar environmental space (PC1 and PC2: r = 0.75; PC1 and PC3: r = 0.65; PC2 and PC3: r = 0.88; all P < 0.001). We projected islands onto the classic Whittaker plot of biomes classified by annual mean temperature and precipitation (Fig. 3 B and C) (35). Overall, cold climates and wet climates were overrepresented on islands, and warm and dry climates underrepresented. Tropical and especially temperate rainforests were overrepresented on islands, which is notable because temperate rainforests are among the rarest ecosystems on Earth (12).

Quantitative Island Regionalizations. We produced a set of classifications of global islands to provide a first environment-driven island ecoregion framework. Because area and elevational range showed no or only low spatial autocorrelation (Table S1), a regionalization considering these variables generated disjunct ecoregions, reflecting that small, flat islands may occur next to large, high islands (Fig. S4). Including only bioclimatic and physical variables with a high level of spatial autocorrelation (Moran's I values from 0.59 to 0.99, all P < 0.001) generated more contiguous ecoregions (38). Excluding area and elevational range and using nonhierarchical clustering [partitioning around medoids (PAM)] of weighted PCA axes, we identified eight distinct sets of islands (Fig. 4, Fig. S5, and Table S4): Clusters I-IV included northern temperate to Arctic islands, with II-IV characterized by LGM mainland connections and differentiated by bioclimate. Clusters V-VIII consisted of temperate to tropical islands, with VI including the majority of highly isolated oceanic islands. The lack of further divisions among highly isolated oceanic islands highlights their comparatively homogeneous bioclimatic conditions. Although this ecoregionalization offers a first quantitative baseline



Fig. 2. Principal component analyses (PCAs) based on bioclimatic and physical variables for 17,883 marine islands >1 km² worldwide. (A–C) Biplots of the first three PCA axes when all 10 variables are included. (*D*–G) Maps of ordination site scores: (*D*) all 10 variables, (*E*) all variables but *Area* and *Elev*, (*F*) contemporary bioclimatic variables only (*Temp*, varT, Prec, varP), and (G) physical variables only (*Area*, *Dist*, *SLMP*, *GMMC*, *Elev*). Colors refer to a red–green–blue (RGB) color space (cubes in legend) projected onto the respective 3D PCA space. Hence, in *A*–*D* each island consistently has the same color. Cubes in *D*–G show PCA results in a 3D space. In *A*–*C*, points are plotted in decreasing order of three-dimensionality, in *D*–*G* in decreasing order of island area, plotting the rare large islands on top if points overlap. Abbreviations follow Fig. 1.

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Fig. 3. Island vs. mainland comparisons. (A) Elevational range (*Elev*) (in \log_{10} meters), annual mean temperature (*Temp*) (in degrees Celsius), annual temperature range (*varT*) (in degrees Celsius), past climate change velocity in temperature (*CCVT*) [in \log_{10} (meters per year)], annual precipitation (*Prec*) (in meters), and variation in precipitation (*varP*) compared for 17,883 islands >1 km² (Isl) and 42,985 equal area mainland grid cells (MI). Significance of differences was assessed using Mann–Whitney *U* tests (****P* < 0.001). Boxes represent the interquartile range around the median; whiskers extend 1.5 times the interquartile range from the box. (*B*) Densities of islands and (*C*) mainland grid cells plotted onto Whittaker's scheme of biomes (35) delineated on the basis of *Temp* and *Prec*. (*D*) PCA for 4,676 oceanic islands (cyan), 13,207 continental islands (magenta), and mainland grid cells (gray). (*E*) Kernel densities of geologic subsets along the first two PCA axes.

for the world's island environments, the specific outcome is contingent on the number of groups chosen and the clustering algorithm. Using the unweighted pair-group method with arithmetic mean (UPGMA) instead of PAM produced groups of vastly different sizes (1–7,092 islands per cluster compared with 1,284–3,289 islands per cluster; Fig. S6), highlighting the methodological sensitivity of the clustering approach. The application of environmentbased regionalizations is also limited by the gradual nature of most environmental changes, which compromises the idea of strict distinctions. Multivariate measures of environmental similarity based on PCA analyses and as mapped in Fig. 2 may represent a more appropriate and powerful tool to account for gradual changes when analyzing and visualizing regional affinities. We suggest carefully checking the results of both the ordination and clustering steps.

Richness Predictions. To showcase possible applications of the presented data and multivariate framework, we used it to predict the species richness of native vascular plants on all 17,883 islands >1 km². Specifically, we used a multimodel approach (46) and included as predictors the 10 presented bioclimatic and physical variables, richness of the nearest mainland region, and spatial position on the sphere (Fig. 5 and Table S5). The averaged model achieved remarkably strong fits with observed richness on the 475 islands used for training (Fig. S7; pseudo- $R^2 = 0.94$; averaged mean error based on 10-fold cross-validation, 0.031; not accounting for spatial nonindependence). The South East Asian Archipelago, the Caribbean, and the Mediterranean emerged as richness centers, attributable to their many large islands, (sub) tropical climates, low degrees of isolation, and high regional mainland diversity (Fig. 5). Oceanic islands were on average less diverse than continental islands with only few exceptionally diverse islands (Figs. 4 and 5). The generalized additive modeling approach presents a flexible way to account for multiple nonlinear effects and complex interactions, as well as spatial richness variation (47). However, the model underestimated species richness on some large, tropical islands (compare Fig. S7) and overestimated it on others (e.g., Britain). Although the model captures the interplay of bioclimatic and physical drivers of insular plant species richness, the predictions only account for the variables selected and do not mechanistically address the historical biogeography of the different plant clades found on islands. We therefore caution against their use without contemplation. Nevertheless, the predictions give a first global overview of vascular plant species richness on islands and may provide a good baseline prediction against which to test ecological and evolutionary processes in island biogeography.

Perspectives. In contrast to alternative global frameworks (39), our study specifically focuses on islands. It represents a first step toward a thorough characterization of the world's islands for island research and conservation. The data may help to address questions in ecology and evolution, such as whether the unique diversity of islands and speciation patterns are due to isolation and lack of gene flow or whether island evolution differs from mainland evolution due to environmental differences (48). The framework also has great potential for island conservation. Island biota are particularly threatened, by biological invasions, habitat loss, and changing climate (1, 3, 8, 9). The majority of historically recorded vertebrate extinctions occurred on islands and 39% of species facing imminent extinction are island species (49). Island communities are highly susceptible to invasioninduced extinction and biotic homogenization (8, 50). Assessing environmental similarity may help to connect potential source and target areas for invaders and aid in proactive measures. Further, climate change particularly affects island ecosystems due to sea level rise and limited space for range shifts (1, 9, 51).





Fig. 5. Predictions of vascular plant species richness for 17,883 islands >1 km² (constituting ~98% of global island land area) worldwide based on generalized additive models and model averaging. Predictors include the 10 bioclimatic and physical variables presented here, richness of the nearest mainland region, and spatial position on the sphere. Circles were plotted in order of increasing species richness. The embedded map indicates the observed species richness of vascular plants for 475 islands used to train the model. The histogram shows the frequency distribution of log_{10} species richness.

We identified islands of high past climate change velocity and areas where species may track future changes in a heterogeneous topography. Finally, human impact is higher on islands and land use-driven changes will still increase (3). An ecoregion framework may assist in assessing habitat loss and conversion and identifying areas of high representativeness, distinctiveness, and priority for nature conservation (11, 12).

Our approach is limited by the accuracy of the underlying bioclimatic and physical data (SI Materials and Methods) and because it is purely environment based. However, the richness models indicate that the environmental factors strongly relate to biogeographic factors. Once available at the global scale, biotic similarity could be used in combination with an abiotic characterization to quantitatively delimit island biogeographic regions that account directly for biogeographic history (37, 40). Until then, the data and approaches described here can serve as a baseline and source for developing and testing hypotheses, and for identifying islands of particular environmental uniqueness or representativeness and the predictions of vascular plant species richness can aid in identifying islands of outstanding biodiversity. The standardized dataset (Dataset S1) and quantitative nature of our characterization and ecoregionalization may contribute to more rigorous and reproducible approaches in island research and conservation.

Materials and Methods

Islands. We defined islands as landmasses surrounded by ocean and smaller than Greenland. This excludes freshwater islands. As geographic reference, we used the GADM database (www.gadm.org/version1), which includes 85,122 high-resolution island polygons. We focused on all 19,392 islands >1 km². Comparison with 90-m resolution elevation data (srtm.csi.cgiar.org) confirmed that these polygons include most islands >1 km² worldwide. For 17,883 islands, we could assemble complete environmental information. The 1,509 missing islands were distributed evenly across island-rich regions of the globe and were only slightly larger than 1 km² (Fig. S1).

Physical Variables. We considered five bioclimatic and five physical variables describing the exogenous physical environments of islands (33). Island area (*Area*) was calculated for each GADM polygon in cylindrical equal area projection. Although polygon area differs from actual surface area, which is influenced by island topography, it is an adequate approximation (26). As measures of isolation, we used the distance to the nearest mainland (*Dist*) and the proportion of surrounding landmass (*SLMP*). *Dist* was calculated as the shortest great circular distance between an island's mass centroid and the mainland coast. This metric is as good an isolation metric at a global scale as the distance from the island coast (42), but its calculation is computationally less demanding. Antarctica was not considered as mainland due to its permanent ice cover. We calculated *SLMP* as the sum of the proportions of landmass within buffer distances of 100, 1,000, and 10,000 km around the island perimeter. *SLMP* has been shown to be the best isolation metric to explain island plant diversity at a global scale (42). Unlike other

isolation metrics, *SLMP* accounts for coastline shape of large landmasses by considering only regions that extend into the measured buffers. As a coarse proxy for island geological history, we noted whether an island was connected to the mainland during the LGM (*GMMC*), assuming a sea level at 18,000 y BP of 122 m below the present level (43). More sophisticated geologic data are not available at reasonable spatial resolution, but *GMMC* differentiates well between oceanic and continental islands (Fig. 1D). We included the maximum elevation of each island as a measure of topographic complexity and a proxy for environmental heterogeneity (*Elev*). *Elev* relates to the number of available habitats as a result of differences between windward and leeward sites, temperature decrease with altitude, and high precipitation regimes in certain altitudinal belts (52). Elevation data at 30-s resolution was from ref. 53. For 1,891 small islands that did not fully enclose a 30-s raster cell, we applied a 1-km buffer to the island perimeter.

Bioclimatic Variables. For most islands, bioclimatic variables came from WorldClim (53). We used maximum values of annual mean temperature (Temp) and annual precipitation (Prec), as these are key drivers of ecosystem processes, vegetation structure (32), and species richness (19). Intraannual seasonality was quantified using the minimum annual temperature range (varT) and the minimum coefficient of variation in monthly precipitation (varP). We focused on extreme values rather than spatial means to capture the climatically most favorable part of each island. A region of French Polynesia and the Pitcairn Islands comprising 129 islands >1 km² and including important volcanic islands like the Marquesas, was not covered by WorldClim temperature data. We therefore modeled Temp and varT for these islands based on the strong correlation of sea surface and air temperatures of neighboring islands (SI Materials and Methods). We calculated climate change velocity in temperature (CCVT) since the LGM 21,000 y BP as the ratio between temporal change and contemporary spatial change in temperature at 30-s resolution and extracted mean values for each island (SI Materials and Methods) (31). Because of the higher uncertainty in paleoclimatic reconstructions of precipitation (31), we did not include climate change velocity in precipitation. We acknowledge the limitations of the bioclimate datasets, as the WorldClim model interpolates from weather station observations using latitude, longitude, and elevation (53). Climate predictions in regions with poor station density and varied topography have limited reliability (54).

Island Age. For 102 volcanic islands unconnected to the mainland during the LGM, we assembled island ages, an important determinant of species diversity and endemism (28), from primary research literature and compilations (e.g., ref. 6). Due to the small sample size, island age did not enter multivariate analyses but we assessed its relation to other variables.

Statistical Analyses. Area, Elev + 1, Dist + 1, SLMP + 0.5, and CCVT + 1 were log_{10} -transformed to reduce skewness and to moderate extreme values. Small constants were added to avoid taking the logarithm of zero. We assessed spatial autocorrelation using Moran's I values. Collinearity was evaluated using pairwise correlations. Coefficients and significances were corrected for spatial autocorrelation following ref. 55. We performed PCAs of both including all standardized variables and for the following subsets: all variables but Area and Elev, contemporary bioclimatic variables only (Temp, varT, Prec, varP), and physical features only (Area, Dist, SLMP, GMMC, Elev).

To compare the environmental characteristics of islands and mainlands, we performed a PCA of all 17,883 islands and 42,985 equal area mainland grid cells spanning all continental areas worldwide (each 3,091 km² but covering less landmass in coastal areas). As input variables, we used all bioclimatic and physical variables not restricted to islands (*Elev, Temp, varT, Prec, varP*, and *CCVT*). We used kernel densities in PCA biplots as a measure of occupancy and correlated them among geologic units (all islands, islands connected to mainland at the LGM, unconnected islands, mainlands).

To delimit island regions of similar bioclimatic and physical conditions, we performed cluster analyses based on the 10 environmental variables and the variable subsets mentioned above. We used agglomerative hierarchical (UPGMA) and nonhierarchical clustering methods (PAM). UPGMA produces a cluster dendrogram representing the relatedness of the delimited regions. From the dendrogram, a preferred number of clusters can be inferred (56). PAM requires a specified number of clusters in advance and does not provide relationships among regions. However, PAM tends to delineate clusters of similar size and upper limits of within-group variance, preventing the creation of regions that greatly differ in within-region variance (38). Due to the strong collinearity of some variables, we used Euclidean distances on PCA axes as input distances; these are most appropriate because of the orthogonal nature of the PCA space (57). PCA axes were weighted by the square root of their eigenvalues to reduce the influence of less important

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axes (57). We chose a number of clusters small enough for presentation and discussion based on the Caliński and Harabasz index (56).

Environment–Richness Model and Global Prediction. As example application of the integrated physical and bioclimatic island data, we produced species richness predictions for all 17,883 islands >1 km². The modeling approach builds on previous work (19, 42). For 475 islands, we collected numbers of native vascular plant species per island from floras, checklists and compilations (19, 42) (*SI Materials and Methods*). As predictor variables, we used the presented physical and bioclimatic variables, and vascular plant richness in the nearest mainland grid cell of the cokriging data in ref. 58 to reflect historical biogeographic influences on the available species pool. We used generalized additive models including penalized regression splines with up to three degrees of freedom, and an isotropic smooth of latitude and longitude on a sphere to account for spatial patterns in the response variable (47). We allowed tensor product interactions among *Area* and *Temp, Dist* and *SRML, Temp* and *Prec,* and *Area* and *Dist.* We made predictions based on multiple candidate models weighted

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by model fit (46) and used 10-fold cross-validation to estimate prediction errors. Methods and results of alternative modeling approaches can be found in *SI Materials and Methods*, Fig. S7, and Table S5.

All bioclimatic and physical variables, ordination and clustering results, richness values of the nearest mainland grid cell, and predicted vascular plant species richness values per island are available in Dataset S1 and at the Dryad Repository (dx.doi.org/10.5061/dryad.fv94v).

ACKNOWLEDGMENTS. We thank the editor, Yael Kisel, Carsten Meyer, and anonymous reviewers for helpful comments on the manuscript; Judith Krobbach for help with digitizing species lists; and Fabian Sobotka for statistical advice. This project was funded by the German Research Foundation (Deutsche Forschungsgemeinschaft) Free Floater Program in the Excellence Initiative at the University of Göttingen and by the Academy of Sciences and Literature Mainz ("Biodiversity in Change" Program). WJ. acknowledges support from National Science Foundation Grants DBI0960550 and DEB1026764 and National Aeronautics and Space Administration Biodiversity Grant NNX11AP72G.

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