Biodiversity Informatics, 17, 2022, pp. 1-5

ENM2020: A FREE ONLINE COURSE AND SET OF RESOURCES ON MODELING SPECIES NICHES AND DISTRIBUTIONS

A. Townsend Peterson[1], Matthew E. Aiello-Lammens[2], Giuseppe Amatulli[3], Robert P. Anderson[4,5], Marlon E. Cobos[1], José Alexandre F. Diniz-Filho[6], Luis E. Escobar[7], Xiao Feng[8], Janet Franklin[9], Luiz M. R. Gadelha Jr.[10,11], D. Georges[12], M. Guéguen[12], Tomer Gueta[13,14], Kate Ingenloff[1,15], Scott Jarvie[16,17,*], Laura Jiménez[1,18], Dirk N. Karger[19], Jamie M. Kass[20], Michael R. Kearney[21], Rafael Loyola[6,22], Fernando Machado-Stredel[1], Enrique Martínez-Meyer[23], Cory Merow[24], Maria Luiza Mondelli[11], Sara Ribeiro Mortara[25,26], Robert Muscarella[27], Corinne E. Myers[28], Babak Naimi[29], Daniel Noesgaard[30], Ian Ondo[31], Luis Osorio-Olvera[1,32], Hannah L. Owens[33,34], Richard Pearson[35], Gonzalo E. Pinilla-Buitrago[4], Andrea Sánchez-Tapia[24], Erin E. Saupe[36], Wilfried Thuiller[12], Sara Varela[37,38], Dan L. Warren[20], John Wieczorek[39], Katherine Yates[40], Gengping Zhu[41], Gabriela Zuquim[16,42], Damaris Zurell[43]

[1]*Biodiversity Institute, University of Kansas, Lawrence, KS 66045, USA*
[2]*Department of Environmental Studies and Science, Pace University, Pleasantville, NY 10570, USA*
[3]*Yale University, School of the Environment, 195 Prospect Street, New Haven, CT, 06511, USA*
[4]*Department of Biology, City College of New York, City University of New York, New York, NY 10031, USA; Ph.D. Program in Biology, Graduate Center, City University of New York, New York, NY 10016, USA*
[5]*Division of Vertebrate Zoology (Mammalogy), American Museum of Natural History, New York, NY 10024, USA*
[6]*Departamento de Ecologia, ICB, Universidade Federal de Goiás, Goiânia, GO, Brazil*
[7]*Department of Fish and Wildlife Conservation, Virginia Tech, Blacksburg, VA, 24061, USA*
[8]*Department of Geography, Florida State University, Tallahassee, FL 32306, USA*
[9]*Department of Botany and Plant Sciences, University of California, Riverside, CA 92521, USA*
[10]*Friedrich-Schiller-University Jena, Germany*
[11]*National Laboratory for Scientific Computing, Petrópolis, Brazil*
[12]*Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, LECA, F-38000 Grenoble, France*
[13]*Department of Civil and Environmental Engineering, The Technion – Israel Institute of Technology, Haifa 3200003, Israel*
[14]*Steinhardt Museum of Natural History, Tel Aviv University, Tel Aviv 6997801, Israel*
[15]*Center for Biodiversity and Global Change, Yale University, New Haven, CT, USA*
[16]*Section for Ecoinformatics & Biodiversity, Department of Biology, Aarhus University, Ny Munkegade 114, 8000 Aarhus, Denmark*
[17]*Centre for Biodiversity Dynamics in a Changing World (BIOCHANGE), Department of Biology, Aarhus University, Ny Munkegade 114, 8000 Aarhus, Denmark*
[*]*Otago Regional Council, Dunedin, Aotearoa, New Zealand*
[18]*School of Life Sciences, University of Hawai'i at Manoa, Honolulu, HI 96822, USA*
[19]*Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland*
[20]*Biodiversity and Biocomplexity Unit, Okinawa Institute of Science and Technology Graduate University, Tancha, Onna-son, Kunigami-gun, Okinawa, Japan*
[21]*School of BioSciences, University of Melbourne, Victoria 3010, Australia*
[22]*Fundação Brasileira para o Desenvolvimento Sustentável, Rio de Janeiro, RJ, Brazil*

[23]*Departamento de Zoología, Instituto de Biología, Universidad Nacional Autónoma de México, Mexico City 04510, Mexico*
[24]*Eversource Energy Center and Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT, USA*
[25]*International Institute for Sustainability IIS-Rio, Rio de Janeiro, Brazil*
[26]*Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Núcleo de Computação Científica e Geoprocessamento, Rio de Janeiro, Brazil*
[27]*Plant Ecology & Evolution, Evolutionary Biology Centre, Uppsala University, Uppsala, Sweden*
[28]*Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA*
[29]*Department of Geosciences and Geography, University of Helsinki, 00014 PO Box 64, Helsinki, Finland*
[30]*Global Biodiversity Information Facility (GBIF) Secretariat, Universitetsparken 15, 2100 Copenhagen Ø, Denmark*
[31]*Department of Biodiversity Informatics and Spatial Analysis (BISA), Royal Botanic Gardens, Kew, Richmond, Surrey TW9 3AB, UK*
[32]*Departamento de Ecología de la Biodiversidad, Instituto de Ecología, Universidad Nacional Autónoma de México, Ciudad de México, 04510, Mexico*
[33]*Center for Macroecology, Evolution and Climate, GLOBE Institute, University of Copenhagen, Copenhagen, Denmark*
[34]*Florida Museum of Natural History, University of Florida, Gainesville, FL, 32611, USA*
[35]*Centre for Biodiversity & Environment Research, Department of Genetics, Evolution & Environment, University College London, UK*
[36]*Department of Earth Sciences, University of Oxford, S Parks Road, OX1 3AN, UK*
[37]*Departamento de Ecoloxía e Bioloxía Animal. Universidade de Vigo, Spain*
[38]*Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Berlin, Germany*
[39]*VertNet, Rauthiflor LLC*
[40]*School of Science, Engineering and Environment, University of Salford, Manchester, UK*
[41]*Department of Entomology, Washington State University, Pullman, WA 99163 USA*
[42]*Department of Biology, University of Turku, Finland*
[43]*Institute of Biochemistry and Biology, University of Potsdam, Potsdam, Germany*

Abstract. The field of distributional ecology has seen considerable recent attention, particularly surrounding the theory, protocols, and tools for Ecological Niche Modeling (ENM) or Species Distribution Modeling (SDM). Such analyses have grown steadily over the past two decades—including a maturation of relevant theory and key concepts—but methodological consensus has yet to be reached. In response, and following an online course taught in Spanish in 2018, we designed a comprehensive English-language course covering much of the underlying theory and methods currently applied in this broad field. Here, we summarize that course, ENM2020, and provide links by which resources produced for it can be accessed into the future. ENM2020 lasted 43 weeks, with presentations from 52 instructors, who engaged with >2500 participants globally through >14,000 hours of viewing and >90,000 views of instructional video and question-and-answer sessions. Each major topic was introduced by an "Overview" talk, followed by more detailed lectures on subtopics. The hierarchical and modular format of the course permits updates, corrections, or alternative viewpoints, and generally facilitates revision and reuse, including the use of only the Overview lectures for introductory courses. All course materials are free and openly accessible (CC-BY license) to ensure these resources remain available to all interested in distributional ecology.

Key words. Ecological niche model, Species distribution model, Course, Open access, Methods

Distributional ecology is a branch of biogeography that focuses on the fundamental question of why species are found where they are and identifying where they could occur given changing environmental, geographic, or biotic conditions. The modern renaissance of the field began in the 1970s (MacArthur 1972, Austin 1987, Ferrier 2002), and has since led to many exciting insights (e.g., novel reflections on the frequency of ecological speciation) and useful products (e.g., detailed range maps and potential distribution maps) (Guisan and Zimmermann 2000, Araújo and Pearson 2005, Peterson and Navarro-Sigüenza 2017). Work in the field of distributional ecology includes theory, protocols, and tools drawn from many areas of inquiry, including ecology, biogeography, evolutionary biology, geographic information science, meteorology, hydrology, remote sensing, statistics, and computer science. Despite at least three book-length syntheses (Franklin 2010, Peterson et al. 2011, Guisan et al. 2017) and numerous synthetic papers on the subject (e.g., Guisan and Thuiller 2005, Elith and Leathwick 2009, Anderson 2013, Araújo et al. 2019, Feng et al. 2019, Zurell et al. 2020), the field still lacks a clearly established set of methodologies by which to guide future advances.

This novelty and speed of development of the field, combined with intense interest, have led to a series of in-person and online training programs and courses, ranging from broad surveys of all biodiversity informatics (e.g., Peterson and Ingenloff 2015) to courses specifically on ecological niche modeling (e.g., Peterson et al. 2019; note, this particular course was in Spanish). However, given the somewhat dated nature of many existing courses and the substantial fees often involved, a significant gap was noted: a free, online course in English spanning the entire suite of theory, protocols, and tools in the ecological niche modeling toolkit. A team of 52 instructors that represents a great breadth of expertise in this area worked to generate the instructional format and content of a new course. Instructors came from many countries and represented a variety of career stages.

The Course

The course was delivered during January–November 2020. It was divided into 18 overarching themes or topics: introduction, applications, key tools, environmental data, occurrence data, visualization, distributional equilibrium, algorithms, uncertainty, evaluation, model selection, model transfers, model comparisons, reproducibility, abundances, frontiers, practicalities, and conclusions (Table 1). Each major topic was initiated by a talk designated as an "Overview." Persons desiring deep knowledge could view all the talks in each set following the corresponding Overview lecture, whereas individuals aiming for a general summary of the field had the option to only watch Overview talks. Completion certificates for the full course required participation in question-and-answer sessions and adequate performance on a short examination at the end of the course. The modular format of the course and its materials also facilitates later addition of updates, corrections, or alternative viewpoints, leading to a set of resources that should be adaptable and easily updated into the future.

The course followed a set weekly schedule. Lectures were pre-recorded to avoid technological and internet-related complications of live presentations, for both instructors and students. Presentations were made available on Monday morning (in the Western Hemisphere, UTC-6) in various formats: YouTube videos, .mp4 video files, .mp3 audio files, and .pdf slide decks. YouTube videos had the advantage of automatically including the option of closed-captioning, which (though not perfect) can assist both deaf and hard-of-hearing individuals and persons for whom English is not a native language. Presentations were accompanied by ancillary materials such as readings from the primary literature, example datasets, and programming code. Participants' questions were due by Wednesday each week, and a live question-and-answer session among instructors was held each Friday, with an archived version made available online directly upon conclusion.

The course reached a large audience. In total, 2541 formal participants joined the course Facebook group[1], but many more took advantage of the materials. The YouTube videos were viewed 90,938 times by participants from at least 72 countries worldwide (Figure 1), representing 14,172 hours of viewership (as of 15 November 2020). In total, 3159 questions were submitted by course participants (see Figure 2 for a word cloud summarizing the terms most frequently used in these questions; R code to produce this figure is provided via KU Scholarworks[2].

Our desire in developing this course was to facilitate and motivate current and future scholars in the field worldwide to explore and innovate in distributional ecology. We also hope that the open format—made available globally via the Internet without cost—will serve to increase the diversity of partici-

[1] https://www.facebook.com/groups/ENM2020/.
[2] http://hdl.handle.net/1808/32540.

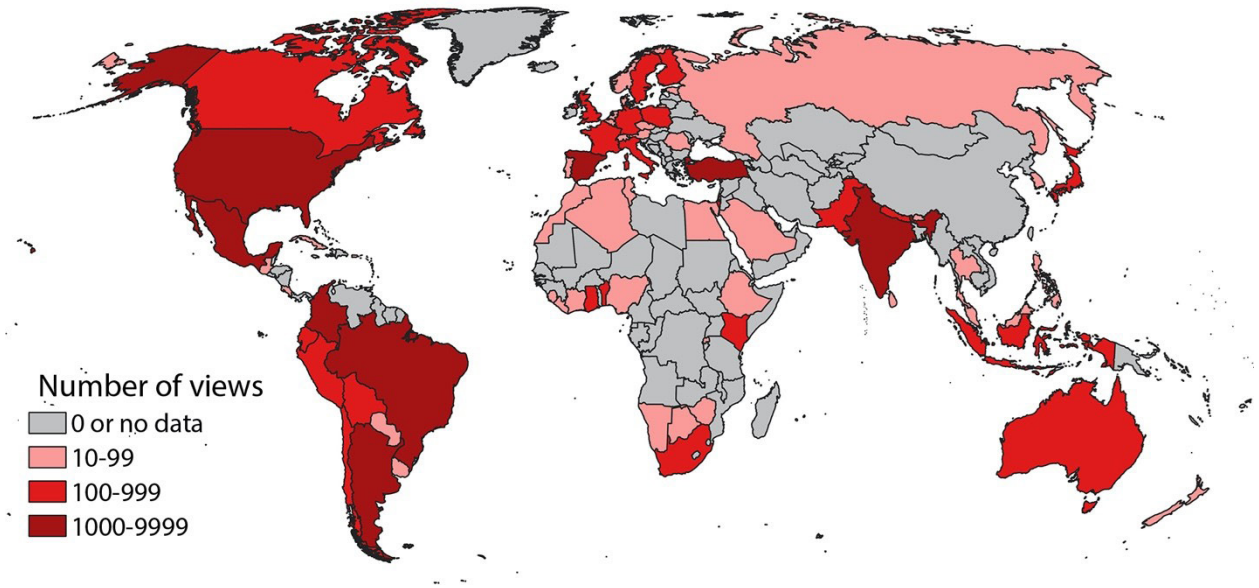

Figure 1. Summary of ENM2020 course video views by country, presented as orders of magnitude of viewership. Note that some countries do not allow access to YouTube, such that viewership from those countries shows as "no data".

pation in the field and improve educational equity by reducing barriers for all interested in these theories, protocols, and tools.

Lessons Learned

This course differs from the usual model for broad, extra-institutional courses in recent years. For ENM2020, we assembled a large proportion of the leading experts in the field and created an open, free-to-all learning platform that presents much of the current knowledge and practice for a complex area of inquiry. Many other courses in this and related areas are presented by one or a few researchers, and are often accompanied by substantial fees that constitute significant barriers to participation for many potentially-interested individuals.

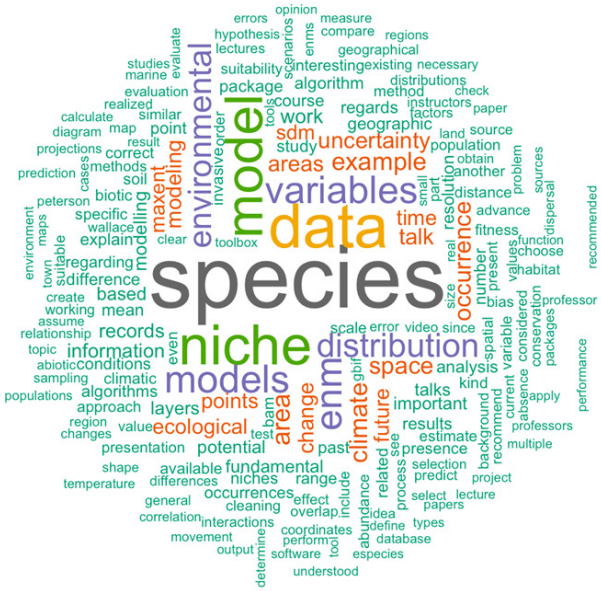

Figure 2. Visualization showing representation of different words among 3159 questions submitted to the instructors by course participants during ENM2020 (developed in R with package *wordcloud*; code included in Supplemental Information).

The key features of ENM2020 were (1) broad participation by many leaders in the area of distributional ecology, as reflected in the long author list for this contribution, and (2) open access to the content. The hefty community participation in the instructor list gave the course an air of plurality towards different, and at times even opposing, ideas regarding particular topics. These differences and debates, while conducted civilly, can be perceived in the ideas presented in various talks in ENM2020, and particularly in the question-and-answer sessions, where differences were at times debated more directly. Open access to the content, which was facilitated by posting course materials on YouTube and making materials available to participants on multiple platforms (e.g., videos for download or streaming, as well as .mp3 audio files and .pdf slide decks for those with poorer internet access), is also a key divergence from previous courses.

In the process of developing and presenting this course, however, we noted ways in which the process could have been improved. Specifically, even a modicum of direct funding might have permitted more sophisticated editing and preparation of the course videos before they were posted. Additionally, developing specific exercises could have supported the learning experience more directly, particularly if

they had been presented on a single learning platform (e.g., Moodle) for more direct and easy access. Notably, ENM2020 was developed and presented with no funding other than support from the authors' institutions and a few software-development grants in the form of the salaries and facilities for each of the instructors.

Acknowledgments

We thank the course participants for their enthusiastic and inquisitive approach to such a large-scale and (at times) seemingly unending course. Although all instructors and their institutions and employers donated the time they spent preparing and delivering the materials, many of them were supported by particular grants and fellowships that achieved widespread outreach through their participation: grants from the U.S. National Science Foundation (DBI-1661510 for MAL, RPA, JMK, CM, and GEPB; IIA-1920946 for MEC and ATP), National Aeronautics and Space Administration (80NSSC18K0406 for MAL, RPA, JMK, and GEPB), and a Japan Society for the Promotion of Science Postdoctoral Fellowship for Foreign Researchers (JMK).

Conflicts of Interest

The authors declare that no conflicts of interest exist.

Literature Cited

Anderson, R. P. 2013. A framework for using niche models to estimate impacts of climate change on species distributions. Ann. NY Acad. Sci. 1297:8–28.

Araújo, M. B., R. P. Anderson, A. M. Barbosa, C. M. Beale, C. F. Dormann, R. Early, R. A. Garcia, A. Guisan, L. Maiorano, B. Naimi, R. B. O'Hara, N. E. Zimmermann, and C. Rahbek. 2019. Standards for distribution models in biodiversity assessments. Science Adv. 5:eaat4858.

Araújo, M. B., and R. G. Pearson. 2005. Equilibrium of species' distributions with climate. Ecography 28:693-695.

Austin, M. 1987. Models for the analysis of species' response to environmental gradients. Vegetatio 69:35-45.

Elith, J., and J. R. Leathwick. 2009. Species distribution models: Ecological explanation and prediction across space and time. Ann. Rev. Ecol. Evol. Syst. 40:677-697.

Feng, X., D. Park, C. Walker, A. T. Peterson, C. Merow, and M. Papes. 2019. A checklist for maximizing reproducibility of ecological niche models. Nature Ecol. Evol. 3:1382-1395.

Ferrier, S. 2002. Mapping spatial pattern in biodiversity for regional conservation planning: Where to from here? Syst. Biol. 51:331-363.

Franklin, J. 2010. Mapping Species Distributions: Spatial Inference and Prediction. Cambridge University Press, Cambridge.

Guisan, A., and W. Thuiller. 2005. Predicting species distribution: Offering more than simple habitat models. Ecol. Lett. 8:993-1009.

Guisan, A., W. Thuiller, and N. E. Zimmermann. 2017. Habitat Suitability and Distribution Models: with Applications in R. Cambridge University Press, Cambridge.

Guisan, A., and N. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecol. Mod. 135:147-186.

MacArthur, R. 1972. Geographical Ecology. Princeton University Press, Princeton.

Peterson, A. T., R. P. Anderson, M. E. Cobos, M. Cuahutle, A. P. Cuervo-Robayo, L. E. Escobar, M. Fernández, D. Jiménez-García, A. Lira-Noriega, J. M. Lobo, F. Machado-Stredel, E. Martínez-Meyer, C. Nuñez-Penichet, J. Nori, L. Osorio-Olvera, M. T. Rodríguez, O. Rojas-Soto, D. Romero-Álvarez, J. Soberón, S. Varela, and C. Yañez-Arenas. 2019. Curso modelado de nicho ecológico, versión 1.0. Biodiv. Inf. 14:1-7.

Peterson, A. T., and K. Ingenloff. 2015. Biodiversity Informatics Training Curriculum, version 1.2. Biodiv. Inf. 10:65-74.

Peterson, A. T., and A. G. Navarro-Sigüenza. 2017. What bird specimens can reveal about species-level distributional ecology. Stud. Av. Biol. 50:111-125.

Peterson, A. T., J. Soberón, R. G. Pearson, R. P. Anderson, E. Martínez-Meyer, M. Nakamura, and M. B. Araújo. 2011. Ecological Niches and Geographic Distributions. Princeton University Press, Princeton.

Zurell, D., J. Franklin, C. König, P. J. Bouchet, J. M. Serra-Diaz, C. F. Dormann, J. Elith, G. Fandos Guzman, X. Feng, G. Guillera-Arroita, A. Guisan, P. J. Leitão, J. J. Lahoz-Monfort, D. S. Park, A. T. Peterson, G. Rapacciuolo, D. R. Schmatz, B. Schröder, W. Thuiller, K. L. Yates, N. E. Zimmermann, and C. Merow. 2020. A standard protocol for reporting species distribution models. Ecography 43:1261-1277.