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

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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—

[1] https://www.facebook.com/groups/ENM2020/.

[2] http://hdl.handle.net/1808/32540.

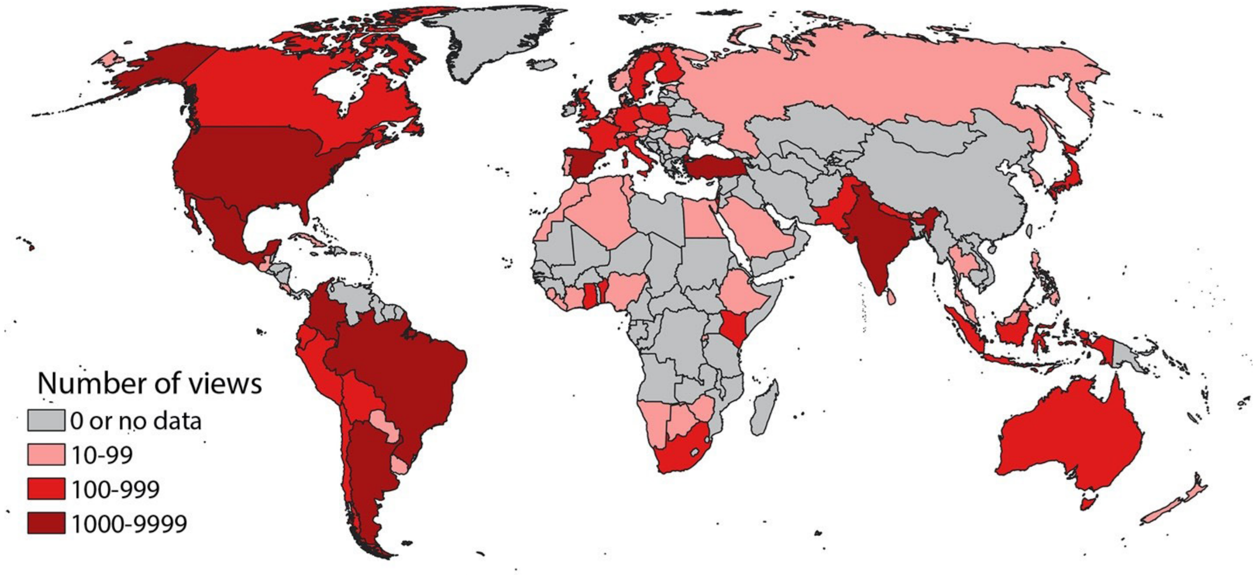

Figure 1. Summary of ENM2020 course video views by country, presented as orders of magnitude of viewership. Note that some countries do not allow access to YouTube, such that viewership from those countries shows as "no data".

made available globally via the Internet without cost—will serve to increase the diversity of participation 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,

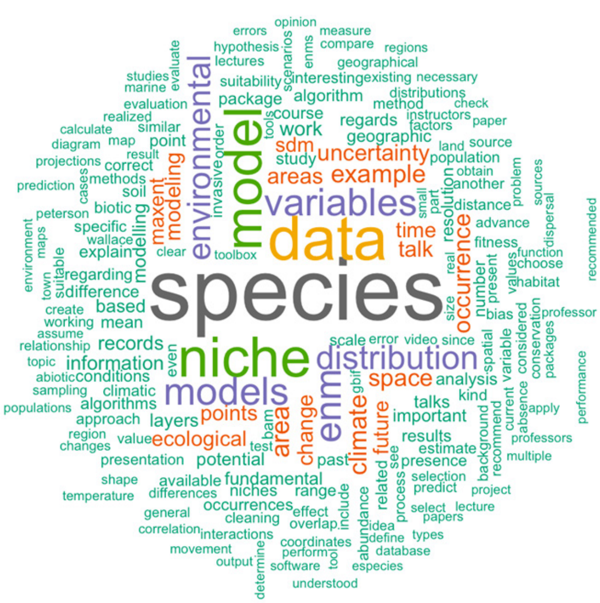

Figure 2. Visualization showing representation of different words among 3159 questions submitted to the instructors by course participants during ENM2020 (developed in R with package *wordcloud*; code included in Supplemental Information).

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.

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.

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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.

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Table 1. Summary of ENM2020 course curriculum. Note that the order of the talks has been rearranged somewhat to reflect better the flow of topics. Talks marked with a cross (†) are "overview" talks, which can be viewed in sequence (without the talks that are not so marked) to provide a much-briefer introductory "short course." This table can also be found in the website of Biodiversity Informatics Training Curriculum[1].

Title	YouTube Link	Instructor(s)*	PDF link	Additional Materials
INTRODUCTION				
Course introduction	Video	ATP	--	--
Introduction to ecological niche theory	Video	JS	Pdf	--
Introduction to distributional ecology†	Video	ATP	Pdf	--
Question and answer	Video	LOO, JS, ATP, HLO	--	Materials
APPLICATIONS				
Applications†	Video	RP	Pdf	--
Niche structure and limits	Video	JS	Pdf	--
Discovery of species and populations	Video	ATP	Pdf	Materials
Question and answer	Video	JS, MC, ATP	--	Materials
Climate change	Video	EMM	Pdf	Materials
Special discussion: Climate Change	Video	JS, EMM, MP, MC, ATP	--	Materials
Reconstructing past distributions	Video	CM1	Pdf	--
Invasive species applications	Video	GZ1	Pdf	Materials
Question and answer	Video	EMM, JS, AST, SM, ATP	Pdf	Materials
Systematic conservation planning	Video	RL1	Pdf	Materials
Large-scale conservation/recovery projects	Video	SJ	Pdf	Materials
Public health	Video	LEE	Pdf	Materials
Question and answer	Video	MP, ATP	--	Materials
KEY TOOLS				
What is the basic toolkit?	Video	ATP	Pdf	Materials
Tools for biodiversity data cleaning	Video	SRM, AST	Pdf	Exercise, Readings
Question and answer	Video	MP, TG, ATP	--	--
Niche Toolbox	Video	LOO	Pdf	Readings, Tutorial.
SDMToolbox	Video	JB	Pdf	Materials
Question and answer	Video	MP, LOO, ATP	--	Materials
ENVIRONMENTAL DATA				
Environmental data / Relation to Theory†	Video	SV	Pdf	Materials
Climate data	Video	DK	Pdf	--
Question and answer	Video	MP, SV, ATP	--	Materials
Remote-sensing data	Video	MP	Pdf	--
Soils databases	Video	GZ2	--	Materials
Question and answer	Video	MP, ATP	--	Materials
Topographic data	Video	GA	Pdf	Materials
Marine environments	Video	HLO	Pdf	--
Question and answer	Video	GA, HLO, MP, ATP	--	Nakazawa, List.
Paleoclimate data	Video	EES	Pdf	--
Question and answer	Video	MC, MP, ATP, EES	--	Ribeiro, Virtual-world, Stigall, Saupe, Myers

[1] http://biodiversity-informatics-training.org/.

OCCURRENCE DATA				
Occurrence data†	Video	ATP	Pdf	Materials
Relation to theory	Video	JS	Pdf	--
Sources	Video	JW	Pdf	--
Question and answer	Video	MP, JW, MC, ATP	--	--
Georeferencing	Video	MP	Pdf	--
Occurrence data cleaning I (simple consistency checks)	Video	ATP	Pdf	Materials
Occurrence data cleaning II (automating the process)	Video	TG	Pdf	--
Question and answer	Video	TG, MP, MC, ATP	--	Materials
Filtering and autocorrelation	Video	MAL	Pdf	R code
Subsetting for evaluation	Video	JMK	Pdf	R code
Data citation	Video	DN	Pdf	--
Question and answer	Video	MAL, JMK, DN, JS, MC, MP, ATP	--	--
VISUALIZATION				
NicheA	Video	LEE, HQ	Pdf	--
Demo with NicheA - further visualization - 3D	Video	LEE	Pdf	--
Question and answer	Video	LEE, MC, MP, ATP	--	GEODA, Reprints
DISTRIBUTIONAL EQUILIBRIUM				
Distributional equilibrium / Relation to Theory†	Video	JS	Pdf	--
Estimating M	Video	FMS	Pdf	--
Question and answer	Video	MC, FMS, MP, JS, ATP	--	Grinnell, Literature.
BAM and M and model success - What you can and cannot model	Video	ATP	Pdf	BAM, Literature.
BAM scenario exercises	Video	ATP	Pdf	--
Question and answer	Video	MC, FMS, MP, ATP	--	Materials
Special discussion: Extent and Resolution	Video	MC, JS, ATP	--	EcoClimate
ALGORITHMS				
Algorithms / Relation to Theory†	Video	JF	Pdf	Hastie, Elith, Elith06
Un Solo Díos	Video	ATP	Pdf	Materials
Question and answer	Video	MC, ATP	--	Paper on uses, Zhu.
Maxent 1	Video	CM2	Pdf	Materials
Maxent 2	Video	CM2	Pdf	--
Question and answer	Video	CM2, MP, MC, ATP	--	--
ModleR platform demo	Video	AST, SRM	Pdf	--
Wallace	Video	JMK, GEPB	Pdf	--
Question and answer	Video	JMK, GEPB, SM, AST, MC, MP, ATP	--	--
Sdm	Video	BN	Pdf	R code
BioMod – Introduction	Video	WT	Pdf	--
BioMod - Single Species	Video	DG	Pdf	R code
BioMod - Multiple Species	Video	DG	Pdf	R code
BioMod – Specifics	Video	MG	Pdf	R code
BioMod – Shiny	Video	IO	--	--
Question and answer	Video	BN, MC, MP, ATP	--	--

Special discussion: Algorithm Choice	Video	JS, MC, MP, ATP, EMM	--	--
Bonus: Model Fit in E	Video	DW	--	--
UNCERTAINTY				
Uncertainty in ENM	Video	ATP	Pdf	Materials
Question and answer	Video	MC, MP, ATP	--	--
EVALUATION				
Model evaluation / Relation to Theory†	Video	RPA	Pdf	Materials
Prediction-based evaluations	Video	ATP	Pdf	Materials
Question and answer	Video	RPA, JMK, MC, MP, ATP	--	Materials
Model evaluation not prediction-based	Video	ATP, SM	Pdf	--
Question and answer	Video	MC, MP, ATP	--	--
MODEL SELECTION				
Relation to theory	Video	DW	Pdf	Materials
ENMEval	Video	BM	Pdf	--
KUENM	Video	MC	Pdf	Materials
Question and answer	Video	MC, MP, ATP	--	Materials
MODEL TRANSFERS				
Model transfers†	Video	KY	--	--
Relation to theory	Video	HLO	Pdf	--
Question and answer	Video	HLO, MP, MC	--	--
Past, present, future	Video	EMM	Pdf	Materials
Extrapolation and measuring extrapolation	Video	HLO	Pdf	Materials
Collinearity	Video	XF	Pdf	--
Question and answer	Video		--	Answers, Literature
MODEL COMPARISONS				
Relation to theory: G or E spaces, Niche Overlap	Video	MC, JS	Pdf	Materials
Niche comparisons in geographic space	Video	DW	Pdf	Materials
Question and answer	Video	MC, MP, ATP	--	--
Niche comparisons in environmental space 1	Video	MC	Pdf	--
Niche comparisons in environmental space 2	Video	MC	Pdf	Materials
Question and answer	Video	MC, MP	--	--
REPEATABILITY				
Introduction to repeatability in ENM†	Video	ATP	Pdf	--
Metadata standards	Video	XF	Pdf	Materials
Quality standards	Video	DZ	Pdf	Materials
Question and answer	Video	DZ, MLM, MP, MC, ATP	--	--
ABUNDANCES				
Relation to theory	Video	JS	Pdf	--
Controversy	Video	LEE, ACR	Pdf	--
Methods and test results	Video	EMM	Pdf	Materials
Question and answer	Video	MP, EMM, JS, MC, ATP	--	Materials

FRONTIERS				
Frontiers†	Video	JADF	Pdf	Materials
Fitting biologically realistic responses	Video	LJ, JS	Pdf	Materials
Question and answer	Video	MP, MC, JS, LJ, ATP	--	--
Mechanistic models. a. Mechanistic niche model concepts	Video	MK	Pdf	--
Mechanistic models. b. Heat budgets and microclimates	Video	MK	Pdf	--
Mechanistic models. c. Energy budgets and their integration	Video	MK	Pdf	--
Mechanistic models. d. Integration with correlative models	Video	MK	Pdf	--
Virtual species and virtual worlds	Video	ATP	Pdf	Materials
Question and answer	Video	MK, JS, MP, MC, ATP	--	Vespa
Scientific workflows in ENM	Video	MLM, LG	Pdf	Materials
Time-specific ecological niche modeling	Video	KRI	Pdf	--
Special discussion: Eltonian Noise	Video	MC, JS, EMM, ATP	--	Co-occurrence debate
Question and answer	Video	MLM, LG, MC, MP, JS, ATP	--	IUCN paper
Genetic basis of niches	Video	DD, ATP	Pdf	Materials
Question and answer	Video	DD, ATP, MC, JS	--	Materials
PRACTICALITIES				
Publishing results from ENMs	Video	ATP, AA	Pdf	Publication course: Intro, Journal Choice, Technology, Words, Figures, Color, Tables, Proofing, Literature Cited, Cover Letter and Reviewers, Authorship, Response to Reviewers, Proofs, Presentation for course.
Open Access to Scientific Literature	Video	ATP	Pdf	Example
Writing effective proposals for funding	Video	ATP	Pdf	Short course
CONCLUSIONS				
Special feature: Interview with Sara Varela	Video	SV, ATP	--	--
Course wrap-up	Video	RP, JS, CM1, EMM, GZ1, HLO, MC, MP, DZ, LEE, ATP, JW	--	--