ADVANCED LANDSCAPE ECOLOGY

Zoology/Forest & Wildlife Ecology/Botany 879

Course Description, Spring Semester 2024

Version: 29 December 2023 and Subject to change!

Instructor: Monica G. Turner, Department of Integrative Biology (turnermg@wisc.edu)
TA: Timon T. Keller, Department of Integrative Biology (ttkeller@wisc.edu)

Credits: 3 credits
Time & place: Tuesdays and Thursdays, 9:55 – 11:50 am, 158 Birge Hall
(The room is off the main lobby, go down the hall to the left (east) as you enter from the main doors; the classroom will be straight ahead at the end of that hallway).
Instruction mode: Face-to-face

Requisites:

- Graduate student status
- General Ecology (e.g., Zoo/Bot/For 460 or equivalent) ***is required***.
- Basic familiarity with landscape ecology ***is required***.
- Familiarity with statistics is strongly recommended, and some knowledge of geographic information systems (GIS) and simulation modeling is desirable.

COURSE DESCRIPTION:
Landscape ecology is a sub-discipline of ecology that emphasizes spatial patterning–its causes, development, and importance for ecological processes. Furthermore, landscape ecology often (but not always) focuses on ecological dynamics over large regions. The field has grown tremendously and matured over the past 35+ years. Students will delve into current concepts, methods, and applications of landscape ecology through (1) class lectures; (2) reading and discussion of literature reflecting state-of-the-art research in the field; (3) completion of hands-on exercises designed to provide experience with some of the quantitative tools of landscape ecology; and (4) completion of an independent research project that allows students to apply these concepts and tools in their own studies.

The Advanced Landscape Ecology course emphasizes the current state-of-the-science of landscape ecology and covers common quantitative methods used in landscape ecology; ***it is recommended for advanced graduate students who are conducting research in this area and is not recommended for students who seek an introduction or general overview of the field. Basic knowledge of landscape ecology is assumed for Advanced Landscape Ecology. Students who have limited background in landscape ecology should read the Turner & Gardner (2015) text, LANDSCAPE ECOLOGY IN THEORY AND PRACTICE, before the semester begins***.
This text provides a foundation in landscape ecology, whereas assigned readings are generally recent and reflect the current state of the field.

COURSE LEARNING OUTCOMES: Ecology graduate students will:

- Read and synthesize current scientific literature in landscape ecology
- Understand the current state-of-the-science in the major research areas of landscape ecology
- Use and interpret quantitative methods used to analyze and interpret spatial heterogeneity in ecology
- Learn how to calculate and interpret commonly used landscape metrics and know their appropriate use
- Implement simple models of landscape change
- Apply landscape ecology concepts and methods to their thesis research

- Practice key professional research skills, including proposal development, research implementation, and communicating results in written and verbal modes

OFFICE HOURS: Office hours are by appointment. Please email Monica or Timon to schedule a time.

HOW ARE CREDIT HOURS MET BY THE COURSE? Learning will take place in at least 135 hours of learning activities, including time spent in class meetings (lecture, discussion, and lab); reading; writing; preparing for class; completing an independent research project related to their thesis work; and any other activities as described in the syllabus or assigned during the semester.

TEXTS (both are posted in Canvas):

Turner, M. G., and R. H Gardner. 2015. LANDSCAPE ECOLOGY IN THEORY AND PRACTICE, 2nd edition. Springer, New York. (Foundation material and used for quantitative chapters).

Gergel, S. E. and M. G. Turner, editors. 2016. LEARNING LANDSCAPE ECOLOGY, 2nd edition. Springer-Verlag, New York. (Needed for lab, available as an e-book through the library).

CLASS SIZE: Admission limited to 20 students.

COURSE STRUCTURE:

Class meetings will generally include either a lecture followed by student-led discussion of assigned readings, or hands-on computational exercises designed to introduce students to the quantitative methods used in landscape ecology. ***Important: UW-Madison no longer makes computer labs available for classes without a hefty hourly fee. Students must bring a laptop to class on lab days. Ideally, Mac computers should also be configured to run Windows programs, as some programs are written only for PCs.*** Students should be able to sign out a computer from the library if needed. Lastly, we reserve classes for oral presentations of the independent projects at the end of the semester (those are always fun!)

ASSIGNMENTS:

All assignments will be submitted online via Canvas.

ABSENCE POLICY:

Attendance is recorded at each class meeting. If you have an anticipated absence (e.g., planned conference travel or necessary field work), please let me know before the class that you will miss. If you are unexpectedly absent (e.g., illness), please inform me at your earliest convenience and let me know what happened.

For lecture/discussion classes that are missed, students are responsible for the material that was covered in class and for completing the readings. A summary of the assigned readings (one single-spaced page maximum for each assigned paper) should be submitted no later than one week after the missed class, but this is flexible for any classes missed to illness. Please communicate with me about timing. The summary should include a brief statement of what was covered in the paper, your thoughts on the primary contribution(s) of the paper, any insights that were new for you, and questions that were raised in your mind by the paper. I want your thoughts about the readings, not a repetition of what the authors wrote.

For labs that are missed, students must complete the lab exercise and turn in the report. Depending on the timing of the due dates and the travel/illness, the deadline may be extended. Students should check with me and confirm arrangements.

COVID SAFETY:

Any campus protocols to ensure COVID safety will be followed in this class. Important lessons we all learned from the pandemic are to stay home when ill, and to wear a mask if you are feeling slightly unwell or need to protect yourself or someone close to you from exposure. If you are ill but able to attend class remotely, it is OK to ask another student to set you up on Zoom, then "carry you along" for small-group discussions. We will work to accommodate situations that arise as needed.

READING ASSIGNMENTS:

The 2nd edition of LANDSCAPE ECOLOGY IN THEORY AND PRACTICE (Turner and Gardner 2015) will be used as reference for the class. It is posted in Canvas. ***Students are expected to be familiar with the text material, as it is the foundation for understanding the recent primary literature.***

This course emphasizes readings from the recent primary literature, with ~4 papers assigned each week for discussion. ***Every student is expected to have read the assignments before class and be prepared to discuss the papers; responses to prompts will either be posted to the Discussion Board or to Assignments in Canvas.*** Responsibility for leading discussion will be rotated among all students. Discussion leaders should raise questions or issues to be discussed; be prepared with an evaluation of the significant contributions of the paper; and facilitate discussion among the group (see notes below). Readings from the primary literature will be on Box and accessible through Canvas or the direct link; of course, readings can also be accessed individually through the electronic collections of the library. I have numbered them by week so that it is easy to locate the grouping of papers for each class. The folder can be downloaded so you have them locally:

https://uwmadison.box.com/s/r0qcjtvlzw8vprlwczqi5ncofj17y17x

Two additional useful references include an edited volume with foundational papers and background (c.f. editors' introductions to each section of the book) and a recent textbook that is especially strong on organisms and conservation, which is Kim's primary expertise. Both are available through the library; these are not in Canvas.

Wiens, J. A., M. R. Moss, M. G. Turner and D. J. Mladenoff, editors. 2007. FOUNDATION PAPERS IN LANDSCAPE ECOLOGY. Columbia University Press, New York.

With, K. A. 2019. ESSENTIALS OF LANDSCAPE ECOLOGY. Oxford University Press.

LEADING DISCUSSION:

Each student will have the opportunity to lead the class discussion of assigned weekly readings. All students will have read the papers prior to class, so discussion leader(s) should **not** provide a detailed review of the paper. The discussion leader(s) should provide a brief summary of the main topic of the paper, just to remind everyone of which paper is being considered. Here are some tips for being effective at leading discussion.

i. Summarize for yourself some of the important points about the paper. It's often useful to have a set of questions that you answer while planning discussion. For example, consider the following: What is the main conceptual contribution of the paper? Why might it be important or influential? Is it a representative example? Does it propose a new direction or idea? How does this paper relate to other papers or general concepts with which you are familiar? Are there any new approaches represented? Are there any problems with the study? How does this reflect the current state of the science?

ii. Prepare in advance some open-ended questions that you can pose to the group to get the discussion going. Remember that questions with a "yes" or "no" answer do not facilitate a discussion! Feel free to call on people if there is silence!

iii. Keep the discussion moving by including all members of the group (this means calling on reticent members of the group and gently redirecting away from individuals who may dominate the conversation) and by curtailing discussion that goes off into tangents or dead ends.

iv. Try to summarize and synthesize as things go along. It's often helpful to use a mechanism like, "So far, we've identified the following main contributions of this paper: ….

v. Be careful not to dominate the discussion. You are a facilitator, and it is harder to do this well than you might expect. You can allow some silence. Encourage discussion by asking question of the group, not by making pronouncements.

vi. You are welcome to come up with activities or try out some new discussion techniques on us. We make good guinea pigs. Be creative, use your imagination!

PARTICIPATING IN DISCUSSION:

Discussions are only effective when everyone is prepared and has perspectives to contribute. ***Everyone is expected to have read the assignment before class and given thought to the paper's content and context.*** A good strategy for being prepared is to write down a couple of questions or observations about each paper as you are reading it. Notating ideas on your hard copy or digital file is also helpful. This class benefits tremendously from the diverse interests and backgrounds of the students, and we all learn a lot by listening to one another.

LABORATORY EXERCISES:
A set of hands-on exercises will be assigned to provide students with experience in various aspects of landscape ecology, particularly the quantitative analyses and modeling often used in landscape ecology. Labs will take place during Thursday class periods (see syllabus for dates). Concise written reports will be turned in the following week; see syllabus for due dates. Lab exercises will mostly be from the 2nd edition of LEARNING LANDSCAPE ECOLOGY with handouts for specific instructions and updates.

Make sure ***always to read the lab exercise prior to coming to the class session***. You will not usually complete the lab during the time period, but you'll get going on it. Write-ups must be short—your gain in learning comes from doing the lab and thinking about it, and I try hard to minimize the busy work (although there is still some). Unless otherwise stated, my rule of thumb is ~2 pages of prose (typed, single space, but excluding figures, tables and references), or ~4 pages of prose when a lab is done in two parts over two weeks. Write-ups are due the following week after the lab was completed. Instructions particular for each lab will be given in class.

INDEPENDENT PROJECTS:

Project Objectives: Students will use landscape-level theory or approaches in an area of particular interest to them, thereby allowing them to apply what they are learning to their own research. The project should be an opportunity for students to augment their research (e.g., thesis or dissertation work). Students will also gain experience with the primary phases of conducting a research study: preparation of a proposal; execution of the study; preparation of a paper based on the study; and oral presentation of the results in the format suitable for a scientific meeting. All graduate students should have as many opportunities to "practice" all aspects of professional science as much as possible!

Topics: Recognizing that there is likely a wide array of interests represented in the class, the choice of topic for the project is not restricted. However, approval of a student's selection is required. Samples of projects might be: (1) analyses of spatial pattern of vegetation or land use in a study landscape; (2) synthesis of literature on how an organism or community responds to changes in habitat heterogeneity, with development of field-testable hypotheses, recommendations for conservation, or reserve design; (3) development of a model to address an interaction between pattern and process; (4) preparation of a management plan for a large heterogeneous landscape. The key is to use this project to develop something you want to learn or want to make progress on in your thesis work–it is your opportunity to apply landscape concepts or methods in your own work!

Format for Project Proposals: Proposals must be typewritten, double spaced with one-inch margins and 12-pt type with a **2-page maximum length,** excluding references. The following should be clear and succinct: Introduction/Background; Question(s); Methods; and Expected Results.

Format for Project Reports: Reports should be written in manuscript form and be double-spaced with one-inch margins with a standard type font (e.g., Times New Roman, Ariel, etc.) no smaller than 11 pt. Main body text (i.e., Introduction through Conclusions) should **not exceed 3000 words** excluding the title page, abstract, acknowledgements, references, figures, and tables. The format should ***exactly*** follow that required for submission to the journal LANDSCAPE ECOLOGY, which is available on the journal's website. Pay careful attention to ALL details in the instructions to authors (which you must do any time you submit your own manuscript for publication.) Please don't forget to proof read your references for completeness, typos and format; use of bibliographic software does not eliminate the obligation to proof read and correct. Clean references reflect well on authors!

Inspire Session: Instead of full-length presentations, we will go with lightning talks for each independent project following the guidelines for Inspire Sessions at the annual meeting of the Ecological Society of America. Don't let the short format fool you, however; these take quite a bit of work to prepare! Details will be forthcoming, but each talk is limited to 20 slides, which advance automatically every 15 seconds. Inspire talks pose an interesting challenge in scientific communication, as they require speakers to have winnowed down to key points, work on

timing, and add some entertainment value. While we always practice our talks in advance, these short ones require a surprising amount of practice and honed delivery and timing.

DUE DATES: See course syllabus for all due dates.

GRADING:
Grades will be based on the laboratory exercises (30%), midterm (15%), class participation (10%), leading discussion (10%), and the final project (35% total: oral presentation 10%, written report 25%). Numerical grades will be assigned to letter grades as follows: 93-100 (A), 90-92 (AB), 83-89 (B), 80-82 (BC).

COURSE EVALUATIONS:
Students will be provided with an opportunity to evaluate this graduate seminar and your learning experience. Please complete the university's general course evaluation when you are notified that it is available. Your feedback is important!

DIVERSITY & INCLUSION STATEMENT
Diversity is a source of strength, creativity, and innovation for UW-Madison. In this course and across the campus, we value the contributions of each person and respect the profound ways their identity, culture, background, experience, status, abilities, and opinion enrich the university community. We commit ourselves to the pursuit of excellence in teaching, research, outreach, and diversity as inextricably linked goals. The University of Wisconsin-Madison fulfills its public mission by creating a welcoming and inclusive community for people from every background – people who as students, faculty, and staff serve Wisconsin and the world.

USE OF ARTIFICIAL INTELLIGENCE (AI) TOOLS:
This year has seen ChatGPT and other AI tools arrive in force and, as with any new technology, understanding of its limitations and establishment of consistent standards for ethical and appropriate use of AI are evolving. There are productive ways to use AI in science, but this course emphasizes the thinking and writing skills each individual needs to develop for themselves; thus, I **always** want your authentic responses (not the hive mind). The abilities to read, think critically, synthesize your understanding, and convey your insights in your own words are fundamental for every scholar, and it takes lots of practice to develop and improve those skills. When using a chatbot to do your writing (or thinking!), you are not providing your original ideas. Furthermore, you are relying on material that cannot be verified, is often (shockingly) incorrect, and is mediocre at best. We will discuss appropriate use of AI tools during class, and getting started on computer code is an appropriate use. Any use of AI tools must be acknowledged in all materials submitted for this course. However, ***the use of artificial intelligence (AI) tools and applications (including, but not limited to, ChatGPT, DALL-E, and others) for course writing assignments and assessments does not support the learning objectives of this course and is prohibited.***

Using AI tools in any way for your written responses to discussion or assignment prompts (e.g., asking ChatGPT to summarize or evaluate an assigned reading), lab write-ups, project proposal, or independent project, is a violation of the course's expectations and will be addressed through UW–Madison's academic misconduct policy, specifically UWS 14.03(1)b (b) Uses unauthorized materials or fabricated data in any academic exercise.

Remember also that when citing to published literature, your citations indicate that you have read and understood the papers cited; you should never cite references that you have not read (remember that AI chatbots are prone to hallucinations, meaning that they make things up, and they often provide citations that are real sources but completely inappropriate to support a given statement).

ACADEMIC INTEGRITY:
By virtue of enrollment, each student agrees to uphold the high academic standards of the University of Wisconsin-Madison; academic misconduct is behavior that negatively impacts the integrity of the institution. Cheating, fabrication, plagiarism, unauthorized collaboration, and helping others commit these previously listed acts are examples of misconduct which may result in disciplinary action. Examples of disciplinary action include, but is not limited to, failure on the assignment/course, written reprimand, disciplinary probation, suspension, or expulsion.

ACCOMODATION FOR STUDENTS WITH DISABILITIES:
The University of Wisconsin-Madison supports the right of all enrolled students to a full and equal educational opportunity. The Americans with Disabilities Act (ADA), Wisconsin State Statute (36.12), and UW-Madison policy (Faculty Document 1071) require that students with disabilities be reasonably accommodated in instruction and campus life. Reasonable accommodations for students with disabilities is a shared faculty and student responsibility. Students are expected to inform faculty [me] of their need for instructional accommodations by the end of the third week of the semester, or as soon as possible after a disability has been incurred or recognized. Faculty [I], will work either directly with the student [you] or in coordination with the McBurney Center to identify and provide reasonable instructional accommodations. Disability information, including instructional accommodations as part of a student's educational record, is confidential and protected under FERPA. (See: McBurney Disability Resource Center)

Additional Information and UW-Madison Policies

Institutional academic policies and statements are reviewed and updated annually, as needed. Please visit the following links for university-wide policies.

- Teaching and Learning Data Transparency Statement
- Privacy of Student Records and the Use of Audio Recorded Lectures Statement
- Campus Resources for Academic Success
- Course Evaluations and Digital Course Evaluations
- Students' Rules, Rights and Responsibilities
- Diversity and Inclusion Statement
- Accommodations for Students with Disabilities
- Academic Calendar and Religious Observances

ADVANCED LANDSCAPE ECOLOGY

Texts

[1]Turner, M. G. and R. H. Gardner. 2015. LANDSCAPE ECOLOGY IN THEORY AND PRACTICE, 2nd edition. Springer-Verlag, New York. *[Foundational reading – important if you have not previously had landscape ecology.]*

[2]Gergel, S. E. and M. G. Turner, editors. 2016. LEARNING LANDSCAPE ECOLOGY, 2nd edition. Springer-Verlag, New York. *[Required for labs.]*

Dates	Topics, [2]Labs (blue), Due dates (red)	[1]Text chap.	Discussion readings or [2]Lab book chap.
Tues Jan 23 (remote)	**(1) Contemporary landscape ecology** (1a) Landscape ecology and scale	1	Swanborn et al. 2021 Fletcher et al. 2023 Banks-Leite et al. 2022
Thurs Jan 25 (remote)	(1b) Ways of studying landscapes Video lecture (TED talk): Greg Asner, Ecology from the air https://www.ted.com/talks/greg_asner_ecology_from_the_air	1	Lepczyk et al. 2021 Markham et al. 2023 Depauw et al. 2022
Tues Jan 30 (remote)	**(2) Causes of landscape pattern** (2a) Contingencies, legacies, path-dependence	2	Phillips 2007 Tappeiner et al. 2021 Johnson-Bice et al. 2022 Lembrecht and Nijs 2020
Thurs Feb 1 (remote)	(2b) Persistent anthropogenic legacies Video lecture (TED talk): Eric Sanderson, New York before the city https://www.ted.com/talks/eric_sanderson_new_york_before_the_city	2	Meyfroidt et al. 2022 Ellis et al. 2021 Sutherland et al. 2023
Tues Feb 6	**(3) Landscape models and landscape change**	3	Bugmann and Seidl 2022 Olson et al. 2021 Etherington et al. 2022 Fu et al. 2022
Thurs Feb 8	**Lab #1** *Introduction to Markov models*	--	LLE Chap. 8, Urban and Wallin
Tues Feb 13	**(4) Ecosystem services in heterogeneous landscapes**	10	Schulte et al. 2017 Qiu et al. 2021 Jha et al. 2022 Ha et al. 2023
Thurs Feb 15	**Lab #2,** *People in Ecosystems/Watersheds integration (PEWI)* ***Lab #1 write up due.***	--	LLE Chap. 19, Schulte and Tyndall; Chennault et al. 2020
Tues Feb 20	**(5) Quantifying pattern I:** why, data and errors, caveats; start metrics	4	Frazier and Kedron 2017 Gustafson 2019 Cushman et al. 2008 Riva and Nielsen 2020

Thurs Feb 22	**Lab #3**, *Understanding landscape metrics, part 1)* ***Lab #2 write up due.***	--	LLE Chap. 4, Cardille & Turner
Thurs-Fri, Feb 22-23	**Lectures by Dr. Lisa Schulte-Moore:** Thursday, 3:30 pm, Noland Hall Friday, 1:30 pm, Moore Hall **Graduate student lunch (optional)** Friday, 12:00 pm, location TBD	--	Please try to attend the Thursday lecture, unless you have a class or TA conflict; or the Friday lecture. Sponsored by University Lectures, Integrative Biology (L&S), and Plant and Agroecosystem Sciences (CALS)
Tues Feb 27	**(6) Quantifying pattern II:** metrics and interpretation, using multiple metrics	4	Eigenbrod et al. 2011 Ramirez-Arce et al. 2022 Iskin and Whohl 2023 Curd et al. 2023
Thurs Feb 29	**Lab #3,** *Understanding landscape metrics, part 2)* ***Independent project proposals due.***	--	LLE Chap. 4, Cardille & Turner [Hesselbarth et al. 2019, R package]
Tues Mar 5	**(7) Spatial statistics:** what, why and how	5	Vasquez et al. 2012 Schregel et al. 2018 Roy et al. 2020 DiFalco et al. 2022
Thurs Mar 7	**Lab #4**, *Scale detection using semivariograms and autocorrelograms* ***Lab #3 write up due (both parts).***	--	LLE Chap. 5, Palmer & McGlinn
Tues Mar 12	**(8) Disturbance and landscapes I:** reciprocal pattern-process, thresholds, interactions	6	Leitold et al. 2021 Senf and Seidl 2021 Rodman et al. 2023 Harvey et al. 2023
Thurs Mar 14	**Lab #5**, *Neutral landscape models (no write up)* ***Lab #4 write up due.***	--	LLE Chap. 6, Gardner
Tues Mar 19	**(9) Disturbance and landscapes II:** compound disturbances, resilience, novel regimes	6	Walden et al. 2023 LeBreton et al. 2022 Pausas and Bond 2020 Turner and Seidl 2023
Thurs Mar 21	**Midterm exam** – in class, closed book	--	--
Mar 26-Mar 28	**Spring Break – No classes!**	**--**	**--**

Tues Apr 2	**(10) Organisms and landscapes I:** reciprocal interactions; habitat amount vs. configuration	7	Fletcher et al. 2018 Fahrig et al. 2019 Fahrig 2019 Valente et al. 2023
Thurs Apr 4	**Lab #6,** *Landscape connectivity and network analysis*	--	LLE Chap. 12, Lookingbill & Minor
Tues Apr 9	**(11) Organisms and landscapes II:** species interactions, landscape connectivity	7	Berger et al. 2022 Belote et al. 2022 Suraci et al. 2023 Cumming et al. 2022
Thurs Apr 11	**Lab #7,** *Advances in quantifying landscape connectivity, Part 1 (no write up)* ***Lab #6 write up due (last one!)***	--	LLE Chap. 14, Saura & de la Fuente
Tues Apr 16	**(12) Ecosystem processes in heterogeneous landscapes**	8	Monk and Schmitz 2021 Gonzalez et al. 2020 Smith et al. 2023 Harvey et al. 2023
Thurs Apr 18	***Lab #8****, Modeling spatial dynamics of ecosystem processes and services (no write up)*	9	LLE Chap. 16, Gergel & Reed
Tues Apr 23	**(13) Frontiers in landscape ecology**	--	**To be determined**
Thurs Apr 25	*No class meeting – work/prep day*	--	--
Tues Apr 30	**Inspire Session** (student presentations)	--	--
Thurs May 2	**Inspire Session** (student presentations)	--	--
Mon May 6	***Final written project report due by 12:00 noon CDT.***	--	--

ADVANCED LANDSCAPE ECOLOGY (879)
Readings for Spring 2024

(Week 1) Tuesday, January 23 – Contemporary landscape ecology

Background:

Rose, K. C., R. A. Graves, W. D. Hansen, B. J. Harvey, J. Qiu, S. A. Wood, C. Ziter, and M. G. Turner. 2017, Historical foundations and future directions in macrosystems ecology. Ecology Letters 20:147-157. [*Macrosystems and macroecology became buzz words, but both rely on foundational work in landscape ecology. What is different? What is the same? Does the Banks-Leite paper add value to what is known? This paper also offers a brief refresher on scale concepts, which underpin much of landscape ecology.]*

Wiersma, Y. F. 2022. Experimental Landscape Ecology. Springer, New York. [*The first 5 chapters of this book offer an overview of landscape concepts and the role of experiments in landscape ecology. Approaches to experimentation are then discussed from small model landscapes to large experiments, and experiments using computer simulation models.*]

(1a) For discussion—current takes on landscape ecology and scale:

Swanborn, D. J. B., V. A. I. Huvene, S. J. Pittman, and L. C. Woodall. 2021. Bringing seascape ecology to the deep seabed: A review and framework for its application. Limnology and Oceanography 9999:1-23. [*Nice review of LE concepts and methods in the context of the deep ocean; useful re-cap and a prompt to think about the generality of LE concepts applying outside of just "land."]*

Fletcher, R. J. Jr., M. G. Betts, E. I. Damschen, T. J. Hefley, J. Hightower, T. A. H. Smith, M.-J. Fortin, and N. M. Haddad. 2023. Addressing the problem of scale that emerges with habitat fragmentation. Global Ecology and Biogeography 10.1111/geb.13658. *[Nice review of scale concepts, illustrated from the viewpoint of habitat fragmentation (which we will re-visit later in the semester). Table 1 is very useful, also ties into neutral landscape models. But key here is distinction between scales of mechanism, scales of sampling and scales of analysis.]*

Banks-Leite, C., M. G. Betts, R. M. Ewers, C. D. L. Orme, and A. L. Pigot. 2022. The macroecology of landscape ecology. TREE 37(6):480-487. [*Thought-provoking – is macroecology coming to the rescue? How does macroecology add value to LE (or does it?) Does the emphasis on biodiversity limit generality of the ideas presented in this paper?]*

(1b) Thursday, January 25–ways of studying landscapes:

For discussion:

Watch the TED Talk by Greg Asner: Ecology from the air
https://www.ted.com/talks/greg_asner_ecology_from_the_air

Lepczyk, C. A., L. M. Wedding, G. P Asner, S. J Pittman, T. Goulden, M. A. Linderman, J. Gand, and R. Wright. 2021. Advancing landscape and seascape ecology from a 2D to a 3D science. BioScience 71:268-279. *[Introduces you to the potential of 3D data, which complements the TED talk and is increasingly used in landscape studies as data become more widely available.]*

Markham, K., A. E. Frazier, K. K. Singh, and M. Madden. 2023. A review of methods for scaling remotely sensed data for spatial pattern analysis. Landscape Ecology 38:619-635. *[Ties issues of scale to the practical side of having to upscale or downscale; timeline for science of scaling; context for quantifying spatial pattern.]*

Depauw, L., H. Blondeel, E. De Lombaerde, K. De Pauw, D. Landuyt, E. Lorer, P. Vangansbeke, T. Vanneste, K. Verheyen, and P. De Frenne. 2022. The use of photos to investigate ecological change. J. Ecol. 110:1220-1236. *[Interesting application of how repeat photography can be useful in landscape studies.]*

(Week 2) Tuesday, January 31 – Causes of landscape pattern

Background (highly recommended):

Jackson, S. T. 2006. Vegetation, environment and time: the origination and termination of ecosystems. Journal of Vegetation Science 17:547-557. [*Such a well written essay. Good thinking on long-term change and links to paleoecology, which provides landscape ecology with a deep time perspective*.]

(2a) For discussion—contingencies, legacies, and path-dependence

Phillips, J. D. 2007. The perfect landscape. Geomorphology 84:159-169. [*Important though under-appreciated conceptual paper that makes the point that every landscape is unique, and many contingencies lead to the development of any particular landscape pattern. Every landscape ecologist should read this!*]

Tappeiner, U., G. Leitinger, A. Zarina, and M. Bürgi. 2021. How to consider history in landscape ecology: patterns, processes and pathways. Landscape Ecology 36:2317-2328. *[Focuses on understanding legacy effects; complements Phillips (2007) in emphasizing path dependence.]*

Johnson-Bice et al. 2022. Relics of beavers past: time and population density drive scale-dependent patterns of ecosystem engineering. Ecography e05814. *[Recent example of a classic ecosystem engineer creating persistent landscape patterns in the Upper Midwest that also deals with legacies -- but instead of land-use or disturbance, it's beavers!]*

Lembrechts, J. L. and I. Nijs. 2020. Microclimate shifts in a dynamic world. Science 368:711-712. *[This quick read is an introduction the recent surge in studies focused on microclimate and microtopography; these are currently hot topics, and this commentary accompanied an excellent paper by Zellweger et al.]*

(2b) Thursday, February 22–For discussion–persistent anthropogenic legacies

Watch the TED Talk by Eric Sanderson, New York before the city
https://www.ted.com/talks/eric_sanderson_new_york_before_the_city

Meyfroidt, P. et al. 2022. Ten facts about land systems for sustainability. PNAS 119(7)e2109217118. *[Thought-provoking article that leans on landscape ecology and emphasizes sustainability challenges and social-ecological systems.]*

Ellis, E. C., et al. 2021. People have shaped most of terrestrial nature for at least 12,000 years. PNAS 118(17):e2023483118. *[Not landscape ecology per se, but an excellent overview of global land-use history; an important paper that offers context for the TED talk on New York.]*

Sutherland, I. J., K. Copes-Gerbitz, L. Parrott, and J. M. Rhemtulla. 2023. Dynamics in the landscape ecology of institutions: lags, legacies, and feedbacks drive path-dependency of forest landscapes in British Columbia, Canada, 1958-2020. Landscape Ecology https://doi.org/10.1007/s10980-023-01721-y. *[Considers the linked social-ecological system and an example of path-dependence in a specific landscape.]*

(Week 3) Tuesday, Feb 22 – Landscape models and landscape change

Good background (highly recommended):

Strayer D. L., H. A. Ewing and S. Bigelow. 2003. What kind of spatial and temporal details are required in models of heterogeneous systems? *Oikos* 102:654-62. [*Excellent treatment of the conceptual issues associated with introducing spatial complexity into models.*]

Gustafson, E. J. 2013. When relationships estimated in the past cannot be used to predict the future: using mechanistic models to predict landscape ecological dynamics in a changing world. Landscape Ecology 28:1429-1437. *[Commentary by a forest landscape ecologist who has been developing and applying spatial models. These points remain important as scientists try to model no-analog future conditions.]*

For discussion–Current examples of landscape modeling:

Bugmann, H. and R. Seidl. 2022. The evolution, complexity and diversity of models of long-term forest dynamics. Journal of Ecology 110:2288-2307. [*Overview of forest models providing context for where forest landscape models fit in. Good entrée for those who do not yet have experience with process-based models. Landscape models sit between stand and global models.*]

Olson, S. K., et al. 2021. Landscape-scale forest reorganization following insect invasion and harvest under future climate change scenarios. Ecosystems 24:1756-1774. *[Regionally relevant research focused on emerald ash borer across 2-million ha of northern WI; uses LANDIS-II, a forest landscape model originally developed by emeritus FWE professor David Mladenoff and still very widely used.]*

Etherington, T. R., F. J. Morgan, D. O'Sullivan. 2022. Binary space partitioning generates hierarchical and rectilinear neutral landscape models suitable for human dominated landscapes. Landscape Ecology 37:1761-1769. [*NLMs are very useful whenever you need replicated landscapes that share similar statistical properties, and this is a recent example of using them for anthropogenic landscapes.*]

Fu, F., S. Deng, D. Wu, W. Liu, and Z. Bai. 2022. Research on the spatiotemporal evolution of land use landscape pattern in a county area based on CA-Markov model. Sustainable Cities and Society

80:103760. [*We will be implementing a simple Markov model of landscape change in lab, and this is a recent paper showing how such transition models are being used in research settings.*]

(Week 4) Tuesday, February 15 – Ecosystem services in heterogeneous landscapes

Background:

Kremen, C. and A. M. Merenlender. 2018. Landscapes that work for biodiversity and people. Science 362: eaau6020. *[Nice overview on the challenges of balancing multiple demands from working landscapes by a thought leader in this field.]*

For discussion –working agricultural and urban landscapes; rich and growing literature

Schulte, L. A., J. Niemi, M. J. Helmers, M. Liebman, J. G. Arbuckle, D. E. James, R. K. Kolka, M. E. O'Neal, M. D. Tomer, J. C. Tyndall, H. Asbjornsen, P. Drobney, J. Neal, G. Van Ryswyk, and C. Witte. 2017. Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn-soybean croplands. Proceedings of the National Academy of Sciences 114:11247-11252. [*Manipulating the landscape to enhance ecosystem services in the agricultural upper Midwest; we are covering this topic and reading this paper before Lisa visits UW-Madison.*]

Qiu, J., C. Queiroz, E. M. Bennett, A. F. Cord, E. Crouzat, S. Lavorel, J. Maes, M. Meacham, A. V. Norstrom, G. D. Peterson, R. Seppelt, and M. G. Turner. 2021. Land-use intensity mediates ecosystem service tradeoffs across regional social-ecological systems. Ecosystems and People 17:264-278. [*Tradeoffs and synergies among ecosystem services reflect current research – how can a portfolio of services be sustained?*]

Jha, S., M. Egerer, P. Bichier, H. Cohen, H. Liere, B. Lin, A. Lucatero, and S. M. Philpott. 2023. Multiple ecosystem service synergies and landscape mediation of biodiversity within urban agroecosystems. Ecology Letters 26:369-383. [*We will read several papers dealing with urban landscapes and the spatial heterogeneity within them. Most of the world's population lives in cities, and understanding how to sustain ES in urban settings is important.*]

Ha, J., H. J. Kim, and K. A. With. 2022. Urban green space alone is not enough: A landscape analysis linking the spatial distribution of urban green space to mental health in the city of Chicago. Landscape and Urban Planning 218:104309. [*This is another urban example, here tying landscape patterns to mental health.*]

(Week 5) Tuesday, February 8– Quantifying pattern I

Background (highly recommended):

Li, H., and J. F. Reynolds. 1995. On definition and quantification of heterogeneity. Oikos 73:280-284. *[Nice conceptual treatment of heterogeneity; foundational paper, good food for thought on what is being quantified, and one with which you should be familiar.]*

Li, H., and J. Wu. 2004. Use and misuse of landscape indices. Landscape Ecology 19:389-399. *[Synthesis of issues associated with quantifying landscape patterns, and you should be aware of all of these!]*

Simova, P., and K. Gdulova. 2012. Landscape indices behavior: A review of scale effects. Applied Geography 34:385-394. *[The tables in this paper are especially helpful summaries of how metrics change with scale; references also provide entrée into more European literature.]*

For discussion–theme is take-home lessons and appropriate application/use:

Frazier, A. E., and P. Kedron. 2017. Landscape metrics: past progress and future directions. Current Landscape Ecology Reports doi 10.1007/s40823-017-0026-0. *[Short paper that reviews development of landscape metrics, includes a nice example that illustrates effect of grain size and the long-time goal of having scaling rules.]*

Gustafson, E. J. 2019. How has state-of-the-art for quantification of landscape pattern advanced in the twenty-first century? Landscape Ecology 34:2065-2072. *[Nice overview/perspective on evolution of landscape pattern analysis since the Gustafson 1998 review in ECOSYSTEMS.]*

Cushman, S. A., K. McGarigal, and M. C. Neel. 2008. Parsimony in landscape metrics: strength, universality and consistency. Ecological Indicators 8:691-703. *[Addresses the correlations among metrics and unique contributions of different kinds.]*

Riva, F., and S. E. Nielsen. 2020. Six key steps for functional landscape analyses of habitat change. Landscape Ecology 35:1495-1504. [*This "rules of thumb" approach focuses on habitat change, but the issues of matching analyses to the question is a general point*.]

(Week 6) Tuesday, February 15– Quantifying pattern II

Background:

Kupfer, J. A. 2012. Landscape ecology and biogeography: Rethinking landscape metrics in a post-FRAGSTATS landscape. Progress in Physical Geography 36:400-420. [*Nice paper for synthesis points and discussion of metrics based on network theory, which we will get to in lab when considering organism movements.*]

For discussion–theme is application and advances with foundational + recent papers:

Eigenbrod, F., S. J. Hecnar and L. Fahrig. 2011. Sub-optimal study design has major impacts on landscape-scale inference. Biological Conservation 144:298-305. [*Lays out practical issues associated with using landscape metrics as predictors. Study design is always key!*]

Ramirez-Arce et al. 2022. Effects of landscape composition and configuration on biodiversity at multiple scales: a case study with amphibians from Sierra Madre del Sur, Oaxaca, Mexico. Landscape Ecology 37:1973-1986. *[Recent example of how landscape metrics are used as predictor variables when trying to explain another ecological response.]*

Iskin, E. P. and E. Whohl. 2023. Quantifying floodplain heterogeneity with field observation, remote sensing, and landscape ecology: Methods and metrics. River Research and Applications 39:911-929. *[While this is a more descriptive study, the paper gives a nice application in the aquatic environment. Shows how they arrived at six metrics to use and how they interpreted these.]*

Curd et al. 2022. Applying landscape metrics to species distribution model predictions to characterize internal range structure and associated changes. Global Change Biology 29:631-647. *[Interesting application that calculates species distributions then uses landscape metrics to describe changes. Novel approach for getting at spatial dimensions of SDMs.]*

*Hesselbarth, M. H. K., M. Sciaini, K. A. With, K. Wiegand, and J. Nowosad. 2019. landscapemetrics: an open-source R tool to calculate landscape metrics. Ecography 42:1548-1657. *[FRAGSTATS was the main analysis tool for several decades, but this powerful R package is excellent and is now being widely used.]*

(Week 7) Tuesday, February 22 – Spatial statistics

For discussion-applications & detecting scale dependence (soils, plants, genetics, corals):

Vasquez, G. M., S. Grunwald and D. B. Myers. 2012. Associations between soil carbon and ecological landscape variables at escalating spatial scales in Florida, USA. Landscape Ecology 27:355-367. [*Geostatistics are increasingly used to quantify spatial heterogeneity in soil attributes, this is a nice example of how they are used.*]

Schregel, J., J. Remm, H. G. Eiken, J. E. Swenson, U. Saarma, and S. B Hagen. 2018. Multi-level patterns in population genetics: Variogram series detects a hidden isolation-by-distance-dominated structure of Scandinavian brown bears *Ursus arctos*. *[Uses semivariograms to assess the spatial clustering of genetic relatedness in Nordic brown bears, thus tying also into landscape genetics.]*

Roy, S., S. M. Robeson, A. C Ortiz, and D. A. Edmonds. 2020. Spatial and temporal patterns of land loss in the Lower Mississippi River Delta from 1983 to 2019. Remote Sensing of Environment 250: 112046. *[Assesses spatial clustering of areas that convert to water or to marsh using remotely sensed data.]*

DiFalco, S., A. T. Morzillo, and D. Ghosh. 2022. Interpolating resident attitudes toward exurban roadside management. Landscape Ecology https://doi.org/10.1007/s10980-022-01537-2. *[Landscape studies are increasingly incorporating people's attitudes or perceptions, or proxies for human activities. This paper includes spatial stats when analyzing social science data.]*

(Week 8) Tuesday, March 8 – Disturbance and landscapes I

Background:

Turner, M. G. 2010. Disturbance and landscape dynamics in a changing world. Ecology 91:2833-2849. [*Overview of the importance of disturbance in landscapes, with examples from Yellowstone.*]

For discussion–disturbance-created spatial patterns:

Leitold, V., et al. 2022. Tracking the rates and mechanisms of canopy damage and recovery following Hurricane Maria using multitemporal Lidar data. Ecosystems 25:892-910. *[Uses continuous variables to assess measuring disturbance severity after Hurricane Maria in Puerto Rico and ties to the growing use of lidar data.]*

Senf, C., and R. Seidl 2021. Storm and fire disturbances in Europe: Distribution and trends. GCB 27:3605-3619. [*As disturbance activity increases globally, there is great interest in understanding the spatial patterns and temporal dynamics; in Europe, back in the day, I was often told that they have no natural disturbances…not the case any more!]*

Rodman, K. C., et al. 2023. Refuge-yeah or refuge-nah? Predicting locations of forest resistance and recruitment in a fiery world. Global Change Biology 001-22. [*Understanding what landscape positions may be shielded from disturbances and serve as a seed source or stepping stone is of high interest*.]

Harvey, B. J., M. Buonaduci, and M. G. Turner. 2023. Spatial interactions among short-interval fires reshape forest landscapes. Global Ecology and Biogeography DOI: 10.1111/geb.13634 [*Interactions among disturbances has been a hot topic for the past decade; this is an example of how such interactions generate novel landscape patterns.*]

(Week 9) Tuesday, March 22 – Disturbance and landscapes II

Good background:

Johnstone, J. F., C. D. Allen, J. F. Franklin, L. E. Frelich, B. J. Harvey, P. E. Higuera, M. C. Mack, R. K. Meentemeyer, M. R. Metz, G. L. W. Perry, T. Schoennagel, and M. G. Turner. 2016. Changing disturbance regimes, climate warming and forest resilience. Frontiers in Ecology and the Environment 14:369-378. *[Overview of resilience ideas in the context of changing climate and disturbance regimes, here applied to forest landscapes.]*

Coop, J. D., et al. 2020. Wildfire-driven forest conversion in western North American landscapes. BioScience 70:659-673. *[Disturbances are interacting with other drivers to shape landscape patterns of vegetation, including conversions.]*

For discussion–disturbance interactions, resilience concept):

Pausas, J. G., and W. J. Bond. 2020. Alternative biome states in terrestrial ecosystems. Trends in Plant Science 25:250-263. [*Understanding what conditions (including disturbances) lead to alternative states in landscapes is necessary to predict future landscape patterns under climate change. This is an easy entrée into a big literature.*]

Walden, L., J. B. Fontaine, K. X. Ruthrof, G. Matusick, and R. J. Harper. 2023. Drought then wildfire reveals a compound disturbance in a resprouting forest. Ecological Applications 33:32775. [*Empirical study testing for disturbance interactions in Australia and how such interactions may destabilize systems.*]

LeBreton, T. D., M. B. Lyons, R. H. Nolan, T. Penman, G. J. Williamson, and M. J. K. Ooi. 2022. Mega-fire induced interval squeeze threatens vegetation at landscape scales. Frontiers in Ecology and the Environment 20:327-334. [*Example from Australia of the potential for losing unique vegetation communities as disturbances intensify.*]

Turner, M. G., and R. Seidl. 2023. Novel disturbance regimes and ecological responses. Annual Review of Ecology, Evolution and Systematics 54:63-83. [*Broad treatment of how to conceptualize novelty in disturbance regimes and think beyond the extremes of transitions from one ecosystem type to another.*]

---- SPRING BREAK ----

(Week 10) Tuesday, March 29 – Organisms and landscapes I

Background – the paper that triggered the debate:

Fahrig, L. 2017. Ecological responses to habitat fragmentation per se. Annual Review of Ecology, Evolution and Systematics 48:1-23. [*Fahrig is one of the leaders in research on how organisms respond to landscape patterns; this plus her earlier paper on the Habitat Amount Hypothesis triggered the spirited debate that has played out in the literature, and which will be our focuse for discussion*.]

For discussion–theme is the contemporary debate on habitat area vs. fragmentation:

Fletcher, R. J., Jr., R. K Didham, C. Banks-Leite, J. Barlow, R. M. Ewers, J. Rosindell, R. D. Holt, A. Gonzalez, R. Pardini, E. I. Damschen, F. P. L. Melo, L. Ries, J. A. Prevedllo, T. Tscharntke, W. F. Laurance, T. Lovejoy, and N. M. Haddad. 2018. Is habitat fragmentation good for biodiversity? Biological Conservation 226:9-15. *[The habitat area hypothesis and effects of habitat fragmentation are critiqued by these authors, all of whom have worked on related topics, often in an experimental framework.]*

Fahrig, L., V. Arroyo-Rodriguez, J. R. Bennett, V. Boucher-Lalonde, E. Cazetta, D. J. Currie, F. Eigenbrod, A. T. Ford, S. P. Harrison, J. A. G. Jaeger, N. Koper, A. E. Martin, J.-L. Martin, J. P. Metzger, P. Morrison, J. R. Rhodes, D. A. Saunders, D. Simberloff, A. C. Smith, L. Tishendorf, M. Vellen, and J. I. Watling. 2019. Is habitat fragmentation bad for biodiversity? Biological Conservation 230:179-186. *[Then Fahrig et al. respond, again with a group of authors who have also worked on these topics.]*

Fahrig, L. 2019. Habitat fragmentation: a long and tangled tale. Global Ecology and Biogeography 28:33-41. [*Fahrig's next (final?) reflections on the origins and outcomes of the controversies surrounding effects of habitat fragmentation.*]

Valente, J. J., D. G. Gannon, J. Hightower, H. Kim, K. G. Leimberger, R. Macedo, J. S. Rousseau, M. J. Weldy, R. A. Zitomer, L. Fahrig, R. J. Fletcher, J. Wu, and M. G. Betts. 2023. Toward conciliation in the habitat fragmentation and biodiversity debate. Landscape Ecology 38:2717-2730. [*Recent paper trying to reconcile these divergent views together.*]

(Week 11) Tuesday, April 5 – Organisms and landscapes II

Background--some more examples from a vast literature

Tscharntke, T., and many coauthors. 2012. Landscape moderation of biodiversity patterns and processes – eight hypotheses. Biological Reviews 87:661-685. *[Older but relevant and thought-provoking paper, timely to consider in context of more recent studies.]*

Gaynor, K. M., J. S. Brown, A. D. Middleton, M. E. Power, and J. S. Brashares. 2019. Landscapes of fear: spatial patterns of risk perception and response. Trends in Ecology & Evolution 34:355-368. *[Effects of landscape patterns on species interactions, including predator-prey dynamics, remains a hot topic. This is deals with perceived predation risk.]*

Martin, E. A., and many co-authors. 2019. The interplay of landscape composition and configuration: new pathways to manage functional biodiversity and agroecosystem services across Europe. Ecology Letters 22:1083-1094. *[Synthetic look at pollinators (also a hot topic), natural enemies and semi-natural habitats in Europe. Community-level example, not just single populations.]*

Littlefield, C. E., M. Krosby, J. L. Michalak, and J. J. Lawler. 2019. Connectivity for species on the move: supporting climate-driven range shifts. Frontiers in Ecology and the Environment doi:10.1002/fee.2043. *[Emphasizes the importance of including effects of climate change as we think about habitat connectivity and organism movements. Climate is not static!]*

For discussion–theme is landscape connectivity and conservation

Berger, M., et al. 2022. Demystifying ecological connectivity for actionable spatial conservation planning. TREE 37(12):1079-1091.*[Useful discussion of the importance of ecological connectivity and the need to incorporate it into planning.]*

Belote, R. T., K. Barnett, K. Zeller, A. Brennan, and J. Gage. 2022. Examining local and regional ecological connectivity throughout North America. Landscape Ecology 37:2977-2990. *[Travis Belote of the Wilderness Society has been leading a major set of studies of connectivity in the US; this is one of the recent papers.]*

Suraci, J. P., C. E. Littlefield, C. C. Nicholson, M. C. Hunter, A. Sorensen, and B. G. Dickson. 2023. Mapping connectivity and conservation opportunity on agricultural lands across the conterminous United States. Biological Conservation 278:209896. *[The ag lands are so often ignored! This paper looks for areas that have potential; did a CONUS-wide analysis.]*

Cumming, G. S. and D. R. Bellwood. 2022. Broad-scale analysis of fish community data suggests critical need to support regional connectivity of coral reefs. Ecological Applications 33:e2849. *[Nice marine example that uses connectivity metrics in a system; Graeme Cumming has also done a lot in landscape ecology, including disease spread.]*

(Week 12) Tuesday, April 12 – Ecosystem processes

Background:

Lovett, G. M., C. G. Jones, M. G. Turner and K. C. Weathers, editors. 2005. ECOSYSTEM FUNCTION IN HETEROGENEOUS LANDSCAPES. Springer-Verlag, New York. *[Edited book, good reference.]*

Schindler, D. E. and A. P. Smits. 2017. Subsidies of aquatic resources in terrestrial ecosystems. Ecosystems 20:78-93. *[Cross-boundary lateral movement of matter and energy is within the scope of landscape and ecosystem ecology, and lots has been done on land-water interactions. This article considers water→land.]*

Soranno, P. A., T. Wagner, S. M. Collins, J.-F. Lapierre, N. R. Lottig, and S. K. Oliver. 2019. Spatial and temporal variation of ecosystem properties at macroscales. Ecology Letters 22:1587-1598. *[Pat Soranno coined the term "landscape limnology" and has been leading several macrosystems projects that have examined lakes over large areas. This paper raises interesting ideas on variation in time and space.]*

For discussion - from ecosystems to landscapes:

Monk, J. D., and O. J. Schmitz. 2021. Landscapes shaped from the top down: predicting cascading predator effects on spatial biogeochemistry. Oikos 00:1-15 (early view). *[Linkages between species and ecosystems contribute to landscape heterogeneity in biogeochemical cycling.]*

Gonzalez, A., et al. 2020. Scaling up biodiversity-ecosystem functioning research. Ecology Letters 23:757-776. *[There is a vast BEF literature, most at fine scales; this is good intro to the BEF literature withing a context of heterogeneity and scale.]*

Smith, A. J., K. McGlathery, Y. Chen, C. J. Ewers, S. C. Doney, K. Gedan, C. K. LaRoche, P. Berg, M. L. Pace, J. C. Zinnert, and M. L. Kirwan. 2023. Compensatory mechanisms absorb regional carbon losses within a rapidly shifting coastal mosaic. Ecosystems (early view). *[Understanding landscape changes and how this affects C sources and sinks, here in a coastal landscape.*]

Harvey, E. et al. 2023. A general meta-ecosystem model to predict ecosystem functions at landscape extents. Ecography 306790.] *[Recent paper trying to generalize approaches for representing ecosystem fluxes, uses a watershed example.*

(Week 13) Tuesday, April 26 —Frontiers in landscape ecology

TBD

---- End of reading list ---