1. Course Information:

A. Expanded course description

This course examines how terrestrial ecosystems and environments developed over geological time scales, particularly during the Cenozoic era and its recent Quaternary period (comprising the Pleistocene and Holocene epochs) and provides a foundation on which to examine contemporary ecological problems in the Anthropocene epoch. Basic ecosystem ecology concepts such as mineral cycling, species and trophic interactions are emphasized throughout. While the temporal focus is on the Quaternary period, a longer-term context for climatic, biogeochemical and biogeographical changes since the Paleozoic era will be examined. This deep-time context informs a better understanding of potential trajectories of Earth's systems in the Anthropocene.

The course begins with a brief background to terrestrial ecosystem ecology and other fundamental ecological and biogeographical concepts important in structuring ecosystems over long temporal and large spatial scales. It continues with an examination of paleo-ecology and -environments. The course concludes with a discussion of the policy and management challenges of altered and "novel" ecosystems in the Anthropocene, that can be informed by the paleoecological context.

B. Course objectives

The course aims to explore the science of paleoecology and apply this knowledge to understand the present. Topics include: Background to ecosystem ecology; development of taxa, ecosystems and biomes on land from the Carboniferous to the Pleistocene; Pleistocene environments and ecosystems: palynological (pollen) and other paleo-records of post-glacial plant species' range changes; human emergence, range changes and global expansion in the Pleistocene and contemporaneous ecosystem changes; megafaunal extinction causes and impacts on trophic dynamics of late Pleistocene-Holocene ecosystems; Anthropocene policy and management dilemmas, including rapid species' range shifts and ecosystem fragmentation, species invasions and novel ecosystems; Climate change biodiversity adaptations e.g., assisted migration; vs. alternatives such as habitat restoration.

The course is designed for a class of 35-60 students because of its upper level designation and need for student led discussions.

C. Potential instructors

Nina Hewitt will be the primary instructor. Greg Henry and Simon Donner, Department of Geography, have related expertise and could potentially teach the course.

2. Course Format:

The course format will be a combination of lecture and class discussion. The introductory lessons will be primarily lecture-based, but as the course progresses, students will increasingly participate in class discussion through structured student-led discussion segments, debates and/or presentations about the scholarly literature on paleoecology and how these inform Anthropocene dilemmas. Assessment is described under Learning Activities and Assessment of Learning, below.

3. Course Schedule:

Weeks are bolded; topics are numbered; readings are underlined; Kolbert readings listed first and in blue font

Week 1: Introduction

Readings

Kolbert, Chap 1 “The 6th Extinction”

Flessa K.W. and Jackson S.T. 2005. Forging a common agenda for ecology and paleoecology. *Bioscience* 55: 1030-103

Weeks 2 and 3: Basic Ecosystem Science Concepts

1. Ecosystem Concept; Energy and Nutrient Flows, Mineral Cycling, Trophic Interactions, Production Ecology

Readings

Chapter 1: Chapin, III, F.S., Matson, P.A. and Vitousek, P.M. 2011. *Principles of terrestrial ecosystem ecology.* 2nd Edition, Springer, New York.

Thomson, R.M et al. 2012. Food webs. Reconciling the structure and function of biodiversity. *Trends in Ecology and Evolution* 27: 689-97.

2. Biological Interactions: Foundation Species, Ecological Engineers; Ecosystem Services

Readings:

Cotee-Jones, H.E.W. and Whittaker, R. J. 2012. The Keystone Species concept: a critical appraisal. *Frontiers of Biogeography* 4: 117-127.

Ellison, A.M. *et a*l. 2005. Loss of foundation species: Consequences for the structure and dynamics of forested ecosystems. *Frontiers of Ecology and the Environment* 3:479-486.

Jones, C.G. Lawton, J.H. and Shachak, M. 1994. Organisms as ecosystem engineers. *Oikos* 69:373-386. (this is a Landmark Paper on the subject)

Silvertown, J. 2015. Have Ecosystem Services been oversold? *Trends in Ecology and Evolution* 13:641-648.

Further Reading:

> Bertness, M.D. and Callaway, R. 1994. Positive interactions in communities. *Trends in Ecology and Evolution* 9:191-193. (This is a Landmark Paper on the subject of positive interactions)
>
> van der Plas, F. et al. 2016. Biotic homogenization can decrease landscape-scale forest multifunctionality, *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, DOI: 10.1073/pnas.1517903113; and related media article “Woodlands in Europe: More tree species, more benefits” Science News at: https://www.eurekalert.org/pub_releases/2016-03/gcfi-wie031516.php
>
> Oliver et al. 2015. Biodiversity and resilience of ecosystem functions. *Trends in Ecology and Evolution* 30: 673-684. http://dx.doi.org/10.1016/j.tree.2015.08.009

3. Biogeographical Processes: Dispersal and Colonization [Processes of Evolution and Extinction will be considered throughout weeks 4-12]

Readings

Kolbert, Chap 2 “The Mastadon’s Molars”
Kolbert, Chap 4 “The Luck of the Ammonites”

Clark, J.S. et al. 2002. Plant Dispersal and Migration, pp 81–93 in Mooney et al., *Encyclopedia of Global Environmental Change*, Volume 2, *The Earth system: biological and ecological dimensions of global environmental change*.

Weeks 4-5: Deep Time Record: Paleobiology and Paleoenvironments

4. Evolutionary and Distributional Changes Among Land Plants; Gymnosperms and Angiosperms; Key Developments in Land Mammals

Sub-topics:

- Geological time scale, paleobiological methods and understanding the biota of the Deep past
- Plate tectonics and biotic (taxonomic and distributional) changes, late Paleozoic to early Cenozoic Eras

Readings:

Klesius, M. 2012. The Big Bloom—How Flowering Plants Changed the World. National Geographic Society; Accessed July 2019. https://www.nationalgeographic.com/science/prehistoric-world/big-bloom/

Berendse, F., Scheffer, M. 2009. The angiosperm radiation revisited, an ecological explanation for Darwin's 'abominable mystery'. *Ecology Letters*. 12:865-872. doi: 10.1111/j.1461-0248.2009.01342.x

Brodribb et al. 2012. Elegance versus speed. Examining the competition between conifer and angiosperm trees. *Int. J. Plant Sci*ence 173(6):673–694. 2012.

(Also see: Bond, W.J. 1989. The tortoise and the hare: ecology of angiosperm dominance and gymnosperm persistence. *Biol. Journal of the Linnean Society* 36: 227-249.)

5: Extinctions and the Geological Record

Kolbert, Chap 6 "The Sea Around Us"
Kolbert, Chap 7 "Dropping Acid"

Benton, M.J. and Twitchett, R.J. (2003) How to kill (almost) all life: the end-Permian extinction event. *Trends in Ecology & Evolution* 18: 358–365.

Clarkson M.O. et al. 2015. Ocean acidification and the Permo-Triassic mass extinction. *Science* 348. 229-232.

Week 6: Ecosystems and Environments: Developments Over the Cenozoic

6. Early to Middle-Cenozoic Environmental Changes and Development and Diversification of Terrestrial Biomes in the Eocene: Development of Cenozoic Climates and Environments; Flora and Fauna; Expansion of Dryland and Alpine Biomes; Evolution of Grazing fauna; American Exchange of Mammals

Readings:

Cox, C.B., Moore, P.D. and Ladle, R. 2016. Chap 11 Setting the Scene for Today, pp. 315-52 in *Biogeography: an ecological and evolutionary approach*, 9th Ed. Wiley-Blackwell.

Montanez I.P. et al.* 2011. Chap 2, Lessons from Past Warm Worlds, pp. 26-62. In *Understanding Earth's Deep Past: Lessons for Our Climate Future.* National Academies Press, Washington D.C. *(Committee on the Importance of Deep-Time Geologic Records for Understanding Climate Change Impacts; National Research Council of the National Academies) Available at: http://www.nap.edu/catalog.php?record_id=13111

Week 7 The Quaternary: Life Inside "*The climate system that raised us*" (quoted from David Wallace-Wells, 2019, Uninhabitable Earth, p. 18)

7. Biogeographic Range Changes during Pleistocene Glacial and Inter-glacial cycles; Refugia Hypotheses

Readings:

Birks HJB (2014) Quantitative palaeoenvironmental reconstructions from Holocene biological data. In: Mackay A, Battarbee R, Birks HJB and Oldfield F (eds.) *Global Change in the Holocene*, pp. 107-123. London: Arnold.

Davis, M. B. and R. G. Shaw (2001). Range shifts and adaptive responses to Quaternary climate change. *Science* 292: 673-679.

Jackson ST and Blois JL (2015) Community ecology in a changing environment: perspectives from the Quaternary. *Proceedings of the National Academy of Sciences of the United States of America* 112:4915–4921.

Leite, Y.L. 2016. Neotropical forest expansion during the last glacial period challenges refuge hypothesis. *Proceedings of the National Academy of Sciences of the United States of America* 113:1008-13.

Specifically for Assignment on Pollen Analysis of Holocene Vegetation Change:
Pielou, E.C. (1992). Pp. 90-102. *After the Ice Age*, U. Chicago Press, Chicago.
Ibid, pp. 47-57 "interpreting the fossil record: pollen, sediment cores and pollen diagrams"

A handy news article that describes C14 dating, see:
https://www.theguardian.com/science/2019/aug/10/most-important-isotope-how-carbon-14-revolutionised-science accessed, Aug 10 2019

Week 9 The Quaternary, cont.

8. Human Emergence and Geographic Range Expansion and Shifting Role in Ecosystems; Humans as a Force of Evolution and Extinction

Readings:

Kolbert, Prologue and Chapter 12, "The Madness Gene"

Harari, Y. N. 2014. Excerpts from: Chap 1 "An animal of no significance", pp. 3-10, and Chap 5, "History's biggest fraud", pp. 77-97 in *Sapiens: a brief history of humankind*. Vintage

Weisman, A. 2008. Chap 4: The World Just Before Us, in *The World Without Us*. Harper Collins, Canada

> Supplementary Readings (optional): Humans and domestication:
> Boivin et al. 2016. Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distributions. Proc. Natl. Acad. Sci. U. S. A. 113, 6388–6396
>
> Smith, B.D., Zeder, M.A., 2013. The onset of the Anthropocene. Anthropocene 4, 8–13.
>
> Zeder, M.A., 2016. Domestication as a model system for niche construction theory. Evol. Ecol.

9. Pleistocene Megafauna Extinctions: Causes and Consequences

Bakker, E.S. et al. 2016. Combining paleo-data and modern exclosure experiments to assess the impact of Megafauna extinctions on woody vegetation. *Proceedings of the National Academy of Sciences of the United States of America* 113:847-55.

Cooper A, Turney C, Hughen KA, et al. 2015. Abrupt warming events drove Late Pleistocene Holarctic megafaunal turnover. *Science* 349: 602–606.

MacDonald G. et al. 2012. Pattern of Woolly mammoth extinction in Beringia. *Nature Communications* 3.

Van Valkenburgh B. et al. 2016. The impact of large terrestrial carnivores on Pleistocene ecosystems. *Proceedings of the National Academy of Sciences of the United States of America* 113 (4) 862-867. https://doi.org/10.1073/pnas.1502554112.

Further reading on megafauna extinction. Some of these will be considered in class debate over causes

Barnosky, 2008. Megafauna biomass tradeoff as a driver of Quaternary and future extinctions. In National Academy of Sciences (ed.). In the Light of Evolution: Volume II: Biodiversity and Extinction. Washington, DC: The National Academies Press. https://doi.org/10.17226/12501. Available at: https://www.nap.edu/read/12501/chapter/16

Zimov, S. A., Chuprynin, V. I., Oreshko, A. P., Chapin, F. S., Reynolds, J. F., and Chapin, M.C. 1995. Steppe-tundra transition - A herbivore-driven biome shift at the end of the Pleistocene. *American Naturalist* 146:765-794.

A resource on debating style and form is available through Simon Fraser U's Commons, at: https://www.sfu.ca/cmns/130d1/HOWTODEBATE.htm (accessed Aug 2019).

And recommended by Camills Speller in Anthropology:

Boivin et al. 2016. Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distributions. *Proc. Natl. Acad. Sci*. U. S. A. 113, 6388–6396;

Smith, B.D., Zeder, M.A., 2013. The onset of the Anthropocene. *Anthropocene* 4, 8–13.;

Zeder, M.A., 2016. Domestication as a model system for niche construction theory. *Evol. Ecol*.

Week 10: Anthropocene Ecosystems and Global Change Drivers

10. Global Change: Taking a Long View

Readings:

Kolbert, Chap 5, "Welcome to the Anthropocene"

Dobson A. et al. 2006. Habitat loss, trophic collapse, and the decline of ecosystem services. *Ecology* 87: 1915-1924.

Wallace-Wells, D. 2019. The Uninhabitable Earth, Chap 1, Cascades, pp. 3-36. Penguin Random House, NY

11. Anthropocene Policy and Management Dilemmas 1: Modern extinction; altered disturbance regimes, biogeochemical changes; Invasive species and emerging epidemics

- Anthropocene Ecosystem that will be examined in relation to topics during Weeks 10-13: Black Oak Savanna in Southern Ontario; Fragmented Eastern Forests; Alpine Ecosystems of Southern B.C. and the Central Karakoram

Readings:

Kolbert, 2014. Chap 3, "The Original Penguin" (The Great Auk as a symbol of human over-exploitation/over-hunting; species extinction immediately Pre-Anthropocene)

Kolbert 2014, Chap 10, "The New Pangaea" (Invasive Species)

Nikoforuk, A. 2006. Chapter 2: Juggling Species: The global circus, pp. 29-53 in *Pandemonium: Bird flu, Mad cow disease, and other biological plagues of the 21st century*. Penguin (Viking) Toronto.
" ", Excerpts, Chap 8: Climate riders, pp. 213-215; 222-226 in ibid

Quammen, D. 1996. *The Song of the Dodo: Island Biogeography in an Age of Extinctions*. Touchstone Pp. 262-75; 289-96; 380-1. (Rarity, island species, extinction).

Smith, A. Hewitt N. et al. 2012 Effects of climate change on the distribution of invasive alien species in Canada: a knowledge synthesis of range change projections in a warming world. *Environmental Reviews* 20:1-16.

Week 11

12. Anthropocene Policy and Management Dilemmas 2: Habitat Destruction, Ecosystem Fragmentation, Climate Change, Shifting Ranges

Readings:

Kolbert, Chap 8 "The Forest and the Trees" and
Chap 9, "Islands on Dry Land"

Hewitt, N., Larocque, G., Greene, D., and Kellman, M. 2019. A model of hardwood tree colonization among fragments: predicting migration across human-dominated landscapes. *Ecoscience* 26: 35-51. https://doi.org/10.1080/11956860.2018.1515596

Kolbert, E. 2006. Field Notes from a Catastrophe, Chap 4, The butterfly and the toad (discusses observed upslope, alpine species migration, pp. 72-73).

Case, M.J. Lawler, J.J. 2017. Integrating mechanistic and empirical model projections to assess climate impacts on tree species distributions in North-western North America. *Global Change Biology* 23: 2005-1015. https://doi.org/10.1111/gcb.13570

Week 12

13. Management Practice and "Novel", "Non-Analog" Ecosystems"

Readings:

Dietl G.P. et al. 2015. Conservation paleobiology: leveraging knowledge of the past to inform conservation and restoration. *Annual Review of Earth and Planetary Sciences* 43: 79–103.

Hewitt N. et al. 2011. Taking stock of the assisted migration debate. *Biological Conservation* 144:2560-72.

Park, A. and Talbot, C. 2018. Information underload: ecological complexity, incomplete knowledge, and data deficits create challenges for the Assisted Migration of forest trees. *BioScience* 68: 251–263. https://doi.org/10.1111/gcb.13570

Williams, J.W. and Jackson, S.T. 2007. Novel climates, no-analog communities, and ecological surprises *Frontiers in Ecology and Environment* 5:475-82.

Week 13

Wrap Up and Volunteer Final Project Presenters

Readings:

Kolbert Chap 13: The Thing with Feathers

4. Learning Outcomes:

Upon completion of this course students will be able to:

1. Identify the time periods on the geological time scale and the timing of key developments in life on land, particularly during the Cenozoic Era (ca. 65 mill. y.a)
2. Explain the major ecosystem responses to environmental changes documented in the paleoecological record (geographic range changes, evolution and adaptation, extinction)
3. Interpret the paleoecological record (e.g., pollen in lake sediments) of biogeographical distributions during glacial and interglacial cycles of the Pleistocene
4. Synthesize the main arguments and evidence in scholarly debates about pre-historic human population interactions with environment (e.g., megafaunal extinction, domestication process and driving factors)
5. Apply their understanding of paleo-environments and paleoecology to assess modern biodiversity policy and management dilemmas (e.g., climate change induced range shifts, ecosystem fragmentation, and invasive species). For example, evaluate current ecosystem responses in relation to historical rates, styles and thresholds of change
6. Evaluate the scholarly literature on paleoecology and ecosystem science

5. Assessment Criteria and Grading:

Include grading rubrics for non-exam based assessments such as oral presentations, papers, etc.

Evaluation:

Grade Component	**Percent of Course Grade**	**Learning Goals**
Participation, Reading Preparedness (3-minute papers)	11 %	1, 2, 3, 4, 5, 6
Reading Response Papers (2, 8.5% each)	16 %	6
Assignments: Late Wisconsinan-Holocene Plant Migration, Dendrochronology (14 % each)	28 %	3, 6
Final Project	20 %	5, 6
Term Test (during lecture, Week 8)	25 %	1, 2, 3, 4, 5

Since the last half of term is increasingly discussion and reading response-based, in lieu of a final exam, students will focus on a final project and their 3-minute papers as reading responses (in addition to their reading response paper) as well as presentations and class discussion about readings. They will write a midterm a little later than midway on course topics that form a foundation to later items.

Readings and Lectures

Readings should be completed prior to the class for which they are scheduled. Students may be asked to prepare one or two questions and answers in response to particular readings to stimulate class discussion. On occasion, 3-minute reading response papers will be schedule, for the lecture in which the reading is assigned. These will be announced the week before.

Assignments

There will be two written assignments, two Reading Response Papers and a Final Project to explore course topics in greater detail than lectures facilitate. **Assignment 1** will examine pollen percentage data and plant species migrations during the Holocene. **Assignment 2** will examine dendrochronological information used to reconstruct Holocene climate signals. Basic knowledge of graphing will be involved in examining and describing simple datasets. The Instructor and TA will assist students needing this. Students will complete two **Reading Response Papers** pertaining to pivotal readings on a topic scheduled for a given lecture (see details, below; a sign-up sheet will be provided at the start of term). Students will have the option, in lieu of *one of* the reading response papers, to present on and lead a class discussion about the readings and topic they address, in pairs. Details are provided below, under Presenters/Discussants.

Reading Response Papers: To encourage critical thinking about course topics and the scholarly literature, and to stimulate discussion students will submit two written critiques of the scheduled readings for two different classes. Additional details on the format will be provided in class, but these will typically be in the form of 1.5-2 pages (typed, double spaced) of text examining the key content in the select reading(s), followed by 2-3 thoughtful questions about the material to ask the class, each accompanied with tentative but reasonable answers.

Presenters/Discussants: In lieu of the written reading response paper, students may volunteer to lead part of a class discussion pertaining to an assigned reading(s) for that day, in pairs. This will involve students being required to:

- complete the reading as normal and prepare a brief (5 minutes) summary and critique of the salient aspects of the reading and its significance (Powerpoint or another presentation tool is recommended)
- prepare a few (2-4) key questions pertaining to the reading to ask fellow students and
- prepare reasonable answers to the questions to fill in gaps and prompt your classmates, as necessary, and indicate these in your materials
- Submit a Powerpoint slide set or a text document detailing main points, along with discussion questions and tentative answers at the start of lecture via electronic submission
- 15 minute allocation

The professor will assist volunteers in leading the discussion by adding or prompting additional questions/ideas, drawing connections to other course content, or suggesting alternative interpretations.

Final Project:

Students will prepare a research paper on a topic related to paleoecology and its connection to particular Anthropocene issue. The instructor will provide a list of topic suggestions, but students may propose their own subject to approval by the Instructor. Papers must be 5-6 pages typed and double-spaced, exclusive of figures, and cite at minimum, 5 scholarly journal articles on the topic as well as other non-academic sources using an acceptable citation method (e.g., MLA format). Papers will be due during the last week of classes via electronic submission to Canvas. A few student volunteers will be asked to briefly present their major findings to the class during the last week of classes. Possible topics include, but are not limited to Paleoecology of:

- A particular region/time period not examined in lecture, e.g., the Mediterranean.
- An important taxonomic group, e.g., Gymnosperms
- A time period that is very relevant to particular questions about the Anthropocene, e.g., the Permian; The Pleistocene

; and how the topic is relevant to understanding the particular aspects of Anthropocene ecosystems and environments.

Prior to beginning your research, and approx. 3 weeks of the due date, students will submit a brief proposal for informal, formative feedback. Your proposal must include the following information:

- A draft title indicating the proposed topic;
- A clear and concise statement of the research questions and objectives
- A brief explanation of the importance of the paper
- A list of the bibliographic references you have identified to date (at least 5 scholarly articles)

The proposal should be no more than 1 page, typed, double spaced, not including the list of references. This will be worth 3 of the 20 percentage points for final project grade.

Attendance and Group Work

There will be a handful of in-class active learning activities, including debates, often dealing with particular readings or topical issues. In some cases, students will be assigned to a group with which to formulate and exchange your ideas. These activities will be logged in the Participation grade.

Term Test

The term test will take place during lecture, and will consist of multiple choice, short answer and short discussion/short essay questions and is designed to determine students' grasp of lecture (primarily) material and provide an opportunity to synthesize what has been learned. Information from the readings and other resources *not* directly covered in class or in the assignments will *not* be tested. Additional details, including a list of study topics and tips, will be provided on Canvas one week before the test/exam.

6. Required and Recommended Readings:

We will draw from a variety of sources including book chapters, scholarly articles as well as science journalism about the scholarly literature. The latter provides an accessible medium to examine scientific findings and data. One source that we will use throughout is:

Kolbert, E. 2014 *The Sixth Extinction: An Unnatural History*. Henry Holt and Co, New York. Cost: about $ 20

Additional articles from the scholarly literature and books will be included. Please see the Schedule.