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The Effects of Climate Change on Tradeoffs in Forest Ecosystem Services

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A thesis
submitted in partial fulfillment of the
requirements for the degree of

Master of Science

University of Washington

2016

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Program Authorized to Offer Degree:
Quantitative Ecology and Resource Management

University of Washington

Abstract

The Effects of Climate Change on
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This sample dissertation is an aid to students who are attempting to format their theses with L^AT_EX, a sophisticated text formatter widely used by mathematicians and scientists everywhere.

- It describes the use of a specialized macro package developed specifically for thesis production at the University. The macros customize L^AT_EX for the correct thesis style, allowing the student to concentrate on the substance of his or her text.¹
- It demonstrates the solutions to a variety of formatting challenges found in thesis production.
- It serves as a template for a real dissertation.

¹See Appendix A to obtain the source to this thesis and the class file.

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GLOSSARY

CLIMATE SCENARIO: A projection of the future climate, specifically one used by the IPCC

ECOSYSTEM SERVICE: benefits that people receive from ecosystems, divided into four categories: supporting, provisioning, regulating and cultural [2]. Examples include food, soil formation, water purification, carbon storage, recreation, and education.

IPCC: the Intergovernmental Panel on Climate Change

ACKNOWLEDGMENTS

I want to thank all those that contributed to my earning this degree.

DEDICATION

To ma femme and my family

Chapter 1

ASSESSING CHANGES IN TRADEOFFS AMONG ECOSYSTEM SERVICES IN THE DESCHUTES NATIONAL FOREST

1.1 Introduction

Forests play an important role in global ecological, social, and economic processes. They provide ecosystem services such as carbon storage, purification of water and air, wildlife habitat, recreation opportunities, and generate raw materials for goods such as food and lumber [10]. In managed forests, the extent to which forests provide these services depends on management practices. Optimal forest management seeks to ensure the sustained provision of these ecosystem services (!CITE bibtex'ed CFR source).

Like other ecosystems, forests will undergo changes as a result of the changing climate. We anticipate new spatial distributions of tree species [19], increased sediment delivery to streams [17], and increasing disturbance regimes such as wildfires, drought, and insect infestation [39]. As this transformation occurs, forests ability to provide ecosystem services will change. NEW GROWING CONDITIONS MAY LEAD TO INC/DEC TIMBER PRODUCTION. TEMPERATURES MAY POSITION FORESTS AS HABITAT FOR MORE/FEWER SPECIES. Increased frequency of wildfires will impact forests ability to store carbon [4] and provide habitat for wildlife [26]. Water supplies that rely on forests filtration capabilities may be impacted by the rising sediment levels predicted by [17].

Optimal forest management must consider the effects of the changing climate, because the time scale of forest development (decades) is the same as that on which climate change is predicted to operate (!CITE SOME REPORT that shows changes by late 21st century). Hence, optimal forest management will likely differ between future climate scenarios !CITE

climate change forest management papers. Decisions that would once have resulted in optimal achievement of ecosystem services, now under different climatic conditions, may no longer do so. Without consideration of climate change, forest management plans may restrict forests' potential to provide ecosystem services most effectively. To determine which management practices will be optimal in the future, we must first understand how climate change will impact forests' ability to provide ecosystem services. For example, how many tons of carbon dioxide will the forest be capable of storing? How many acres of forest will still qualify as suitable habitat for a particular species? Many studies have considered these questions !CITE SOME PEOPLE.

However, previous studies have addressed the impact of climate change on forest ecosystem services in isolation. Because forests provide these ecosystem services in concert with one another (see, for example, [37]), we must also understand how climate impacts the tradeoffs that exist among them. Consider the simultaneous provision of wildlife habitat, carbon storage, and resistance to wildfire. How does an increase in any one service alter our ability to acquire an amount of another? Relationships such as a marginal sacrifice in one service for substantial improvement in another may no longer exist under a new climate. To better ensure the sustained provision of ecosystem services, we must understand how these tradeoffs evolve as a function of climate.

Here, I use a watershed in the Deschutes National Forest as a case study to determine how climate change impacts optimal forest management and the changes in tradeoffs among ecosystem services.

1.2 Methods

In this thesis the typist refers to the user of L^AT_EX—the one who makes formatting decisions and chooses the appropriate formatting commands. He or she will most often be the degree candidate.

This document deals with L^AT_EX typesetting commands and their functions. Wherever possible the conventions used to display text entered by the typist and the resulting formatted

output are the same as those used by the T_EXbooks. Therefore, `typewriter type` is used to indicate text as typed by the computer or entered by the typist. It is quite the opposite of *italics*, which indicates a category rather than exact text. For example, `alpha` and `beta` might each be an example of a *label*.

1.3 Results and Discussion

This sample thesis was produced by the L^AT_EX document class it describes and its format is consonant with the Graduate School's electronic dissertation guidelines, as of November, 2014, at least. However, use of this package does not guarantee acceptability of a particular thesis.

1.4 Conclusion

Here's a conclusion.

BIBLIOGRAPHY

- [1] Fouad Ben Abdelaziz. Solution approaches for the multiobjective stochastic programming. *European Journal of Operational Research*, 216(1):1–16, 2012.
- [2] Millennium Ecosystem Assessment et al. *Ecosystems and human well-being*, volume 5. Island press Washington, DC:, 2005.
- [3] Brad Bass, Guohe Huang, and Joe Russo. Incorporating climate change into risk assessment using grey mathematical programming. *Journal of Environmental Management*, 49(1):107 – 123, 1997.
- [4] Gordon B Bonan. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science*, 320(5882):1444–1449, 2008.
- [5] Jose G Borges, Jordi Garcia-Gonzalo, Vladimir Bushenkov, Marc E McDill, Susete Marques, and Manuela M Oliveira. Addressing multicriteria forest management with pareto frontier methods: An application in portugal. *Forest Science*, 60(1):63–72, 2014.
- [6] Brett A. Bryan and Neville D. Crossman. Systematic regional planning for multiple objective natural resource management. *Journal of Environmental Management*, 88(4):1175 – 1189, 2008.
- [7] Kai MA Chan, M Rebecca Shaw, David R Cameron, Emma C Underwood, and Gretchen C Daily. Conservation planning for ecosystem services. *PLoS biology*, 4(11):e379, 2006.
- [8] Ira R. Cooke, Simon A. Queenborough, Elizabeth H. A. Mattison, Alison P. Bailey, Daniel L. Sandars, A. R. Graves, J. Morris, Philip W. Atkinson, Paul Trawick, Robert P. Freckleton, Andrew R. Watkinson, and William J. Sutherland. Integrating socio-economics and ecology: a taxonomy of quantitative methods and a review of their use in agro-ecology. *Journal of Applied Ecology*, 46(2):269–277, 2009.
- [9] Steven P Courtney and Andrew B Carey. *Scientific evaluation of the status of the Northern Spotted Owl*. Sustainable Ecosystems Institute Portland, OR, 2004.
- [10] Gretchen C Daily, Susan Alexander, Paul R Ehrlich, Larry Goulder, Jane Lubchenco, Pamela A Matson, Harold A Mooney, Sandra Postel, Stephen H Schneider, David

- Tilman, et al. *Ecosystem services: benefits supplied to human societies by natural ecosystems*, volume 2. Ecological Society of America Washington (DC), 1997.
- [11] Luis Diaz-Balteiro and Carlos Romero. Making forestry decisions with multiple criteria: a review and an assessment. *Forest Ecology and Management*, 255(8):3222–3241, 2008.
 - [12] Gary E Dixon et al. Essential fvs: A users guide to the forest vegetation simulator. *Fort Collins, CO: USDA-Forest Service, Forest Management Service Center*, 2002.
 - [13] Oregon Fish and Wildlife Office. Species fact sheet: Northern spotted owl. <http://www.fws.gov/oregonfwo/Species/Data/NorthernSpottedOwl/default.asp>. Accessed: 2015-02-06.
 - [14] Eclipse Foundation. Eclipse, 2014.
 - [15] William L Gaines, Richy J Harrod, James Dickinson, Andrea L Lyons, and Karl Halupka. Integration of northern spotted owl habitat and fuels treatments in the eastern cascades, washington, usa. *Forest Ecology and Management*, 260(11):2045–2052, 2010.
 - [16] J Garcia-Gonzalo, JG Borges, JHN Palma, and A Zubizarreta-Gerendiain. A decision support system for management planning of eucalyptus plantations facing climate change. *Annals of Forest Science*, 71(2):187–199, 2014.
 - [17] Jaime R. Goode, Charles H. Luce, and John M. Buffington. Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern rocky mountains. *Geomorphology*, 139140(0):1 – 15, 2012.
 - [18] Grant Hauer, Steve Cumming, Fiona Schmiegelow, Wiktor Adamowicz, Marian Weber, and Robert Jagodzinski. Tradeoffs between forestry resource and conservation values under alternate policy regimes: A spatial analysis of the western canadian boreal plains. *Ecological Modelling*, 221(21):2590 – 2603, 2010.
 - [19] Louis R Iverson and Anantha M Prasad. Predicting abundance of 80 tree species following climate change in the eastern united states. *Ecological Monographs*, 68(4):465–485, 1998.
 - [20] Amit Kanudia and Richard Loulou. Robust responses to climate change via stochastic markal: The case of qubec. *European Journal of Operational Research*, 106(1):15 – 30, 1998.

- [21] Danny C Lee and Larry L Irwin. Assessing risks to spotted owls from forest thinning in fire-adapted forests of the western united states. *Forest Ecology and Management*, 211(1):191–209, 2005.
- [22] Alexander V Lotov, Vladimir A Bushenkov, and Georgy K Kamenev. *Interactive decision maps: Approximation and visualization of Pareto frontier*, volume 89. Springer, 2004.
- [23] Alexander V Lotov and Kaisa Miettinen. Visualizing the pareto frontier. In *Multiobjective optimization*, pages 213–243. Springer, 2008.
- [24] B Luo, I Maqsood, YY Yin, GH Huang, and SJ Cohen. Adaption to climate change through water trading under uncertainty- an inexact two-stage nonlinear programming approach. *Journal of Environmental Informatics*, 2(2):58–68, 2003.
- [25] Shunsuke Managi. Evaluation and policy analysis of japanese forestry. In *2005 Annual meeting, July 24-27, Providence, RI*, number 19358. American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association), 2005.
- [26] Donald McKenzie, Ze’ev Gedalof, David L Peterson, and Philip Mote. Climatic change, wildfire, and conservation. *Conservation Biology*, 18(4):890–902, 2004.
- [27] Robin Naidoo, Andrew Balmford, Robert Costanza, Brendan Fisher, Rhys E Green, B Lehner, TR Malcolm, and Taylor H Ricketts. Global mapping of ecosystem services and conservation priorities. *Proceedings of the National Academy of Sciences*, 105(28):9495–9500, 2008.
- [28] Craig R. Nitschke and John L. Innes. Integrating climate change into forest management in south-central british columbia: An assessment of landscape vulnerability and development of a climate-smart framework. 2008.
- [29] Intergovernmental Panel on Climate Change. Scenario Process for AR5. http://sedac.ipcc-data.org/ddc/ar5_scenario_process/scenario_background.html, 2014.
- [30] M. Pasalodos-Tato, A. Mkinen, J. Garcia-Gonzalo, J.G. Borges, T. Lms, and L.O. Eriksson. Review. assessing uncertainty and risk in forest planning and decision support systems: review of classical methods and introduction of new approaches. *Forest Systems*, 22(2), 2013.
- [31] Svetlana Kushch Schroder. *Optimizing forest management in consideration of environmental regulations, economic constraints, and ecosystem services*. PhD thesis, 2013.

- [32] Rupert Seidl, Werner Rammer, Dietmar Jäger, and Manfred J Lexer. Impact of bark beetle (*Ips typographus* L.) disturbance on timber production and carbon sequestration in different management strategies under climate change. *Forest Ecology and Management*, 256(3):209–220, 2008.
- [33] Chris D Thomas, Alison Cameron, Rhys E Green, Michel Bakkenes, Linda J Beaumont, Yvonne C Collingham, Barend FN Erasmus, Marinez Ferreira De Siqueira, Alan Grainger, Lee Hannah, et al. Extinction risk from climate change. *Nature*, 427(6970):145–148, 2004.
- [34] Sandor Toth. *Modeling Timber and Non-timber Trade-offs in Spatially-Explicit Forest Planning*. PhD thesis.
- [35] Sandor Toth and Marc McDill. Finding efficient harvest schedules under three conflicting objectives. 2009.
- [36] Sandor Toth, Marc McDill, and Stephanie Rebain. Finding the efficient frontier of a bi-criteria, spatially explicit, harvest scheduling problem. 2006.
- [37] Sándor F Tóth and Marc E McDill. Finding efficient harvest schedules under three conflicting objectives. *Forest Science*, 55(2):117–131, 2009.
- [38] Fernando Badilla Veliz, Jean-Paul Watson, Andres Weintraub, Roger J-B Wets, and David L Woodruff. Stochastic optimization models in forest planning: a progressive hedging solution approach. *Annals of Operations Research*, pages 1–16, 2014.
- [39] James M Vose, David Lawrence Peterson, Toral Patel-Weynand, et al. *Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the US forest sector*. US Department of Agriculture, Forest Service, Pacific Northwest Research Station Portland, OR, 2012.
- [40] Andy White and Alejandra Martin. Who owns the worlds forests. *Forest Trends, Washington, DC*, 2002.
- [41] Steven M Wondzell and John G King. Postfire erosional processes in the pacific northwest and rocky mountain regions. *Forest Ecology and Management*, 178(1):75–87, 2003.
- [42] Rasoul Yousefpour, Jette Bredahl Jacobsen, Bo Jellesmark Thorsen, Henrik Meilby, Marc Hanewinkel, and Karoline Oehler. A review of decision-making approaches to handle uncertainty and risk in adaptive forest management under climate change. *Annals of forest science*, 69(1):1–15, 2012.

Appendix A

WHERE TO FIND THE FILES

The uwthesis class file, `uwthesis.cls`, contains the parameter settings, macro definitions, and other T_EXnical commands which allow L^AT_EX to format a thesis. The source to the document you are reading, `kullman_thesis.tex`, contains many formatting examples which you may find useful. The bibliography database, `kullman_thesis.bib`, contains instructions to BibT_EX to create and format the bibliography. You can find the latest of these files on:

- My page.

`http://staff.washington.edu/fox/tex/uwthesis.html`

- CTAN

`http://tug.ctan.org/tex-archive/macros/latex/contrib/uwthesis/`

(not always as up-to-date as my site)