Quantitative Ecology and Resource Management

APPLIED QUALIFYING EXAMINATION INSTRUCTIONS

Spring Quarter 2015 (Wednesday, June 17 – Tuesday, June 23, 2015)

This exam includes 4 examination questions (each question is independent) and 4 data sets (text file attachments have been emailed to you).

Please open immediately and confirm by email that you are able to open all attachments.

INSTRUCTIONS:

1. Your unique ID number is: *(emailed to you)*. Please list this ID number on the top of each page. **DO NOT INCLUDE YOUR NAME ON THE EXAM.**

2. Number each page of the exam. Appendices should also be numbered so that any reference to the appendix refers to a particular set of pages.

3. Provide a 1-3 page summary at the beginning of your exam.

4. Your write-up should include a narrative (including any pasted in tables, graphics, etc.) for each question showing the thought process of the analysis, the results at each step, and how that leads to the next step.

5. Clearly describe in your text the points that any diagrams or tables demonstrate.

6. All graphs should be clearly labeled and computer output annotated as need be.

7. Please send an electronic copy of your exam (PDF format) and any appendices, *directly to Joanne* at jbesch@u.washington.edu, **no later than 12:00 p.m. on Tuesday, June 23rd**. She will forward an electronic copy to each exam committee member.

OTHER INFORMATION:

REMEMBER libraries will most likely be CLOSED Saturday and Sunday, so any reference materials you may need should be checked out before then.

You will need CPLEX for the optimization question.

QUESTIONS?

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John Skalski (Question #1) skalski@uw.edu ****ONLY available until June 19th**** and will be traveling out of the country after that. After June 19th Tim Essington can address any questions.

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**** Sandor is currently traveling and will only be available periodically by email****

If you need to reach Joanne you may email her at jbesch@u.washington.edu.

Good luck!

QERM Applied Examination for 2015

Question #1. Bat Barotrauma Analysis

An unanticipated effect of wind turbine facilities has been the barotrauma mortalities of bats. Blade strikes were anticipated as a potential problem, but a larger source of mortality at wind farms is from embolisms induced by bats flying too close to the underside of the turbine blades. Like airplane wings, there is a low pressure field formed under the blade associated with rotation. Entire wind farms can be shut down by the U.S. Fish and Wildlife Service if as few as three bats listed as endangered species are killed on an annual basis.

One way wind farms are modifying their operations to mitigate for bat mortalities is to curtail turbine operations at lower wind speeds. Bats reduce their foraging activities as wind speeds increase; therefore, one way to reduce risk to bats is to operate the wind turbines at higher wind speeds than required for minimal turbine operations. The trade-off is between lost electrical generation and reduced bat kills. Standard wind turbine operations begin when wind speeds are ≥3 m/s. Curtailment operations for bat mitigation begin electrical generation when wind speeds are ≥4.5–5 m/s.

Experimental Design

Ten wind turbines were dedicated to a test of the effect of curtailment operations on reducing bat mortalities.

A randomized block design was used to assess the effects of cut-in speed on bat mortality. The test blocks were of 6-day duration. During the first 3 days, half of the turbines were randomized to control and half to treatment conditions. Bat mortalities were monitored, and daily carcass counts tallied. For days 4–6 of the test block, the control and treatment conditions will be flipped at the individual turbines (Figure 1), and bat mortalities further monitored. Between blocks, test conditions were re-randomized to the turbines. The table below illustrates the nature of the randomized block design.

Turbine Unit	1	2	3	4	5	6	7	8	9	10	
3 days	T	C	T	T	C	C	T	C	T	C	Block I
3 days	C	T	C	C	T	T	C	T	C	T	
	⋮									⋮	
3 days	T	T	C	T	C	T	C	C	T	C	Block II
3 days	C	C	T	C	T	C	T	T	C	T	

Figure 1. Schematic of 6-day test blocks with 3 days of treatment (T) or control (C) conditions, followed by treatment flip.

Carcass searches were performed after each 3-day period, and observed counts converted to estimates of total carcass abundance based on search efficiency of field crews and maximum likelihood estimates of total mortality $(\widehat{M})$, along with SEs. The maximum likelihood estimation produces standard errors that are proportional to the mortality estimates, i.e., Var $(\widehat{M}) \propto \widehat{M}^2$); therefore, weight $1/\mathrm{CV}^2$ is most appropriate. Each 6-day block produced two estimates of bat kill under each of control (i.e., ≥3 m/s) and treatment (i.e., ≥4.5–5 m/s) conditions. The experiment was conducted for a total of 11 6-day test blocks.

Covariates associated with the experiment include:

1. Actual number of turbines operational within a test period for each treatment (e.g., mechanical failures sometimes reduced the number below 5).
2. Actual number of turbine operational hours within a test period on a per-treatment basis.

Objectives

1. Assess whether the curtailment treatment (i.e., wind speed ≥4.5–5 m/s) had a significant (P = 0.10) reduction on bat mortalities. In your analysis, estimate the relative size of the reduction (SE) as well as assess what may be the underlying cause of the reduction (i.e., could it be fewer bats are at risk or are there are less opportunities for mortality). Partition your estimate of treatment effects into sources of reduction.
2. Present associated graphs, ANOVAs, *F*-tests, and confidence intervals to support your conclusions.

Data

Illustrated below are the headers for the data fields to be analyzed with associated definitions. The data have been modified to protect the proprietary nature of the information.

block	replicate	Treatment[a]	number.turbines[b]	total.op.hrs[c]	est.total.dead[d]	est.total.dead.se[e]
1	1	C	5	120.4167	6.61297	3.32241
1	1	T	3	18.5000	0.00024	0.07248
1	2	C	3	116.8333	4.48175	2.60468
1	2	T	5	67.4167	1.31688	1.32168
⋮	⋮	⋮	⋮	⋮	⋮	⋮
11	1	C	4	118.2500	0.00026	0.07852
11	1	T	4	155.4167	7.25532	3.33852
11	2	C	4	162.8333	0.00026	0.07852
11	2	T	4	90.0833	2.6214	1.86600

a. Control (wind speeds ≥ 3 m/s), treatment (wind speeds ≥ 4.5–5 m/s)
b. Actual number of turbines used after accounting for mechanical downtimes
c. Actual night operating hours of the turbines in column b
d. MLE of total bat mortality at operating turbines during 3-day period
e. SE associated with mortality estimate

block	replicate	treatment	number.turbines	total.op.hrs	est.total.dead	est.total.dead.se
1	1	C	5	120.4166667	6.61297	3.32241
1	1	T	3	18.5	0.00024	0.07248
1	2	C	3	116.8333333	4.48175	2.60468
1	2	T	5	67.41666667	1.31688	1.32168
2	1	C	4	163	1.63384	1.64645
2	1	T	4	92.66666667	1.53492	1.54044
2	2	C	4	143.4166667	1.63384	1.64645
2	2	T	4	71.83333333	1.53492	1.54044
3	1	C	4	162	3.30135	2.35846
3	1	T	4	95.08333333	2.6214	1.866
3	2	C	4	150.25	3.30135	2.35846
3	2	T	4	64.58333333	2.82864	2.00832
4	1	C	4	160.9166666	6.34153	3.18916
4	1	T	4	103.25	1.31688	1.32168
4	2	C	4	137.4166666	14.17299	4.76762
4	2	T	4	70.33333334	2.6214	1.866
5	1	C	4	152.0833333	27.8811	6.89468
5	1	T	4	76.83333333	2.6214	1.866
5	2	C	4	157.3333333	27.47758	6.56656
5	2	T	4	95.24999999	7.25532	3.33852
6	1	C	4	155.8333333	4.71913	2.73962
6	1	T	4	84.66666667	3.96624	2.29188
6	2	C	4	160.5	4.9894	2.8938
6	2	T	4	95.5	2.82924	2.01084
7	1	C	4	161	9.68656	3.98476
7	1	T	4	39.33333333	0.00024	0.07248
7	2	C	4	162.9166666	10.78779	4.10982
7	2	T	4	97.91666667	6.9114	3.10812
8	1	C	4	129.3333333	0.00026	0.07852
8	1	T	4	55.24999999	0.00024	0.07248
8	2	C	4	121.6666667	17.10878	5.21365
8	2	T	4	17.83333333	1.31688	1.32168
9	1	C	4	163	1.66283	1.66881
9	1	T	4	141.0833333	1.53492	1.54044
9	2	C	4	149.5833333	18.00422	5.18882
9	2	T	4	43.08333333	2.6214	1.866
10	1	C	4	23.83333334	1.42662	1.43182
10	1	T	4	143.8333333	0.00024	0.07248
10	2	C	4	142.4166667	1.42662	1.43182
10	2	T	4	137.0833333	1.31688	1.32168
11	1	C	4	118.25	0.00026	0.07852
11	1	T	4	155.4166666	7.25532	3.33852
11	2	C	4	162.8333333	0.00026	0.07852
11	2	T	4	90.08333333	2.6214	1.866

Question 2

Background

Bats provide a number of useful ecosystem services (Kunz et al., 2011). One of the most important of these services is the suppression of insect populations (e.g., Williams-Guillen et al., 2008). Boyles et al. (2011) recently estimated that losses of bats, due to both white-nose syndrome and the increased development of wind-power facilities, could lead to agricultural economic losses of more than 3.7 billion dollars each year.

You have accepted a new postdoctoral position to study the effects of bat mortality (from a new wind farm) on insect population levels. As part of this assessment, your research group has constructed a predator-prey model to study the interaction of bats and insects. Since Muller et al. (2012) recently showed that open-country bats show a significant aggregative response to increasing prey abundance, your group has decided to allow for predator interference, i.e., for the fact that your bats may interfere with each other's searching at high (bat) densities.

Your group's model is

$$\frac{dI}{dT} = r\,I\left[1-\left(\frac{I}{K}\right)^{\theta}\right] - \frac{c\,I\,B}{1+a\,I+h\,B}\,, \tag{1.1a}$$

$$\frac{dB}{dT} = \frac{b\,I\,B}{1+a\,I+h\,B} - m\,B\,, \tag{1.1b}$$

where I is insect density, B is bat density, T is time, and all parameters are nonnegative.

1. Basic interpretation

Describe the biological meaning of the terms and parameters in this predator-prey model. Be succinct but accurate. If there are names or if there is standard terminology associated with particular terms or parameters, be sure to state these.

2. Simplification and nondimensionalization

The above model is a little too complicated for this exam. Set $\theta = 1$. In addition, a mammalogist in your group has pointed out that your species is a generalist and that it has negligible prey handling times (Altringham, 2011; Fenton, 1990). Set $a = 0$. This leaves you with

$$\frac{dI}{dT} = r\,I\left(1-\frac{I}{K}\right) - \frac{c\,I\,B}{1+h\,B}\,, \tag{1.2a}$$

$$\frac{dB}{dT} = \frac{b\,I\,B}{1+h\,B} - m\,B\,. \tag{1.2b}$$

In order to simplify the above differential equations, introduce the dimensionless variables

$$x \equiv \frac{I}{K}\,,\quad y \equiv \frac{c}{r}B\,,\quad t \equiv r\,T \tag{1.3}$$

and reduce your differential equations to a system of the form

$$\frac{dx}{dt} = x\,[\,1 - x - f(y)\,]\,, \tag{1.4a}$$

$$\frac{dy}{dt} = \beta\,[\,x\,f(y) - \alpha\,y\,]\,, \tag{1.4b}$$

for an appropriate function $f(y)$.

Identify the function $f(y)$. How are your your new parameters (α, β, and any other new dimensionless parameters) defined in terms of your original parameters (r, K, c, h, b, m)? If possible, describe the biological meaning of your dimensionless parameters.

3. Closed orbits

Show (prove) that system (1.4) has no closed orbits (i.e., no limit cycles) contained entirely within the first quadrant of the (x, y) phase plane.

4. Zero-growth isoclines and equilibria

Find and draw the prey and predator zero-growth isoclines in the first quadrant of the predator-prey plane. (Be sure to consider all *reasonable* configurations for your zero-growth isoclines.) What is the direction of the vector field in each portion of the subdivided first quadrant? Describe how changes in bat mortality (m) and the strength of bat interference (h) affect the shape of your zero-growth isoclines. What can you conclude about the effects of m and h on insect and bat numbers at their coexistence equilibrium?

5. Easy stability analyses

Determine the stability and the nature of the equilibria at $(0, 0)$ and at $(1, 0)$ (for your nondimensionalized system) using linearized stability analyses. Be sure to state all relevant community matrices (Jacobians). Keep your analyses lean and clean. (I don't want to see lots of ugly algebra for this or the next question.)

6. Qualitative stability analysis at coexistence

For system (1.4), state (formally) the conditions that are satisfied at the coexistence equilibrium. (Please leave everything in terms of $f(y)$.) Use these conditions to simplify the Jacobian at this equilibrium. Determine the sign of each element a_{ij} of your Jacobian matrix. In evaluating the sign of a_{22}, you may find it useful to note that

$$f'(y) \le \frac{f(y)}{y}\,. \tag{1.5}$$

Use the signs from your Jacobian matrix, the signs of the coefficients of your characteristic equation (and the Routh-Hurwitz criteria) to determine the stability of the coexistence equilibrium. What can you conclude about the effect of predator interference on the stability of the coexistence equilibrium?

7. Discussion

Briefly discuss what you think the effects of (a) $\theta \neq 1$ and (b) of reintroducing prey handling time would be.

References

Altringham, J. D. 2011. *Bats: From Evolution to Conservation*. Oxford University Press, Oxford, UK.

Boyles, J. G., Cryan, P. M., McCracken, G. F., and Kunz, T. H. 2011. Economic importance of bats in agriculture. *Science*, **332**, 41–42.

Fenton, M. B. 1990. The foraging behaviour and ecology of animal-eating bats. *Canadian Journal of Zoology*, **68**, 411–422.

Kunz, T. H., Braun de Torrez, E., Bauer, D., Lobova, T., and Fleming, T. H. 2011. Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*, **1223**, 1–38.

Muller, J., Mehr, M., Bassler, C., Fenton, M. B., Horhorn, T., Pretzsch, H., Lemmt, H.-J., and Brandl, R. 2012. Aggregative response in bats: prey abundance versus habitat. *Oecologia*, **169**, 673–684.

Williams-Guillen, K., Perfecto, I., and Vandermeer, J. 2008. Bats limit insects in a tropical agroforestry system. *Science*, **320, 70.**

QUESTION 3.

You are assigned to study bat mortality due to collisions with turbines on wind farms. Numbers of bat mortalities during some period of time are available across 38 wind farms. The dataset also contains the number of turbines installed on each wind farm (`http://www.stat.washington.edu/vminin/QERM/2015/bat_death_data.txt`).

(3.a) Formulate a simple Bayesian hierarchical model with the following specifications. The model should allow for differences in rates of bat mortality across farms, even in a setting where all farms have an equal number of turbines. However, the model should also take into account differences in the numbers of turbines across farms. Since the data are sparse, your model should allow farms to borrow information from each other — here is where the hierarchical part of the model should come into play. Let's collect mortality rates and a small set of hyperparameters into a vector $\boldsymbol{\theta}$. Conditional on $\boldsymbol{\theta}$, the number of bat deaths should be independent across farms. This means, for example, that you should not try to model potential spatial dependence of bat mortalities across farms. Provide prior specifications for all model parameters.

(3.b) Let $\mathbf{y} = (y_1, \ldots, y_{38})$, where y_i is the number of bat deaths on the wind farm i. Show that you can compute (up to proportionality constant) the posterior distribution of model parameters from part (3.a):

$$p(\boldsymbol{\theta} \mid \mathbf{y}) \tag{1}$$

for each set of model parameters $\boldsymbol{\theta}$.

(3.c) Devise and implement a Markov chain Monte Carlo (MCMC) algorithm to approximate the posterior (1). Provide mathematical details of MCMC steps and report results of MCMC diagnostics after running the algorithm. Summarize and report the posterior distribution using histograms and boxplots.

(3.d) Suppose you would like to use your model to predict the number of bat deaths, y_{new}, for a farm with 100 turbines. Using MCMC output from part (3.c), approximate the predictive distribution with the following probability mass function:

$$p(y_{\text{new}} \mid \mathbf{y}) = \int p(y_{\text{new}} \mid \boldsymbol{\theta}) p(\boldsymbol{\theta} \mid \mathbf{y}) d\boldsymbol{\theta}.$$

(3.e) Explain how you would alter your model formulation from part (3.a) if you wanted to incorporate multiple farm specific covariates into your model (e.g., distance between the farm and the closest bat migratory path). Do not perform any computations with this model.

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"bat_deaths" "wind_turbines_num"
19 132
11 116
6 124
4 75
10 124
2 73
11 135
7 86
4 63
4 89
3 72
5 107
20 112
12 143
2 110
6 81
10 73
6 100
22 133
2 64
17 128
17 128
21 64
5 111
12 78
17 99
23 146
3 77
4 120
26 129
7 118
1 79
3 142
13 102
13 140
8 66
2 95
4 69
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Question 4: Optimization:

Typhoon Inc. is a wind energy provider who is exploring opportunities to establish a wind farm on Topaz Island. The company purchased a geographic database that covers the Island and found 100 developable lots suitable for wind turbine installation. The installation costs run at $350,000 for the 100kW turbines that Typhoon works with. In addition, the company must purchase each lot on which it wishes to install a turbine. The size of the lots are such that each can only host one turbine at the most. Unfortunately for Typhoon, Topaz Island is in the dispersion zone of a rare Myotis bat species, a few colonies of which have established themselves on the neighboring Zephier Island. The local environmental protection agency is willing to make an agreement with Typhoon whereby the company is permitted to install as many wind turbines as it wishes as long as they ensure the habitat protection of an equal number of dispersing Myotis populations. In other words, for every wind turbine, Typhoon has to protect at least one potential roost site along with adequate amounts of accessible forage and water habitat to support a prospective sub-population of bats that could potentially disperse over from Zephier to Topaz Island. The environmental agency has determined that each of 100 lots can serve as potential roosting sites for the bats. However, to provide protection for any one Myotis population, not only does the lot have to be purchased for roost site, but lots containing at least 50 hectares of foraging habitat and 1 hectare of open water must also be purchased. The forage and water habitat must be available either on the lot of the roost site or on an adjacent parcel. Foraging habitat is available on even numbered while water is available on odd numbered parcels. The effective forage and water areas of the 100 parcels on Topaz Island are listed in the attached Parcel table in the second field. The third field is the purchase price of the parcels in US dollars.

One issue that Typhoon faces is the threat of wind turbine blade and bat collisions. The company negotiated an agreement with the environmental agency whereby the turbines can only be established on lots that are neither overlapping with nor are adjacent to parcels that host protected roost sites or forage or water habitats that serve the roosts. An adjacency table that shows which lots are adjacent to each other is also enclosed.

What is the maximum number of wind turbines Typhoon can install on Topaz Island with a $20 and $50 million budget, respectively? Please build and code an integer program that can determine the answer to this question for both budgets using the enclosed parcel and adjacency databases. Please clearly define your decision variables and the parameters and sets that you use in your mathematical formulation. Please explain each constraint and function one by one.

Please submit:

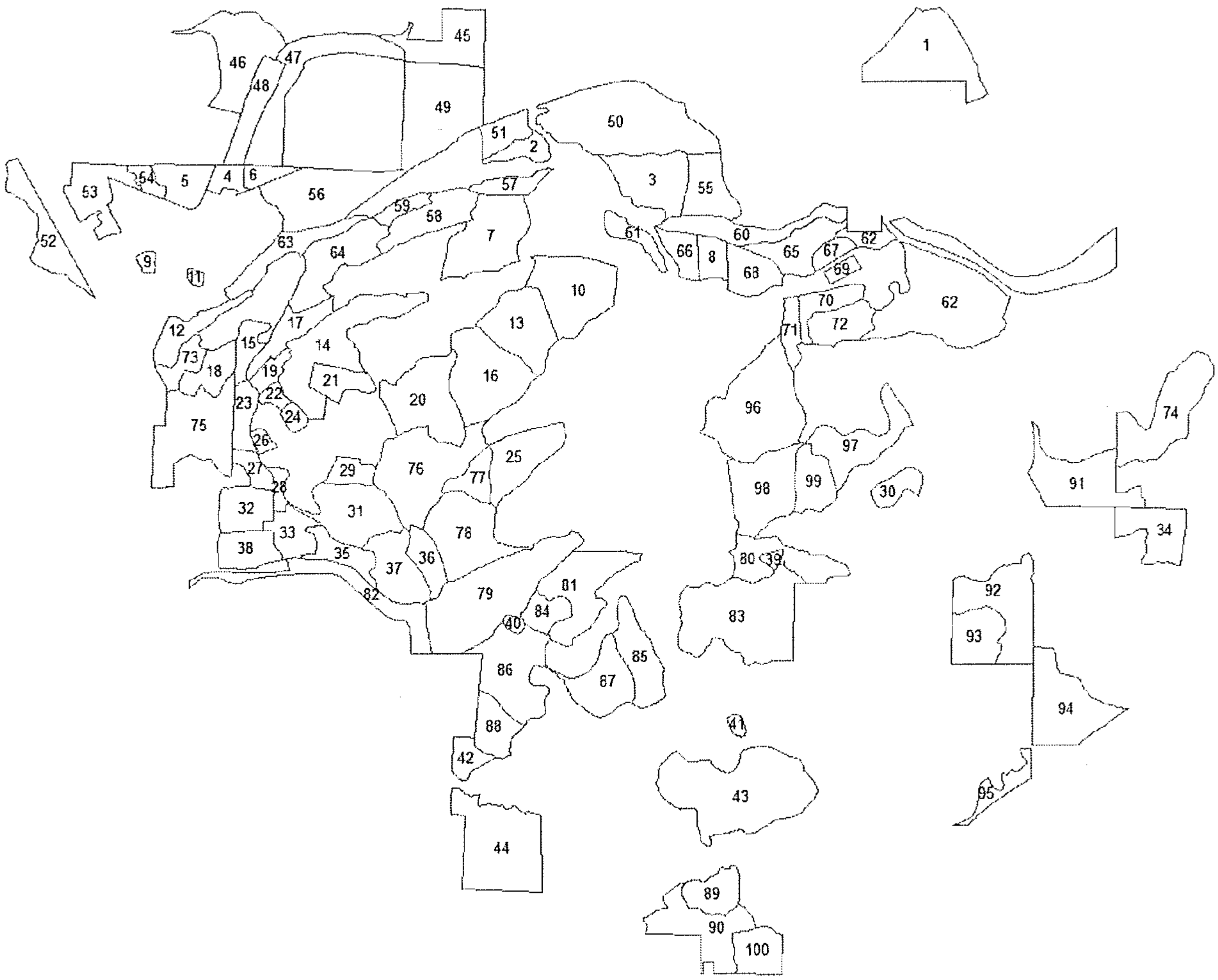
(1) the mathematical formulation of your proposed model along with the variable definitions and explanations;

(2) a text file in CPLEX format that shows the model populated with the real data;

(3) a CPLEX solution file;

(4) a map of solutions (see map on next page); and

(5) a solution analysis, discussion and conclusions.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21,9.311,46555.00
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Parcels.txt Pg. 18

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Parcels.txt Pg. 19

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