A Non-Exhaustive List of Quantitative Course Recommendations for Biology Graduate Students (December 2017)

1. **CAS – Biology**
2. **CAS – Anthropology**
3. **CAS – Earth and Environment**
4. **CAS – Neuroscience**
5. **CAS – Mathematics**
6. **CAS – Computer Science**
7. **College of Engineering**
8. **School of Public Health**

1. Biology

CAS BI 502: Topics in the Mathematical Structure of Biol. Systems (4 cr.)
Prereq: *MA 123; MA 124; BI 203; (or BI213), or consent of instructor*.
Examines mathematical principles for the control of biological systems, including themes of behavioral switching, adaptation, noise, and memory. Subjects range from bacteria to vertebrates. Assignments include student presentations on primary literature, and the option of computational modeling. (2nd sem.)

CAS BI 519: Theoretical Evolutionary Ecology (4 credits)
Familiarizes students with the theory of evolutionary ecology. Students gain enough background to read theoretical evolutionary ecology literature, do simple modeling, and move on to more complex theory. Students gain experience through homework assignments and computer labs.

2. Anthropology

CAS AN 597: Project Design and Statistics in Biological Anthropology (4 credits)
Statistical methods are the backbone of scientific research, but are often given short shrift when designing research in biological anthropology. The purpose of this seminar is two-fold: 1) to familiarize students with the use of relevant statistical programming packages (primarily R), and 2) to discuss select advances in statistical techniques from related disciplines that may help students while designing and implementing their own research projects.

3. Earth and Environment

CAS GE 507 Dynamical Oceanography
Introduction to the physical ocean system. Physical properties of seawater; essential ocean dynamics; mixing and stirring in the ocean; simple waves; observed current systems and water masses; and coupled atmosphere-ocean variability.

CAS GE 509 Applied Environmental Statistics
Survey of modern probability-based statistical methods in environmental science. Core concepts in likelihood and Bayesian approaches are used to address spatial, time-series, and latent variable models and non-Gaussian, non-linear, heterogenous, and missing data. Project-based course focused on applications to data.

CAS GE 516 Multivariate Analysis for Geographers (Friedl)
Prereq: CAS MA 214 or equivalent, or consent of instructor. Applications of multivariate techniques to problems in spatial context, emphasizing interpretation. Review of regression and analysis of variance. Introduction to topics including canonical correlation, factor analysis, discriminant and clustering analyses.

CAS GE 585 Ecological Forecasting and Informatics (Dietze)
Undergraduate Prerequisites: CAS BI 303 or CAS BI 306; CAS MA 121 or CAS MA 123; CAS MA 115 or CAS MA 213 or CAS GE 375; or consent of instructor. The statistics and informatics of model-data fusion and forecasting: data management, workflows, Bayesian statistics, uncertainty analysis, fusing multiple data sources, assessing model performance, scenario development, decision analysis, and data assimilation. Case studies highlight ecological forecasting across a range of subdisciplines.

4. Neuroscience

CAS CN 500 - Computational Methods in Cognitive and Neural Systems (4 cr.)
Introduction to mathematical methods and computer simulation for modeling cognitive and neural systems. Topics include computer simulation methods, control theory, difference and differential equations, digital signal processing, image processing, optimization, and statistics. Readings from current literature emphasize theory and applications relevant to the study of cognitive and neural systems.

CAS CN 510 - Principles and Methods of Cognitive and Neural Modeling I (4 cr.)
Prereq: *CASMA226 (or equivalent; can be taken in parallel); and CASCS108 or CASCS111 or ENGEK127 (or equivalent); and CASNE101 (or equivalent; can be taken in parallel); or consent of instructor.*
Explores psychological, biological, mathematical, and computational foundations of behavioral and brain modeling. Topics include organizational principles, mechanisms, local circuits, network architectures, cooperative and competitive non-linear feedback systems,

associative learning systems, and self-organizing code-compression systems. The adaptive resonance theory model unifies many course themes. CAS CN 510 and 520 may be taken concurrently.

CAS CN 520 - Principles and Methods of Cognitive and Neural Modeling II (4 cr.)
Analyzes three main traditions in models of learning: unsupervised (self-organized) learning, supervised learning (learning with a teacher), and reinforcement learning. Architectures studied include adaptive filters, back propagation, competitive learning, self-organizing feature maps, gradient descent procedures, Boltzmann machines, simulated annealing, neocognitron, and gated dipoles. CAS CN 510 and 520 may be taken concurrently.

C**AS CN 530 - Neural and Computational Models of Vision (4 cr.)**
Prereq: *CAS CN 510; or consent of instructor.*
Grad Prereq: *CAS CN 510; or consent of instructor.*
Current models of mammalian visual processes are constrained by experimental and theoretical results from psychology, physiology, computer science, and mathematics. The course evaluates the explanatory adequacy of competing neural and computational models of such processes as edge detection, textural grouping, shape-from-shading, stereopsis, motion detection, and color perception. Students perform computer simulations of some of the examined models.

CAS CN 540 - Neural and Computational Models of Adaptive Movement Planning and Control (4 cr.)
Prereq: *CAS CN 510; or consent of instructor.*
Grad Prereq: *CAS CN 510; or consent of instructor.*
Neural models of eye, arm, hand, orofacial, and leg movements are presented and compared to reveal general organizational principles and specialized neural circuit designs for motor learning and performance. Issues include trajectory formation, synchronization of synergists, variable velocity control, adaptive gain control, map formation, load compensation, serial order, and inflow versus outflow as sources of sensory-motor information.

CAS CN 550 - Neural and Computational Models of Recognition, Memory, and Attention (4 cr.)
Prereq: *CAS CN 510; or consent of instructor.*
Grad Prereq: *CAS CN 510; or consent of instructor.*
Develops neural network models of how internal representations of sensory events and cognitive hypotheses are learned and remembered, and how such internal representations enable recognition and recall of these events to occur. Various neural pattern recognition models are analyzed. Special emphasis is placed on stable self-organization of pattern recognition and recall codes in unpredictable and noisy environments, notably by adaptive resonance theory models, and on how such codes direct attention toward predictively relevant combinations of features, while attenuating irrelevant background cues. Experimental data and theoretical predictions from cognitive psychology, neuropsychology, and neurophysiology of normal and abnormal individuals are analyzed.

CAS CN 560 - Neural and Computational Models of Speech Perception and Production (4 cr.)
Covers auditory perception, physiology, and modeling. Examines how sound is transduced and transmitted through the auditory pathway. Introduces and uses basic mathematical concepts from signal processing, probability, signal detection theory, and psychophysical methods. Also offered as CAS NE 560.
Prereq: *CAS CN 510; or consent of instructor.*

CAS CN 570 - Neural and Computational Models of Conditioning, Reinforcement, Motivation, and Rhythm (4 cr.)
Prereq: *CAS CN 510; or consent of instructor.*
Develops neural and computational models of how humans and animals learn to successfully predict environmental events and generate behavioral actions that satisfy internally defined criteria of success or failure. Reinforcement learning and its homeostatic (drive, arousal, rhythm) and nonhomeostatic (reinforcement) modulators are analyzed in depth. Recognition learning and recall learning networks are joined to the reinforcement learning network to analyze how these several processes cooperate to generate successful goal-oriented behavior. Maladaptive behaviors and certain mental disorders are analyzed from a unified theoretical perspective. Applications to the design of freely moving adaptive robots are noted.

CAS CN 580 - Introduction to Computational Neuroscience (4 cr.)
Prereq: *Senior standing in the mathematics or natural science department or consent of instructor.* **Grad Prereq:** *senior standing in a natural science or Department of Mathematics or consent of instructor.*
This introductory level course focuses on building a background in neuroscience, but with emphasis on computational approaches. Topics include basic biophysics of ion channels, Hodgkin-Huxley theory, use of stimulators such as NEURON and GENESIS, recent applications of the compartmental modeling technique, and a survey of neuronal architectures of the retina, cerebellum, basal ganglia, and neocortex.

GRS CN 700: Computational and Mathematical Methods in Neural Modeling (4 cr.)
Grad Prereq: *Consent of instructor.*
Introduction to advanced computational topics used in quantitative modeling. Techniques from signal processing, probability, statistics, vector quantization, optimal control, and ordinary and partial differential equations. Theory, simulations, and techniques illustrated with neural networks and other behavioral and biological models.

5. Mathematics

CAS MA 565: Mathematical Models in the Life Sciences (4 cr.)
Prereq: *MA226 or MA231*

An introduction to mathematical modeling, using applications in the biological sciences. Mathematics includes linear difference and differential equations, and an introduction to nonlinear phenomena and qualitative methods. An elementary knowledge of differential equations and linear algebra is assumed. **(Inst: Vo)**

CAS MA 581: Probability (4 cr.)
Prereq: *MA225 or MA230*
Basic probability, conditional probability, independence. Discrete and continuous random variables, mean and variance, functions of random variables, moment generating function. Jointly distributed random variables, conditional distributions, independent random variables. Methods of transformations, law of large numbers, central limit theorem. Cannot be taken for credit in addition to CAS MA 381. **(Inst: Salins)**

GRS MA 665-666: An Introduction to Mathematical Models & Data Analysis in Neuroscience (2 cr.)
This introductory course combines lectures and hands-on computer time to treat real laboratory data like case studies and motivates students to use the mathematical approach as a means to better understand their own research via statistical data analysis and modeling. Students are required to take the first module of the course (2 cr) but have the option to also take the second module for additional credit if they want to go further into the subject area. (Instructor: Kramer)

CAS MA 681: Accelerated Introduction to Statistical Methods for Quantitative Research (4 cr.)
Prereq: *MA225 & MA242 or their equivalents.*
Introduction to statistical methods relevant to research in the computational sciences. Core topics include probability theory, estimation theory, hypothesis testing, linear models, GLMs, and experimental design. Emphasis on developing a firm conceptual understanding of the statistical paradigm through data analyses. Required for entering Bioinformatics Ph.D. students. **(Inst: Eden)**

GRS MA 684: Applied Multiple Regression and Multivariable Methods (4 cr.)
Prereq: *Grad prereq: one year of statistics*
Application of multivariate data analytic techniques. Multiple regression and correlation, confounding and interaction, variable selection, categorical predictors and outcomes, logistic regression, factor analysis, MANOVA, discriminant analysis, regression with longitudinal data, repeated measures, ANOVA. **(Inst: Heeren)**

GRS MA 770: Mathematical and Statistical Methods of Bioinformatics (4 cr.)
Prereq: *Graduate standing or advanced undergraduate math/stats, (MA225),(MA242), and previous work in mathematical analysis and probability*
Mathematical and statistical bases of bioinformatics methods and their applications. Hidden Markov models, kernel methods, mathematics of machine learning approaches, probabilistic sequence alignment, Markov chain Monte Carlo and Gibbs sampling, mathematics of phylogenetic trees, and statistical methods in microarray analysis. **(Inst: XX)**

6. Computer Science

CAS CS 542: Machine Learning (4 cr.)
Prereq: *(CS112) or equivalent programming experience, and familiarity with linear algebra, probability and statistics*
Introduction to modern machine learning concepts, techniques, and algorithms. Topics include regression, kernels, support vector machines, feature selection, boosting, clustering, hidden Markov models, and Bayesian networks. Programming assignments emphasize taking theory into practice, through applications on real-world data sets **(Inst: Sclaroff)**

7. College of Engineering

ENG BF 527: Applications in Bioinformatics (4 cr.) Prereq: Graduate standing or consent of instructor
The field of bioinformatics is concerned with the management and analysis of large biological datasets (such as the human genome) for the purpose of improving our understanding of complex living systems. This course introduces graduate students and upper-level undergraduate students to the core problems in bioinformatics, along with the databases and tools that have been developed to study them. Computer labs emphasize the acquisition of practical bioinformatics skills for use in students research. Familiarity with basic molecular biology is a prerequisite; no prior programming knowledge is assumed. Specific topics will include the analysis of biological sequences, structures, and networks. **(Inst: Leyfer)**

ENG BF 562: Computational Biology: Genomes, Networks, Evolution
Prereq: *Fundamentals of programming and algorithm design (EK 127 or equivalent), basic molecular biology (BE 209 or equivalent), statistics and probability (BE 200 or equivalent), or consent of instructor.*
The algorithmic and machine learning foundations of computational biology, combining theory with practice are covered. Principles of algorithm design and core methods in computational biology, and an introduction of important problems in computational biology. Hands on experience analyzing large-scale biological data sets. **(Inst: Galagan)**

ENG BF 568: Computational Systems Biology of Human Disease
Prereq: *The course is aimed at junior/seniors and graduate students in biomedical engineering or bioinformatics. However, students or fellows from other disciplines ranging from medicine and biology to physics or computer science can attend the class with permission of instructor.*
The main aim is to prepare students to apply and develop new concepts in integrative and systems biology of human disease. This involves developing a familiarity with current high- throughput omics technologies, probing the complex systems biology of disease using these biotechnologies: storing, querying and manipulating massive amount of data, performing analysis of clinically relevant integrative data,

producing models of systems across scales, capturing anomalous behavior in biological networks and making and validating predictions made by these network models. **(Inst: Kasif)**

ENG BF 571: Dynamics and Evolution of Biological Networks
Prereq: *CAS MA 226 & CAS MA 242. ENG EK 102 can be used in lieu of the CAS MA 242 pre-req. Familiarity with differential equations and linear algebra at equivalent levels and the consent of instructor can be used in lieu of both pre-reqs.*
The course focuses on mathematical models for exploring the organization, dynamics, and evolution of biochemical and genetic networks. Topics include: introductions to metabolic and genetic networks, deterministic and stochastic kinetics of biochemical pathways; genome-scale models of metabolic reaction fluxes; models of regulatory networks; modular architecture of biological networks. **(Inst: Segre)**

ENG BE 700: Advanced Topics in Biomedical Engineering
Prereq: *Graduate standing or consent of instructor*
Advanced study of a specific research topic in biomedical engineering. Intended primariy for advanced graduate students.
(Inst: Chen)

ENG BF 778: Physical Chemistry for Systems Biology (4 cr.)
Prereq: Not sure if still offered
his course introduces students to quantitative modeling in bioinformatics and systems biology. We begin with basic principles of statistical thermodynamics, chemical kinetics, with selected applications in biomolecular systems. Next we describe molecular driving forces in biology, and computation with biomolecular structures. Finally we discuss quantitative models of biomolecular networks, and design principles of biological circuits **(Inst: X)**

ENG BF 768: Biological Database Analysis
Prereq: None listed
Describes relational data models and database management systems. Teaches the theories and techniques of constructing relational databases with emphasis on those aspects needed for various biological data, including sequences, structures, genetic linkages and maps, and signal pathways. Introduces relational database query language SQL. Summarizes currently existing biological databases and the Web-based programming tools for their access. Object-oriented modeling is introduced primarily as a design aid for dealing with the particular complexities of biological information in standard RDB design. Emphasis will be on those problems associated with dealing with data whose nomenclature and interrelationships are undergoing rapid change. **(Inst: Benson)**

8. School of Public Health

SPH BS 704: Introduction to Biostatistics, (3 credits)
This course meets the biostatistics core course requirement for all degrees and concentrations at SPH. The course replaces BS701 and BS703. Topics include the collection, classification, and presentation of descriptive data; the rationale of estimation and hypothesis testing; analysis of variance; analysis of contingency tables; correlation and regression analysis; multiple regression, logistic regression, and the statistical control of confounding; sample size and power considerations; survival analysis. Special attention is directed to the ability to recognize and interpret statistical procedures in articles from the current literature. This course gives students the skills to perform, present, and interpret basic statistical analyses using the R statistical package.

SPH BS 723: Introduction to Statistical Computing (4 credits)
This course introduces students to statistical computing with focus on the SAS package. Emphasis is on manipulating data sets and basic statistical procedures such as t-tests, chi-square tests, correlation and regression. Conditions underlying the appropriate use of these statistical procedures are reviewed. Upon completion of this course, the student will be able to use SAS to: read raw data files and SAS data sets, subset data, create SAS variables, recode data values, analyze data and summarize the results using the statistical methods enumerated above. This course includes hands-on exercises and projects designed to facilitate understanding of all the topics covered in the course. Students use equipment and software available through the Boston University Medical Center. This course is a prerequisite for BS805, BS820, BS821, BS851, BS852, BS853 and BS858.
R-equivalent: Introduction to R: software for statistical computing environment, SPH BS 730

SPH BS 730: Introduction to R (4 credits)
Students will learn how to conduct statistical analysis using the public domain and free statistical software, R. Many public, private, and international organizations use R to conduct analysis, thus experience with R is a great skill to add to one's credentials. R offers flexibility, ranging from ease of writing code for simple tasks (e.g. using R as a calculator) to implementing complex analyses using cutting-edge statistical methods and models. Additionally, the R language provides a rich environment for working with data, especially for statistical modeling, graphics, and data visualization. This course will emphasize data manipulation and basic statistical analysis including exploratory data analysis, classical statistical tests, categorical data analysis, and regression. Students will be able to identify appropriate statistical methods for the data or problems and conduct their own analysis using the R environment. This hands-on and project-based course will enable students to develop skills to solve statistical problems using R. R can be used as an alternative or in addition to SAS (BS723). R is compatible with Apple OS, Windows, and Unix environments.

SPH BS 805: Intermediate Statistical Computing and Applied Regression Analysis (4 cr)
This course is a sequel to BS723. Emphasis is placed on the use of intermediate-level programming with the SAS statistical computer package to perform analyses using statistical models with emphasis on linear models. Computing topics include advanced data file manipulation, concatenating and merging data sets, working with date variables, array and do-loop programming, and macro construction. Statistical topics include analysis of variance and covariance, multiple linear regression, logistic regression, survival analysis, the analysis of correlated data, and statistical power. Includes a required lab section. R-equivalent: There is no R equivalent at this intermediate level

SPH BS 822: Advanced Methods in Statistical Computing, (4 credits)
This course introduces advanced statistical methods and programming techniques that allow students to examine advanced statistical models that go beyond that available with standard SAS procedures taught in BS805. Topics include simulation studies, bootstrapping and Bayesian analysis. Students will apply these methods in homework assignments.
R-equivalent: Applied Statistical Modeling and Programming in R SPH BS 845 (4 credits)

SPH BS 860: Statistical Genetics II (4 cr.)
Prereq: *SPH BS858 or consent of instructor*
This course covers current topics in statistical genetics, with emphasis on how statistical techniques can be used with various types of genetics data for mapping genes responsible/contributing to complex human diseases. Topics such as genetics map functions, gene mapping in experimental organisms, advanced linkage analysis methods, statistical approaches for the analysis of genome-wide high density SNP scans in unrelated and family samples will be discussed. **(Inst: Dupuis)**