**Quantitative ecology at the graduate level**

Quantitative reasoning is fundamental to ecology, and its importance will only continue to grow over time. The abundance of quantitative methods and applications that are now in practice is a profound achievement for the discipline, yet navigating through this labyrinth of options can be overwhelming for beginning graduate students, especially those with limited prior training in mathematics, statistics, or programming. Advisors and other faculty naturally have great expectations for incoming graduate students to quickly become proficient in multiple quantitative approaches, correctly apply them to imperfect data, and eloquently justify their decisions. However, this level of quantitative aptitude is often far beyond what is typically acquired from an introductory undergraduate-level statistics course, which could be the only experience that some incoming students may have. This leaves students underequipped and ill-prepared to conduct a basic tenet of the scientific process. Consequently, improved quantitative standards and scaffolding at the graduate level will be needed to better guide new students through the myriad of choices available.

In December 2020, the National Institute for Mathematical and Biological Synthesis (NIMBioS; nimbios.org) hosted an international group of educators, researchers, and students for an investigative workshop on quantitative education in life-science graduate programs. Participants solicited evidence for effective pedagogical approaches, and professional ecologists shared their unique insights. Because considerable work has already focused on the undergraduate level, this workshop concentrated exclusively on the graduate experience.

Like their peers in other sciences, graduate students in ecology have multiple concurrent obligations, including taking courses, conducting research, and serving as teaching assistants. However, for ecologists, extensive field seasons consume considerable time, which is already limited for Master's students, many of whom are enrolled in two-year programs. This "rushed" experience frequently leaves students scrambling to analyze their data to meet graduation-dependent deadlines, making their work more susceptible to errors and markedly reducing the confidence necessary to conduct subsequent independent inquiry.

Nearly all ecological research relies in some fashion on quantitative reasoning. Instructors should emphasize the importance of quantitative techniques to the discipline beyond their use as tools, and that anyone can master them. Even so, a dichotomy exists in ecology, where we label ourselves as quantitatively minded or not. When responsibilities in a collaborative research project are partitioned so that all quantitative duties fall to a single person, this existing divide may be exacerbated. In contrast, our research would benefit if we prepared all ecologists to sufficiently critique methodological choices in collaborative projects.

A balance must be found in teaching foundational principles and providing exposure to the breadth of choices available. Requiring coursework in basic descriptive and inferential statistics *before* students select applications that align with their individual research projects would represent an early step in the right direction. Likewise, because the popularity of specific models is likely to change over the course of one's career, prioritization should be given to teaching the skills and concepts likely to be common across many applications, perhaps through establishing and adhering to an international set of standards. In this manner, students would be able to scrutinize multiple forms of inference with greater confidence and graduate knowing the appropriate circumstances in which to deploy certain techniques.

College graduates arrive in graduate-level ecology programs with degrees in various subjects, with differing exposure to statistics or data science. Similarly, science departments vary in their ability to host quantitative classes, often forcing students to take courses in other departments, which may have different learning priorities. Thus, it is the shared responsibility of the department, advisor, and student to co-create an individual development plan at the beginning of the student's graduate experience to assemble various modes of instruction – including but not limited to formal courses, short courses, workshops, online tutorials, bootcamps, and peer groups – that offer the desired competencies. Everyone would benefit if students carefully defined their quantitative goals, advisors were flexible and eager to facilitate learning opportunities, and departments were responsive to the evolving needs of students. Whether as peers, collaborators, mentors, or formal educators, we all have a role to play in properly preparing the next generation of ecologists.

The short-term goal of ensuring that students can correctly select and apply the appropriate quantitative methods in their research is paramount. However, this experience should not come at the expense of students' self-confidence. We are all lifelong learners and, as ecologists, we have the responsibility to keep up with recent advancements. The graduate experience should prepare us to wholly assume that duty. The world needs competent ecologists. Let us seek and create more opportunities for quantitative success.

**Alexander K Killion**

*University of Michigan, Ann Arbor, MI*

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