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Integrated ecological trend analysis from combining GAMs with meta-analysis

Many ecological systems undergo long-term monitoring with mismatches between the time-scale of monitoring and the time-scale of important trends. In our motivating problem, chlorophyll-a (chl-a, a proxy for phytoplankton) levels have been measured in San Francisco Bay roughly every two weeks for several decades. Chl-a is a basic aspect of water quality and aquatic ecosystem status that can fluctuate rapidly over time scales of weeks. We sought to estimate long-term trends in seasonally-averaged chl-a levels but found that existing methods from the water research literature were not well-suited for this purpose. Most existing methods try to separate time-series data into components such as a long-term trend and a seasonal component but in various ways either: do not easily provide uncertainties; assume seasonal components are consistent across years; do not accommodate different sampling in different years; or do not easily incorporate other variables. GAMs provide a natural solution to smooth the raw data and estimate uncertainties for integrated features such as seasonal (e.g. spring) averages or timing or magnitudes of seasonal peaks. We estimate and test long-term (across-year) trends in seasonal (within-year) features by propagating standard errors derived from GAMs into mixed-effects meta-analysis models. Meta-analysis is usually used for combining results from multiple studies, but the key feature of meta-analysis models is to include an already-estimated standard deviation for each response datum. Mixed-effects meta-analysis also includes unexplained ecological variation as a random effect. This methodology is appealing because it allows a "data product" from GAMs fitted to the raw data to be used in further analyses while propagating uncertainties. It also avoids difficult problems that would be encountered if trying to formulate a single model for the entire analysis, which is often a desirable goal. The combination of GAMs and meta-analysis to mesh different scales of monitoring vs. analysis questions is new in the domain of aquatic trend analysis, and indeed the use of meta-analysis as a general tool for uncertainty propagation may be under-appreciated. Examples, results, and a software package from the San Francisco Bay system will be presented.