AQUATIC ECOSYSTEM SIMULATOR (AES):
a computer based learning resource in ecology

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AES provides a flexible learning aid for experimental study in aquatic ecology, separate from the process of mathematical modeling. It simulates the physico-chemical and trophic dynamics of freshwater systems containing functional groups (guilds) of organisms forming planktonic and benthic food webs. Primary production is limited by solar radiation (varies seasonally and spatially) and nutrient supply (via inflow and recycling). Producer organisms comprise green algae, cyanobacteria, diatoms, and aquatic macrophytes, limited by silicate, nitrate, phosphate, and carbon dioxide. Herbivorous and carnivorous zooplankton, benthic invertebrates and fish comprise higher trophic levels. Temporal and spatial variations in conductivity, pH, and dissolved oxygen are also included. The model is calibrated by default to emulate alternative scenarios (mesotrophic-temperate, eutrophic-temperate, hyper-eutrophic tropical, and oligotrophic-arctic systems), and a range of experiments can be performed by manipulating the realistic system variables (e.g. eutrophication, competitive exclusion, climate change, flood impact, and biomanipulation).

Over the course of some twenty years in the Biological Sciences degree schemes at Cardiff University (Bowker & Randerson, 1989), we have developed AES with the aim of motivating students and enriching their existing knowledge of ecology as well as developing generic skills (hypothesis testing, problem-solving, enquiry learning, and critical evaluation of quantitative data) (Corderoy *et al.*, 1993). In our experience, biology students lack interest in the mathematics underlying computer simulations of biological systems (Korfiatis *et al.*, 1999). To put forward theories and equations at the outset would serve to confuse rather than to illuminate. We use AES as a tool to promote understanding of ecological processes and the practicalities of research in the natural environment. Simulation challenges students to interpret large quantities of data, considerably more data than they could possibly generate by traditional practical work (laboratory or field). It shows the value of a computer model for demonstrating fundamental ecological concepts (biomass pyramids, food chain efficiency, competitive exclusion), and for predicting the impact of anthropogenic activities on a complex aquatic ecosystem (manipulation of trophic status, climate change, and trophic cascades). We have adopted a similar practical approach to teaching statistical analysis of biological data using a workbook which leads students through analysis and interpretation, without involving the underlying mathematics (Bowker & Randerson, 2007).

AES is operated by on-screen option buttons connected by a flow diagram to assist navigation. Instructions on how to perform hypothesis-driven experiments are presented in text boxes and help windows, so that a conventional handbook is not necessary. Simulation proceeds by numerical integration of 27 differential equations with respect to time. Values of state variables, driving variables, rate processes, and other simulated data at daily intervals for up to five years are output numerically in tables, and graphically as line-graphs, bar-charts, and pyramid-charts. Data can be saved as text files and Microsoft Excel spreadsheets for further analysis. Graphs and charts can be saved as bitmap files to be added to Microsoft Word documents. Photographs of typical ecosystems and organisms are included (in response to student demand). The equations and constants used in AES are well known (e.g. Spain, 1982; Straskraba & Gnauk, 1985; Pauly & Cristensen, 2002). AES is pre-calibrated with values of 121 parameters (36 fixed constants; 85 of which can be changed by the user). Randomness, associated with natural biological variation and analytical error is a primary characteristic of all biological data; AES includes an option for some parameters to vary randomly around deterministic values.

Students may use AES independently to pursue their own simulation experiments rather than following pre-assigned structured lesson plans (Feurzeig & Roberts 1999), but some preparation regarding ecological community structure and dynamics is necessary. AES enables students to formulate and test their own hypotheses and to report results both as an oral presentation and conventional written report.

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