Biodiversity, Systematics, and Tom Sawyer Science

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Habitats are being destroyed at an alarming rate throughout the world, and as they are lost, so is biological diversity. Lost diversity means irreplaceable loss of resources of untold value to medicine, agriculture, and industry (Reid et al. 1993). Most of the lost species are undescribed and undiscovered insects (Wilson 1992) and, although estimates of the extent of such loss are crude, they suggest that undescribed species of insects outnumber described species by at least an order of magnitude. Current estimates of the number of species of insects range from 2 to 30 million (Erwin 1982; Stork 1988, 1993; Stork & Gaston 1990; Gaston 1991). For many of those species extinction is imminent.

Given the enormous and urgent task of documenting and understanding such diversity, the need for systematists—the people equipped to describe and predict the relationships among taxa—is great. Time is short and our current supply of scientists cannot possibly meet the challenges of protecting, describing, and classifying those species without help (Wheeler 1990; Feldmann & Manning 1992). The acute need to sample and document diversity has spawned new techniques for collecting and curating biodiversity (Erwin 1982; Stork 1988; Janzen 1991; Longino 1993). These efforts can be intensified and expanded. Recruitment of students and their teachers to help solve real problems can create a new scientific community that promotes conservation and research on biodiversity, advances education, and helps generate new careers for scientists.

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Systematics and the Quest for Characters

Progress in systematics depends upon enhancement of collections, theory, and practice. Among the most rate-limiting steps in the practice of systematics are the discovery, selection, and scoring of data (characters). No algorithm can predict the genes or the morphological units that will reveal common ancestry among taxa. Because taxonomic usefulness of particular characters (molecules or morphology) varies from lineage to lineage (Hillis 1987), taxonomic tradition plays an important role in character selection. Taxonomists who work on particular groups of organisms learn which traits are useful in that group and learn to ignore others (Mayr & Ashlock 1991).

Although tradition may expedite systematic work in relatively well-known groups, tradition may actually impair our ability to find traits in newly discovered groups or in groups that include cryptic (difficult to distinguish) species. Fresh eyes and brains can help reveal characters that well-trained systematists have learned not to see (Sokal & Rohlf 1970; Sneath & Sokal 1973; Condon 1991). This is where Tom Sawyer Science and the active participation of the public in science can help.

Evolution of Tom Sawyer Science

Tom Sawyer Science, named after Mark Twain's character, is an unconventional process that generates novel observations. I began my experience with Tom Sawyer Science when I faced a fence with an unknown number of pickets: multiple sets of undescribed cryptic species of tropical flies. Cryptic species are morphologically so similar that they are often considered a single species. Although often overlooked by systematists and ecologists, cryptic species may be quite common in nature (Bush 1969; Oliver 1988; Perring et al. 1993). In one of the most thoroughly studied communities in the Neotropics (Gilbert 1975; Condon & Gilbert 1990), I discovered many cryptic sympatric species of fruit flies (Condon & Norrbom, 1994). Although these flies are members of an economically important family (Tephritidae, the medfly family), attack economically important hosts (Cucurbitaceae), and occur in accessible habitat frequently sampled by ecologists (plants visited by *Heliconius* butterflies), specimens of the flies (*Blepharoneura*) are rare in collections, and the genus is poorly understood taxonomically. My estimates, based on discoveries of cryptic species and many species

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new to collections, suggest the genus includes at least an order of magnitude more species than are currently recognized.

To unravel the ecology, natural history, and evolution of these insects I had to find ways to distinguish species in the field, and I had to learn more about their phylogenetic relationships. Both tasks demanded research in systematics. Because many traditional taxonomic characters had failed to distinguish the taxa, I tried an unconventional Tom Sawyer method for discovering new characters: I let children do the work. While at the National Museum of Natural History in Washington, D.C., I gave a talk to visiting junior high school students and ended the talk with an invitation: Could the students find any differences between wings of two similar species? The students doubled the number of characters I could use to distinguish the two species (Condon 1991). Following that experience, I visited over 20 elementary school classrooms in search of characters that would help me distinguish among over 20 new species of fruit flies.

Elementary school students described countless "differences" among wings. I soon realized that I lacked the time and patience needed to decipher children's written descriptions of traits, let alone check the distributions of those traits within samples of specimens. So, I challenged children to solve the taxonomic problem themselves. I felt very much like Tom Sawyer when he "reluctantly" gave other children the privilege of painting his fence. I gave each class photographs of wings of 20 individuals of each of two species, and the children proceeded to test their own hypotheses.

Some students shuffled photographs like cards to find out if their peers could use traits the class discovered to sort species. In some classes children were careful about controls and protected against cheating by covering characters that had already proved useful. Variable characters led to vigorous debate. One student decided that variation was due to the sex of the specimens. (I had to go back to the specimens and note their sex on photographs.) In another class students debated the utility of characters for which error occurred in 1 out of 20 specimens (some kids tried flipping coins). Children produced a seven-taxon 50-character matrix and then wondered what they were supposed to do with it. I explained, and the teacher prepared to learn programs for phylogenetic analysis. In all the classes students struggled with the challenges presented by description. Students who had never heard the term "ratio" measured wings and manipulated ratios in order to communicate "fat" versus "skinny." Children found several excellent diagnostic characters, as well as some very useful field characters (Figs. 1 and 2). To acknowledge their contributions I am naming new species after the elementary schools where children found useful characters (Condon & Norrbom, 1994).

Tom Sawyer Science has been enlightening and productive. I gained new characters and new ways of looking at problems. Students and teachers gained first-hand experience in testing hypotheses and describing patterns of biological variation, a process that requires skills children should acquire during elementary school. They also gained experience solving a problem for which a solution was unknown: The answers were not at the back of a book or hidden in my pockets. Children and teachers learned that science is about "trying to find out," and everyone had fun.

In the process of making real discoveries children learned that most species on Earth have not been formally "discovered" and do not yet have scientific names. Students learned that most of those unidentified species are insects that live in tropical forests, which are disappearing rapidly. Interest and concern shown by one multilingual fourth grade class opened an opportunity for a cultural exchange with one of the parataxonomists from the Instituto Nacional de Biodiversidad (INBio) in Costa Rica. Other students demonstrated their enthusiasm during interviews on two Baltimore television stations. Reporters recognized and effectively communicated students' interest in sci-

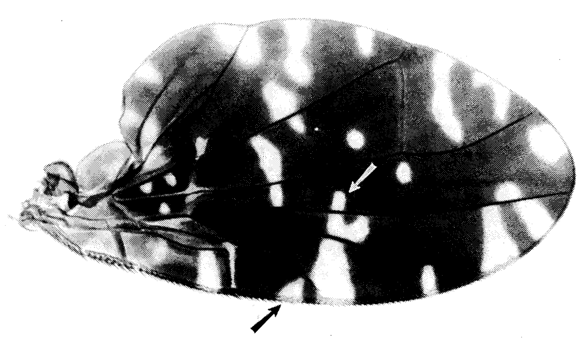

Figure 1. A profile of a "man sitting down" is formed by spots on the wings of manchesteri Blepharoneura *(Condon and Norrbom). This distinctive character was discovered by children in Manchester Elementary School. The white arrow points to the man's head and the black arrow points to the stool upon which he sits.*

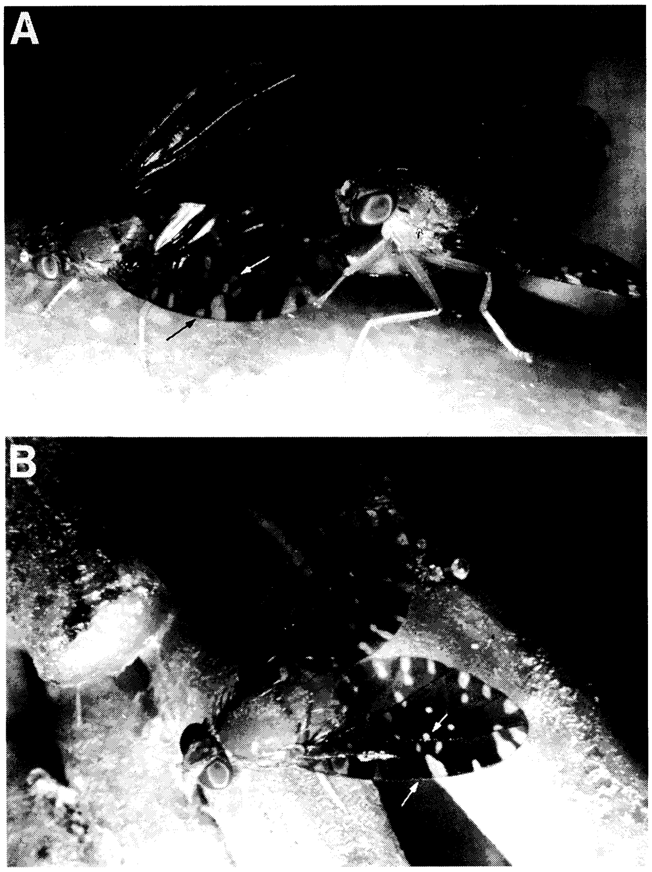

Figure 2. In the field, the "man sitting down" allows immediate identification of B. manchesteri *on its host plant* Gurania spinulosa *Cogn. in Venezuela (a). The absence of the stool and the absence of the man's torso readily distinguish this species from* B. manchesteri *(b).*

ence, their excitement about their discoveries, and their concern about numbers of undescribed species, shortage of systematists, and tropical deforestation.

A New Scientific Community

Tom Sawyer Science represents a process that can have a strong, positive effect on conservation, systematics, and science education. Children can be effective conservation activists (Kinsman 1991). Many children are fascinated and emotionally touched by the "mysteries" of remote places and respond immediately and enthusiastically to problems that involve organisms and the history of life. Although tropical rainforests are an endless source of unsolved problems, so is a child's own backyard (Feinsinger 1987). Children involved in Tom Sawyer Science could be recruited as participants in the National Biological Service (Cohn 1993; National Research Council 1993). Children's natural curiosity about organisms leads directly to investigation of problems that demand basic verbal and quantitative skills. Interest in chemistry and physics is stimulated when children ask, "Why do insects eat this plant and not that one?" or "Why do wings differ in shape?"

Tom Sawyer Science offers a new paradigm for science that promotes interactions among people whose worlds rarely meet. It represents an effective way of making science more exciting and accessible, not just to children, but to the public and to scientists themselves. Using telecommunication technologies, children and teachers across the nation and the world could contribute to active research programs. Tom Sawyer Scientists would not be teachers per se but leaders in a new kind of scientific collaboration that could result in the development of more effective science education and a better informed general public.

Are such interactions viable? They are if universities and funding agencies embrace and reward new measures of scientific productivity (Mervis 1994*b*; Mikulski 1994). The National Science Foundation, through programs like Visiting Professorships for Women (VPW) or CAREER (not an acronym), supports research of scientists willing to give high priority to role model activities or teaching (Mervis 1994*b*). However, those awards are available for a limited time only and send conflicting signals to scientists whose future proposals will be judged by different criteria. As long as the success of standard proposals depends upon traditional measures of scientific productivity, research programs that attempt to include new populations of scientists may suffer. For programs like Tom Sawyer Science to succeed, universities and funding agencies must reward such activities with more than lip service and short-term awards (Alper 1994). In turn, scientists' involvement must reflect a real professional engagement, not a token service or volunteer activity. Scientists who enter this community must do so because of their talent in science and their talent for engaging the public, not because of their lack of success in science (Mervis 1994*a*).

Public participation in basic research would highlight the challenge, excitement, and importance of knowing the unknown on Earth. By revealing the limits of our knowledge and by giving the public a chance to tackle the unknown, a program like Tom Sawyer Science could advance science, teach the process of science, and underscore the need and urgency to understand and protect our biological resources (Orr 1991).

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