CONTRIBUTIONS

Commentary

Error Bars: Are They the King's Clothes?

Graphs are an integral part of most ecological publications and presumably should be integrated with the rest of the text. However, the use of error bars in *Ecology*, and other ecological journals, usually serves no purpose, or duplicates information that is given in the text. In this paper, I will show that scientific communication would be facilitated if editors discouraged authors from using error bars, and promoted the use of scatterplots (dispersion graphs) or their categorical equivalents.

Ecological papers are usually some mix of data reporting, statistical or inferential data manipulation, and biological interpretation. I am advocating that graphs in empirical publications should be used primarily for data reporting. Tukey (1972) discussed many types of graphs that can be used for data evaluation. However, despite the continual "discovery" that inferential tests are overused (e.g., Nunnally 1960, Deming 1975, Guttman 1985, Yoccoz 1991, Johnson 1999), graphical evaluations have generally not replaced standard statistical tests.

I reviewed a recent issue of *Ecology* (80[5], 1999). Error bars represented one standard error of the mean (1 SE) on 27 graphs, 2 SEs on 7 graphs, standard deviations (*S*) on 4 graphs, and 95% confidence intervals (95% CI) on 3 graphs. Two papers (5 graphs) did not report what the error bars represented in the figure legend. Error bars represented SEs in other figures in one of those papers, but this is not a good indication, as authors who presented *S*s on some graphs presented SEs on others. The authors of one paper did not indicate what the error bars represented in any part of the paper. *Ecology* is not unusual. I checked two recent issues of *Oikos*, 85(1) and (2), 1999. Error bars on graphs represented least significant differences, standard deviations, standard errors, and 95% confidence intervals. One paper did not mention what the bars represented, and one simply stated that they were "error bars." Sample sizes were rarely given in legends to figures containing error bars.

The presentation of 95% CIs could indicate that graphs were being used to allow graphical inferential tests of hypotheses. However, in every case where 95% CIs were used, the author also presented an independent statistical test in the text or figure legend. These are what Tukey (1972) impolitely referred to as "propaganda graphs," graphs intended to show the reader what has already been learned by other techniques. In most, but not all, cases, the statistical tests and the construction of the 95% CIs were based on theories of normal distributions. The authors therefore appeared to be saying the following: "If the assumptions of the statistical test were correct, the graph could be summarized in this way." That is more propaganda than empirical justification.

There have been many recent calls to substitute conventional statistical tests with inferences made from inspection of 95% CIs (e.g., Cherry 1999, Smithson 1999). I have no quibble with the philosophy behind such suggestions, but the operative word is "substitute." Many researchers do not understand what Neyman (1937) confidence intervals represent (Albert 1997, Johnson 1999), and Bayesian and Maximum Likelihood methods are even less generally understood. Using them with a conventional statistical test is often a philosophical contradiction. If confidence intervals are calculated only after a significant difference has been detected, the interval widths are biased downward (Meeks and D'Agostino 1983).

Whatever their limitations, CIs always imply an inferential test. However, most error bars on graphs in ecological journals represent SEs (estimates of the standard deviation of the means). This is strange, as SEs are not very useful statistics for visual evaluations. There is a different SE for every sample size that it is possible to take from a population. It is possible to calculate CIs from SEs given the usual, possibly improbable, assumptions. However, for this you need the sample size. The authors of only one paper (four graphs) in the issue of *Ecology* gave the sample sizes on which the error bars were based in the figure legends. It might be possible to work out the sample sizes for each treatment level on each graph by carefully reading the *Methods* and *Results*, and making notes relevant to each graph in each paper. However, this defeats the purpose of rapid visual evaluation of the graphs, and I know of no researcher who routinely does this. In fact, even given the sample sizes, most researchers would have to refer to a textbook to calculate CIs. Many of the graphs had letter codes to indicate treatments that were significantly different at P = 0.05, so it is hard to imagine why a reader would want to calculate the 95% CIs anyway.

Standard errors are usually given in experimental situations in which there is limited replication for each treatment. Estimates of SEs based on samples of less than 10 are very imprecise. Fig. 1 shows the distribution of 60 standard errors based on random samples of 5 taken from a population of numbers with a normal distribution and an SE (for samples of 5) of 0.78. The variability of the estimates is so great for small samples that statistical summaries do not increase our ability to make visual interpretations.

A small percentage (10%) of graphs presented *S*s, rather than SEs or CIs. Estimates of population standard deviations are not biased by sample size, although they may be very imprecise for small samples. Presumably, the authors of those papers were not interested in statistical inference, but wished to describe their data. The question therefore arises as to why they needed statistical summaries with all the attendant assumptions. Although SEs are insensitive to the form of the distribution of the original data, *S* is only interpretable for data from normal distributions. The fact that almost all ecological data sets are too small for valid tests of normality hardly gives us confidence in the statistical summary. If the graph reports the original data, why not use a scatterplot and report all the data? Moore (1997), a statistician, emphasized that “The data take priority over any model (such as normal distribution or a linear relationship) used to analyze them.”

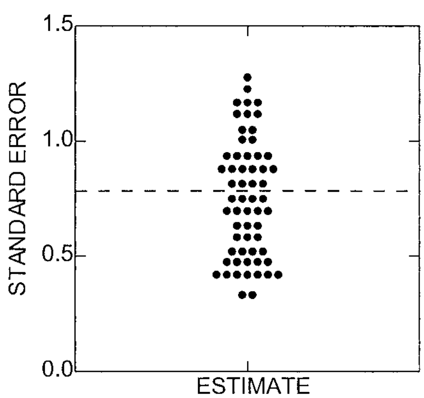

Fig. 1. Standard errors of means based on 60 samples of five taken from a normal distribution. The true standard error for samples of 5 is indicated by the horizontal line.

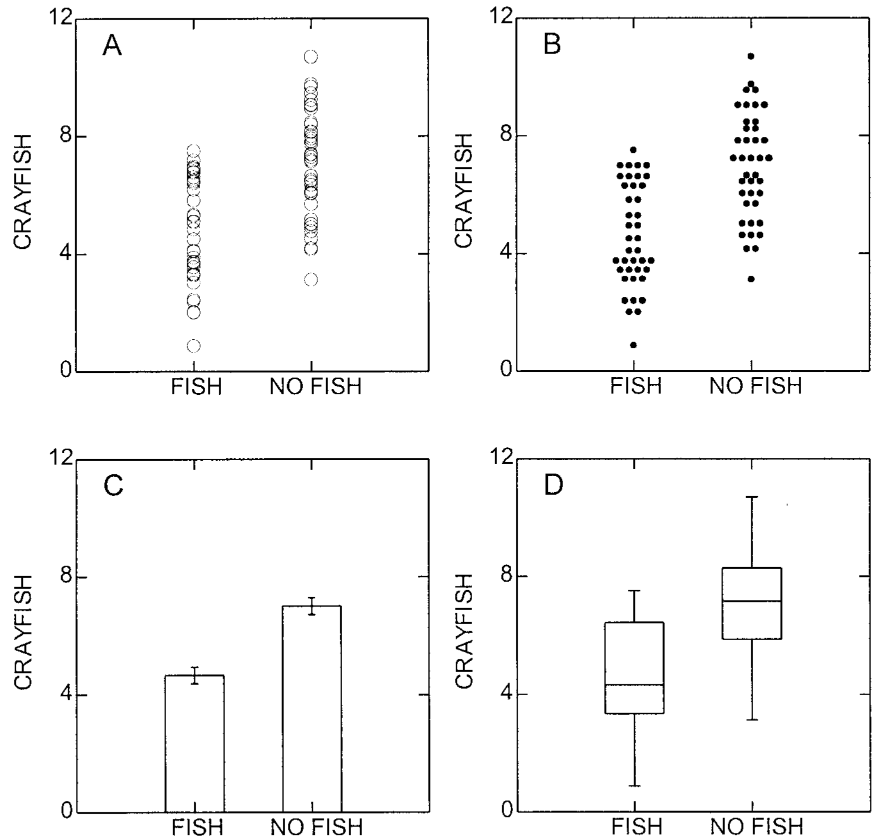

Fig. 2. (A) A scatterplot of observations of crayfish density in 40 streams with fish and 40 streams without fish. (B) A dot histogram of the data presented in part A. (C) A bar graph with error bars indicating the estimate of the standard deviation of the mean (standard error) for samples of 40 for the data presented in part A. (B) The data in part A presented as a box plot.

In some cases, there may be too many data for a scatterplot. However, if there are too many points to put on a scatterplot (or their categorical equivalents, such as dot histograms), the study was probably very inefficient, and far more information was collected than was necessary to make the point. Fig. 2A shows a distribution of 40 points with such high degrees of overlap that interpretation is difficult. A better representation offsets the overlapping points (Fig. 2B). This is technically a dot histogram, but it approximates a scatterplot. The presentations in Fig. 2 A,B are not very scientific. After all, anyone, even a nonscientist, could interpret them. Scientists prefer the presentations in the lower part of Fig. 2. The bar graph with SEs (Fig. 2C) is largely uninterpretable, even by most scientists. The box plot (Fig. 2D), which few ecologists use, shows much more detail, but all information about the amount of data used to construct the graph has been lost.

The amount of data used to construct a graph is very important. Many authors have recommended statistical evaluation of the probability of Type II errors (e.g., Toft and Shea 1983). However, a posteriori evaluations do not have a mathematical justification (Gerard et al. 1988). Power analyses are mainly useful for planning future studies, and few ecologists publish explicit power analyses. Most readers evaluate power by looking at graphs and considering whether the differences look convincing. This is not very sophisticated, but perhaps is not a bad method of deciding whether to repeat experiments. As independent statistical tests are almost always presented as well, the most important use of graphs by readers should be to evaluate whether the assumptions of statistical analyses were justified, and to evaluate the level of replication. Anscombe (1973) presented a sobering example of five graphs with different biological interpretations that all had the same statistical summary. Evaluation of gross violation of assumptions can be done at a glance with a scatterplot, but is impossible with error bars. With modern computer techniques, scatterplots can be scanned and the original data recovered with a high degree of accuracy. Scatterplots can therefore substitute for expensive tables. If, on the other hand, the data are put in a bar graph, with or without error bars, they are lost forever.

Scatterplots can also reveal Type I errors (e.g., Anscombe 1973). A partial plot of any significant variables should indicate the amount of replication on which the conclusion was based. The most striking discrepancy between the degrees of freedom in a statistical test and the number of data points that would have been on a partial plot of which I am aware is in a paper by Didham et al. (1998) in *Ecological Monographs*. Those authors studied eight reserves. However, their analyses of reserve size (their Table 5) had 42–45 degrees of freedom in the denominator, implying about 50 reserves. Such errors are easy to make with complex data sets, and I am sure that I have inadvertently done so. However, without graphs, or with graphs that do not show individual observations, they easily go undetected by authors, reviewers, and editors.

Behaviorists know that communication only works effectively when the signal and the signal-detection units are in harmony. There is strong evidence that the capabilities of the receiver drive the evolution of communication at least as much as the capabilities of the sender (e.g., Sullivan et al. 1995). Scatterplots are tuned to the greatest number of receivers. As most people with a high school education can interpret them, the data become available to politicians, administrators, conservationists, and educators. A critical evaluation will show that in most cases, even when they are statistically correct, the advantages of error bars are far outweighed by the reduction in the audience that is capable of interpreting them.

The amount of literature available to be read is becoming overwhelming (Lawton 1999). Therefore, economy of presentation is important. Editors usually do not permit the same data to be presented in graphs and tables. However, they do not object to inferential tests being made in tabular or textual form, and on graphs. I believe that is inefficient. Analytical graphs should compete for space with inferential analyses. Data presentation graphs should compete for space with tables and appendices. A paper that does not have tables or scatterplots to back up inferential statistical or graphical analyses is difficult to interpret unless you know the author personally. These comments apply whether one is a Popperian, a Bayesian, or any other –ian. Analytical methods come and go but data are forever.

Acknowledgments

This paper was written while I was a Visiting Fellow at Griffith University. During that time I was at Bolsista da CAPES—Brasília/Brasil, and received salary support from INPA. Carla Catterall and Marc Hero made my time at Griffith University possible and productive. Comments by Carla Catterall on a previous draft much improved the manuscript.

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I Have Met the Enemy and He is Us!

My initial education at the university level many years ago was in life science disciplines. However, during the more recent pursuit of my doctoral degree I have been affiliated with professional organizations for the physical sciences, as I have been cultivating an in-depth multidisciplinary background. It also was my belief that these organizations needed help in developing an "environmental conscience."

After finally establishing a small niche in the realm of the physical sciences, I indulged myself by finally joining ESA. When I received my first issue of the *ESA Bulletin*, this month, I was in a state of shock and disbelief. The *Bulletin* arrived encased in a thick sheet of "grade 4" plastic.

I had just spent the past 6 years of my life attempting to educate staff and elected officials of nonecological professional organizations that I had joined regarding the ecological harm caused by production and disposal of these types of plastics. I finally resorted to canceling my membership in these organizations because they failed to discontinue use of these unnecessary plastic wraps for journal issues and related publications. Never could I have imagined that ESA would be using the same plastics I had campaigned against for so many years.

The plastic sheet covering my *ESA Bulletin* is stamped with the statement, "100% recyclable," and is marked as Number 4 grade plastic. However, my last inquiries revealed that no recycling centers in Georgia or Florida (the states where I live and conduct research) accept Number 4 plastics. The recycling program in Athens, Georgia is very progressive. When the administrator of the program was questioned about why they and other recycling programs don't accept Number 4 plastics, the response was that there is virtually no market for these plastics.

The 1999 ESA Annual Report indicates that the total ESA membership is 7683, with 1328 members located in other countries. Additionally, an unspecified number of nonmembers also receive the *ESA Bulletin*. That means that landfills (garbage dumps) are the most likely destinations of the thousands of plastic wrappers mailed throughout the US and abroad by ESA with each issue.

In my former home state of Florida (as probably is the case in most comparable states) landfills are located in or adjacent to wetlands. This means that by needlessly generating huge quantities of plastic that is not recyclable, *ESA is promoting expansion of landfills and destruction of wetlands—valuable ecological habits and resources*. Additionally, it is my understanding that this type of plastic is made from petroleum-based products, which are nonrenewable resources. This compounds the problem of ESA promoting environmentally unsound practices. To protect my local resources, I have returned this unrecyclable contaminant to the President of ESA, for disposal in Colorado.

A survey I conducted a couple of years ago at the University of Georgia libraries revealed that the majority of journals they receive are mailed without any wrappers, and many of the journals that are wrapped, are in unbleached paper (like the *National Geographic* issues). These unbleached paper wrappings are recyclable virtually anywhere (and are made from renewable resources). Embarrassingly, my copies of *Physics Today* arrive in perfect condition, with no wrapping at all. How can a bunch of physicists be more ecologically in tune than the top ecological organization in the US?

As if this is not bad enough (and I assure you, it is), Number 4 plastics reportedly are low-density polyethylene (LDPE). Polyethylene plastics can contain nonylphenol ethoxylates (NPE), some of which are endocrine disrupters. In addition, benzopyrene can be a thermal degradation product of polyethylene, and benzopyrene disrupts the thyroid and the reproductive system, suggesting that incinerated plastic is equally hazardous to the environment. If ESA members and other *Bulletin* recipients are not familiar with the devastating consequences linked to endocrine disrupters I urge you and your constituents to read "Our Stolen Future" by Colborn, Dumanoski, and Myers (1997).

Once a year, The Institute of Ecology at UGA invites a world-renowned scientist to be the keynote speaker of the "Odum Lecture Series" (initiated by Dr. Eugene Odum), with related panel discussions. The theme of the lecture series generally is the most pressing environmental problem on a global scale. Of course there are a plethora from which to choose, but last year's winner was "*endocrine disrupters.*" During the lecture and panel presentation/discussion section, the most recent findings were described and discussed. Some of the presentations subjected us to gruesome slides of *birth deformities* and defects of the male reproductive organs, including *undescended and diseased testicles*, and *deformed penises* (where the urethra does not extend to the end of the penis), in addition to research findings suggesting causal relationships between endocrine disrupters and *prostate disease, immune deficiency, learning deficit diseases* and *auditory deficits*. These problems are becoming widespread globally in both wildlife and humans, and are being linked to increasing pollution by environmental contaminants containing endocrine disrupters.

Shifting gears slightly, the *glossy color cover* of the *ESA Bulletin* I received was very impressive, but there was no indication that it was made using environmentally friendly vegetable inks, or that the paper the *Bulletin* is printed on is from recycled paper. Many recycling facilities refuse to accept documents printed on glossy white paper because it is difficult to recycle. It is coated with clay and the clay turns into *sludge* in the recycling process. Consequently, most documents printed on glossy paper end up in the landfills (see comments about landfills/ garbage dumps, above). According to *Garbage* magazine, when the coating is removed from a ton of glossy paper, only about 1/4–1/2 ton of paper is left. Consequently, even when this paper is recycled it generates at least an equivalent amount of byproduct that is hazardous to the environment. For example, clay sludge "spills" in Florida have been devastating to wetlands and streams, with restoration rarely attempted because of the difficulty and expense.

We also must consider the environmental damage associated with the source—mining the clay to coat the paper. To add insult to injury, this bleached white paper reportedly contains titanium as a whitening agent. Recently, the DuPont Company proposed to mine Trail Ridge in Georgia to recover titanium. This relict sandy beach ridge is rich in titanium, but also serves as the local recharge source for the internationally revered Okefenokee Swamp and National Wildlife Refuge. Public outcry has halted this proposal, at least temporarily, but you can be certain DuPont will relocate to another area. Similar titanium mining in Florida has resulted in the destruction of countless wetlands adjacent to the mined area due to hydroperiod perturbations, and drastic pH changes in streams.

Fortunately ESA has confined its color-glossy paper to the covers (unlike some organizations which use it throughout). However, ESA should consider either switching to a more environmentally sound alternative, such as the colored vegetable dyes and use of recycled paper for its publications, or state that it uses these options, if that is the case.

The fact that ESA contributes to the problems addressed above with its use of plastic wrapping for the *Bulletin*, etc. is not only disturbing, but perplexing. The article by Baron and Parsons in the first ESA issue of the new millennium provides a summary of the impressive background of the new President and concludes by indicating that the President intends to extend the tradition begun by earlier ESA presidents of "positioning the Ecological Society of America as an invaluable resource for solving environmental problems." The Long-Range Goals stated in the Annual Report include, "Enhance Public Awareness" and "Increase Resources." One of the stated aims of ESA is "promoting the responsible application of ecological data and principles to the solution of environmental problems." I am concerned that ESA cannot be taken seriously regarding these goals and aims when they are promoting countless environmental problems, including the depletion of nonrenewable resources, by acts such as the unnecessary use of plastic wrappers for the *Bulletin*.

I am hopeful that ESA's current actions are simply the result of lack of knowledge of these problems, and that the organization will act rapidly to solve these crucial problems that have such simple solutions.

Just say no!

The response I received from one "professional" organization (with which I am no longer affiliated) was that they contacted their publisher about possible alternatives to wrapping their journals in plastic and the publisher informed them that they had just made a very large investment to purchase a machine that wrapped all the journals in plastic, and they intended to continue encasing in plastic all of the publications they printed! I fear this could be the very publisher handling ESA's products. Will ESA have the cajones to "just say no"?

It is apparent that the professional organizations need a leader—an organization that can contact the publisher and say, "Our publications will no longer be wrapped in plastic and we expect a discount for reducing the huge volume of hazardous waste that will no longer be generated by these wrappers being used on our publications. If that's not acceptable to you, we will take our business elsewhere." This type of action is needed if ESA is to achieve its goal of "enhancing public awareness." It also is my hope that ESA will take whatever steps are necessary to convince other professional organizations to abandon this absurd, environmentally destructive practice of using plastic wrappers for their publications. As you know, if we are not part of the solution, we are part of the problem.

My letter is not meant to be critical of the contents of the *Bulletin*, which appear to be exemplary. However, I am concerned about "judging the book by its cover"—the environmentally destructive plastic wrapping of the *Bulletin*—which sends a strong message that contradicts the aims, goals, and intent of ESA. I look forward to the responses of the readers and particularly ESA officers regarding how this problem will be resolved and how ESA will become the ecological role model it should be for all other professional organizations regarding this problem.

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Response to S. Bacchus

We hope that Dr. Bacchus will be pleased to receive his second issue of the *ESA Bulletin* absent any encasing plastic bag. The *Bulletin* is, in fact, designed to be a self-mailer; the back cover is largely blank and contains only the required postal service notices. Only when the *Bulletin* mails with a supplement (e.g., ESA's Annual Report, accompanying the January 2000 issue), must we bundle it in a polybag.

ESA's journals, in contrast, are always mailed in polybags. Here we must balance environmental issues with other considerations. First, the postal service requires all journal issues sent overseas to be in polybags. Second, our subscribers complain if their journal issues arrive in damaged condition, especially institutional subscribers. Let us remember that the journals are not throwaway publications; they serve an archival function for ecological science.

Bags used for mailing our journals are indeed 100% recyclable, and used bags may be taken to the local grocery store and put with other plastic bags. Alternatively, anyone who does not live in an area with a recycling center that accepts number 4 grade plastic bags may send them to the following address: Carlisle Recycling Plant, 1401 W. 94th St., Bloomington, MN 55431.

Dr. Bacchus raises several issues concerning inks and papers used by ESA journals. Our publisher, the Ecological Society of America, and our printer, the Allen Press, take great pride in leading the way toward more responsible printing practices, using soy-based inks in all our publications, and using paper stocks that are acid-free and have the highest ratings possible for recycled content (and use of post-consumer waste) while still allowing our publications to be printed on high-speed web presses (keeping costs low for subscribers) and meeting the high archival standards we require. This includes the coated stock we use for the *Bulletin* covers. Coated stocks are necessary for high-quality color reproduction (which is why we use them occasionally for journal pages with color).

In fact, effective with the January 2000 issues, we switched paper stocks for covers and text pages of all ESA publications. The new papers have even more environmentally desirable characteristics than those we used previously. Perhaps most significantly, all papers used in ESA publications are now produced using an elemental-chlorine-free bleaching process. (The older bleaching process is a significant source of dioxins, which contaminate streams and rivers.)

Finally, the most important step ESA has taken to diminish environmental insults associated with production and distribution of its publications has been its investment in online publishing. ESA was an early advocate of electronic publishing and was among the very first independent society publishers taking steps to bring the promise to fruition. In lieu of (or in addition to) the print publications, ESA members may now subscribe to the full content of our publications online—no paper and no plastic wrappers!

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Higher Education: Good for the Planet?

Reports from researchers at institutions of higher education indicate that humans have put our future on Earth at risk. Atmospheric chemists note steady rises in greenhouse gases; soil scientists report that soils in many areas are eroding more rapidly than they are forming; human physiologists cite increases in harmful foreign chemicals in our bodies; ecologists register the impoverishment of ecosystems and the extinction of species; sociologists observe the breakdown of families and deterioration of communities; and philosophers and theologians discuss the dissolution of moral principles and the alienation of humans from the natural world.

It is clear that humans face an urgent challenge to learn how to live in a manner that does not endanger the Earth. Even as universities teach students that the planet's vital signs are in decline, graduates leave college as well-trained consumers who generally contribute to, rather than mitigate, the growing array of environmental and social problems now plaguing the earth. This paper rethinks the university's role in light of our current global dilemma, suggesting a way in which universities can contribute a brighter future.

The antidote: sustainability

We contend that the concept of sustainability (meeting present needs without compromising the ability of future generations to meet their needs) should become a central organizing idea for higher education. Little mentioned by the popular press, a sustainability revolution is simmering below the surface of contemporary life. Examples: new companies offering solar technologies; farmers who commit to sustainable organic farming practices; builders who design highly efficient structures requiring little energy to heat and cool; cities that discourage the use of inefficient forms of transportation while setting a priority to promote forms that are environmentally benign; and businesses that are as concerned with treating their employees justly and protecting the environment as they are with growth and profit maximization.

Sustainability may be understood in reference to five core principles:

- *Respect life.* Avoid actions that harm the integrity, stability, and beauty of the biotic community upon which we all depend.
- *Live within limits.* Recognize that our natural resources are finite endowments to be used with care and prudence at a rate consonant with their capacity for regeneration.
- *Value the local.* Create strong regional economies that respect the natural and cultural components of our local landscape and community.
- *Account for full costs.* Recognize that a product's price should reflect the burden it places on the environment and society. Confine purchases to products that promote sustainable practices.

Table 1. Sustainability principles in the U.S. consumption-based culture.

Principle	Consumption-based culture	Sustainability-based culture
Respect life	Human destiny is to control and dominate the planet; earth regarded as a resource pool to be exploited.	Humans understand themselves as embedded in and interconnected with the earth's ecosystems.
Live within limits	There are no limits to growth and consumption; resource supplies are infinite.	There are limits to growth and consumption; resource supplies are finite.
Value the local	Emphasis on the global economy and mass culture.	Emphasis on the local economy, face- to-face interaction, and community culture.
Account for full costs	Most decisions based on narrow economic concerns; focus on present generation only.	Decisions are based on full-cost accounting; concern for future generations.
Share power	Power and wealth are concentrated; citizenry passive and without significant influence.	Power and wealth are shared; citizenry empowered and active.

• *Share power.* Acknowledge that people, biota, and the physical world are interconnected; problems are best solved when all components of the community are given equal consideration.

The present U.S. consumer-based growth culture violates each of these principles to varying degrees (Table 1). It fails to respect life, often regarding the natural world as raw material for human ends. It fails to live within limits; instead it seems to view resources as infinite and emphasizes ever-increasing consumption. It fails to account for full costs, often selling things for less at the expense of workers' rights, the environment, and future generations. It often damages local economies, traditions, and cultures in the rush for global competitiveness and short-term profits. This culture fails to share power in any meaningful way, generally regarding citizens as mere "consumers" while increasing the centralization of power and decision making.

Although the concept of sustainability may be relatively new, the substance of its principles is already deeply embedded in human values. What is respect for life but an appreciation for the intricacy and diversity of the natural world? Living within limits embodies traditional values of frugality and thrift. Full-cost accounting calls people to remember the value of honesty and complete disclosure. Respect for what is local honors history and traditions, and sharing power should be what democracy is all about.

Sustainable practices at Penn State: a case study

Recently a group of professors and students at Penn State examined their university through the lens of sustainability in an effort to make its ecological and societal impacts more visible. They visited the landfill that receives Penn State's trash, journeyed to open-pit mines that provide Penn State's coal, and walked through the well fields supplying the campus with water. The team looked into dumpsters to see what Penn State was throwing away, traced the sources of the food served in University dining halls, studied land transactions at the county deeds office, conducted botanical surveys on the campus grounds, administered questionnaires to characterize the ecological literacy of graduating seniors, and much more.

The results

• Each Penn Stater (i.e., full-time students, faculty, and staff) consumes about 7,000 pounds of coal per year, resulting in the emissions of about 10 tons of carbon dioxide per person.

• Students use about 60 gallons of water per person per day: 40 in showers, 10 in toilet flushing, 3 in the sink, and 7 in clothes washing.

• The typical Penn Stater uses about 90 pounds of paper per year; a plot of forest measuring about 55 feet on a side would be necessary to sustainably supply each person's paper needs.

• The food ingredients consumed in University dining halls travel, on average, almost 1000 miles between the last distribution point and the University. The amount of energy required to process, package, and ship this food is many times greater than the energy contained in the food itself.

• The University produces about 240,000 pounds of hazardous and infectious waste each year (equivalent to seven pounds per student); the burden of this waste is put on distant communities far from PSU's own backyard.

• Forty percent of graduating seniors do not know the world's population to the nearest billion; 63% are unable to name one law that protects the environment; 43% are not aware that acid rain is a common phenomenon in Pennsylvania; 40% are unable to name even two tree types on campus.

The group compiled data for a total of 34 sustainability indicators <www.bio.psu.edu/indicators>. The data often indicated a movement toward or away from sustainable practices. For example, per capita energy use at Penn State is higher today than a decade ago, while the amount of solid waste that is recycled has increased in recent years.

Overall, the study depicted an institution whose performance, measured by sustainability indicators, was merely mediocre. Penn State's practices depart little from the U.S. status quo. For category after category (energy, food, materials, transportation, buildings, decision making), Penn State seemed locked in to the assumption that it can continue with business as usual, growing and consuming without worry. Consequently, its graduates, like those of most other universities, leave with little sense of their ecological identity and are more likely to contribute to the growing planetary crisis than to its solution.

Like Penn State, most universities treat their physical resources with a "frontier" mentality: they seem to imagine that energy and water are forever abundant, goods forever disposable, and land forever available. This conveys a powerful message to students. For example, the prolific consumption of materials teaches that the Earth can supply our needs, no matter how grand. The unrestrained consumption of fossil fuels and resulting release of greenhouse gases implies that the transformation of our atmosphere is really not something to worry much about. Food purchased from all over the world suggests that we need not concern ourselves with how or where our food is produced, or with the loss of farmland at home. Highly manicured campus grounds convey the lesson that we need to control and manage nature. And dumpsters bulging with refuse mistakenly assure students that there is always an "away" where things can be thrown. In sum, our universities reinforce the dominant cultural message that it is sufficient only to learn about ecological deterioration, without having to do anything about it (Orr 1994).

Paradoxically, institutions designed to provide students and faculty with freedom to question prevailing values and practices and to reflect critically on the culture in which they live behave increasingly like corporations: task-oriented, economistic, and focused on generating revenue through growth (Solomons and Solomons 1993). But universities are not businesses. They have a huge advantage over companies. They can, if they choose, act on a vision that is not hobbled by bottom-line thinking. They can, if they exercise vision and courage, leverage society into a sustainable future.

Because their mission is education, some may seek to excuse colleges and universities from the call to embrace a new constitution grounded in citizenship and sustainability. But what is education for, if not to play a fundamental role in how our society moves forward to deal with its many challenges? David Orr puts it this way: "The planetary emergency unfolding around us is, first and foremost ... a crisis of thought, values, perceptions, ideas and judgments. In other words, it is a crisis of mind, which makes it a crisis of those institutions which purport to improve minds."

Integrating sustainability into higher education: first steps

Our contention is that sustainability, a whole-systems framework within which a broad range of environmental, technological, and cultural problems can be researched, addressed, and solved, should be an important central organizing idea for higher education.

During the last several decades, environmental awareness has been slowly spreading through our colleges and universities. Over 250 schools have now signed the Talloires Declaration, a document drafted as part of the 1992 United Nations Earth Summit that pledges signatories to promoting environmental education and ecological literacy. Scores of other schools have committed to their own "greening" initiatives, from environmental audits and the creation of recycling programs to the infusion of sustainabil-ity issues into curricula (Smith 1993, Keniry 1995, Creighton 1998). Here are examples of sustainability initiatives at U.S. colleges and universities:

Energy. Some universities are showing that it is possible to fashion energy systems based on renewable resources and energy conservation. For example, Carleton University in Ottawa, Canada, has launched a $20 million energy conservation program that includes the use of geothermal systems to heat buildings in winter. And the University of Rochester has embarked on a program to reduce energy consumption by more than half without affecting university program delivery. So far, Rochester has been successful in reducing energy consumption despite the addition of two new buildings and more intensive use of existing facilities.

Water. Some universities are making efforts to increase the sustainability of their water systems by reducing water use. For example, California State University/Northridge has adopted a combination of measures—including retrofitting all showers, flush valves, and faucets with water-saving devices, posting water conservation information throughout campus, and using reclaimed water for landscaping purposes—aimed at reducing water consumption by 25% (Smith 1993). Other universities have focused on waste water: Penn State shunts its treated waste water back to the land through a spray irrigation system rather than discharging it into the local coldwater stream.

Food. A sustainable food system has a strong regional orientation and is grounded in sound farming practices. Hendrix College in Arkansas is a pioneer in this regard. Hendrix requires that food served in its cafeterias: (1) be local when possible, (2) be grown using sustainable agricultural methods, (3) use minimal energy, (4) leave marginal land out of production, and (5) involve the humane treatment of animals. Hendrix aims to purchase at least 50% of its food from Arkansas. Following the lead of Hendrix College, both Carleton and Saint Olaf Colleges in Minnesota are also redesigning their food systems. Even in their more northerly latitude, close to half of their food purchases could be local (Bakko and Woodwell 1992).

Buildings. Sustainable buildings are safe, energy efficient, aesthetically pleasing, and relatively harmless in their construction and use. The new residence hall at Northland College in Wisconsin contains community and classroom space, passive solar design, supplemental photovoltaic and wind generators for electricity, composting toilets, low-volume showers, and energy-efficient appliances and lighting (Koziol et al. 1997). Northland is not alone. Oberlin College in Ohio is constructing a "green" environmental science building that will be a net producer of energy (Orr 1997).

Campus grounds. Many universities have begun the process of harmonizing their humanly constructed landscapes with nature. Connecticut College has committed one-third of its property to serve as an arboretum devoted to the propagation of native plants. Besides providing a source of native seeds and plants for regional restoration projects, the arboretum is devoted to developing a regional identity. Nebraska Wesleyan University, also recognizing the value of native vegetation, has begun replanting campus zones disturbed by construction or other activity with native grasses and wildflowers.

Money management. On the investment front, some universities now pass their investment decisions through a "screen" to eliminate companies that treat employees unjustly, produce dangerous products, or pollute the environment, all of which undermine sustainability. For example, Harvard, Johns Hopkins, Tufts, and Northwestern do not invest in companies that manufacture tobacco products. Tufts includes manufacturers of alcoholic beverages in its "screen."

Deep integration: the university as a moral beacon

These examples represent a small beginning, but much more is required. Our universities have the knowledge and moral authority to chart the way to a sustainable future. They could lead the way by making bold commitments to such things as:

• The elimination of fossil fuel use in favor of nonpolluting, renewable energy sources. There is a near consensus among scientists that emissions from the burning of fossil fuels are leading to the warming of the earth, with possible disastrous consequences. The federal government has pledged to reduce U.S. emissions to below 1990 levels over the next decade, but there is little evidence of serious commitment undergirding this pledge. In the absence of national leadership, American universities could set an example by voluntarily reducing their energy use and greenhouse gas emissions. Imagine a university that declared it was deeply committed to achieving total fossil fuel independence, not today or tomorrow, but incrementally, in a relentless sequence of "green" steps over the next 50 years.

• The total elimination of the concept of "waste" from campuses. Exploding consumption has become the defining characteristic of our times. Universities continually receive materials from distant sources, consume these materials, and then shunt enormous quantities of waste to distant landfills and incinerators. Materials move from cradle to grave along linear—nonsustainable—pathways. But imagine a university declaring that its goal was to move, step-by-step, toward becoming a "zero-waste" university. Such a university might begin by announcing that it would, when given the choice, only purchase products from companies that endorse the Valdez Principles (i.e., companies that publicly commit to waste reduction, wise use of energy, sustainable use of natural resources, etc.). Such a model university might also endorse the concept of "Extended Producer Responsibility" by announcing that it would give special preference to companies that assumed responsibility for taking back (and recycling) their products at the end of their useful life. Consider how university students, faculty, and staff would feel, having the privilege to be part of such a sensible and noble endeavor.

• The adoption of "sustainability ethics" in decision making. Imagine a university where administrators and trustees passed all decisions through "sustainability filters" by asking questions such as: Does this decision lead to a respect for the biota and natural processes? Does it account for full costs (or are there subtle forms of environmental and/or human exploitation that are not accounted for)? Does the decision recognize and respect natural limits to growth? Does it enhance civic responsibility and the sharing of power? The use of such "sustainability" filters would help universities to address the ethics of heretofore often ignored issues, such as the appropriateness of military research on campus, or the investment of university monies in corporations with a history of environmental and/or human exploitation.

In sum, our universities are much too timid. They contain enormous brain power, but a dearth of vision, courage, and moral responsibility. By and large, they seem to be more concerned about "training" students to fit into a status quo world that is unraveling, rather than forthrightly addressing the causes of this "unraveling" and offering our young people a sense of hope and purpose. Our universities have great leverage but they fail to use it in creative and exciting ways. This, of course, need not be so.

The ecological crisis is upon us because we never imagined that there were limits to the Earth's bounty and resilience. We now know that such limits exist, and we are faced with a grand challenge: How do we live sustainably? Universities could provide the model by serving as loci of hope and transformation—"do tanks" for thinkers. If ever there was an interdisciplinary problem, this is it. It will require not just our scientists and engineers, but also sociologists, geographers, anthropologists, philosophers, economists, artists, and word-smiths, working across disciplines with students in an ennobling endeavor.

We spent much of the past century showing how clever we could be; we will only flourish in the present century if we can muster great wisdom. At a time when we desperately need our universities to offer vision and serve as models of integrity and wisdom, may they grasp the opportunity to light the way.

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