A Winter Field-based Course on Limnology and Paleolimnology

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ABSTRACT

The Union College (New York) course *Lakes and Environmental Change* balances the practical constraints of offering a field-based limnology / paleolimnology course during a winter term without the availability of a large lake or research vessel. Reliable ice conditions and an abundance of nearby small lakes assure a variety of candidate lake systems. Beginning with drainage basin analysis and progressing through water-column measurements, analysis of spatial distribution of surface sediment characteristics, and culminating with collection and analysis of sediment cores, this inherently interdisciplinary course ties together aspects of geochemistry, ecology, sedimentology, and physics. We compare two lake systems each year and in most cases the field and laboratory work represents some of the first limnologic work done on the lakes. Through this systematic framework for investigating each year's lakes, the course resembles an authentic research project, rather than a series of unrelated lab exercises. Classroom activities consist of lectures and literature discussions divided about equally between limnology and paleolimnology. Lab exercises take place in the field, where students learn to use a variety of field gear, and in the laboratory, where students master techniques for sampling and analyzing sediment cores.

INTRODUCTION

The Geology Department at Union College has adopted a hand's-on approach to teaching and most of our upper level courses fully integrate traditional teaching with investigative learning (e.g., Garver, 1992; Hollocher, 1994). These courses typically include term-long research projects that emphasize research design, field and/or laboratory components, and oral and written reports. The trimester calendar that we follow is ideal for field-based courses during the Fall (September-November) and Spring (April-early June) trimesters. However, it has been difficult to incorporate this approach to teaching during the winter term, when northeastern U.S. winters make traditional fieldwork impossible.

The course described herein differs from similar courses taught elsewhere in that this course relies on lake ice rather than a large research vessel as the floating classroom. Smith (1995) developed a course at Lawrence College to introduce students to basic limnology and oceanography, with an emphasis on geology and biology. This novel course was ideally suited for that institution because of its proximity to a large lake (Lake Winnebago, WI), and because the College had already invested in a large research vessel. Similarly, courses on basic limnology and oceanography are offered at Hobart and William Smith College, which is located on the edge of Seneca Lake, NY, and which also has a large research vessel. Inasmuch as Union College is not located near a large lake, and does not have access to a large research vessel, any introductory limnology course taught here would have to follow a somewhat different model than that developed elsewhere.

We developed our course *Lakes and Environmental Change* for three principal reasons: (1) it provides our students with an opportunity to do field work during the winter term; (2) it takes advantage of the abundance of nearby small lakes (Figure 1), one of which is chemically stratified (meromictic), that are typically safely frozen during the Winter trimester at Union College (January-mid March); and (3) it is fundamentally interdisciplinary and incorporates aspects of geochemistry, ecology, sedimentology, and physics, and encourages students and teachers to break down the walls between traditional disciplines. The course has been taught by a single professor, and team-taught by as many as three faculty, which have included a geologist, a biologist, and a civil engineer. The course has drawn students from each of these departments.

COURSE OBJECTIVES

The main objective of this course is to introduce undergraduate students to limnology and paleolimnology using an approach that resembles an authentic research project rather than a contrived series of unrelated lab exercises. The only prerequisite for the course is that students take one introductory-level course in Geology. Each year two lakes are chosen for study, and in most cases the field and laboratory work completed during the course represents the first limnologic work on these lakes. Because the faculty do not know the outcome of the weekly projects beforehand, the lab sequence becomes a legitimate research project that evolves through the term in a logical manner from drainage basin analyses to water column measurements to surface sediment properties to sediment core analysis.

All students are required to actively participate in collecting data and samples in the field, and in processing these data and samples in the laboratory. As with any research project, students are introduced to the primary published literature so that they can critique papers in class, and integrate these papers into the interpretation of their own data sets. The course emphasizes scientific writing so that students become aware of what it takes to present the results of scientific research in a concise and clear report, and to use this understanding in the preparation of their lab reports.

COURSE STRUCTURE AND CONTENT

The course is designed around four basic elements: (1) classroom activities, (2) field activities, (3) indoor lab activities, and (4) integrative laboratory reports. A web page (http://www1.union.edu/%7Erodbelld/courses

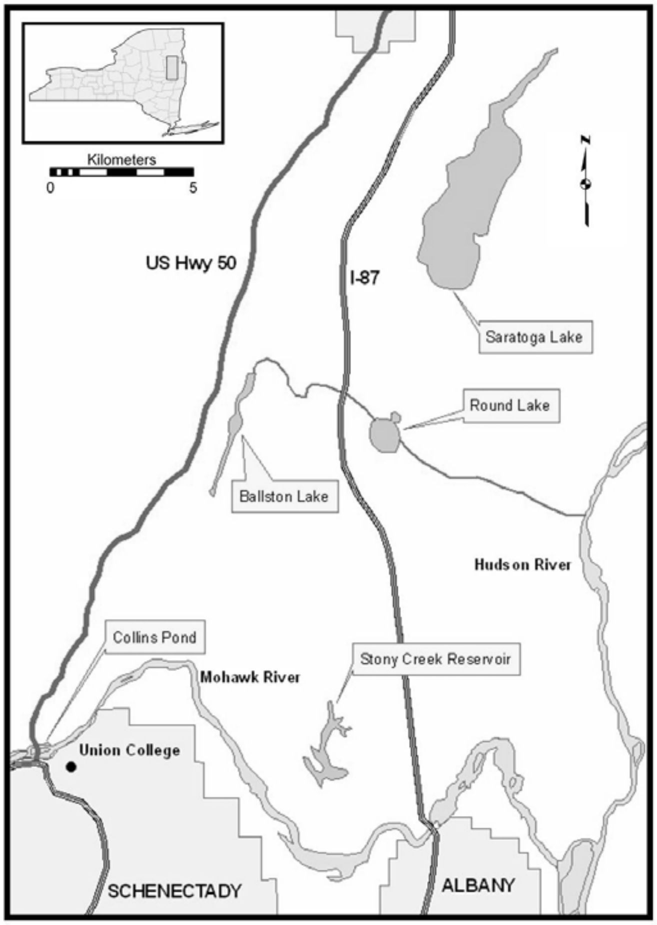

Figure 1. Location of Union College in Schenectady NY relative to several small lakes in the Hudson-Mohawk Valley region.

/lakes/lakes.htm) is available to provide guidelines for all aspects of the course.

Classroom Activities - The class meets three times a week for 65 minutes each (11:15 AM-12:20 PM), and labs are scheduled once a week from 1:35- 4:25 PM. Labs meet on the same day as one of the lectures, and the lecture slot used is the latest one in the morning so that field outings encompassing both the lecture and lab times (11:15AM-4:25 PM) are possible; this typically occurs once or twice a term.

Classroom activities consist of lectures, literature discussions, and discussion of data sets required for lab reports, and exams. The 10-week winter term is divided approximately equally into 5 weeks of limnology and 5 weeks of paleolimnology. Topics included for the limnology portion of the course include the origin of lake basins, heat budgets of lakes, meromixsis and dissolved gases in lake water, ion budgets, alkalinity, P; N; and C in lake water, lake water circulation and sediment dispersion, sedimentation in lakes, physical and chemical properties of lake sediments, and stable isotopes in lake sediments. The paleolimnology portion of the course includes dating methods, physical sedimentologic records of glacial lakes, stable isotope geochemical records from lakes, and the basics of palynology.

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Wetzel, R. G., and Likens, G. E., 1991, Limnological Analyses: New York, Springer Verlag, 391 p.

Table 1. Examples of texts on limnology and paleolimnology.

One of the major obstacles that we have encountered has been the lack of an appropriate textbook for this course. Texts on lakes tend to either focus on ecology, chemistry, physics, or geology (Table 1), and none that we have found provides a comprehensive overview of limnology and paleolimnology at a level appropriate for upper level undergraduates. One recently published exception to this is Cohen (2003), and we plan to adopt this text in the future. In past years, because of a lack of appropriate textbooks for the course, we have placed on reserve at the College library many of the textbooks in Table 1, and we recommend that students read from several of these, especially Hakanson and Jansson (1983) and Wetzel (1975). In addition, we have developed a packet of photocopied figures and tables of data from the published literature, which we use to illustrate lecture material. We distribute the packet of materials to the class free of charge at the beginning of the term.

Five published papers are chosen each term from the primary literature for discussion in class (Table 2). Papers are chosen to provide additional background information that will be helpful for an upcoming lab report. For each discussion session, students are required to come to class having read the paper and having prepared answers to questions regarding the paper. Questions for all the biweekly readings are posted on the course web page at the beginning of the term. In addition, for each discussion session, from 1-3 students present the paper to the rest of class for 20-25 minutes. All students are required to participate in one literature presentation, and students sign up for a presentation time during the first week of the term. Most of the students' presentation time is spent discussing the implicit and explicit assumptions that went into the paper, and a fairly thorough review of the key figures in the paper. Student presentations often highlight aspects

Date	Paper
1/16/04	Kling, G. W., et al., 1987, The 1986 Lake Nyos Gas Disaster in Cameroon, West Africa, Science, v. 236, p. 169-174. Stager, C., 1987, Silent death from Cameroon's killer lake, National Geographic Society, September, 1987, p. 404-421.
2/6/04	Dean, W. E., 1999, The carbon cycle and biogeochemical dynamics in lake sediments, Journal of Paleolimnology, v. 21, p. 375-393.
2/20/04	Seltzer, G. O., Rodbell, D. T., and Burns, S., 2000, Isotopic evidence for late Quaternary climate change in tropical South America, Geology, v. 28, p. 35-38.
2/27/04	Bierman, P., Lini, A., Zehfuss, P., Church, A., Davis, P. T., Southon, J., Baldwin, L., 1997, Postglacial ponds and alluvial fans: recorders of landscape history, GSA Today, v. 7, p. 1-8.
3/12/04	Overpeck, J. T., 1985, A pollen study of a late Quaternary peat bog in the south-central Adirondack Mountains, Geological Society of America, v. 96, p. 145-154.

Table 2. Papers read and discussed for 2004.

Location	Instrument Name	Purpose
Field	ice augurs (2 hand powered 8")	drill holes in ice when ice is thin (< 25 cm) and/or when relatively few holes are needed
	ice augurs (1 gas powered 10")	drill holes in ice when ice is thick (>25 cm) and/or when many holes are needed
	secchi disk on 50 m measuring tape	measure light penetration and to measure water depth for coring
	HYDROLAB™	measure water: temperature conductivity/salinity dissolved oxygen content (% saturation and mg l-1) redox pH
	van Dorn sampler	sample water at specific water depths
	Ekman sampler	sample mud at sediment-water interface
	Verschuren surface corer	sample the sediment-water interface and top ~50 cm of mud
	Glew surface corer	sample the sediment-water interface and top ~50 cm of mud; especially useful if water depth is >30 m.
	Alkalinity kit	For measurement of alkalinity of water samples collected with van Dorn sampler
Laboratory	Coulter LS 230™	measure the particle size distribution of sediment from grab samples and from cores
	UIC™ CO_2 coulometer, and automated acidification unit and automated furnace	measure total C (TC; 1000°C) and inorganic C (TIC; acidification) calculate total organic carbon concentration (TOC=TC-TIC)
	Bartington MS2B™	measure the mass specific magnetic susceptibility of lake sediments from single samples
	Bartington MS2E™	measure the volume specific magnetic susceptibility of lake sediments from split cores
	ion chromatograph	measure cations and anions in water and b_{SiO2} in lake sediments
	inductively coupled plasma mass spectrometer	measure trace elements in water

Table 3. Principal field and laboratory instruments used.

of a paper that are confusing, and this can provide a good segue into an open discussion of the paper with the rest of class. We have found that it is important for faculty to direct the discussion of papers to avoid getting bogged down in details, to encourage students to realize that even though a paper has been published there are commonly alternative interpretations to any data set, and to push students to see connections between the paper and their research. Finally, to ensure that students are taking this element of the course seriously, we ask students questions at random during class regarding the paper, and ~10% of exams are based on papers read during the term.

Lab reports are the major component of the work load for this course (see below). Because of this, part of one class period is dedicated to clarifying instructions and expectations for each upcoming lab report. We have found that at these times students are especially interested in how to interpret data sets, so we commonly open the class into a discussion of a particular data set, and let students propose various explanations.

Figure 2. Students with personal flotation devices on Ballston Lake, NY.

Figure 3. Students sampling an ~50 cm-long core that contains the sediment-water interface.

Field Activities - Field activities are aimed at providing students with the opportunity to use a variety of instruments (Table 3) for the direct measurement of water properties or the acquisition of samples of lake water and sediment. Safety, of course, is our first priority and we follow basic recommendations for safe travel on frozen lakes (http://www.crrel.usace.army.mil/ierd/ice_safety/safety.html). All students and faculty wear personal flotation devices (Figure 2) and carry small hand ice picks, which are designed to help one pull oneself out of lake water and onto the floating ice surface should one break through. In addition, we always bring at least one ~25-meter-long 11 mm-thick rope. Exposure to sub-freezing air temperatures for several hours is also a concern. The Geology Department supplies all participants with pack boots that are rated to -25°F, and students are strongly encouraged to dress for the elements.

The first field lab sequence covers two weeks (Weeks 2-3) and is focused on measuring physical properties of lake water. We drill holes through the ice with hand-powered and/or gas powered ice augurs, and measure water properties such as temperature, conductivity, dissolved oxyen (mg l^{-1} and % saturation), and redox at regular increments (~every 20-50 cm) with a HYDROLAB™ water quality multiprobe instrument. In addition we employ a van Dorn sampler to acquire samples of lake water from discrete depth intervals. We use these samples for the field titration for alkalinity, and for the lab measurement of ion budgets by ion chromatography. We ask students to relate watershed geology with the acid buffering capacity, ionic composition, and ionic strength of lake water. The ion balance itself is instructive as an exercise in precision and accuracy in analytical chemistry. Traditional measures of primary productivity, such as chlorophyll-*a* and change in oxygen content, are less useful during the winter. As a result, we infer gross biological metabolism in the lakes by loss in oxygen saturation since winter ice formation (Wetzel and Lickens, 1991).

The second field lab also covers 2 weeks (Weeks 4-5), and is designed to document the spatial variation of physical properties of lake sediments. Students and faculty drill numerous (~10-20) holes at various water depths with increasing distance from shore and from input streams. They use an Ekman sampler to sample mud at the mud-water interface. They also record water depth, distance from shore, and GPS location for each sampling locality.

The final field lab, which also covers 2 weeks (Weeks 7-8), is aimed at acquiring cores to provide continuous sediment records from the mud-water interface to the base of the lake sediment. Short cores (40-60 cm long; Figure 3) that contain the sediment-water interface are acquired using a Verschuren (1993) or a Glew corer, whereas the remainder of the lacustrine sediment section (~9-14 m) is acquired in 1-meter-long sections using a square rod piston corer (Wright et al., 1984).

Indoor Lab Activities - Indoor labs are an integral part of the course's research project. The first lab of the term (Week 1) focuses on a drainage basin analysis of the two lakes to be studied. Students study topographic maps of the lakes' drainage basins to determine the drainage basin:lake surface area ratio, the relief and unit relief of the drainage basin, and how the lakes' drainage basins have been impacted by anthropogenic activities. In addition, maps of regional bedrock and surficial deposits are examined so that students can characterize the geology of each lake's drainage basin.

During the second indoor lab (Week 4) students analyze the surface sediment samples that they obtained during the prior 2 weeks. Students dry samples in a freeze drier and low temperature oven, and then follow standard procedure for the measurement of magnetic susceptibility (MS), total C (TC), inorganic C (TIC), and organic C (TOC), biogenic silica (b_{SiO2}), and particle size distribution. An Instrumentation and Laboratory Improvement Grant from the U.S. National Science Foundation for this course provided funds for the purchase of a UIC™ coulometer with automated furnace and acidification modules for the measurement of the different C fractions (as CO_2), and for the purchase of a Coulter LS 230 particle size analyzer. All lab procedures are available on the web page for the Union College

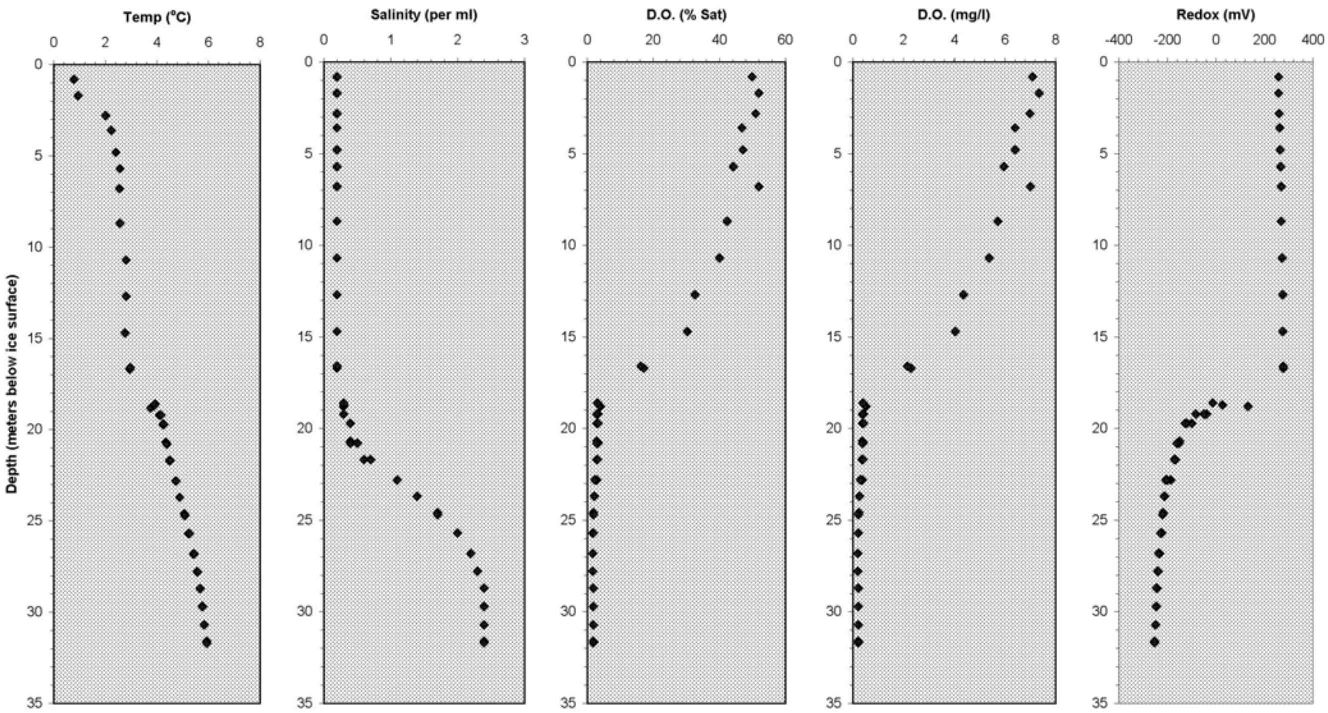

Figure 4. Hydrolab data from the meromictic south basin of Ballston Lake (Figure 1). The lake chemocline is located between ~18 and 25 m; water below ~20 m does not mix with the surface water and is anoxic throughout the year.

Sediment Core Lab (http://www1.union.edu/%7Erodbelld/courses/lakes/lakes.htm).

The final indoor lab sequence covers the final two weeks of the term (Weeks 9 and 10), and is aimed at analyzing the sediment cores that were collected during the prior two weeks. Since this is a repetition of many of the analytical procedures that were used during the previous indoor lab sequence, students are encouraged to perform a different set of procedures than they used during the prior indoor labs. Typically the class has acquired at least 15 m of core in the previous two weeks, so it is a challenge to complete enough analyses so that at least some basic interpretations may be made for the final lab report.

Lab Reports - Students prepare four lab reports, which progress logically through the research project. The first lab report covers a single relatively simple data set-the drainage basin characteristics of the two lakes. This lab report serves as an opportunity to get students up to speed on the expectations of lab reports, which are detailed on the course web page. For this first lab report students are asked to predict and explain, based on drainage basin characteristics and geology, which lake should support the highest alkalinity, productivity and sedimentation rate. The second lab report, which is based on the water quality measurements made during Weeks 2 and 3, is focused on explaining water-column variations in a variety of water properties (Figure 4), and to compare and contrast the two lakes studied, one of which is usually the meromictic south basin of Ballston Lake (Figures 1 and 4). In addition, students are asked to compare their predictions from the first lab report with the observed data, and to explain differences noted. The third lab report addresses the spatial distribution of sediment properties in the two lakes based on two weeks of field sampling (Weeks 4 and 5) and one week of laboratory analyses (Week 6). Students are asked to explain spatial variations in particle size, MS, TOC, TIC, and b_{SiO2} in terms of the location of sampling sites relative to input streams, distance from shore, water depth, and the underlying water chemistry noted in the previous lab report. The final lab report is meant to wrap up the entire research project in comparing and contrasting sediment cores taken from the two lake basins in terms of the various sedimentologic parameters noted above. Inasmuch as it is not possible to provide students with a radiocarbon chronology for the cores, we ask the students to compare their records with published records from around the northeastern U.S. to propose a basic chronology for the two cores. The most striking feature seen in most cores from this area is the Pleistocene-Holocene transition, which is marked by a dramatic increase in TOC, bSiO2, and decrease in mean particle size and MS. Students compare their records with published records from the region, some of which were part of the published articles discussed in class. Other papers are provided to the class prior to the final lab report.

ASSESSMENT

We consider three criteria in assessing the effectiveness of this course. First, does the lecture material adequately prepare students to interpret field and lab data? Second, do field and lab exercises demand the variety and depth of inquiry appropriate for the course? And, finally, did the course appear to affect how students viewed a career in research or other geo-environmental disciplines? Within the time scale of the course itself, we view the first

Year Course Taught (number of students)	Rating of Course Quality (1-5 scale, 5 is best; ±1σ)	Rating of Increase in Knowledge of Subject Area (1-5 scale, 5 is best; ±1σ)	Examples of Positive Comments from Students on Course Evaluation Forms	Examples of Negative Comments from Students on Course Evaluation Forms
1997 (11)	4.7 ± 0.10	4.8 ± 0.10	Labs were time-consuming but very useful; published literature to review was effective at illustrating real research and practical aspects of geology.	[Instructor] should eliminate the tests as it is really difficult to have tests, lab work, lab reports, field work and articles to review with two other classes. This should be taught as a T/Th course so that some labs can go all day.
1999 (14)	4.40 ± 0.20	4.4 ± 0.20	Lab reports were very intensive, but generally stimulated thinking and allowed for reasoning *[sic]* the data.	Course should try to coincide better between instructors. [Course] feels unstructured, but is due to fact that we are conducting research and outcome is unknown.
2000 (13)	4.23 ± 0.60	4.38 ± 0.65	Having to analyze real data that we gathered ourselves was a tremendous help in seeing science at work. The lab reports and discussion readings were very helpful. My writing improved greatly.	Course needs more structure and a book. This was an extremely challenging course
2002 (10)	4.30 ± 0.82	4.60 ± 0.70	Without labs, the course would have been useless. Lab component is critical.	[Instructor] needs to explain sediment core data more fully; I was lost as to the importance of certain parameters of core data. Lots of time required to get a good grade; material was complex at times.
2004 (11)	4.64 ± 0.67	4.60 ± 0.70	Lab reports and research paper reviews tied together well to demonstrate practical concepts. This course significantly improved my writing.	The labs were not always fully explained before hand. There was a great deal of written work for the course, sometimes too much.

Table 4. Course evaluations by students.

two criteria as being somewhat interdependent. We have made corrections to course content during the term in response to students' understanding of material as reflected in early lab reports. In a broader time scale, we have observed the ability of students to interpret and clearly present scientific information in their senior theses and reports in the Geology Department and Environmental Studies Program. We are unable to attribute greater success in conducting their senior projects directly to this course, but we do believe that this course, in combination with courses which take similar hands-on approaches, has been effective in honing the analytical, interpretive, and writing skills of our students.

As for the third criterion, although we have not formally tracked student histories, a number of students have either selected senior honors theses directly related to the course or have chosen related career paths. For example, Newell (1997), Hodges (1998), Moxham (1998), Ruggiero (1999), Garrand (2000), White (2000), and Daigle (2003) all developed senior honors theses from research intiated in *Lakes and Environmental Change*. One senior thesis resulted in a peer-reviewed paper, on which the student became the first author (Toney, et al., 2003). Another student (Hodges, 1999) examined the hydrogeology of the Ballston Lake system and went on to a career in hydrogeologic consulting.

STUDENT EVALUATIONS OF THE COURSE

Evaluations from 5 years of teaching this course contain several consistent comments (Table 4). Most students found the course to be very challenging, and a minority thought it was overly so. The great majority of students found the field and indoor labs to be especially useful for integrating material included in the lectures. The intensive writing of in-depth lab reports, and the reviews of published literature are often cited as having improved student's writing skills. Most students seem to enjoy the challenge of interpreting their own data, though a minority of students felt the need for more detailed explanations from the faculty. This is a difficult balancing act-to leave most of the interpretations of data sets for students to work through while at the same time to provide enough coaching to others. Finally, in the first years that the course was taught, several students complained that the course needed a text book it. It was these comments that led us to develop a packet of notes, tables, and graphs that students receive on the first day of class. Finally, on those years when the class was taught by multiple professors, a minority of students found the transition between faculty to be less than smooth.

LIMITATIONS AND POTENTIAL MODIFICATIONS

The major limitations of this course are climate and weather. It is unlikely that this course could be taught south of ~41°N in North America as average winter temperatures are too high for significant ice development during most winters. Even in our region of upstate NY (~43°N), a warm early winter or a midwinter thaw can make it impossible to work on the ice safely. In the 5 years that this course has been taught, there have been several scheduled outdoor labs that had to be postponed because of insufficient ice, and one lab that was postponed because of excessive cold.

Although this course is ideally suited for the winter term of a trimester calendar, because this focuses the course on the coldest months of the year, when ice thickness are the most reliable, it could be modified to be taught on other academic schedules. The January term of a 4-1-4 calendar could provide an intensive block of time for this course. Probably the least ideal schedule for this course is the spring term of a typical semester calendar (late January-early May) as this provides only about the first 5 or 6 weeks of reliable ice.

This course could also be modified in the relative emphasis placed on limnology versus paleolimnology, and in the relative emphasis placed on geology versus biology and chemistry. To date, the modern limnology covered in the course has been oriented primarily toward understanding fundamental water-column processes and those chemical, physical, and biological processes that create and modify the sediment record.

ACKNOWLEDGEMENTS

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