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# Course-based undergraduate research to advance environmental science and management

Main text

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## 29 **Abstract**

30 Course-based Undergraduate Research Experiences (CUREs) are widely regarded as a powerful  
31 way to engage students in experiential learning that results in well-documented pedagogical  
32 benefits. Much less appreciated, however, is the potential for CUREs to contribute long-term  
33 data that advance scientific knowledge and management. By providing the first global synthesis  
34 of CUREs in ecology, we map the geography and temporal extent of CUREs, review the data  
35 collected, highlight the benefits of these experiences to both students and instructors, explore the  
36 challenges that instructors face to maintain these research opportunities, and offer perspectives  
37 on how CUREs can more broadly contribute to science, management, and policy. To address  
38 missed opportunities associated with CUREs, we highlight how existing networks and resources,  
39 enhanced institutional support, and synergies with the broader science community can help them  
40 achieve their full potential for contributing to both education and ecological science for society.

## 42 **In a nutshell**

- 43 • CUREs collect diverse environmental data over time scales comparable to long-term  
44 ecological monitoring efforts.
- 45 • Instructors reported significant personal benefits to teaching CUREs, but modest  
46 academic gains and insufficient financial and institutional support.
- 47 • Students were perceived to gain a suite of academic skills through CUREs, a heightened  
48 understanding of the scientific process, and improved ability for collaboration.
- 49 • Most data collected by CUREs are inaccessible to the scientific community.
- 50 • For CUREs to realize their potential, we recommend full democratization of CURE data  
51 with online repositories, leveraging synergies with long-term ecological research and  
52 citizen science initiatives, and higher levels of institutional support.

53

55 Inquiry-based instruction is a fundamental science teaching strategy in higher education with  
56 wide-ranging and well-recognized benefits (Schwab 1958; National Research Council 2012;  
57 Eagan *et al.* 2013). This form of research-driven learning is viewed as a welcome departure from  
58 education focused solely on content. It promotes engagement in the scientific process by  
59 encouraging students to pose research questions, generate and analyze data, draw conclusions,  
60 and communicate findings to diverse audiences. Teaching through inquiry is thought to foster  
61 scientific literacy and has the potential to improve both student understanding of science and  
62 engagement in science (Minner *et al.* 2010).

63 Inquiry-based instruction typically occurs in one of two types: project-based  
64 Undergraduate Research Experiences (UREs) occurring outside of curriculum requirements, or  
65 Course-based Undergraduate Research Experiences (CUREs) (Linn *et al.* 2015). UREs are  
66 considered apprenticeships where individual students spend multiple semesters in a research  
67 laboratory receiving one-on-one mentoring. However, most institutions of higher education lack  
68 the resources to involve all or even most undergraduates in UREs, and the structure of how  
69 students are selected for these positions can also be exclusive and perpetuate inequities in the  
70 research community (Auchincloss *et al.* 2014; Bangera and Brownell 2014). CUREs, by contrast,  
71 provide research opportunities and educational benefits to a broader number and diversity of  
72 students (Auchincloss *et al.* 2014; Corwin *et al.* 2015). CUREs offer students opportunities to  
73 develop their conceptual understanding by integrating lectures and readings with hands-on  
74 research experiences (Shaffer *et al.* 2014) and can significantly influence their academic and  
75 career paths (Eagan *et al.* 2013; Auchincloss *et al.* 2014).

76 Ongoing research focuses on the educational and psychosocial outcomes associated with  
77 CUREs (e.g., Linn *et al.* 2015; Anderson *et al.* 2020). Much less appreciated, however, is the  
78 potential for these efforts to contribute to greater and more widespread understanding of  
79 ecological systems. Long-term environmental research is considered fundamental for testing and  
80 developing theory, for understanding complex ecological and evolutionary patterns, and for  
81 capturing non-stationary processes and ecological surprises, all of which are critical to inform  
82 natural resource management and policy (Callahan 1984; Lindenmayer *et al.* 2010; Kuebbing *et al.*  
83 *et al.* 2018). In fact, the last decade has seen a rise in the number of synthesis centers that capitalize  
84 on large ecological datasets, ranging in subject from the gene to the biosphere, to fuel  
85 transdisciplinary collaborations (Hampton and Parker 2011; Baron *et al.* 2017). Many scientists

86 and funding agencies approach long-term projects with trepidation because of perceived  
87 financial and logistical obstacles. However, recent attention has focused on leveraging the  
88 enthusiasm of students, and more broadly citizen scientists, to generate valuable long-term  
89 environmental datasets (Dickinson *et al.* 2010; Hoopes *et al.* 2013; Quinn 2015; Ryan *et al.*  
90 2017).

91         Given the seemingly widespread occurrence of CUREs across institutions of higher  
92 education, we ask whether ecological and environmental data collected by undergraduate  
93 students as part of course curricula represent a valuable, albeit underappreciated, contribution to  
94 the natural sciences. By providing the first global synthesis of CUREs in ecology, we map the  
95 geography and temporal extent of CUREs, review the data collected, highlight the benefits of  
96 these experiences to both students and instructors, and explore the challenges that instructors  
97 face to maintain these research opportunities. We then explore opportunities for the better  
98 assimilation and dissemination of the vast data generated from CUREs, as well as call attention  
99 to existing resources and networks for supporting CURE instructors. Finally, we share our  
100 perspectives on how CUREs can more broadly contribute to science and management, including  
101 through enhanced collaborations with existing Long-Term Ecological Research (LTER) and  
102 citizen science initiatives.

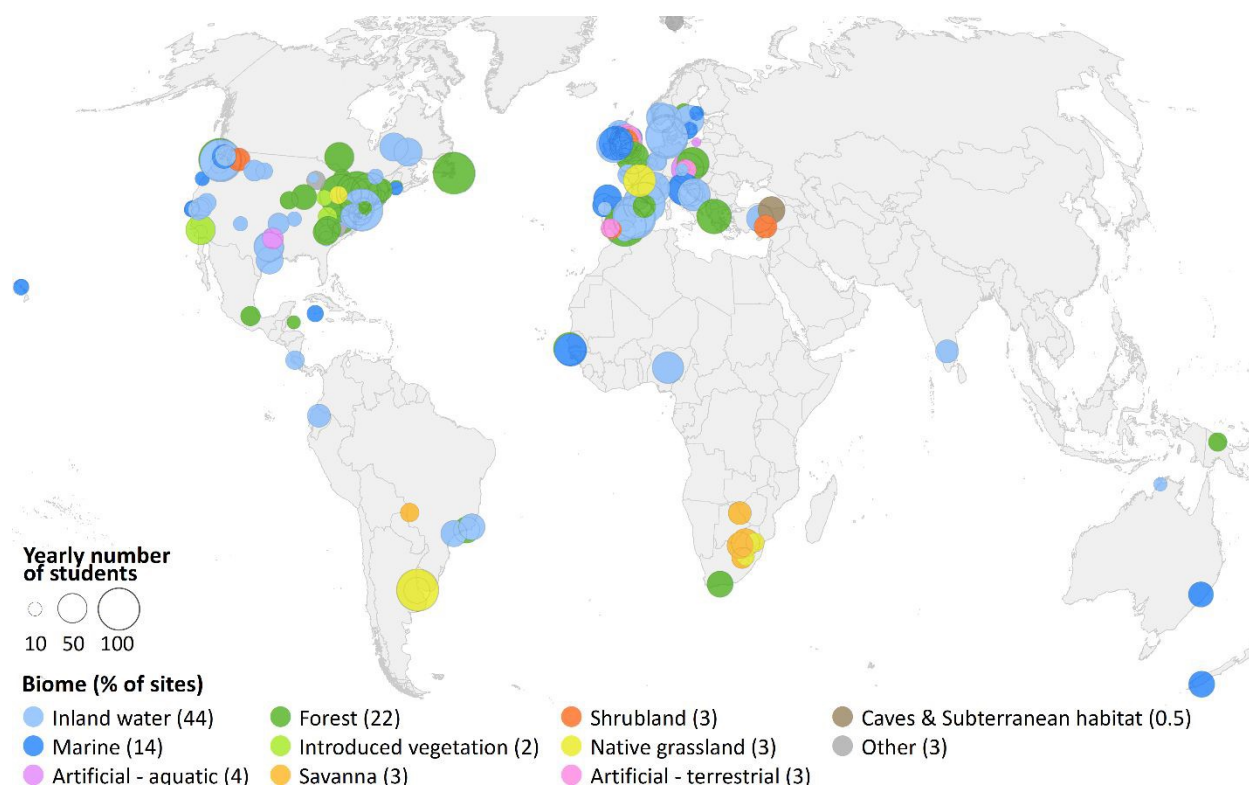
### 103 **A global survey of CURE instructors**

104 We conducted a standardized online survey of CUREs involving the collection of ecological and  
105 environmental data with the aim to gather information about their distribution and  
106 characteristics, challenges in implementation, and the scientific opportunities and outcomes  
107 associated with data collection for both students and instructors. The survey was targeted at  
108 instructors from institutions of higher-education who are currently leading, or have led,  
109 undergraduate student collection of ecological data through course-based activities. To reach  
110 survey participants, we systematically searched for and contacted ecological scientific societies  
111 (via e-mail and social media, if applicable) to request that the survey be announced to all society  
112 members (see **WebPanel 1** for details on survey deployment, and **WebPanel 2** for the survey).  
113 The invitation also included a request that society members forward the survey on to relevant  
114 contacts and colleagues within their network. The final list included 103 ecological societies  
115 located in 50 countries, and an additional 26 ecological societies with significant continental or

116 international membership (**WebTable 1**). A summary of survey responses is presented in  
 117 **WebPanel 3**.

### 118 **Widespread and diverse long-term data collection by CUREs**

119 The distribution of CUREs is widespread, both geographically and ecologically (**Fig. 1**). The 132  
 120 respondents surveyed here were affiliated with at least 111 institutions of higher education in 31  
 121 countries. Through their work, at least 60,500 students have been involved in ecological data  
 122 collection across 220 field locations spanning most biomes on the planet.

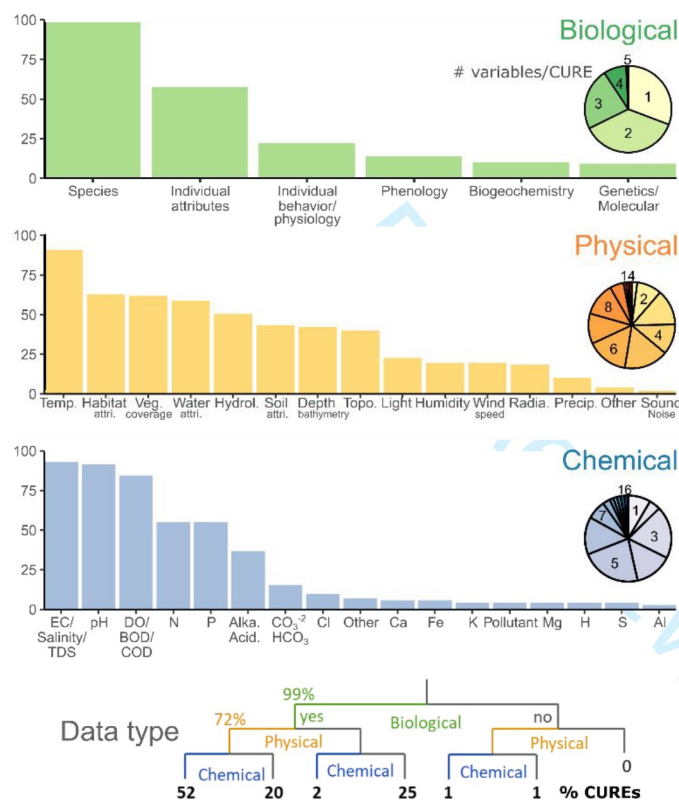


123  
 124 **Figure 1. Global distribution of ecological field data collection through course-based**  
 125 **undergraduate research experiences.** Point colors show the biome of the field sites ( $n_{\text{sites}}=220$ )  
 126 associated with CUREs ( $n_{\text{CUREs}}=115$ , some CUREs were associated with multiple field sites, and 17 out of  
 127 132 respondents did not provide site locations), and point sizes reflect the yearly student enrollment  
 128 participating in data collection. The percentages of sites per biome do not add up to 100 due to rounding.

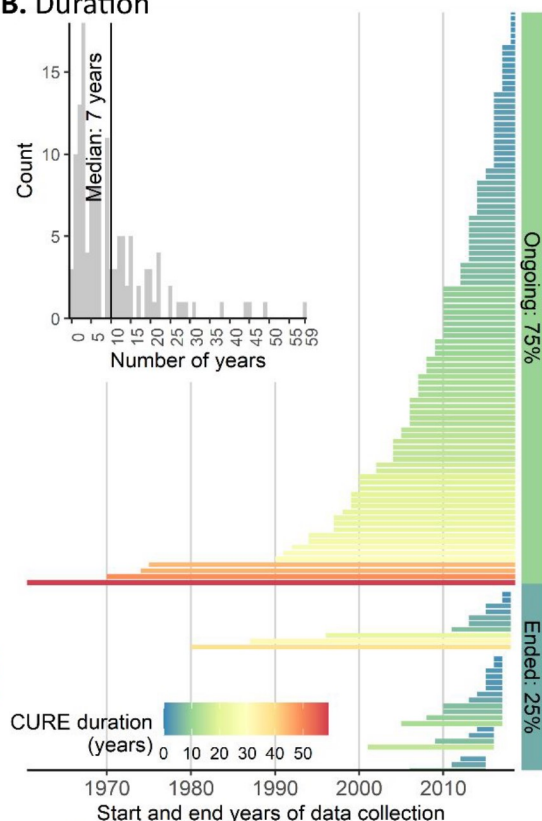
129  
 130 The wealth of data collected through CUREs represents an ecological record of global  
 131 significance, further underlining their scientific and educational value (**Fig. 2A**). Nearly all  
 132 (99%) CUREs surveyed here collected biological data, including information on the occurrence,

133 abundance, density, or biomass of one or more plant or animal species (95%). More than half of  
 134 field excursions involved the simultaneous collection of biological, physical, and chemical data,  
 135 with each investigating an average of three biological, five physical, and five chemical variables.  
 136 In total, the respondents reported nearly 15,500 days of data collection.

### A. Data collected



### B. Duration



137  
 138 **Figure 2. Types and duration of ecological field data collected by course-based**  
 139 **undergraduate research experiences (n=132 CUREs).** (A) Histograms indicate the percentage of  
 140 surveyed CUREs collecting each variable by data type (biological, physical, or chemical), pie charts  
 141 indicate the number of variables by data type per CURE, and the classification tree shows the % of  
 142 CUREs collecting different combinations of data types. (B) The colored bar chart shows the start and end  
 143 year of field data collection across all CUREs and the inset (grey) histogram shows the distribution of  
 144 CURE durations.

145 Our study confirms that CUREs offer opportunities for longer-term data collection  
 146 (Quinn 2015). Being embedded in a standard educational curriculum can afford CUREs relative  
 147 stability over time (**Fig. 2B**). More than a fifth of the CUREs documented through this study  
 148 have collected datasets exceeding 15 years, with a median and maximum duration of 7 and 59

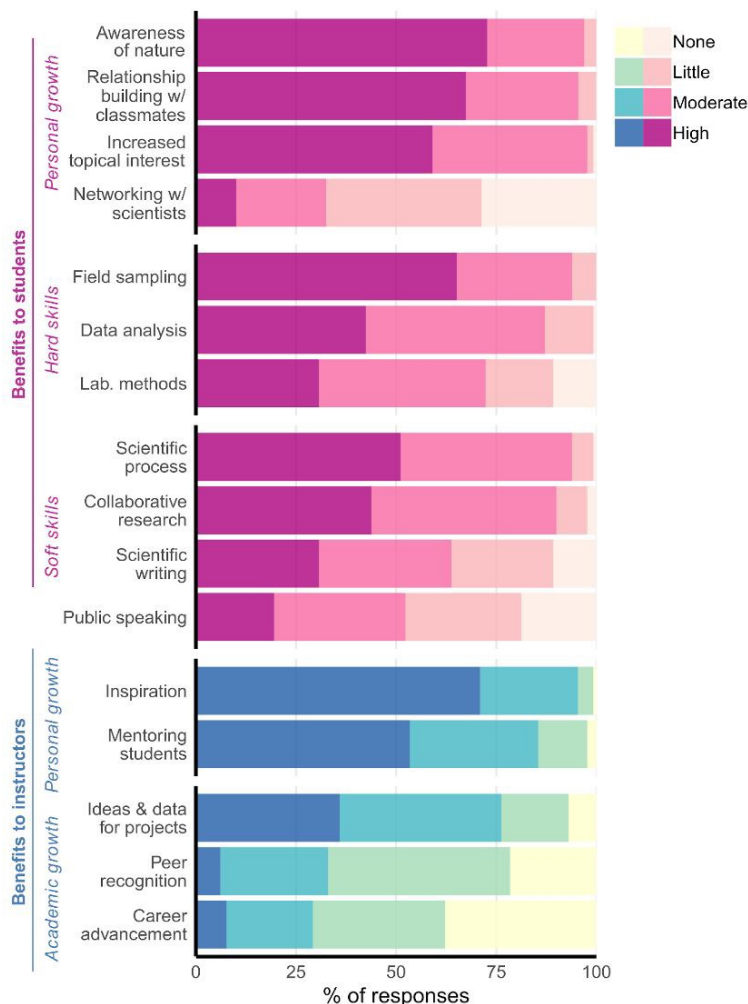
149 years, respectively. By comparison, the median time since establishment of the 733 sites in the  
150 International Long Term Ecological Research (ILTER, Mirtl *et al.* 2018) network is 24 years,  
151 and a quarter have been established for 14 years or less (as of 2018 at the time of the survey; year  
152 of establishment retrieved from the ILTER data repository API at <https://deims.org/>; Wohner *et*  
153 *al.* 2019). The duration and scope of data collection by CUREs creates the potential to  
154 meaningfully contribute to long-term ecological research.

## 155 **CUREs benefit students and instructors, but are associated with significant challenges**

### 156 *Benefits of implementing CUREs*

157 Respondents strongly agreed that both students and instructors benefit from participating in  
158 CUREs in terms of personal growth (**Fig. 3**). Over 95% of instructors moderately to strongly  
159 agreed that students likely benefitted from collecting and analyzing ecological data by  
160 developing a heightened awareness of the natural world, an increased interest in the topic area,  
161 and deepened relationships with classmates. By contrast, few instructors found that CUREs  
162 allow students to network with scientists, with over half (58%) reporting little to no networking  
163 benefits. Students were also reported to gain a suite of academic skills, both hard and soft. The  
164 most noticeable gains in terms of hard skills were increased fluency in field sampling (average  
165 score = 2.6 out of 3.0, based on a Likert scale from 0 “no gain” to 3 “high gain”) and data  
166 analysis (2.3). In terms of soft skills, students were perceived by instructors to grow most in their  
167 understanding of the scientific process (2.4) and ability to perform collaborative research (2.3).  
168 However, instructors reported varied skill gains in laboratory methods (1.9), scientific writing  
169 (1.8) and public speaking (1.5), presumably due to our focus on field-based CUREs. We  
170 acknowledge that these results reflect the instructors’ perceptions of benefits to students rather  
171 than the perception of students themselves, which we recognize is highly valuable. However, the  
172 multifaceted goal of our survey required that we target instructors. Moreover, our results are  
173 consistent with student-oriented studies that found increased long-term interest and connection  
174 with research associated with participation in CUREs. For instance, CUREs facilitate stronger  
175 research connections as a result of greater ownership in data collection and analysis (Corwin *et*  
176 *al.* 2018; Cooper *et al.* 2020), better understanding of the scientific process (Olimpo *et al.* 2016),  
177 and increased opportunities to engage with an instructor and classmates (Quinn 2015). In this

178 way, CUREs may also play a significant role in (re-)establishing connections with nature that  
 179 facilitate long-term environmental engagement and conservation advocacy (Mitchell *et al.* 2017).

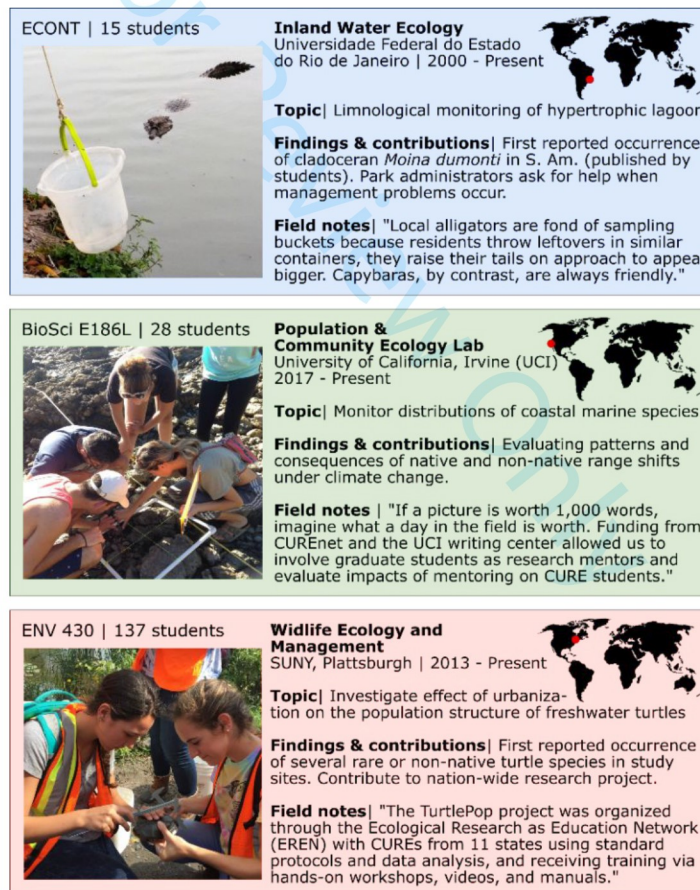


180  
 181 **Figure 3. Benefits to students and instructors from participating in and teaching CUREs,**  
 182 **respectively, as perceived by current and past instructors (n = 132).**

183 Instructors were nearly unanimous in reporting high to moderate personal benefits from  
 184 mentoring students (2.4), and the inspiration (2.7) that comes with teaching a class involving  
 185 ecological data collection. CUREs also often sparked new ideas for future projects (2.1). Of  
 186 those instructors that have organized CURE field excursions for more than five years, close to  
 187 half (45%) have also used the class data for other projects. For example, more than a quarter of  
 188 CUREs surveyed here have helped inform a management or conservation outcome, led to  
 189 environmental outreach, or supported other long-term data collection efforts (see **Fig. 4** for  
 190 examples). Further, 19% of surveyed instructors reported publishing peer-reviewed articles based

191 on CURE field data for a total of 67 publications, of which a high proportion (74%) involved  
 192 students. Generally speaking, these results align with a qualitative study of faculty perspectives  
 193 by Shortlidge *et al.* (2016), where high percentages of instructors reported personal enjoyment,  
 194 expanded research ideas and publications as benefits of teaching CUREs.

195 With respect to personal benefits, CURE instructors reported only modest academic  
 196 gains. Most respondents (56%) reported earning little to no peer recognition (1.2) or career  
 197 advancement (1.0) from teaching a CURE (**Fig. 3**). This result presents a troubling contrast with  
 198 Shortlidge *et al.* (2016), who reported that more than two-thirds of instructors agreed that  
 199 teaching a CURE could contribute to promotion or tenure — although this discrepancy may be  
 200 explained, at least in part, by the high levels of institutional or structural support reported in their  
 201 study (discussed more below).



202  
 203 **Figure 4. CUREs contribute to education, environmental science and management.**  
 204 *Photographs credits and associated publication: Christina Castelo Branco, Da Silva Farias et*  
 205 *al. 2017 (top); Cascade Sorte (middle); and Danielle Garneau, Bowne et al. 2018 (bottom).*

206

## 207 *Challenges to implementing CUREs*

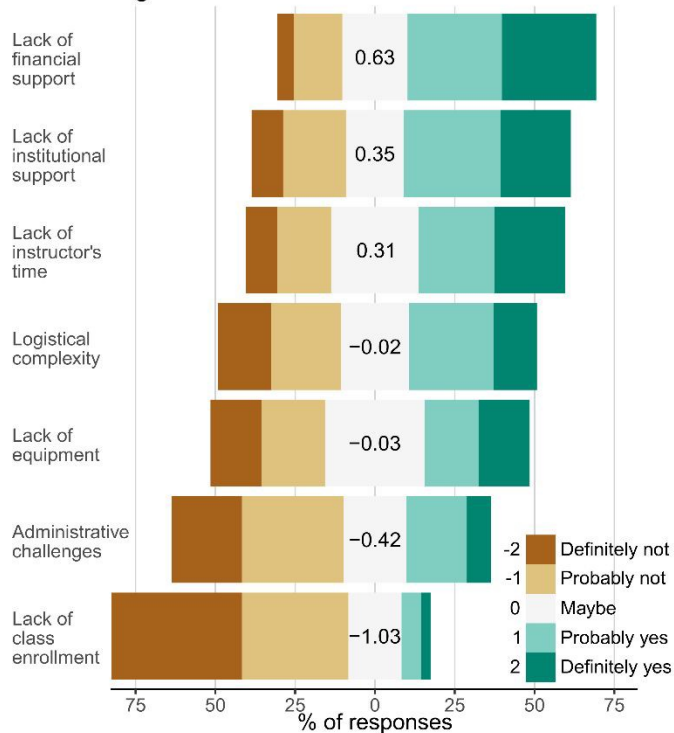
208 Several widespread challenges were reported in implementing or sustaining CUREs (**Fig. 5A**).  
209 Most instructors reported insufficient financial and institutional support (e.g., lack of technicians,  
210 teaching assistants, academic recognition) as their two top challenges, followed by a lack of time  
211 to invest in the course. These difficulties are likely what led instructors to enlist outside help:  
212 while 51% of CUREs were entirely financed by their university or academic department, the  
213 remaining relied at least partially on additional fees paid by students (34%), personal funds  
214 contributed by the instructors (13%), and funds from an outside organization that included other  
215 universities, government agencies, and citizen science groups (10%). Beyond financial support,  
216 nearly half of CUREs also depended on an outside organization for logistical assistance,  
217 including access to field locations, staff, and equipment. These findings reflect the logistical  
218 complexity, additional instructor time, and higher costs that are often cited as a hurdle to  
219 implementing CUREs as compared with standard courses in ecology (Quinn 2015; Shortlidge *et*  
220 *al.* 2016). Our survey therefore suggests that, despite the well-documented pedagogical benefits  
221 of CUREs, standard institutional support is a consistent challenge to implementing and  
222 sustaining them.

223 Beyond benefits to students and instructors, the potential for CUREs to contribute more  
224 broadly to science and management largely resides in reliable access to datasets and publication  
225 of CURE-based research. Despite this, instructors in our survey reported that their ecological  
226 data are rarely shared and are vulnerable to being lost or destroyed. Only 28% of respondents  
227 currently share data collected as part of a CURE (**Fig. 5B**). Of these, most datasets are available  
228 only upon request, with varied conditions of use including authorship (30%) or  
229 acknowledgement (19%). Encouragingly, one third of those who do not currently share data are  
230 willing to make them openly available online, the majority of which (89%) requiring at least an  
231 acknowledgement or citation, and half (49%) requiring authorship.

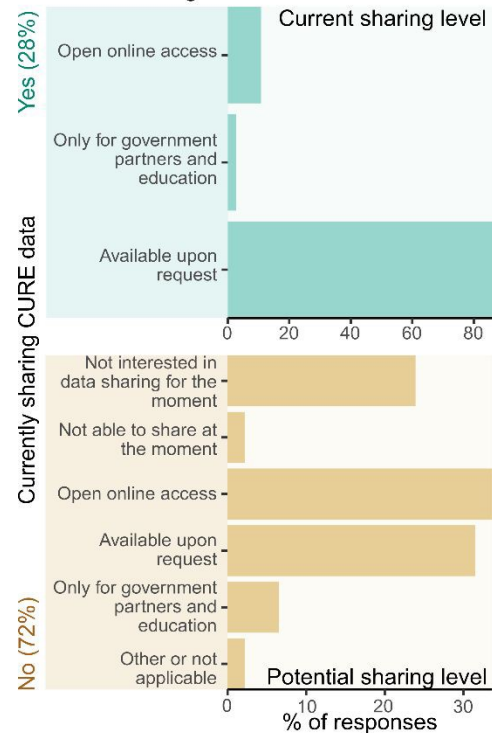
232 The lack of accessibility of CURE data partly compounds their vulnerability to being  
233 pushed to obscurity. As previously discussed, 19% of respondents had published peer-reviewed  
234 articles based on CURE collected data, indicating the potential for CURE data to routinely  
235 contribute to broader research knowledge. However, difficulties in synthesizing and analyzing  
236 CURE data were commonly reported. A main challenge identified by instructors was inputting  
237 the raw field data into a database (48%). Furthermore, more than half (54%) of instructors

238 reported having data archived only locally either as hard copies or on local computer storage; an  
 239 additional 11% have not analyzed the samples or archived data. Temporal or spatial gaps in data  
 240 collection were also frequently cited (46% of respondents) as an analytical challenge. Gaps were  
 241 typically due to logistical difficulties in implementing the protocol (e.g., weather, safety  
 242 concerns, 64%), staff or funding shortages (33%), or a lack of instructor time (31%). It is worth  
 243 noting, however, that only a third of the surveyed CUREs reported gaps amounting to more than  
 244 10% of the study period. Finally, respondents listed low confidence in data quality (60%), class-  
 245 specific design (70%), and lack of time (41%) as the primary reasons for not using the data  
 246 outside of class-based projects.

### A. Challenges



### B. Data sharing



247  
 248 **Figure 5. Challenges and data sharing practices reported by past and current CURE**  
 249 **instructors (n = 132).** (A) Main challenges in teaching a CURE reported by instructors. The numbers  
 250 in black are the average scores based on a Likert scale from “definitely not” (-2) to “definitely yes” (2).  
 251 (B) Levels of CURE data sharing by instructors; the top-right histogram shows the levels of sharing for  
 252 instructors that currently share data; the bottom-right histogram shows the levels of sharing at which  
 253 instructors who do not currently share data would be willing to share.

## 255 **Perspectives on ensuring the scientific value and sustainability of CUREs**

256 CUREs require careful implementation, robust institutional backing, and support from the  
257 broader science community to achieve both educational and scientific goals. Instructors are  
258 responsible for the educational experience of students and the maintenance of collected data, yet  
259 the burden of realizing the dual potential of CUREs to both educate students and advance  
260 ecological knowledge cannot fall on instructors alone. Networks and published guidance can  
261 assist instructors with launching and maintaining a CURE (Quinn 2015; Govindan *et al.* 2020,  
262 **Table 1**), but a suite of additional actions is necessary to ensure its value in supporting scientific  
263 research and management.

264 Leveraging existing frameworks and resources may help instructors design and  
265 implement CUREs more easily and efficiently, and support democratizing the collected data.  
266 Existing networks of CURE instructors such as the Ecological Research as Education Network  
267 (EREN) and CUREnet (**Table 1**) provide networking opportunities, project ideas, course  
268 material, and other practical advice to design and sustain CUREs. As open science continues to  
269 be promoted in the ecological sciences, equipping students with the skills required for data  
270 sharing as part of the course curriculum is critical (Hampton *et al.* 2013). Data repositories  
271 hosted by CURE networks provide low-barrier opportunities to archive and pool collected data  
272 among instructors while generalized data repositories (e.g., Dryad, figshare, Environmental Data  
273 Initiative) can be leveraged to connect and share data more broadly (**Table 1**). Journals  
274 specializing in the publication and description of datasets also offer a way to cite and credit  
275 dataset authors, combining open-access with peer-review and citation tracking (Walters 2020).

276 Along with networking opportunities and published guidance that assist instructors, we  
277 urge established networks of CURE instructors to continue advocating for increased institutional  
278 support. Increased support in the form of time, funding, and recognition can help alleviate the  
279 individual burden assumed by instructors to ensure CURE longevity and impact, including  
280 archiving data in publicly accessible data repositories with standardized metadata (Fegraus *et al.*  
281 2005; Karasti *et al.* 2006; Jones *et al.* 2019). Individual researchers remain reluctant to develop  
282 CUREs because their professional success depends on producing publications at high frequency  
283 and on shorter-time frames (Kuebbing *et al.* 2018, see **WebPanel 4** for comments by surveyed  
284 instructors). Establishing or maintaining a CURE warrants institutional recognition as mentoring,

285 teaching and research, and should be valued for academic promotion and tenure (Morrison *et al.*  
286 2019).

287 In evaluating the potential of CUREs to advance scientific research, we find strong  
288 convergence with two practices in ecology: long-term ecological research (LTER) and citizen  
289 science. Survey respondents emphasized similar challenges in implementing CUREs as have  
290 been identified in LTER. Common challenges include maintaining resources and research focus  
291 over time, and reconciling the value of long-term investment with institutional and professional  
292 rewards for short-term outcomes (Kuebbing *et al.* 2018). CURE instructors can leverage the  
293 structure and consistency of data collection protocols developed by LTER observatories with  
294 minimal time investment, while expanding and using datasets that promote student learning,  
295 analysis, and publication (Langen *et al.* 2014). One of at least three existing networks to promote  
296 and facilitate CUREs (**Table 1**) is already associated with two well-established LTER  
297 observatories: the U.S. National Ecological Observatory Network and the Global Lake  
298 Ecological Observatory Network. Some LTER networks even provide ready-made teaching  
299 modules (e.g., <https://www.neonscience.org/resources/learning-hub/teaching-modules>) that  
300 emphasize the analysis of long-term, high-frequency, and sensor-based datasets, which is  
301 especially needed to equip the next generation of ecologists with the quantitative literacy to enter  
302 the era of ecological big data (Langen *et al.* 2014; Klug *et al.* 2017). Simultaneously, LTER  
303 stands to gain through broadened exposure, new or expanded data collection, and value-added  
304 contributions to undergraduate education and training.

305 We also found that CUREs share many challenges and opportunities with community-  
306 based monitoring and citizen science initiatives. Citizen science is similarly tasked with the  
307 creation of meaningful research and protocols that can be implemented with consistency over  
308 time and by diverse practitioners. Surveyed CURE instructors reported challenges in consistent  
309 implementation of protocols by students, leading at times to low confidence in data quality. This  
310 is also a common problem in community-based and citizen science projects, leading to the  
311 development of mitigating processes and techniques (Dobson *et al.* 2020). Like CURE  
312 instructors, citizen science practitioners must also find ways to manage, archive, and publicize  
313 data (i.e., via analysis and publication of research or data) that may be collected over long time  
314 periods (Quinn 2015; Ryan *et al.* 2017). Citizen science platforms may offer features that can  
315 help instructors implement CUREs more efficiently and sustainably (**Table 1**). For example,

316 CUREs could be designed around existing citizen science projects (e.g., Rowland *et al.* 2016), or  
317 students could collect and contribute observations to global datasets (e.g., eBird or iNaturalist).  
318 The benefits of this approach for instructors include access to larger datasets and less time spent  
319 developing protocols and creating systems to archive and manage data — although additional  
320 considerations regarding the learning outcomes of the class would be required (Mitchell *et al.*  
321 2017).

322 Alongside collaborating with and leveraging strategies from successful LTER and citizen  
323 science programs, instructors and students could benefit from the support of the global science  
324 community. For example, there is opportunity for those with robust open science backgrounds to  
325 strengthen networks and establish tools for integrating data across globally dispersed projects  
326 and platforms. CURE repositories from independent projects worldwide, similar to the one  
327 hosted by EREN, could also be included within a repository network like DataONE  
328 (<https://www.dataone.org/>) in order to bolster their visibility and prompt collaborations.  
329 Alternatively, national CURE networks could be expanded or launched to connect with  
330 international long term monitoring efforts (e.g., ILTER <https://www.ilter.network/>). When  
331 buttressed through networks, institutional support, and the broader science community, the  
332 many-fold benefits of CUREs such as training the next generation of scientists, making  
333 environmentalists of students, and providing data for research on crucial global processes cannot  
334 be understated.

335

### 336 **Leveraging CUREs to advance science, management, and policy**

337 CUREs are fostering the next generation of science professionals through their unique  
338 ability to include more students in experiential learning (NAS 2017). The technical skills and  
339 research experiences that students gain in the field, reported by our survey participants and  
340 across other studies, translate to intrinsic benefits such as increased scientific identity, perception  
341 of research ability, and emotional attachment to research (Cooper *et al.* 2020). Such intrinsic  
342 value associated with participation in CUREs promotes students' persistence in scientific fields,  
343 chance of graduating with a science degree, and intention to pursue a research-related career  
344 (NAS 2017; Hanauer *et al.* 2017; Corwin *et al.* 2018). Because CUREs reach more students than  
345 UREs while providing similar benefits, they increase the diversity and recruitment of graduates  
346 to meet the demands of the scientific workforce (Bangera and Brownell 2014; Hernandez *et al.*

347 2018). The role of CUREs in supporting more inclusive retention and recruitment of students to  
348 scientific careers alone should garner more institutional support and encourage broader  
349 implementation.

350 In addition to training students to become well-prepared scientists, CUREs are poised to  
351 contribute multiple benefits to ecological science by generating valuable long-term datasets that  
352 provide insight into ecological phenomena. A quarter of the CUREs we surveyed have already  
353 informed management or conservation actions, or contributed to ongoing long-term data  
354 collection efforts; a fifth have led to peer-reviewed articles. These results are indicative of the  
355 potential for CUREs to be more broadly integrated into the knowledge-generating process of  
356 research and subsequent management efforts in ecology. With sufficient support from their  
357 respective institutions, instructors and students can transfer the valuable research output  
358 generated by CUREs to the broader scientific community.

359 Finally, CUREs are comparable to other long-term ecological research practices in their  
360 potential to inform management and policy. The relative stability of CUREs afford them  
361 sufficient longevity to detect long-term trends and assess drivers of environmental change (White  
362 2019; Cusser *et al.* 2021). Understanding such trends can disproportionately contribute to  
363 science-based management actions and shape policy discussions (Hughes *et al.* 2017). These  
364 contributions are unlikely to be reported outside survey tools or may be difficult to identify  
365 through typical keyword searches in publication databases. Additionally, data from CUREs may  
366 be subject to negative perceptions of reliability which could limit their application to decision-  
367 making (Kosmala *et al.* 2016; Lee *et al.* 2020). Continued use and development of best practices  
368 in data collection, management and archiving will only serve to facilitate greater confidence in  
369 CURE-generated data. By utilizing existing research structures, democratizing collected data and  
370 publishing research findings, CUREs can simultaneously provide robust science and train the  
371 next generation of scientists needed to tackle the grand environmental challenges faced by  
372 society.

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- 494

496 **Table 1. Available resources to support current and prospective CURE instructors.**

Type	Resource	Features to support CUREs
CURE network	CUREnet	<ul style="list-style-type: none"> <li>· National network to share information, opportunities, and best practices for CUREs</li> <li>· Training (e.g., CURE Institutes) for instructors to implement CUREs</li> <li>· Curated collection of CURE projects that can be implemented locally</li> </ul>
	Ecological Research as Education Network (EREN)	<ul style="list-style-type: none"> <li>· Ecological research and education network aimed at primarily undergraduate institutions</li> <li>· Curated collection of CURE projects that can be implemented locally</li> <li>· Data repository and sharing platform</li> <li>· Strong links with national monitoring efforts (e.g., NEON, GLEON)</li> </ul>
	Undergraduate Field Experiences Research Network (U-FERN)	<ul style="list-style-type: none"> <li>· Collaborative network focused on fostering effective undergraduate field experiences by identifying and sharing evidence-based practices</li> <li>· Interdisciplinary network promoting inclusive research experiences</li> </ul>
Citizen science project finders	Zooniverse, SciStarter	<ul style="list-style-type: none"> <li>· Platform to engage a broader community in research projects</li> <li>· Development of protocols using citizen-science based platforms may address need to rapidly train students</li> <li>· Fosters a strong community of practice in support of project sustainability</li> </ul>
Crowdsourced data	eBird, iNaturalist	<ul style="list-style-type: none"> <li>· Offers existing standards (e.g., BioBlitz) for data collection and submission</li> <li>· Data archiving and sharing is immediate</li> <li>· Similar data collected from other locations can be queried for analysis</li> </ul>
General digital repository	Dryad, figshare	<ul style="list-style-type: none"> <li>· Universal digital repository for diverse data types</li> <li>· Meets journal standards for public access in publishing</li> <li>· Tags allow grouping and searching of similar data types</li> </ul>
Environmental digital repository	Knowledge Network for Biocomplexity, Environmental Data Initiative	<ul style="list-style-type: none"> <li>· Provides a platform to publish datasets that are readily cataloged with Digital Object Identifiers</li> <li>· Ensures detailed metadata to improve proper and increased use of data</li> </ul>
Peer-reviewed data publication	Scientific Data, Biodiversity Data Journal, Data in Brief	<ul style="list-style-type: none"> <li>· Allows for data publishing with metadata</li> <li>· Provides citable credit to authors for datasets</li> <li>· Standardized detailed descriptions and open-access make data easier to find and reuse</li> </ul>

497

# Course-based undergraduate research to advance environmental science and management

Web material

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### **WebPanel 1. Survey deployment.**

We used the Google search engine to compile a list of international, continental, and national-level scientific societies focused on ecological research using the key terms: “ecology”, “conservation”, “limnology”, “marine ecology”, “restoration”, “society”, and “association” for the following seven global regions: “Africa”, “Asia”, “Central America”, “Caribbean”, “Europe”, “Oceania”, “North America”, “South America”. After the compilation of this list (**WebTable 1**), we contacted societies individually and requested that they circulate our survey within their members and collaborator network through email lists and social media platforms (i.e., Twitter and Facebook). The survey invitation also included a request that society members pass forward the survey on to relevant contacts and colleagues within their professional and social media network (the full invitation letter template is provided below). A summary of survey responses is provided in **WebPanel 3**.

#### *Invitation letter template:*

Dear <<society name >> Members,

We are seeking information from instructors at institutions of [higher-education](#) who are currently leading, or are interested in leading, efforts to collect ecological data through class-based activities. This survey takes approximately 15 - 20 minutes to complete, and will contribute to a global review on the extent and types of ecological data collected by students, and provide insight into the opportunities and challenges associated with these class-based efforts to support desired educational and scientific outcomes. We ask that you complete this survey and/or forward this survey to colleagues or your association list-serve (if applicable). The survey can be found here: <https://tinyurl.com/EcolDataSurvey>. We ask that you complete the survey by **May 17, 2018**. All responses are anonymous.

### **Background**

Many classes (courses, units, modules) in institutions of higher-education (universities, colleges) have field excursions where instructors guide students in the collection of ecological and environmental data. Although data collection during class field excursions are undoubtedly occurring, there is little understanding of the geographic extent and characteristics of these

efforts, and the institutional and logistic challenges and opportunities that instructors have when maintaining, or considering new, class field excursions.

In order to address this issue, we are seeking the opinion of instructors from institutions of higher-education. Please click [here](#) for the survey link and complete the survey. Also, we ask that you forward this e-mail to any colleagues or organizations to reach other instructors who are currently, or might be interested in, leading class-based efforts to collect ecological data. If you have any questions or concerns, please feel free to contact the Olden Research Lab ([oldenlab@uw.edu](mailto:oldenlab@uw.edu)). Thank you very much for your time!

Sincerely,

Higher Education Ecological Data Survey (HEED) Team  
School of Aquatic and Fishery Sciences, University of Washington

For Review Only

## WebPanel 2. Survey instrument.

See PDF attached.

# Higher Education Ecological Data (HEED)

---

Start of Block: 1. Introduction/Survey invite

### Q1.1 Welcome to the Higher Education Ecological Data (HEED) survey!

We are seeking information from instructors from institutions of higher education\* who are currently, or are interested in, leading class-based activities to collect ecological data. This survey takes approximately 15-20 minutes to complete. Your participation will contribute to a global review on the extent and types of student ecological data collection, and provide insight into the opportunities and challenges associated with these class-based efforts to support desired educational outcomes. We ask that you complete this survey and/or forward this survey to colleagues or your association listserv (if applicable). All responses are anonymous.

We welcome any questions or comments and thank you for your help. Sincerely, The Freshwater Ecology and Conservation Lab

School of Aquatic and Fishery Sciences, University of Washington  
website: <https://depts.washington.edu/oldenlab/> | email: [oldenlab@uw.edu](mailto:oldenlab@uw.edu) \*teachers, professors, lecturers in universities or colleges

---

Q1.2 Do you consent to taking this survey? All respondents that complete this survey by May 17th can be entered into a drawing for one of two \$50 gift cards by entering their email address at the end.

Yes

No

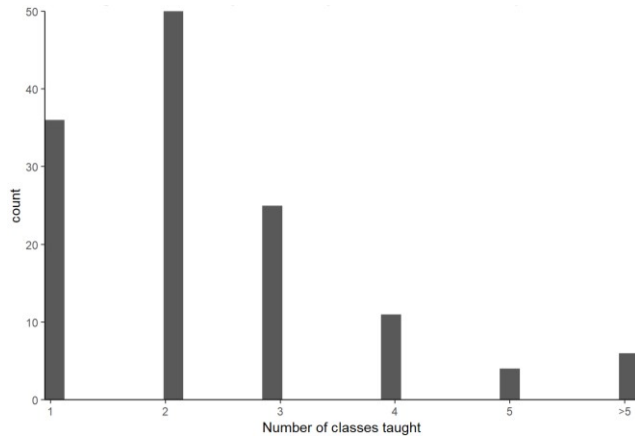
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End of Block: 1. Introduction/Survey invite

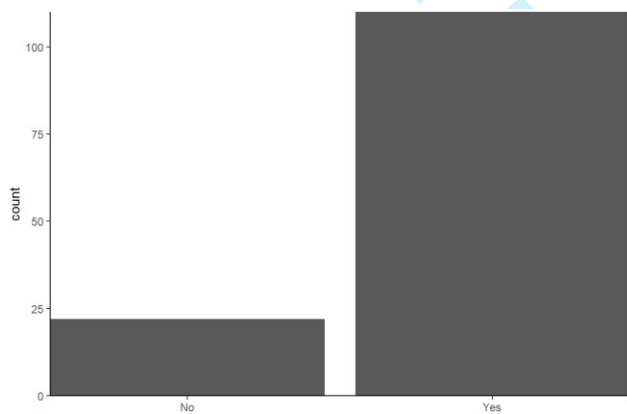
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Start of Block: 2. Have Data

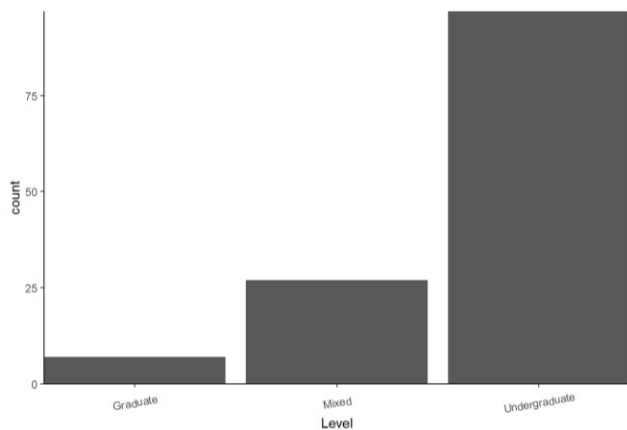
**WebPanel 3. Summary of survey responses (n = 132).** Numbering (e.g., Q2.2) corresponds to survey instrument (WebPanel 2). Only questions for which the results were not plotted in the main text are included.



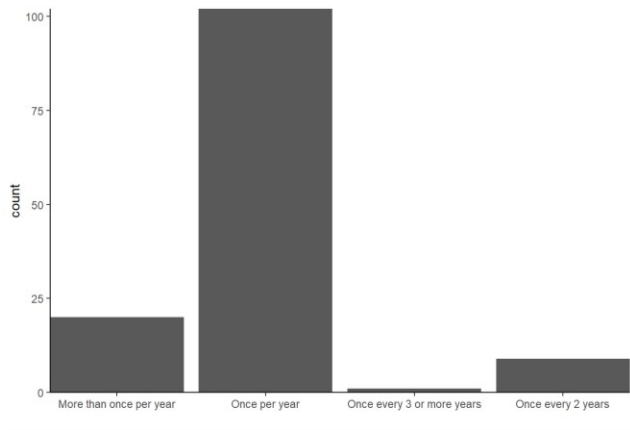
**Figure S3.1.** Survey responses to Q2.2 “How many classes have you or do you currently teach that involve at least one field excursion to collect ecological data?”



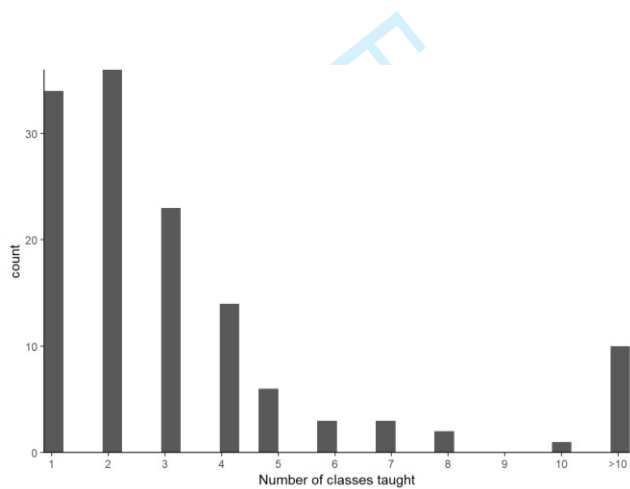
**Figure S3.2.** Survey responses to Q2.4 “Are/were the ecological data collected during the field excursion(s) retained after the class' end date?”



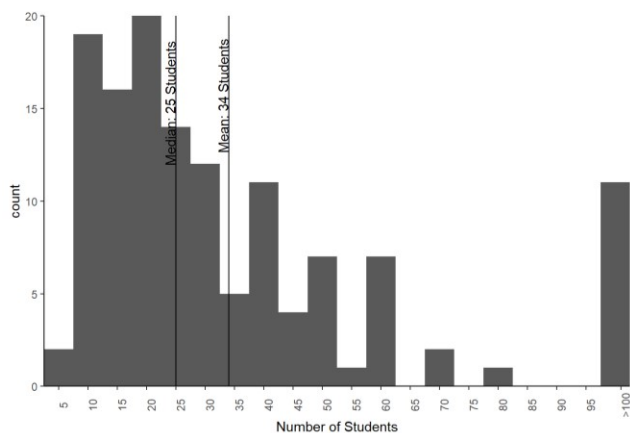
**Figure S3.3.** Survey response to Q8.2 “For what level of higher education is/was the class offered?”



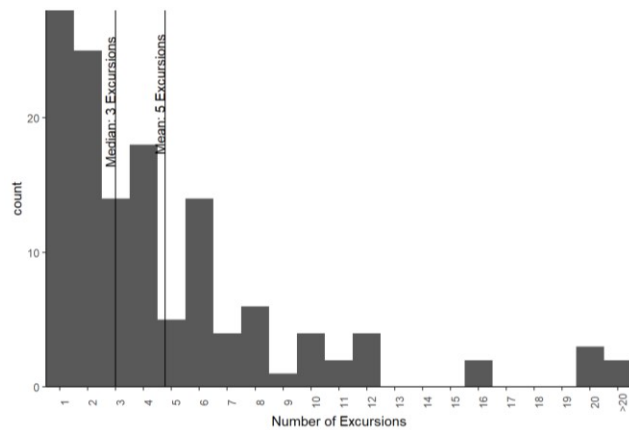
**Figure S3.4.** Survey responses to Q8.3 “How often is/was the class offered?”



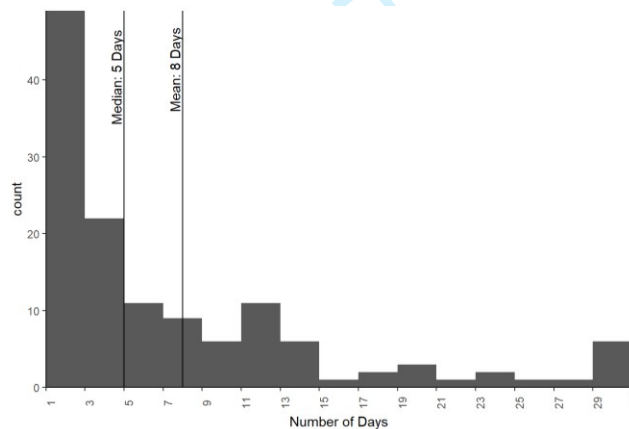
**Figure S3.5.** Survey responses to Q8.4 “Including yourself, how many instructors (and teaching assistants) are/were involved in implementing the field excursion(s) in a typical year?”



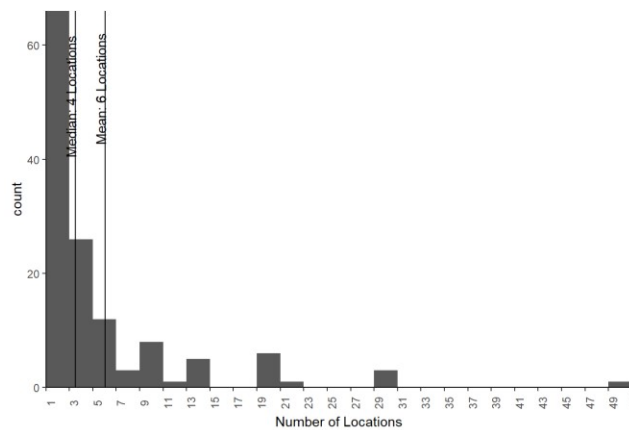
**Figure S3.6.** Survey responses to Q9.2 “What is/was the total number of students participating in the field excursions in a typical year?”



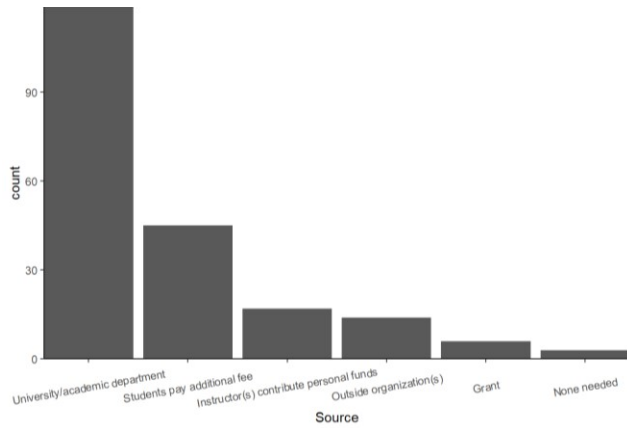
**Figure S3.7.** Survey responses to Q9.3 “In how many field excursions are/were ecological data collected during the class?”



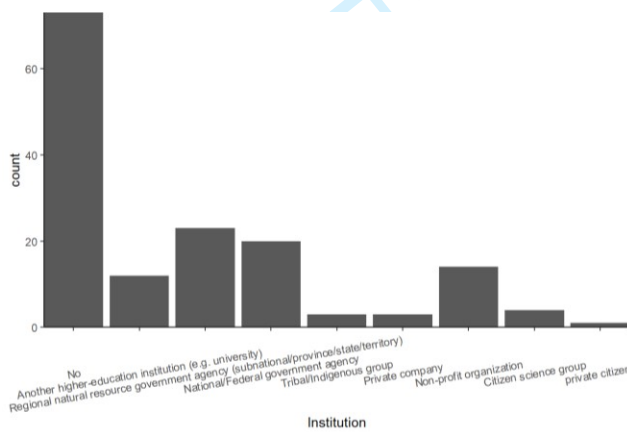
**Figure S3.8.** Survey responses to Q9.4 “How many total days of ecological data collection are/were involved across all field excursions in a typical year?”



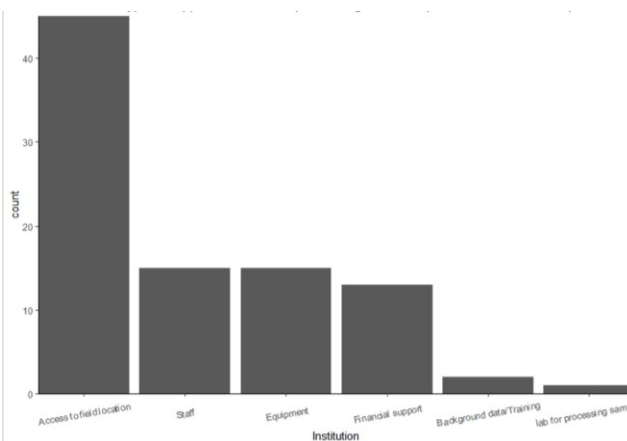
**Figure S3.9.** Survey responses to Q9.5 “Across all field excursions, in how many locations does/did the class collect ecological data?”



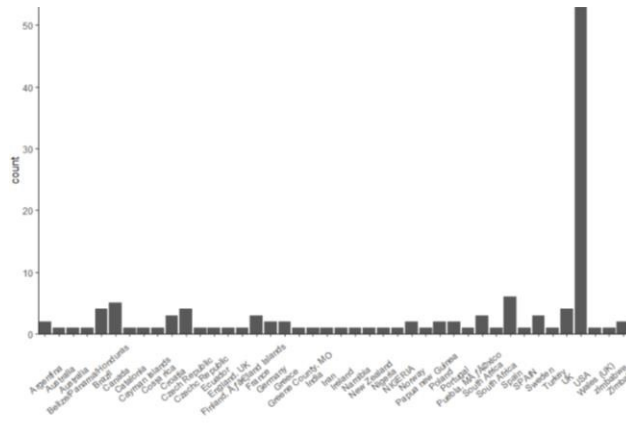
**Figure S3.10.** Survey responses to Q10.3 “What are/were the typical funding sources to support the field excursion(s) costs?”



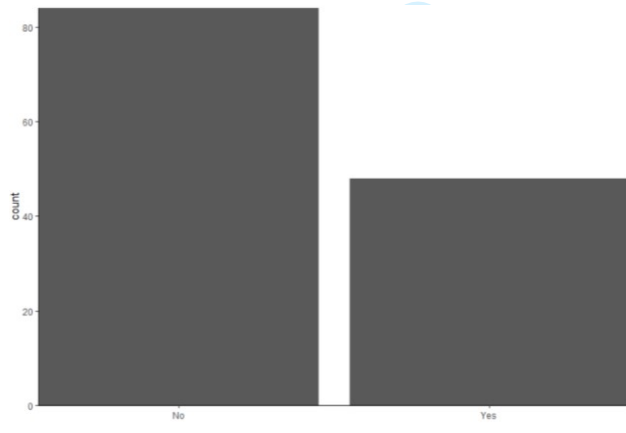
**Figure S3.11.** Survey responses to Q10.4 “Does/did an organization outside of your higher-education institution provide some level of support to the field excursion(s), including financial, staff, equipment, and other logistical support like site access?”



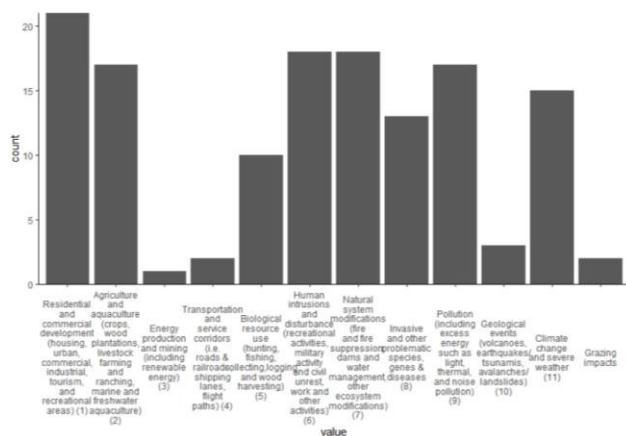
**Figure S3.12.** Survey responses to Q10.5 “What type of support do/did these partner organizations provide?”



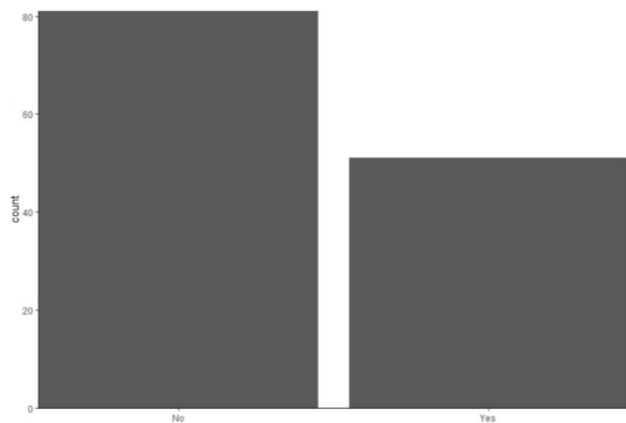
**Figure S3.13.** Survey responses to Q11.2 “Please enter the country where the ecological data are/were collected in the text box below.”



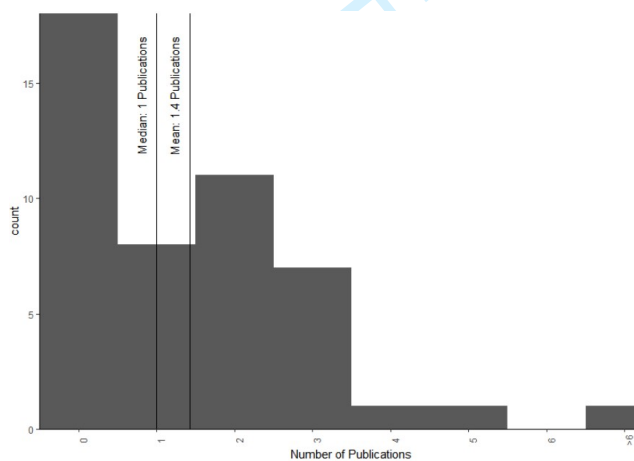
**Figure S3.14.** Survey responses to Q13.2 “Did you collect the data with the intention to study a specific threat to the factors of interest/environment?”



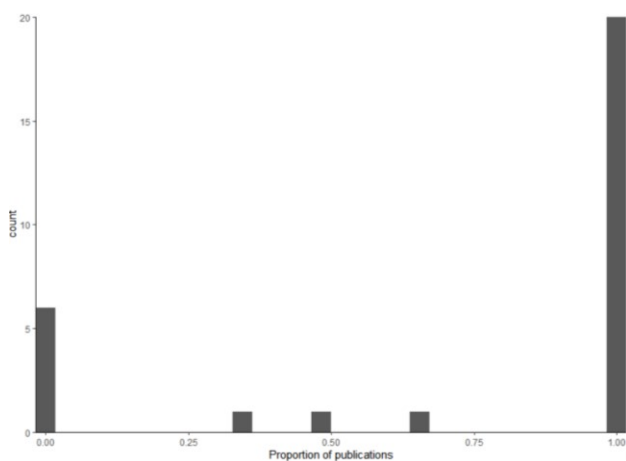
**Figure S3.15.** Survey responses to Q13.3 “What threat(s) is/was the data collection intended to study? Please check all the threats that apply (for more details on the Threats Classification Scheme, Version 3.2, see IUCN documentation).”



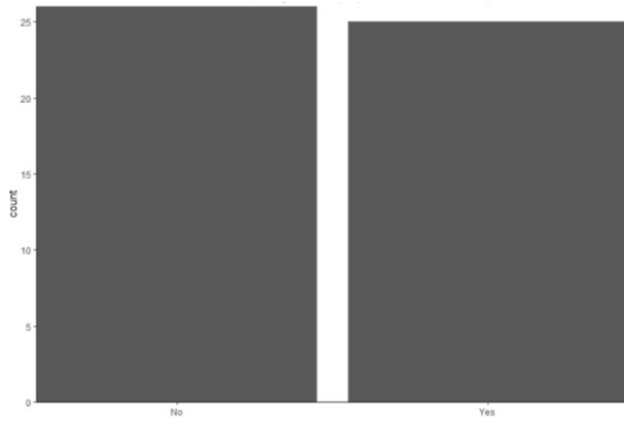
**Figure S3.16.** Survey responses to Q15.3 “Have you ever used the data collected in this class outside of class-based projects (e.g. publications, blog posts, grant proposals)?”



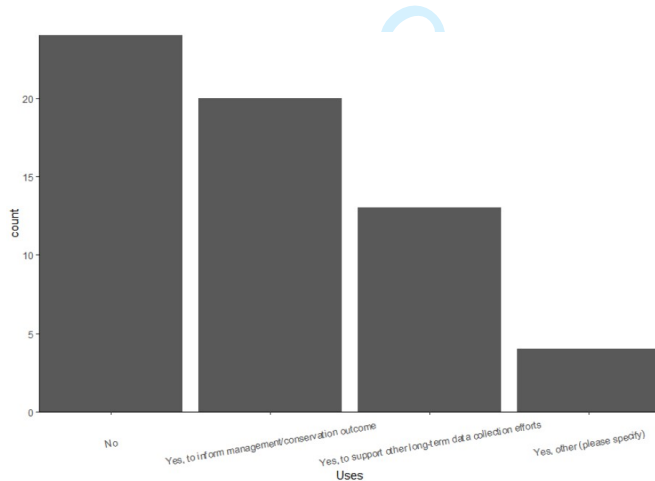
**Figure S3.17.** Survey responses to Q15.4 “How many peer-reviewed publications have resulted from the data collected in this class?” (n=47, answered yes to Q15.3).



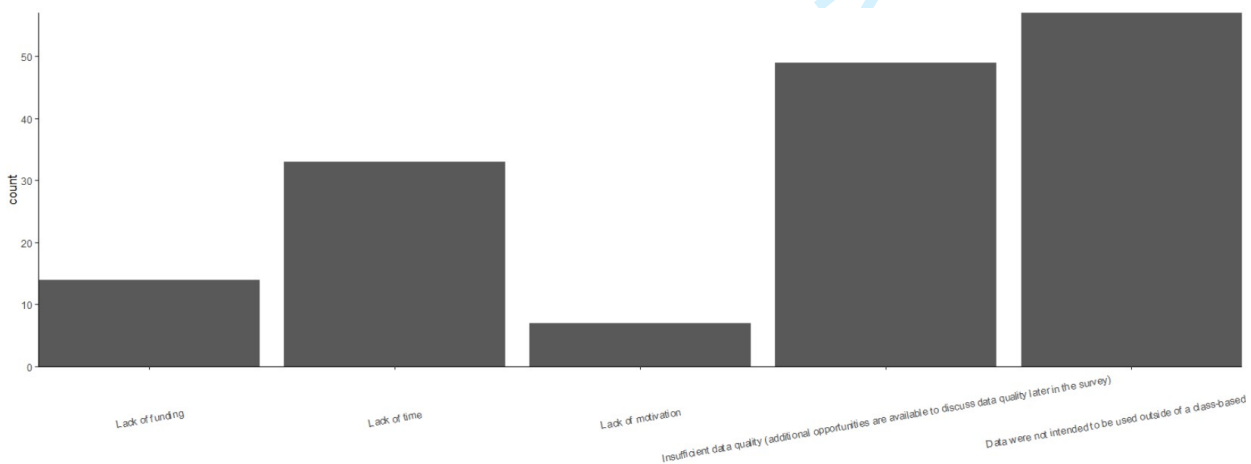
**Figure S3.18.** Survey responses to Q15.5 “How many peer-reviewed publications were the students involved in?” (n=29, answered > 0 to Q15.4).



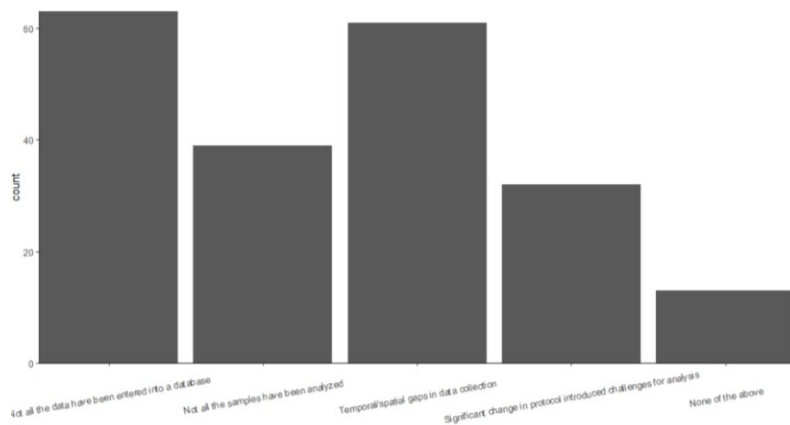
**Figure S3.19.** Survey responses to Q15.6 “Have these data resulted in subsequent grants or projects?” (n=51, answered yes to Q15.3).



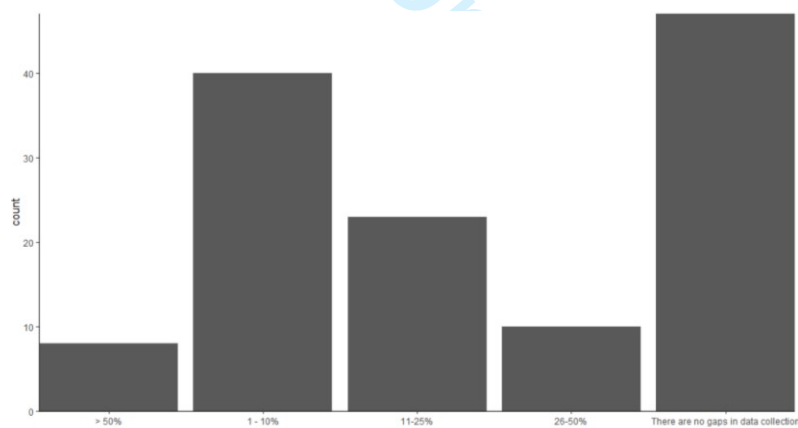
**Figure S3.20.** Survey responses to Q15.7 “Have these data been used by local or national government agencies?” (n=51, answered yes to Q15.3).



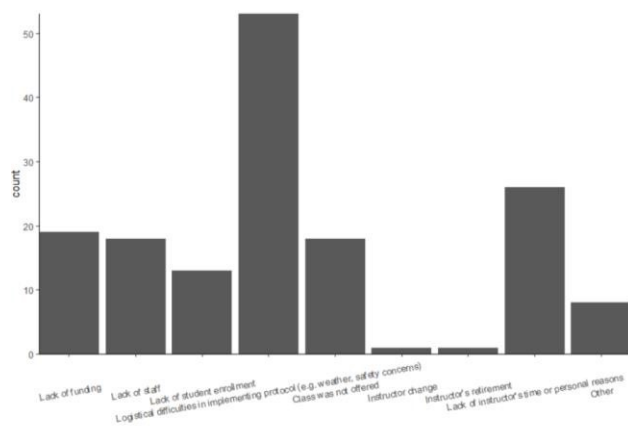
**Figure S3.21.** Survey responses to Q15.10 “For what main reasons have the data not been used outside of class-based projects?” (n=81, answered no to Q15.3).



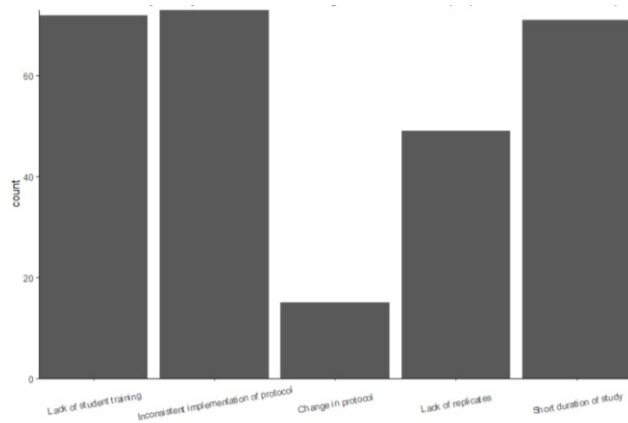
**Figure S3.22.** Survey responses to Q16.4 “In your experience, what are the main challenges to analyzing data collected as part of field excursions?”



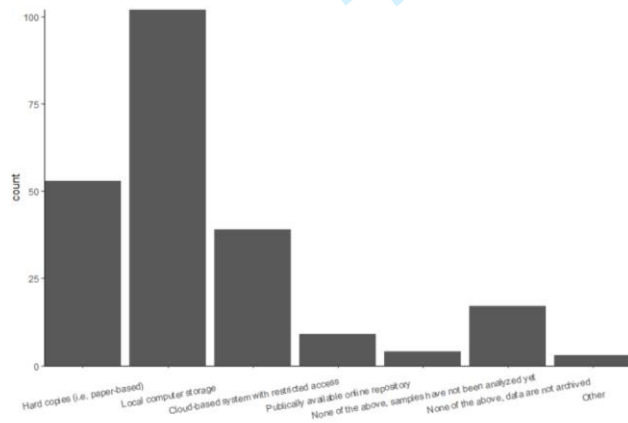
**Figure S3.23.** Survey responses to Q16.5 “For what percentage of the study period do gaps in data collection exist?”



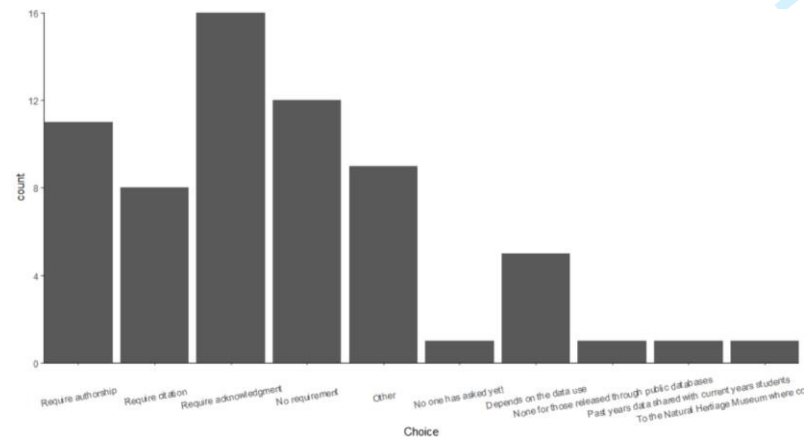
**Figure S3.24.** Survey responses to Q16.6 “What are the main reasons for these gaps in data collection?” (n=83, answered > 0 to Q16.5)



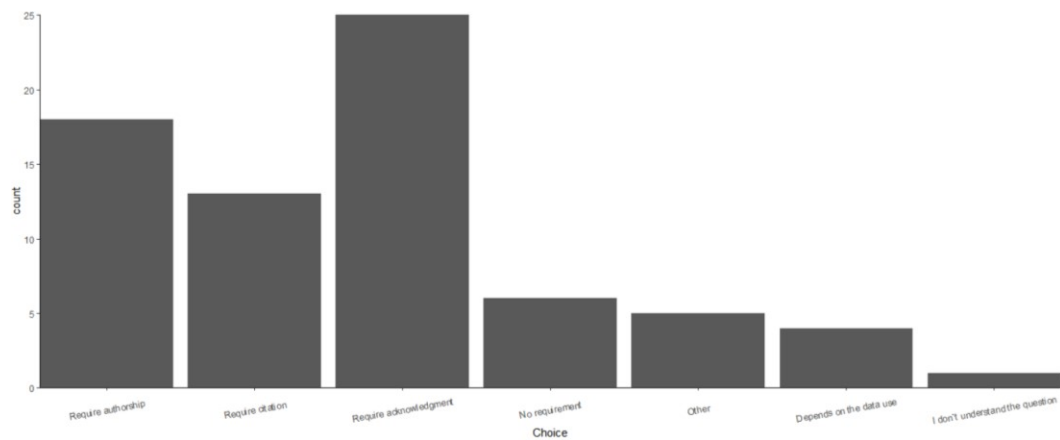
**Figure S3.25.** Survey responses to Q16.8 “What factors, if any, limit your confidence in using the data for other purposes than the class requirements?”



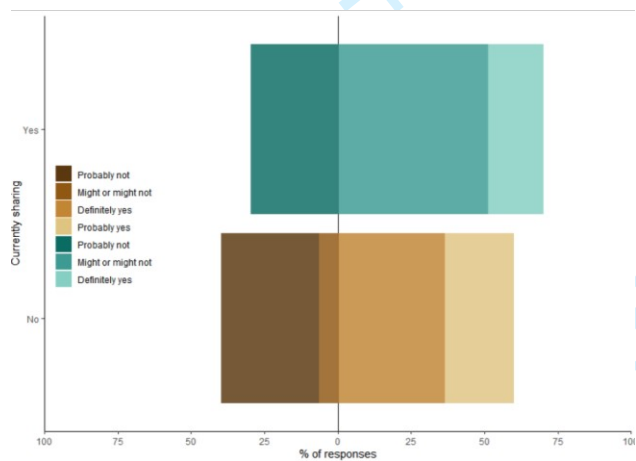
**Figure S3.26.** Survey responses to Q18.2 “How are/were data stored for purposes other than the class (e.g. subsequent analysis for peer-reviewed publication)?”



**Figure S3.27.** Survey responses to Q18.6 “Under what condition(s) do you share your data?” (n=32, currently share their data)



**Figure S3.28.** Survey responses to Q18.7 “Under what condition(s) would you be interested in sharing your data, if any?” (n=37, do not currently share their data)



**Figure S3.29.** Survey responses to Q18.8 “Would you be interested in sharing your class-collected data with your peers in an online community repository specifically designed to host class-based ecological datasets?”

**WebPanel 4. Highlighted comments from surveyed instructors.** Square brackets show sections that have been edited for clarity and for the maintenance of respondents' anonymity.

**1) Tips and advice for instructors:**

- a) "Get something simple started ASAP that you can build on. Realize that any data will be useful as populations are always changing and climate change makes this imperative".
- b) "To ensure data quality, organize students into groups as analytical replicates! This is key to maintaining the overall data for the project because if one group fails, it only decreases your sample size slightly [but does not] compromise the entire endeavor!"
- c) "For better accuracy in data collection it is best to have different groups of students collect the same data, and then delete flagrant outliers/take the mean of the student measurements".
- d) "All our pubs have come from adding data to the NUTNET project [<https://nutnet.org/>]. All other data is being used in house to measure CO<sub>2</sub> uptake or use by the local land manager to manage their non-profit site. NutNet works because they have clear data sheets upfront".
- e) "It takes tenacity and a "can-do" approach to maintain a program that continues to collect consistent class-based data. At our institution there is usually a way to overcome obstacles that repeatedly get in the way (liability issues, availability of transportation, changes in administrative support), but one needs to be persistent and make a strong case for the importance of collection class-based data. We have been able to do this for this course and another that we have taught every fall since [the 1970s]".
- f) "Programs like I-Naturalist might make this super easy in the future".
- g) "As a professor at a PUI [Primarily Undergraduate Institution] it has helped me continue my field data collection into the fall while carrying a full teaching load".

## 2) Challenges for CURE persistence and maintenance:

- a) "Most grant funding agencies and reviewers do not think undergraduates are capable of high enough data quality for publication. This biased perspective needs to change. With enough guidance, undergraduates can collect high quality data and massive experiments can be conducted within organized classes to the benefit of both students and faculty — especially at small teaching colleges with few resources for faculty research".
- b) "It is important to stay consistent with the protocols and the training of students. This may mean deciding to collect data with lower taxonomic resolution, or that are less dependent on expertise. This can limit the kinds of questions to be addressed, but hopefully eventually provide valuable long-term information".
- c) "We are planning to apply for funding [for long-term data collection by students]. I think that if we can get the project going the challenge will be to [keep it running over the long term]. There is a need for continuity, and since teachers come and go that is a challenge".
- d) "I have been advocating for a "research as curriculum" modality since I started my tenure track job here [20 years ago]. I gained tenure and am now a full professor only because a small number of powerful advocates agreed with me. Every time I mentioned "citizen science" or "policy application", or any synonym of either, it has cost me dearly – I have had to combat blatant myopic resistance to these dimensions of ecological research scholarship in my courses [since the 90s]. So, I learned early to keep that quiet".
- e) "Much personal effort required, next year when I retire probably the data will not be maintained".

**WebTable 1. Scientific ecological societies contacted in order to distribute the survey to members via email, Twitter and/or Facebook.**

<b>Society Name</b>	<b>Email</b>	<b>Twitter</b>	<b>Facebook</b>
<i>National</i>			
Association for the Sciences of Limnology & Oceanography	•	•	•
Australian Centre for Ecological Analysis & Synthesis	•	•	•
Austrian Limnological Association	•		
BIOTICA Ecological Society	•		
Brazilian Association of Ecological Science & Conservation	•		•
Brazilian Association of Limnology	•		•
Brazilian Ecological Society	•		
British Ecological Society	•	•	•
Canadian Institute for Ecology & Evolution	•	•	•
Canadian Society for Ecology & Evolution	•	•	•
Chilean Society of Limnology	•		•
Croatian Association of Freshwater Ecologists	•		
Czech Limnological Society	•		•
Czech Society for Ecology	•		•
Eastern Asian Federation of Ecological Societies	•		
Ecological Association of Argentina	•		•
Ecological Movement of Uzbekistan	•		
Ecological Protection Society Malaysia	•		•
Ecological Society of America	•	•	•
Ecological Society of Australia	•	•	•
Ecological Society of Bangladesh	•		•
Ecological Society of Chile	•	•	•
Ecological Society of Iceland	•		•
Ecological Society of Iran	•		
Ecological Society of Japan	•		
Ecological Society of Korea	•		
Ecological Society of New Zealand	•	•	•
Ecological Society of the Philippines	•		•
Ecology & Evolutionary Biology Society of Turkey	•	•	•
Estonian Naturalists' Society	•		•
French Ecological Society	•	•	•
French Limnological Society	•	•	•
Freshwater Biological Association	•	•	•
German Limnological Society	•		
Green Salvation Ecological Society	•		
Hellenic Ecological Society	•		
Hungarian Ecological Society	•		
Hungarian Hydrological Society	•		•
Indian Ecological Society	•		•
Indonesian Journal of Marine Sciences	•	•	
Institute of Landscape Ecology (Slovakia)	•		
Italian Association for Oceanography & Limnology	•		•
Italian Ecological Society	•		•
Japan Association for Landscape Ecology	•		•
Japanese Society of Limnology	•		
Landscape Ecology & Environment in Vietnam	•		
Limnological Association of Argentina	•		
Limnological Society of India	•		
Macedonian Ecological Society	•	•	•
Malaysian Nature Society	•	•	•

Mexican Scientific Ecological Society	•	•	
Murmansk Marine Biological Institute	•		
National Center for Ecological Analysis & Synthesis	•		•
National Institute of Ecology	•		
Nature Society Singapore	•		•
Papua New Guinea Institute of Biological Research	•		
Polish Ecological Society	•		
Polish Hydrobiological Society	•		
Polish Limnological Society	•		•
Portuguese Ecological Society	•	•	•
Romanian Ecological Society	•		
Russian Society for Ecological Economics	•		•
Sálim Ali Centre for Ornithology & Natural History	•		•
Slovak Ecological Society	•		
Slovakian Limnological Society	•		
Soil & Water Conservation Society	•		•
Spanish Association of Terrestrial Ecology	•	•	•
Student Conservation Association	•	•	•
Swedish Society Oikos	•		
Swiss Society for Hydrology & Limnology	•		
The Finnish Limnological Society	•		•
The Israel Society of Ecology & Environmental Science	•		
The Limnological Society of Turkey	•		
Toucan Ridge Ecological & Educational Society	•	•	•
Turkish Ecological Society	•		
<i>Continental</i>			
East African Wildlife Society	•	•	•
Ecological Society for Eastern Africa	•	•	•
Ecological Society of Germany, Switzerland & Austria	•	•	•
EFYR Representatives	•	•	
European Ecological Federation	•	•	
European Federation for Freshwater Science	•	•	
Federation of European Societies of Plant Biology	•		•
Iberian Limnological Association	•	•	
Netherlands-Flemish Ecological Society	•		
Nordic Society Oikos	•	•	•
Society for the Advancement of Science in Africa	•		
South African Department of Agriculture, Forestry & Fisheries	•	•	•
Southern African Society of Aquatic Scientists	•		
Southern African Wildlife Management Association	•		•
<i>International</i>			
Aquatic Ecosystem Health & Management Society	•	•	•
Association for the Sciences of Limnology & Oceanography	•	•	•
Association for Tropical Biology & Conservation	•	•	•
International Association for Ecology	•		
International Association of Landscape Ecology	•		•
International Society of Limnology	•	•	•
Society for Conservation Biology	•		
Society for Conservation Biology	•		•
Society for Ecological Restoration	•	•	•
Society for Freshwater Science	•	•	•
Society for Human Ecology	•	•	•
Society for Urban Ecology	•		
Society of Environmental Toxicology & Chemistry	•	•	•
The International Society for Ecological Modelling	•		

# Higher Education Ecological Data (HEED)

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## Start of Block: 1. Introduction/Survey invite

### Q1.1 Welcome to the Higher Education Ecological Data (HEED) survey!

We are seeking information from instructors from institutions of higher education\* who are currently, or are interested in, leading class-based activities to collect ecological data. This survey takes approximately 15-20 minutes to complete. Your participation will contribute to a global review on the extent and types of student ecological data collection, and provide insight into the opportunities and challenges associated with these class-based efforts to support desired educational outcomes. We ask that you complete this survey and/or forward this survey to colleagues or your association listserv (if applicable). All responses are anonymous.

We welcome any questions or comments and thank you for your help. Sincerely, The Freshwater Ecology and Conservation Lab

School of Aquatic and Fishery Sciences, University of Washington

website: <https://depts.washington.edu/oldenlab/> | email: [oldenlab@uw.edu](mailto:oldenlab@uw.edu) \*teachers, professors, lecturers in universities or colleges

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Q1.2 Do you consent to taking this survey? All respondents that complete this survey by May 17th can be entered into a drawing for one of two \$50 gift cards by entering their email address at the end.

Yes

No

## End of Block: 1. Introduction/Survey invite

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## Start of Block: 2. Have Data

Q2.1 Have you or do you currently teach one or more classes that involve at least one field excursion to collect ecological data?

Yes

No


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Q2.2 We are interested in hearing about your perspective.

To begin, how many classes have you or do you currently teach that involve at least one field excursion to collect ecological data? *Please click and drag slider to choose a number of classes.*

More than 5 classes

1      2      3      4      5

Number of classes	
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Q2.3 If you have taught multiple classes or plan on teaching multiple classes, please focus for the remainder of this survey on the most recent class that you have taught. If you currently teach more than one class, please focus on the one that has been collecting data for the longest time.

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Q2.4


Are/were the ecological data collected during the field excursion(s) retained after the class' end date?

Yes

No


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Q2.5 In what year did data collection start in the context of this class? Include years when the class was taught by previous instructors if relevant. *Please click and drag slider to choose a start year.*

	1900	2018
Start year		

Q2.6 When was the last year of data collection, if applicable? *Please click and drag slider to choose an end year, or check 'Data collection has not stopped'.*

Data collection has not stopped.

	1900	2018
End year		

End of Block: 2. Have Data

Start of Block: 3. Considering

Q3.1 Are you interested or planning on teaching a class that would include ecological data collection through field excursions?

- Yes
- No

Q3.2 Do you have an expected start date for teaching a class that would include ecological data collection through field excursions? *If so, please click and drag slider to choose a date. If not, please check 'I do not have an expected start date'*

I do not have an expected start date.

2018 2019 2020 2021 2022 2022 2023 2024 2025

Start date		
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End of Block: 3. Considering

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Start of Block: 4. Not considering

Q4.1 Thank you for your willingness to participate in this survey, but we are looking for instructors at higher-education institutions who have taught, are currently teaching, or are interested in teaching a class involving field collection of ecological data.

If you would like to recommend peer instructors for us to contact with this survey, please provide us with their email address. If you would like to directly provide them with a link to this survey, please send them the following link: <https://tinyurl.com/EcolDataSurvey>

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End of Block: 4. Not considering

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Start of Block: 5. Considering - outcomes and challenges



For Review Only

Q5.1 What benefits would you intend your students to gain from collecting and working with ecological data as part of your class?

	None	Little	Moderate	High
Field sampling techniques	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Laboratory/sample processing techniques	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Data analysis and interpretation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Collaborative research	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Scientific writing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public speaking	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Understanding of the scientific process	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Networking with scientists	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Relationship building with classmates	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increased interest in topic area	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Awareness of the natural world	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



Q5.2 What scientific outcomes and personal benefits would you aim for by teaching a class involving ecological data collection?

	None	Little	Moderate	High
Peer-reviewed publication	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Blog/social media post	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Inform natural resource management/conservation outcome	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Presentation at a conference	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Guide the design of future research projects	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Facilitate the funding of future research projects	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Peer recognition and awards (including institutional recognition)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Career advancement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Bonding time with students	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enjoyable time in the field	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Page Break

Q5.3 What would you anticipate to be the main challenges to implementing and continuing class-based data collection?

	Definitely not	Probably not	Maybe	Probably yes	Definitely yes
Lack of financial support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of institutional support (lack of staff/technicians or teaching assistants, lack of academic recognition)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of class enrollment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of equipment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of instructor's time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Logistical complexity (e.g. access, permits, landowner permission)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Administrative changes (e.g. change in class requirements)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q5.4 Do you have additional comments about potential challenges and benefits to implementing and maintaining a class-based data collection?

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Q5.5 What do you think would be the main challenges to analyzing **data** collected as part of class-based field excursions? *Please select all that apply or 'None of the above'*

- Entering data/converting data to digital form
- Analyzing samples
- Potential temporal/spatial gaps in data collection
- Significant change in protocol introducing challenges for analysis
- Limited data quality
- Other \_\_\_\_\_
- None of the above



Q5.6 What factors do you think would most limit your confidence in ecological data collected as part of field excursions? *Please select all that apply or 'None of the above'*

- Lack of student training
- Inconsistent implementation of protocol
- Change in protocol
- Inappropriate sampling design
- Lack of replicates
- Short duration of study
- Other (please specify)  

---
- None of the above

Q5.7 Do you have additional comments about analyzing and disseminating data collected as part of field excursions?

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Page Break

End of Block: 5. Considering - outcomes and challenges

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Start of Block: 6. Considering - Open ended

Q6.1 Do you have additional comments on classes involving ecological data collection you would like to share?

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End of Block: 6. Considering - Open ended

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Start of Block: 7. Considering - Closing questions

Q7.1 Please enter the name of your institution of higher education below.

Name of institution \_\_\_\_\_

---

Q7.2 What country is your institution of higher education in?

Country of institution

▼ AD - Andorra ... ZW - Zimbabwe

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Q7.3 How did you hear about this survey?

Scientific society (please specify)

\_\_\_\_\_

University email list

Colleague/Friend

Social media

Other (please specify) \_\_\_\_\_



Q7.4 To receive updates about this study, please provide us with your email address so that we may reach you (email addresses will be kept confidential and will not be used for any other purpose).

\_\_\_\_\_

Q7.5 If you would like to recommend peer instructors for us to contact with this survey, please provide us with their email address. If you would like to directly provide them with a link to this survey, please send them the following link: <https://tinyurl.com/EcolDataSurvey>

\_\_\_\_\_

End of Block: 7. Considering - Closing questions

Start of Block: 8. Have data - Class

Q8.1 Please provide a general description of the class by answering the following questions:



Q8.2 For what level of higher education is/was the class offered? *Please select all that apply.*

- First year - undergraduate
- Second year - undergraduate
- Third year - undergraduate
- Fourth Year - undergraduate
- Graduate
- Other (please specify)
- 

Q8.3 How often is/was the class offered?

- More than once per year
- Once per year
- Once every 2 years
- Once every 3 or more years
- 

Q8.4 Including yourself, how many instructors (and teaching assistants) are/were involved in implementing the field excursion(s) in a typical year? *Please click and drag slider to choose a number or check 'More than 10'.*

More than 10

0 1 2 3 4 5 6 7 8 9 10

Number of instructors



End of Block: 8. Have data - Class

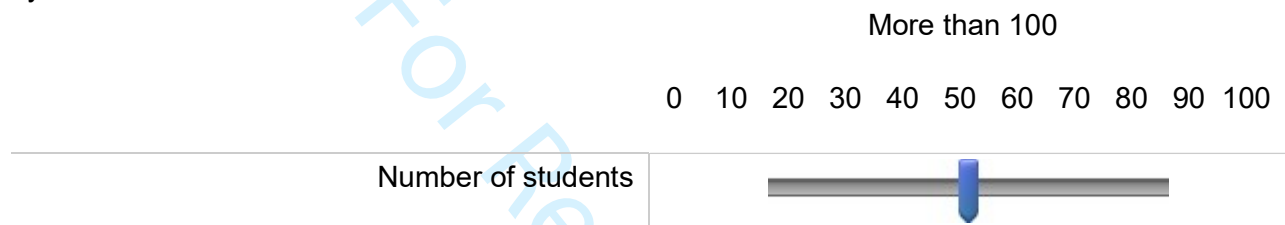
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**Start of Block: 9. Have data - Excursion**

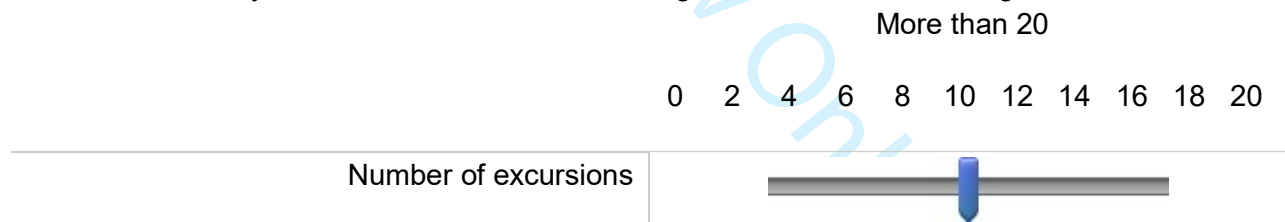
Q9.1 Please provide a general description of the field excursion(s) by answering the following questions. *Click and drag sliders to choose a number or check the box to the right of the slider if it applies (e.g. 'More than 20' field excursions).*

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Q9.2 What is/was the total number of students participating in the field excursions in a typical year?



Q9.3 In how many field excursions are/were ecological data collected during the class?

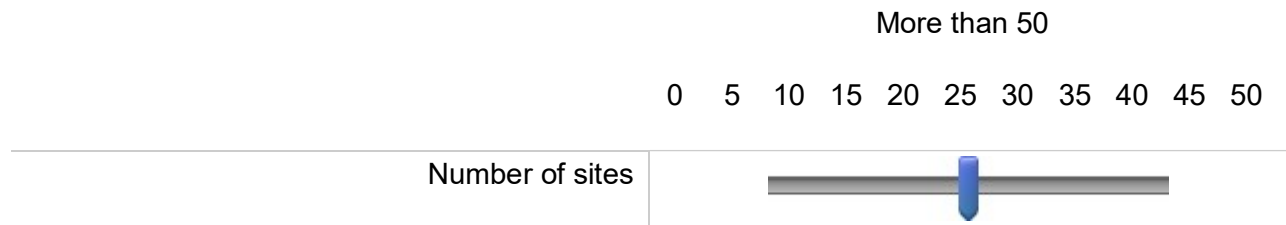


Q9.4 How many total days of ecological data collection are/were involved across all field excursions in a typical year?



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Q9.5 Across all field excursions, in how many locations does/did the class collect ecological data?



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End of Block: 9. Have data - Excursion

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Start of Block: 10. Have data - Instructor/institution/partners

Q10.1 Please provide information regarding financial and institutional support for the field excursion(s) by answering the following questions:

---

Q10.2 What is/was the total cost of running the field excursion(s) for the class (\$US) in a typical year?

- < \$1000
  - \$1000-\$2499
  - \$2500-\$4999
  - \$5000-\$9999
  - > \$10000
-

Q10.3 What are/were the typical funding sources to support the field excursion(s) costs?  
*Please select all that apply.*

- University/academic department
- Students pay additional fee
- Instructor(s) contribute personal funds
- Outside organization(s)
- Other #1 (please specify)  
\_\_\_\_\_
- Other #2 (please specify)  
\_\_\_\_\_

Page Break \_\_\_\_\_



Q10.4 Does/did an organization outside of your higher-education institution provide some level of support to the field excursion(s), including financial, staff, equipment, and other logistical support like site access. ? *Please select all that apply or check 'No'.*

- No
  - Another higher-education institution (e.g. university)
  - Regional natural resource government agency (subnational/province/state/territory)
  - National/Federal government agency
  - Tribal/Indigenous group
  - Private company
  - Non-profit organization
  - Citizen science group
  - Other (please specify)
- 



Q10.5 What type of support do/did these partner organizations provide? *Please select all that apply.*

- Access to field location
  - Staff
  - Equipment
  - Financial support
  - Other (please specify)
- 

End of Block: 10. Have data - Instructor/institution/partners

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Start of Block: 11. Have data - Data attributes

Q11.1 Please provide information regarding the ecological data collected during the field excursion(s):

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Q11.2 Please enter the country where the ecological data are/were collected in the text box below.

---

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Q11.3 Please drag the pin to the field location as precisely as possible in the map below. *If data are/were collected in more than one region, you will be able to add additional locations below.*

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Q11.4 In what type of ecosystem do/did you collect ecological data as part of the class? *Please choose the ecosystem/habitat that best applies (for more details on the Habitats Classification Scheme , Version 3.1, see IUCN documentation).*

Habitat class - level 1

Habitat class - level 2

Habitat class - level 3

▼ 1. Forest ... 18. Unknown ~ Not applicable ~ Not applicable

Q11.5 Does/did your field data collection also take place in another location or ecosystem type?

No, I have entered all the locations and ecosystem types where the class collects ecological data.

Yes, I would like to enter information on an additional location or ecosystem type.

End of Block: 11. Have data - Data attributes

Start of Block: 12. Have data - Data attributes II

Q12.1 Please provide information regarding the ecological data collected during the field excursion(s), including variables collected across all field locations:

Q12.2 What type(s) of variables are/were collected during the field excursion(s)? Please check all that apply.

Biological

Physical

Chemical



Q12.3 What biological variables are/were collected during the field excursion(s)? *Please check all that apply.*

- Occurrence/abundance/density/biomass (single species or multiple species)
- Individual physical attributes (body length, mass, leaf area, DBH, sex, age)
- Individual behavior
- Life history (e.g. fecundity, age)
- Physiology
- Phenology (e.g. migration timing, date of flowering)
- Genetics
- Molecular/Biochemistry
- Biogeochemistry (e.g. stable isotope, nutrient cycling, metabolism)
- Other (specify) \_\_\_\_\_



Q12.4 What physical variables are/were collected during the field excursion(s)? *Please check all that apply.*

- Temperature
- Luminosity
- Albedo
- Moonlight/lunar phase
- Pluviosity/precipitation
- Altitude/elevation
- Topography/slope/aspect
- Humidity
- Radiation
- Sound/Noise
- Granulometry/soil texture
- Substrate composition
- Erosion/sedimentation
- Vegetation coverage
- Ice coverage
- Distance (e.g. from habitat patches, matrix, water,...)

- Area (e.g. patch area, lake area)
- Intermittence/hydroperiod
- Depth/bathymetry (e.g. waterbody, sea, soil, litter)
- Wind speed
- Discharge/water flow/current
- Width (e.g. hedge width, river width)
- Water hardness
- Turbidity/transparency
- Color
- Other (specify) \_\_\_\_\_



Q12.5 What chemical variables are/were collected during the field excursion(s)? *Please check all that apply.*

- pH
- Electric conductivity/Salinity/Total Dissolved Solids (TDS)
- Chemical pollutant (specify) \_\_\_\_\_
- 
- Nitrogen/NH<sub>3</sub>/NH<sub>4</sub>/NO<sub>3</sub>/NO<sub>2</sub>
- Phosphorus/phosphate
- Carbonate/bicarbonates
- Calcium/Ca<sup>2+</sup>
- Iron/Fe<sup>2+</sup>/Fe<sup>3+</sup>
- Magnesium/Mg<sup>2+</sup>
- Aluminium/Al<sup>3+</sup>
- Potassium/K<sup>+</sup>
- Hydrogen/H<sup>+</sup>
- Sulfur/sulphate
- Chlorum/chloride
- Dissolved oxygen/BOD/COD
- Alkalinity/acidity
- Others (specify) \_\_\_\_\_

End of Block: 12. Have data - Data attributes II

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Start of Block: 13. Have data - threats

Q13.1 Please provide information regarding the ecological data collected during the field excursion(s):

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Q13.2 Did you collect the data with the intention to study a specific threat to the factors of interest/environment?

Yes

No

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Q13.3 What threat(s) is/was the data collection intended to study? *Please check all the threats that apply (for more details on the Threats Classification Scheme , Version 3.2, see IUCN documentation).*

- Residential and commercial development (housing, urban, commercial, industrial, tourism, and recreational areas) (1)
- Agriculture and aquaculture (crops, wood plantations, livestock farming and ranching, marine and freshwater aquaculture) (2)
- Energy production and mining (including renewable energy) (3)
- Transportation and service corridors (i.e. roads & railroads, shipping lanes, flight paths) (4)
- Biological resource use (hunting, fishing, collecting, logging and wood harvesting) (5)
- Human intrusions and disturbance (recreational activities, military activity and civil unrest, work and other activities) (6)
- Natural system modifications (fire and fire suppression, dams and water management, other ecosystem modifications) (7)
- Invasive and other problematic species, genes & diseases (8)
- Pollution (including excess energy such as light, thermal, and noise pollution) (9)
- Geological events (volcanoes, earthquakes/tsunamis, avalanches/landslides) (10)
- Climate change and severe weather (11)
- Other (please specify)
- 

End of Block: 13. Have data - threats

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Start of Block: 14. Have data - break/thank you

Q14.1 You are more than halfway done, thank you for your response to these questions. Now we want to ask you about the outcomes of class-based ecological data collection for you and your students.

End of Block: 14. Have data - break/thank you

---

Start of Block: 15. Have data - Outcomes

Q15.1 Please provide information regarding the outcomes of the field excursions:

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Q15.2 What benefits do you think your students gain/gained from collecting and working with the class' ecological dataset?

	None	Little	Moderate	High
Field sampling techniques	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Laboratory/sample processing techniques	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Data analysis and interpretation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Collaborative research	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Scientific writing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public speaking	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Understanding of scientific process	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Networking with scientists	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Relationship-building with classmates	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increased interest in topic area	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Awareness of the natural world	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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Q15.3 Have you ever used the data collected in this class outside of class-based projects (e.g. publications, blog posts, grant proposals)?

Yes

No

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Q15.4 How many peer-reviewed publications have resulted from the data collected in this class? *Please click and drag slider to choose a number or check 'More than 10'.*

More than 10

0 1 2 3 4 5 6 7 8 9 10

Number of publications



Q15.5 How many peer-reviewed publications were the students involved in? *Please click and drag slider to choose a number or check 'More than 10'.*

More than 10

0 1 2 3 4 5 6 7 8 9 10

Number of publications



Q15.6 Have these data resulted in subsequent grants or projects?

Yes

No

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Q15.7 Have these data been used by local or national government agencies? *Please check all that apply.*

- No
- Yes, to inform management/conservation outcome
- Yes, to support other long-term data collection efforts
- Yes, other (please specify)
- 

Q15.8 What other personal benefits have you gained from teaching a class involving ecological data collection?

	None	Little	Moderate	High
Ideas and data for future project(s)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Career advancement (publications, awards)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Peer recognition	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mentoring students	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Inspiration (e.g. enjoyable time in the field)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q15.9 What other significant outcomes have you seen as a result of your class-based ecological data collection?

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Q15.10 For what main reasons have the data not been used outside of class-based projects?  
*Please check all that apply.*

- Lack of funding
- Lack of time
- Lack of motivation
- Insufficient data quality (additional opportunities are available to discuss data quality later in the survey)
- Data were not intended to be used outside of a class-based project
- Other (please specify)
- 

End of Block: 15. Have data - Outcomes

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Start of Block: 16. Have data - Challenges

Q16.1 Please provide information regarding the challenges you have encountered in teaching a class involving field excursions:

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Q16.2 In your experience, what are the main challenges to implementing and maintaining class-based data collection?

	Definitely not	Probably not	Maybe	Probably yes	Definitely yes
Lack of financial support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of institutional support (e.g. lack of technicians, teaching assistants, academic recognition)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of class enrollment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of equipment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of instructor's time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Logistical complexity (e.g. access, permits, landowner permission)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Administrative challenges (e.g. change in class requirements)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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Q16.3 Do you have additional comments or advice from your experience implementing and maintaining class-based data collection?

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For Review Only

Q16.4 In your experience, what are the main challenges to analyzing data collected as part of field excursions? *Please select all that apply.*

- Not all the data have been entered into a database
  - Not all the samples have been analyzed
  - Temporal/spatial gaps in data collection
  - Significant change in protocol introduced challenges for analysis
  - Other (please specify)  
\_\_\_\_\_
  - None of the above
- 

Q16.5 For what percentage of the study period do gaps in data collection exist?  
*Here a gap refers to a period for which data were supposed to be collected according to the sampling protocol but for which no data were collected (e.g. data were not collected for one out of five years: 20% gap).*

- 1 - 10%
  - 11-25%
  - 26-50%
  - > 50%
  - There are no gaps in data collection
-

Q16.6 What are the main reasons for these gaps in data collection? *Please select all that apply.*

- Lack of funding
- Lack of staff
- Lack of student enrollment
- Logistical difficulties in implementing protocol (e.g. weather, safety concerns)
- Class was not offered
- Instructor's retirement
- Lack of instructor's time or personal reasons
- Other \_\_\_\_\_

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Q16.7 For which of the following applications do you feel comfortable using your class-based dataset?

	Extremely unlikely	Somewhat unlikely	Neither likely nor unlikely	Somewhat likely	Extremely likely
Post on internet (e.g. blog, social media)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Presentation at a conference	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Natural resource management	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Peer-reviewed publication	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Guidance for future study design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



Q16.8 What factors, if any, limit your confidence in using the data for other purposes than the class requirements? *Please check all that apply or 'None of the above'.*

- Lack of student training
  - Inconsistent implementation of protocol
  - Change in protocol
  - Lack of replicates
  - Short duration of study
  - Other (please specify)  
\_\_\_\_\_
  - None of the above
- 

Q16.9 Do you have additional comments or advice from your experience analyzing and disseminating data from a class-based ecological dataset?

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End of Block: 16. Have data - Challenges

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Start of Block: 17. Have data - break/thank you

Q17.1 Almost done, **thank you**. Just a few very important questions to ask.

End of Block: 17. Have data - break/thank you

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Start of Block: 18. Have data - Data management and sharing

Q18.1 We are considering to create an online data repository to promote a network of collaboration and integration of class-based research in ecology. In this section of the survey, you will be asked about your current practices in data archiving, management, and availability.

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Q18.2 How are/were data stored for purposes other than the class (e.g. subsequent analysis for peer-reviewed publication)? *Please select all that apply.*

- Hard copies (i.e. paper-based)
- Local computer storage
- Cloud-based system with restricted access
- Publically available online repository
- None of the above, samples have not been analyzed yet
- None of the above, data are not archived
- Other \_\_\_\_\_

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Q18.3 Do you currently share the data collected as part of this class?

Yes

No



Q18.4 At what level(s) do you currently share your data? *Please select all that apply.*

Available upon request

Only for government agency partners and educational purpose

Open online access

Other \_\_\_\_\_



Q18.5 What level(s) of data sharing would you be interested in, if any? *Please select all that apply.*

Available upon request

Only for government agency partners and educational purpose

Open online access

Not interested in data sharing for the moment

Other \_\_\_\_\_



Q18.6 Under what condition(s) do you share your data? *Please select all that apply, including if conditions depend on the nature of the data request.*

- Require authorship
- Require citation
- Require acknowledgment
- No requirement
- Other \_\_\_\_\_



Q18.7 Under what condition(s) would you be interested in sharing your data, if any? *Please select all that apply, including if conditions depend on the nature of the data request.*

- Require authorship
- Require citation
- Require acknowledgment
- No requirement
- Other \_\_\_\_\_

Q18.8 Would you be interested in sharing your class-collected data with your peers in an online community repository specifically designed to host class-based ecological datasets?

	Definitely yes	Probably yes	Might or might not	Probably not	Definitely not
Interest level	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>