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Teaching and learning in ecology: a horizon scan of emerging challenges and solutions

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Abstract:	We currently face significant, anthropogenic, global environmental challenges, and the role of ecologists in mitigating these challenges is arguably more important than ever. Consequently there is an urgent need to recruit and train future generations of ecologists, both those whose main area is ecology, but also those involved in the geological, biological, and environmental sciences. Here we present the results of a horizon scanning exercise that identified current and future challenges facing the teaching of ecology, through surveys of teachers, students, and employers of ecologists. Key challenges identified were grouped in terms of the perspectives of three groups: students, for example the increasing disconnect between people and nature; teachers, for example the challenges associated with teaching the quantitative skills that are inherent to the study of ecology; and society, for example poor societal perceptions of the field of ecology. In addition to the challenges identified, we propose a number of solutions developed at a workshop by a team of ecology teaching experts, with supporting evidence of their potential to address many of the problems raised. These proposed solutions include developing living labs, teaching students to be ecological entrepreneurs and influencers, embedding skills-based learning and coding in the curriculum, an increased role for learned societies in teaching and learning, and using new technology to enhance fieldwork studies including virtual reality, artificial intelligence and real-time spoken language translation.

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2 **challenges and solutions**

3

4 **Abstract**

5

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7 ecologists in mitigating these challenges is arguably more important than ever. Consequently

8 there is an urgent need to recruit and train future generations of ecologists, both those whose

9 main area is ecology, but also those involved in the geological, biological, and environmental

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13 challenges facing the teaching of ecology, through surveys of teachers, students, and

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17 inherent to the study of ecology; and society, for example poor societal perceptions of the field

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20 In addition to the challenges identified, we propose a number of solutions developed at a

21 workshop by a team of ecology teaching experts, with supporting evidence of their potential

22 to address many of the problems raised. These proposed solutions include developing living

23 labs, teaching students to be ecological entrepreneurs and influencers, embedding skills-

24 based learning and coding in the curriculum, an increased role for learned societies in teaching

25 and learning, and using new technology to enhance fieldwork studies including virtual reality,

26 artificial intelligence and real-time spoken language translation.

27

28 Our findings are focused towards UK higher education, but they should be informative for

29 students and teachers of a wide range of educational levels, policy makers, and professional

30 ecologists worldwide.

31

32 **Keywords**: horizon scan, teaching and learning, ecology, global challenges

33

34 **Data statement:** We intend to deposit our data in Dryad.

35

36 ## **Introduction**

37

38 It is increasingly recognised that we are advancing into 'The Anthropocene' epoch (Crutzen

39 and Stoermer 2000) and facing human-induced environmental challenges on a global scale.

40 Temperatures are rising, species' ranges are changing, the oceans are acidifying, biodiversity

41 is decreasing, and we are losing natural habitat, all at alarming and unprecedented rates

42 (Oliver et al. 2015). The rate of change is causing concerns that life on Earth will not have

43 sufficient time to adapt and that provision of a safe operating space for humanity is a challenge

44 (Rockström et al. 2009). Ecology is the study of organisms and their relationships with other

45 living things as well as their environment and thus ecological expertise is becoming

46 increasingly important to understand the impacts of global change and species loss. Arguably

47 therefore, the recruitment and training of future ecologists is critical, and people with ecological

48 knowledge and a non-traditional suite of skills may also be needed if ecologists are to have

49 an impact beyond academia (European Union 2014, Longhurst et al. 2014).

50

51 Despite this, to our knowledge, there has been no attempt to explore the future challenges

52 that face the teaching of ecology as a discipline, and no recent review of the skills

53 requirements for future generations of ecologists. Forecasting challenges is valuable for the

54 prevention and mitigation of potential threats, but also allows the identification of potential

solutions, and indeed opportunities (reviewed in Sutherland and Woodroof 2009). Such an exercise is particularly opportune as we move into the fourth industrial revolution, a time of rapid technological advancement (Maynard et al. 2015). Shifts in teaching and skills provision are expected, based on patterns of past revolutions, such as increased access to higher education through the rise of online distance education, and the development of MOOCs (Massive Open Online Courses) during the third industrial revolution (Penprase 2018). The impact of this 4th revolution is particularly relevant to ecology teaching with shifts to more sustainable industries predicted as a result of understanding product life-cycles and their ecological impact on the environment (Carvalho et al. 2018).

Here we present the findings of a horizon scan of learning and teaching in ecology, held in Milton Keynes, UK in 2019. Horizon scanning seeks to investigate what the future might look like in order to attempt to predict changes and challenges that could be mitigated by decision makers and practitioners (e.g. Sutherland et al. 2010, Roy et al. 2014, Antwis et al. 2017, Peyton et al. 2019). We sought to identify the most important challenges that are likely to be faced in teaching and learning in ecology, but also to identify potential solutions and opportunities for students, teachers and employers of ecologists.

Materials and Methods

We combined information from both the broader ecological community, in addition to those who teach ecology. We used a combination of surveys and workshop discussions to identify future issues and solutions for teaching and learning in ecology (process summarised Figure 1). First, we conducted a two-part Delphi survey; an efficient, inclusive, systematic approach that allows a group of individuals to collectively consider complex problems with reduced social pressure bias (Mukherjee et al. 2015). We sought to contact teachers of ecology at a range of levels, from both formal and informal learning, students of ecology, and employers of

82   ecologists. Each survey was open for four weeks and advertised on Twitter and through

83   targeted emails, asking participants to circulate the link more broadly still. The surveys

84   received ethical approval from The Open University Ethics Committee (HREC/3170/Cooke).

85

86   In Survey 1 we asked "What do you think are the most important challenges we are likely to

87   face in teaching and learning in ecology, including those associated with the employment of

88   ecology graduates, in the future?" allowing respondents to raise up to 20 issues each. Ninety-

89   seven people completed the survey, responding with nearly 700 issues (demographic data in

90   Table S1 and S2). Three people collated the responses, removing duplicates, and shortening

91   long answers. The remaining 298 responses were grouped into 17 categories, outlined in

92   more detail in the next section. The challenges were associated with (listed here

93   alphabetically):

94

95   ●   Basic language, numerical and computer skills in students

96   ●   Careers of teachers/lecturers

97   ●   Data handling and analysis, including statistics

98   ●   Disconnect between people and nature

99   ●   Emerging biological challenges (e.g. climate change)

100   ●   Equality and diversity

101   ●   Fieldwork and practical science

102   ●   Funding

103   ●   Graduate career opportunities

104   ●   Pedagogy and teaching

105   ●   Political impacts (with Brexit an additional category, here merged)

106   ●   Provision of graduate capabilities

107   ●   School (primary and secondary) curricula

108   ●   Societal perceptions of ecology

109   ● Technology and its use in ecology

110   ● University-level issues

111

112 We sought to leave subtle differences and perspectives in the responses, and to

113 approximately reflect the volume of responses relating to issues (i.e. if there were ~2% of

114 responses relating to funding for fieldwork, there should be ~2% of issues in the final list

115 relating to funding).

116

117 In Survey 2, participants first ranked the categories, and then issues within each category. An

118 option to indicate "I do not think it is important to rank any issues below this line" allowed issue

119 exclusion by respondents. Each category was ranked by 45 to 62 people as not all

120 respondents ranked issues in every category. The purpose of the ranking was to more

121 rigorously determine which issues respondents viewed as most important, but cross-linkages

122 between categories and issues meant few or no issues existed in isolation and hence the

123 result would not form a list which should be tackled in order. Two people then compiled the

124 survey data, providing a set of ranked issues for each main category as well as the overall

125 category rankings (see Figures S1-19).

126

127 The ranked data formed the basis for a workshop on May 23rd, 2019, which brought ecology

128 teachers together to consider the issues and solutions that could be used to mitigate and

129 address them. Attendees comprised postgraduate students with some experience of teaching

130 ecology and a vested interest in the future of the subject, through to academics with extensive

131 teaching experience. Thirteen UK universities were represented, across all categories typically

132 used to describe UK universities, including Russell Group, pre-92, and post-92; these

133 classifications represent research-focussed institutions, other traditional UK universities, and

134 former technical colleges, respectively. All attendees are named as co-authors on this paper.

135 Although all workshop attendees were based at UK universities, this profile was not

136   unexpected given engagement required physical attendance at the workshop, and the event

137   was communicated through British Ecological Society channels. However, respondents to the

138   surveys were based in diverse countries, with most continents represented except for Africa

139   (surveys 1 and 2) and Asia (survey 2; Table S1). Indeed, a range of nationalities, backgrounds,

140   experience, and research expertise were represented, and perspectives of non-academics

141   such as schoolteachers and NGO workers were gathered via the surveys (see table S2).

142

143   It was decided as a group that three categories "Funding", "Politics" and "Brexit", would not be

144   discussed explicitly in the workshop, as these were addressed in other categories, affected all

145   education, and/or focussed on very immediate issues, and we wished to focus on future

146   ecology-specific challenges. All other categories were discussed, in order to maintain, as

147   much as possible, the breadth of the topics suggested by survey respondents. For each

148   category, self-selecting groups (minimum 4 people) considered the ranked issues, examining

149   if there were many perspectives on few issues, or many issues, and then considered solutions

150   that could address or mitigate the issues, with a focus on the most highly ranked. Each group

151   discussion was facilitated by a member of the British Ecological Society Teaching and

152   Learning Special Interest Group committee, who also kept notes of the discussions. Groups

153   were directed to identify main issues, grouping similar topics or similarly ranked topics where

154   possible, and innovative solutions using new knowledge, technologies, opportunities and

155   tools, for the main issues. Each discussion lasted for 60 minutes and then participants re-

156   organised into different self-selecting groups for the next topic.

157

158   The project leads attended parts of each session and collated notes during the workshop.

159   They noted that issues were routinely considered from three main perspectives: student,

160   teacher and society, and therefore we have presented the challenges in these groups,

161   mapped with the original categories under which they were discussed. Perhaps surprisingly,

162   many of the challenges raised and discussed were current, rather than the more futuristic

163   challenges we had expected. Across the day, solutions that could address multiple challenges

164   emerged, and were brought up in multiple discussion groups. These were identified by the

165   workshop organisers and are reported in the form of an evidence-based forward-thinking

166   essay. Perhaps unsurprisingly there were significant overlaps across both challenges and

167   solutions; these are mapped in Figure 2.

168

169   Horizon scans harness the knowledge and thinking of experts to make predictions for the

170   future and therefore innately involve uncertainty. Unlike predictions from mathematical

171   modelling, the qualitative and subjective nature of horizon scans makes providing measures

172   of this uncertainty (including practicality in this case) difficult. Hence, we interrogated the

173   literature and sought to present any existing support for each of the solutions suggested –

174   either with teaching or learning examples or, where that was not available, in work associated

175   with other fields/applications. We considered that this approach would identify where our

176   predictions were ideas resurfacing, those at the forefront of current thinking and application,

177   and those incorporating concepts and technology only in the early stages of development.

178   Through this we sought to provide information to allow ecology teachers to assess the

179   practicality of the proposed for solutions for their given situations.

180

181   **Challenges**

182

183   *Student challenges*

184   **Mapped to: Basic language, numerical and computer skills in students; equality and**

185   **diversity; graduate career opportunities; disconnect between people and nature;**

186   **school (primary and secondary) curricula; emerging biological challenges (e.g. climate**

187   **change); university-level challenges**

188   In recent years there has been broad recognition that there is an increasing disconnect

189   between people, particularly children and young people, and nature (reviewed in Soga and

190   Gaston 2016). Increasingly we live in suburban areas and cities

191 (https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-

192 prospects.html). This, in conjunction with parental fear for child safety (Carver et al. 2010), the

193 rising popularity of sedentary pastimes, and overscheduling of children's lives (Hofferth 2009),

194 means that children and young people are spending less time outdoors (Clements 2004).

195 There is now very limited practical and fieldwork learning in the UK school curricula and,

196 coupled with the disconnect with nature, the lack of experience of ecology may mean that

197 students either do not understand what ecology means, or do not appreciate its value, to the

198 extent of self-excluding from the discipline at a young age.

199

200 Even when students do know and understand what ecology is, a perceived lack of jobs in the

201 field may discourage students from studying ecology. This is potentially exacerbated by the

202 increasing focus on graduate income as a measure for ranking the value of degrees, as there

203 is a tendency for ecology jobs to be more poorly paid than those in other bioscience

204 professions. The importance of quantitative skills to the field may also represent a barrier to

205 young people engaging with ecology. Advanced statistics are routinely required to analyse the

206 complex datasets encountered in ecological research (Barraquand et al. 2018), yet it is well

207 documented, in the UK at least, that many bioscience students fear mathematics, and

208 students exhibit a broad range of maths-related abilities, particularly in the first year of their

209 studies (Koenig 2011, 2012). Teaching quantitative skills is therefore a challenge, and

210 concerningly, it can be tempting to remove them from the curriculum in favour of more popular

211 subjects, as these tend to receive more favourable student evaluations (Uttl and Smibert

212 2017). However, early career ecologists report that more quantitative training in both

213 theoretical and statistical modeling specifically applied to ecological problems, would have

214 been very beneficial for their career (Barraquand et al. 2018), suggesting that efforts in

215 teaching quantitative skills for ecology should be increased rather than decreased. An

216 additional factor reducing engagement with ecology is the lack of diversity in the field, which,

217 like most sciences, is not representative of broader cultural and societal diversity (e.g. Holman

218 et al. 2018, Wanelik et al. 2020). A diverse workforce is perhaps particularly important in

219 ecology, which deals with global issues; practitioners need to have diverse cultural and

220 societal norms to be able to constructively engage with those living on the frontline of where

221 the issues are being played out.

222

223 Finally, students that decide to study ecology are likely to be increasingly aware of their own

224 impact on the environment, and of purported impacts and biases associated with neo-

225 colonialism on research practices (reviewed in Baker et al. 2019). While in the past, higher

226 education institutions have sought to introduce international field trips to attract students to

227 courses (Smith, 2004), in the future there may be a backlash against the current trend for

228 flagship overseas field courses and fieldwork due to the environmental and ethical impacts

229 (e.g. Wynes et al. 2019). This in turn could make it harder to recruit students.

230

231 *Teacher challenges*

232 **Mapped to: Fieldwork and practical science; data handling and analysis, including**

233 **statistics; basic language, numerical and computer skills in students; equality and**

234 **diversity; careers of teachers/lecturers; pedagogy and teaching; technology and its use**

235 **in ecology; provision of graduate capabilities; emerging biological challenges (e.g.**

236 **climate change); university-level challenges**

237 There are significant institutional barriers with potential to impact on ecology teaching, if they

238 are not already doing so. Although ecology does not necessarily have to be field-based, field

239 work can be an important component. There are conflicting views as to whether there has

240 been a reduction in the amount of field teaching in UK universities in past decades (e.g. Smith

241 2004, Ashton et al. 2015), or whether it has remained stable (e.g. Mauchline et al. 2013,

242 reviewed in Goulder and Scott 2016). However, given funding challenges and increasing

243 corporatisation (Robertson 2010), there is a risk that university administration and

244 management will consider field-based teaching too expensive in both money and staff time.

245   Despite field-based teaching often being less costly than laboratory practicals (Fleischner et

246   al. 2017), and invaluable in terms of student skills development (Andrews et al. 2003), student

247   satisfaction (Griset 2010, Hix 2015), bridging the staff-student divide in higher education (Hart

248   et al. 2011) and institutional marketing (Mauchline et al. 2013), ecology educators increasingly

249   struggle to justify field courses to budget holders.

250

251   The way in which universities tend to operate can also inhibit the successful and sustainable

252   delivery of ecology learning and teaching. The science of ecology benefits from working

253   across diverse disciplines including mathematics and all sciences, but also the arts and

254   humanities (Likens 1992). The multidisciplinary nature of ecology is highly beneficial to student

255   development and employability (Newing 2010), yet university education is often

256   compartmentalised and modularised, making it progressively difficult to teach across

257   departments and disciplines with a view to multidisciplinarity (Carson 2019). Rigid timetabling

258   across the calendar year can also be problematic; in the UK at least, most teaching occurs

259   between October and April, when biodiversity is least visible and most difficult to identify.

260

261   Putting aside the challenges of teaching new ecologists, the current generation of ecology

262   practitioners themselves face problems. Ecology positions tend to be short-term and low-paid

263   contracts (Hance 2017). Many positions require prior experience, and work experience is often

264   unpaid, or in some cases demands payment, which is likely to be impacting on sector retention

265   of personnel, in addition to contributing to low diversity in the discipline (Fournier and Bond

266   2015, Wanelik et al. 2020). In the age of the UK Research Excellence Framework, and the

267   focus on 'impact' as a measure of scientific quality, there is the potential for significant barriers

268   to progression for university-based ecologists, especially as ecological research is typically

269   long-term in comparison to other STEM disciplines; for example, at least a decade of

270   consistent monitoring is needed to capture statistically significant trends in vertebrate

271   populations (White 2018) and a resulting impact case would take even longer to develop.

272   Exercises such as the Research Excellence Framework are highly metric-driven, yet for

273   ecology and its sub-disciplines metrics can be poor predictors of scientific quality (Tyler 2018).

274   There is a risk that metric-induced barriers to progression will be further compounded by the

275   UK Teaching Excellence Framework (Whalley 2019) given the additional burden on teachers,

276   and the potential conflict between teaching and research (Perkins 2019).

277

278   ***Societal challenges***

279   **Mapped to: Emerging biological challenges (e.g. climate change); societal perceptions**

280   **of ecology; disconnect between people and nature**

281   A key challenge for teaching and learning is how the field of ecology and ecologists are

282   perceived by society. The public likely underestimates the complexity of ecology, a perception

283   exacerbated by documentaries simplifying nature and focussing on the behavioural ecology

284   of charismatic species (Dingwall and Aldridge 2006). Ecologists are often viewed as being

285   'nice' preservers of harmony (Ladle and Gillson 2009) rather than, for example, climate

286   scientists who are potentially perceived more as activists. The public may be unaware that

287   ecologists are tackling major societal challenges as diverse as disease epidemiology,

288   conservation and population dynamics. Where wider issues related to ecology are discussed

289   in public arenas, there is a focus on negative stories rather than the success stories, a

290   reflection of media appetite for bad rather than good news. In addition, ecologists tend to be

291   unwilling to use strong or polarising language, more commonly used by environmental activists

292   to successfully garner attention (Derville 2005). In part this is because the many sources of

293   variation in complex ecosystems, mean ecological research tends to explain part rather than

294   all sources in any given study.

295

296   A related challenge is the long-term nature of ecological research. The public perceive many

297   of the problems that ecologists are trying to address, for example the impacts of climate

298   change, as distant in both time and space (Lorenzoni and Hulme 2009), which can cause a

11

299   barrier to engagement and understanding. Similarly, ecologists are comfortable with the

300   uncertainty of science in contrast to the public, and it has been argued that uncertainty can be

301   and has been used by the media to drive a wedge between the scientific and public

302   communities (Zehr 2000). Instances where government policy has publicly ignored ecological

303   studies, such as in the case of the UK badger cull (e.g. https://www.bbc.co.uk/news/science-

304   environment-39418554), damages societal perceptions of the credibility of ecology.

305

306   These challenges, coupled with the perception that ecology careers are limited and poorly

307   paid, and the increasing disconnect between people and nature, both discussed above,

308   suggest that ecology has an image problem. The resultant impact on engagement with the

309   wider society, is in turn likely to be reducing the interest of young people in ecological careers,

310   and encouragement from parents and advisors to pursue them.

311

312

313   **Solutions**

314

315   The following solutions are not listed in any particular order.

316

317   ***Living labs on campus***

318

319   The living lab approach means taking students out of the classroom and into the local

320   environment, be it natural or artificial habitats close by or on campus. Such environments may

321   already exist, or may be developed specifically for the intention of being a living lab. Examples

322   include the use of campus wetlands to introduce ecological surveying at Mahidol University,

323   Thailand (Sukhontapatipak and Srikosamatara 2012), the development of a student campus

324   stewardship organisation at Cornell University, USA (Krasny and Delia 2015), and the

325   restoration of a local woodland by students from the Musahi Institute of Technology, Japan

326   (Kobori and Primack 2003).

327

328   Living labs initially gained traction in the discipline of urban sustainable development (Hossain

329   et al. 2019), but there are increasing calls to utilise such an approach in ecology teaching (e.g.

330   AASHE 2013). This is timely, as many if not all school and university campuses are seeking

331   to make the educational environment more sustainable in line with national calls (e.g.

332   McCoshan and Martin 2012). Living labs offer a multitude of benefits. At pre-school and school

333   level, encouraging children to engage with the natural world in their local area is beneficial to

334   their physical and mental wellbeing (reviewed in Louv 2006), and can also result in a more

335   positive attitude towards conserving it (e.g. Bizerril 2004, Soga et al. 2016). At higher

336   education levels, living labs can be used to engage local wildlife trusts and charities to share

337   their expertise, and to train students in working in an interdisciplinary manner with external

338   stakeholders (e.g. Evans et al. 2015). Active, inquiry-based learning and the gaining of real-

339   world experience help students develop enhanced research and employability skills (Healey

340   2005, Healey and Jenkins 2009), and such projects can be used to introduce credit-bearing

341   work experience to the curriculum, which has been shown to be beneficial to student

342   development and learning (e.g. Toledano-O'Farrill 2017). Data collected can also contribute

343   towards citizen science projects which can aid in training students to consider robust research

344   methods and data accuracy. Field work in a familiar local environment can increase

345   accessibility and inclusivity, and also helps students build confidence, for resilience in the face

346   of uncertainty of unfamiliar sites, by initiating fieldwork in a familiar setting (Leon-Beck and

347   Dodick 2012). In addition, local sites facilitate fieldwork with a limited or negligible budget

348   (Bacon and Peacock 2016) and still allow the social benefits among peers and staff-student

349   collegiality that develops during fieldwork (Peacock et al. 2018). It is notoriously difficult to

350   collect 'real' data on short, intensive, residential field courses. In contrast, long-term collection

351   of field data from local environs provides the opportunity to generate meaningful scientific

352   data, particularly with involvement across departments and even across institutions. Finally,

353   living labs may help mitigate increasing student concerns about the impacts of travelling for

354   fieldwork on the environment.

355

356   At the institutional level, living labs save both money and staff time, and there is also an

357   appreciable reduction in the level of health and safety risks. At society level, the living labs

358   approach can result in positive and sustainable change in the local environment, and can be

359   used to engage the general public in ecological and sustainability initiatives (e.g. Farrell et al.

360   2015, Steppe et al. 2016).

361

362   ***Teacher memberships in professional societies***

363

364   Benade (2016) argues that while learned and/or professional societies aim to advance their

365   cause through research and dissemination primarily, a closer relationship between academics

366   and practitioners can have mutual benefit. The capacity of ecology professional societies to

367   collate and facilitate communication of new findings and best practice amongst researchers

368   could be extended to better provide accurate, relevant, up-to-date information to teachers.

369   Reciprocal benefits could see learned societies increasing teacher knowledge and confidence

370   in ecological teaching, which should in turn increase the ecology knowledge and skills of

371   students entering further education and/or the workforce. Currently ecology societies vary in

372   their membership offers and provision of resources for teachers, who in turn are often unaware

373   the societies and resources exist.

374

375   Tilling (2018) showed that, in English secondary schools, "quantity and quality of ecology

376   fieldwork has been declining in recent decades at a time when the scope, complexity, and

377   interdisciplinarity of ecological science has been growing". Increased cross-sector sharing and

378   collaboration would make the production of teaching materials more efficient, and introduce

379   an interdisciplinary approach to help address issues of rapidly changing environments.

380   Provision of protocols for ecological experiments appropriate for specific regions (countries)

381   or environments (urban vs rural) are possible, and the rise of distance education using the

382   internet (tutor-supported paid online courses, webinars, Badged Open Courses etc.) could

383   allow efficient delivery for time-poor teachers (Kyriacou 2001). However, to ensure effective

384   use of professional societal resources, memberships likely need to be actively advertised to

385   teachers. Mentorship programs could allow strong and direct connections between ecology

386   researchers and teachers (for example Howitt et al. 2009 and the related Akres et al. 2016),

387   and increase confidence in field trips.

388

389   ***Integration of coding***

390

391   In the modern age, there are many fundamental applications of coding to most fields of

392   biology. In ecology, coding is used, amongst other techniques, to analyse molecular data,

393   model population interactions, and construct phylogenetic pathways, in addition to performing

394   more 'traditional' data analyses (Baker 2017). It is increasingly common for job advertisements

395   to specifically require coding as a skill in candidates (Auker and Barthelmess 2019), and

396   ecology PhD students and post-grads often find subsequent employment using their coding

397   skills in fields in governmental and charitable organisations and departments.

398

399   Yet despite coding being fundamental to ecological research, and to students' personal

400   development more broadly (Tu and Johnson 1990), it is still rarely taught in the UK at any level

401   of education (Koenig 2012). It has been suggested that the best way to introduce coding is to

402   start at an early age, preferably at primary school (Flórez et al. 2017). At university level,

403   strategies that have been shown to be effective in teaching coding to beginners include the

404   use of peer-peer assessment (e.g. ArchMiller et al. 2017), the use of blended learning (Cigdem

405   2015), and the development of automated e-learning and assessment systems to facilitate

406   student learning with reduced educator input (Alu-Mutka 2005). To foster collaborative

407   approaches, single platform coding across degrees is recommended, with the programme 'R'

408   (Ihaka and Gentleman 1996; R Core Team 2018) in particular gaining traction within ecology

409   (Petchey et al. 2009, Auker and Barthelmess 2019).

410

411   There are challenges to learning and teaching coding. Like maths, students, and in particular

412   biology students, tend to have a fear of coding (Koenig 2011). Students may quickly become

413   frustrated and lose motivation if they experience repetitive failure, and the fact that there is no

414   'correct' answer can be difficult for students to come to terms with. Hence to properly integrate

415   coding into curriculum, staff development and/or interdisciplinary teaching will likely be needed

416   to break down barriers to education and facilitate. These approaches above, with early

417   integration and the use of a single platform, could enable the teaching of coding and reduce

418   both student and staff concerns about engaging with maths and coding.

419

420   ***Ecological entrepreneurships***

421

422   Ecological entrepreneurship involves identifying and translating environmental concerns into

423   actionable solutions which can involve policies, technologies, products and business

424   engagement (Koch-Weser, 2015). Marsden and Smith (2005) provide examples of networks

425   which encourage development in local communities through increased quality (rather than

426   quantity) through sustainable food production and branding which identifies local produce.

427   There is an opportunity to provide ecology students with training - both the ecological

428   knowledge and skills, but also approaches from business - to allow the development and

429   participation in ecological entrepreneurial initiatives. Interdisciplinary ecology

430   projects/assessments and challenge-based learning, and also the integration of other subjects

431   could be included in the current curriculum to equip students with the necessary skills to allow

432   them to incorporate environmental responsibility into businesses (Valeryanovna 2012).

433

16

434   Ecology teachers could make use of existing entrepreneurship education programs, at

435   assignment and/or module levels, to equip students to be ecological business participants

436   and drivers of solutions to environmental problems. Categories of ecological entrepreneurs

437   include inventors/pioneers of green technical, policy, and business solutions as well as

438   communicators, forecasters, watchdogs and transformers (Koch-Weser 2015). In this way

439   there is potential more easily employed and integrated into corporate positions and for society

440   to perceive ecology and ecologists as entrepreneurial contributors to solutions.

441

442   ***Developing skills-based learning and skills-based degrees***

443

444   It is now well documented that passive learning in the lecture theatre is not as effective as

445   student-centred active learning (Tanner 2009), and when students can simply web search for

446   information on their mobile phones, there are calls for a more enquiry-based approach to

447   education (Chong 2010). In addition, in this, the age of the fourth industrial revolution,

448   technology is evolving at an ever-increasing pace, skills are increasingly viewed as more

449   valuable than knowledge, and the nature of work is changing. As a result, universities are

450   progressively incorporating skills and employability development into their curricula, utilising

451   more active and flexible learning approaches, and working collaboratively with employers to

452   provide work experience opportunities for students (UUK 2018). Such initiatives are

453   particularly important in ecology teaching. Ecology is inherently interdisciplinary, and, given

454   the rapid manner in which the planet is changing, ecology students need to learn to be

455   adaptable, utilise ever-changing technology, and work in an interdisciplinary manner with

456   diverse stakeholders.

457

458   While enquiry-based learning is an effective mode of student learning (Healey 2005),

459   educators are increasingly introducing work-integrated learning into the curriculum, which has

460   been shown to be extremely beneficial to students in terms of employability (Reddan and

461 Rauchle 2012). Work-integrated learning can encompass a variety of forms including

462 sandwich degrees, placements, internships, and field work, and exposing students to the

463 world of work through such activities can lead to the development of key transferable skills

464 and better preparedness for entry into the workforce (Jackson 2015). Furthermore,

465 encouraging students to reflect on their skills profile and career-readiness as part of a work-

466 integrated learning experience compounds the positive impact of student learning, and assists

467 them in articulating their assets to employers in later life (Manathunga and Lant 2006, Hansen

468 et al. 2018). Enabling students to undertake work-integrated learning as part of, or associated

469 with, the curriculum also enables them to gain valuable work experience without having to

470 undertake unpaid voluntary positions, which are rare, tend to be highly competitive, and can

471 exclude certain groups of students (Fournier and Bond 2015). Related, degree

472 apprenticeships are a relatively new idea in the UK and offer students the opportunity to gain

473 a degree whilst also undertaking on-the-job training (Prospects 2019). However, there are

474 concerns that apprenticeships can be used to fund low-skilled jobs

475 (https://www.bbc.co.uk/news/education-50973579), and thus such courses require careful

476 design. In addition, to date, such apprenticeships tend to be related to biomedical subjects,

477 and have not been adopted by fields such as ecology.

478

479 As for the living labs concept discussed above, the introduction of more skills-based and work-

480 integrated learning affords the opportunity for academics and students to work more closely

481 with local ecological organisations. Bringing employer-led learning onto campus, and the

482 introduction of challenge-type activities, would be beneficial for students with respect to skill

483 development and network expansion (Tejedor and Segalas 2018), and input from such

484 organisations would ensure that we are teaching the skills sought by employers.

485

486 One of the challenges identified was that the diversity of topics and skills required (both new

487 and traditional) is difficult to fit into an ecology curriculum. One solution to this would be to

488   offer skills based degrees embedded in a specific field of ecological knowledge (e.g. ecological

489   engineering, ecological microbiology). Such degrees could have the benefit of equipping

490   students with good ecological understanding (or another field), but also well-developed and

491   specific, but transferable skills. Co-teaching of modules in such a degree would allow subject

492   specialists to contribute key concepts and knowledge to students, while their skills would be

493   developed by specialist practitioners. In this way graduates would have in-depth ecological

494   knowledge, but highly developed specific skills, with degrees in science communication

495   (ecology), microbiology (ecology), field studies (ecology), engineering (ecology) or data

496   analysis/science (ecology) as examples.

497

498   ***Ecological influencers***

499

500   Researchers are frequently encouraged to do more to communicate with the public, while at

501   the same time, the rise of social media offers a platform for communication that is immediate,

502   accessible, direct and visual, and easily curated. Social media has allowed an explosion of

503   influencers, defined as people who endorse products or ideas associated with a particular

504   identity (Khamis et al. 2017). An increasing societal awareness of environmental and climate

505   change concerns means the public need explanations of complex science issues and

506   accessible information on positive, practical ways to take action and mitigate feelings of

507   climate change anxiety and depression (Moser and Boykoff 2013). Such explanations are

508   perhaps particularly important in this age of distrust of 'experts'. Real behavioural change for

509   action on climate change and ecological preservation is most likely with community

510   involvement (Moser and Pike 2015). Hence there is scope for large impact from ecological

511   influencers recommending products such education resources, behaviours, and experiences

512   associated with ecological awareness, benefits or learning, well supported by research. This

513   will rely on ecologists self-branding, that is, individuals "having a unique selling point, or a

514   public identity that is singularly charismatic and responsive to the needs and interests of target

515   audiences" (Khamis et al. 2017).

516

517   STEM academics as influencers have had a demonstrated impact on other science fields; for

518   example Prof. Brian Cox is credited with increasing interest in particle physics, influencing

519   public debate on science, and recruiting students to physics/science and societal education

520   through unique broadcasts (Manchester REF 2014). Information from authentic and expert

521   endorsers can lead to "internalization and deeper processing of the endorsers message"

522   (Kapitain and Silvera 2016). Ecological influencers have the potential to increase the visibility

523   and societal valuing of ecologists and facilitate the valuing and understanding of both applied

524   and fundamental ecology (Courchamp et al. 2015). Influencing is, however, not without it

525   costs, as it takes substantial time and energy to have an impact. An alternative is for ecologists

526   to engage with existing influencers more effectively, rather than 'reinventing the wheel'.

527

528   ***Virtual reality and field trips***

529

530   Virtual reality is the replacement of the real world with a simulated version, while augmented

531   reality is a simulation enhanced with additional perceptual information. Both technologies have

532   the potential to revolutionise ecology teaching, and indeed have already gained traction,

533   particularly in the geographical sciences (e.g. Bursztyn et al. 2017, Friess et al. 2016). Virtual

534   reality is a tool to complement traditional ecology teaching, both in the classroom and in the

535   field, rather than a replacement, but with potential to increase accessibility and remove some

536   of the barriers associated with field teaching. Virtual resources that can supplement more

537   traditional ecology teaching range from simple virtual guides and resources (reviewed in

538   France et al. 2015), through to fully immersive virtual reality experiences (e.g. Tarng et al.

539   2015). For example, Markowitz et al. (2018) used a virtual reality underwater experience to

540   teach school and university students about the effects of climate change on seawater acidity.

541

542 Using virtual or augmented technologies in teaching has several benefits. In the Markowitz

543 (2018) study, virtual reality resulted in the students developing more positive attitudes about

544 the environment. Student use of digital video technology in the field can develop employability

545 skills (Fuller and France 2016), while virtual or augmented technologies can enable remote

546 fieldwork for students with mobility impairments (e.g. Stokes et al. 2012), or overcome financial

547 barriers to a field course (Cliffe 2017) and allow students an experience of inaccessible

548 locations such the ocean floor (Whitelock 1999). Virtual introductions to field sites pre-field trip

549 can enhance student confidence and allay fears of the unknown. However, while evidence

550 shows benefits of virtual or augmented reality technologies as additional teaching resource to

551 traditional field courses, students suggest that they should not replace them (Spicer and

552 Stratford 2001). It is worth noting that some studies show immersive virtual reality can be

553 detrimental to learning (e.g. Makransky et al. 2017), while others demonstrate no additional

554 benefits to learning compared to non-immersive virtual reality technology (e.g. Moreno and

555 Mayer 2002).

556

557 ***Artificial intelligence***

558

559 Artificial intelligence (AI), defined as the capacity of computers or other machines to exhibit or

560 simulate intelligent behaviour (Oxford English Dictionary), is a burgeoning field. It has many

561 applications for ecology, including the identification of individual animals from video data (eg.

562 Sherley et al. 2010), investigating complex animal behaviours (Kunz and Hemelrijk 2012) and

563 to collate complex information from multiple sources, including feedback loops, to facilitate

564 decision making in natural research management decision making (eg. Liu et al. 2018).

565 Computer programs are already routinely used in both ecology teaching and research to help

566 identify vegetation communities from field data (eg. MATCH and MAVIS facilitate using the

567 National Vegetation Classification system), and online keys aid species identification using

568 known or available features (eg. EUCLID for Eucalyptus identification), hence using AI in

569 teaching is a logical next step. This scan identified that employers are concerned future

570 graduates should have species identification skills (See supplementary Table/Figure). There

571 is potential to use AI to assist species identification (MacLeod et al. 2010), while teaching the

572 limitations of technology (such as the impressive but imperfect Seek by iNaturalist) will serve

573 to maintain an appreciation for the role and value of traditional species identification skills. For

574 example, in arthropod species identification, the frequent requirement to use minute external

575 or internal morphological traits makes it unlikely that a photo-based AI app identification

576 system could replace human experts.

577

578 In addition to using AI to aid in species identification, ecology teaching and learning could

579 benefit from being an early adopting sector of AI to increase capacity to process large numbers

580 of samples or big data sets and facilitate consistency during student research, increasing

581 student satisfaction and also the potential for data publication. Long-term ecological data

582 (such as that collected across multiple student cohorts) is more likely to contribute to

583 ecological theory and policy (Hughes et al. 2017), and the publication of long-term data

584 collected in field teaching has been a persistent and rarely achieved aim, though there are

585 successful models (Bishop et al. 2014).

586

587 Ecology teachers, however, are concerned about managing their own knowledge of fast-

588 evolving technology as well as finding space in the curriculum to embed new as well as

589 traditional skills (See Supplementary information table/figure). To embed AI in ecology

590 teaching, communication and cooperation between teachers and machine learning specialists

591 would be essential. This collaboration could in turn contribute to overcoming the major

592 challenges in collaborative aspects of using AI in ecology and environmental sciences more

593 broadly, identified Liu et al. (2018). Given the rise of AI in both ecology and many other sectors

594 (Russell and Norvig 2016), training students in using and developing AI systems will increase

595   their employability. Including machine learning specialists in course and curriculum

596   development could serve to form a link between consumers versus producers of technology,

597   as well as facilitate the enhanced employability.

598

599   ***Real time spoken language translation***

600

601   A more audacious solution, with less supporting evidence for success but worthy potential, is

602   real time spoken language translation. Technology enabling students to engage with people

603   speaking any language, could reduce language barriers affecting diversity and equality in

604   teaching and learning. Attainment gaps in science are in part due to different language

605   knowledge and skills in students (Lee 2005) and excluding studies in languages other than

606   English introduces large bias (Morrison et al. 2012). Real time spoken language translation

607   technology could benefit field teaching in ecology, where much information is exchanged orally

608   rather than in writing. For field studies in international locations, this technology could also

609   enhance learning by enabling students to hear from all knowledge holders, not just those

610   speaking a common language. For example, the knowledge, perspectives and approaches of

611   traditional and indigenous landowners are recognised as critical for developing effective

612   conservation plans, and language differences between interested parties can be both a barrier

613   and enrich knowledge exchange (Gadgil et al. 1993, Moritz et al. 2015). It could contribute to

614   the decolonisation of ecology and related fields, through improved collaborative relationships,

615   and recognition of these, and reducing assumptions that perpetuate colonial attitudes

616   (Eichhorn et al. 2019)

617

618   This technology, however, is currently far from ready for the applications outlined above, not

619   least for localised, indigenous languages. Text translation is increasingly sophisticated for

620   more common languages, but automated translations from audio still often render problematic

621   results for all languages, as algorithms struggle to include correct punctuation, frequently fail

622 to recognise uncommon words (including scientific terminology) and cannot interpret speakers

623 with accents on which the program has not been trained (Heer 2019). In addition, for functional

624 real-time language translation, cadence, intonation and expression will need to be

625 incorporated, adding another layer of complexity. However, automated translation is an active

626 area of technological development, and increasingly common in computer programs and

627 social media platforms. Programs are beginning to use artificial intelligence to predict the

628 likelihood of the next spoken word to enable real time translations for widely spoken languages

629 (https://www.technologyreview.com/f/612730/google-assistant-now-comes-with-a-real-time-

630 translator-for-27-languages/). While real-time spoken language translation is currently

631 aspirational for field teaching, it is noteworthy that various forms of translation technologies

632 are already used to increase accessibility for students in STEM, such as speech-to-text and

633 text-to-speech (Lee and Templeton 2008), sonograms (visual displays of sound waves e.g.

634 Huffling et al. 2018) and sonification (audible versions of data e.g. Vines et al. 2019).

635

636 **Discussion and Conclusions**

637

638 The solutions identified during the workshop were a mixture of novel ideas and building on

639 recent innovative approaches participants had encountered. It is noteworthy that supporting

640 evidence for the potential success of the nine solutions was available, due to reports from

641 early adopters of technology and pedagogy, or where ideas have been successfully developed

642 and applied in other fields. For example, *ecological entrepreneurs* is a term already in

643 circulation (for example Koch-Weser 2015), but equipping students with the skills for this role

644 is as yet not part of the ecology curriculum. Similarly, real time translation technology for

645 speech is in development, but its potential to enhance fieldwork learning has not been

646 explored and articulated.

647

648   Four of the nine solutions arising from the workshop are linked to advances in technology, and

649   while some of their specific limitations were considered above, there are additional broader

650   issues. Managing privacy and security in e-learning (El-Khatib et al. 2003), as well as archiving

651   and storing digital data properly for the future (Michener and Jones, 2012) are essential. In

652   addition, dependence on technology for field trips where electricity and reception/signal are

653   unreliable or unavailable may limit the use of some proposed solutions. Technology evolves

654   rapidly, hence technological hardware and software can quickly become dated and resourcing

655   new technology may be problematic for some. Encouraging students to bring their own

656   devices is a way of ensuring cohorts have new and updated technology, but this approach

657   can easily introduce inequality among student learning (Afreen 2014). Finally, as noted in the

658   section on virtual reality above, technology should be seen as a tool to complement and

659   enhance traditional skills and techniques, rather than replace them. In short, although

660   technology offers innovative solutions to a wide range of challenges, there are numerous limits

661   surrounding its use about which ecology teachers must not be complacent.

662

663   The challenges identified comprised a mixture of emerging challenges and persistent

664   challenges for which we as yet have not identified solutions. Although we asked people to

665   predict issues in teaching and learning for the future, we did not constrain this with a particular

666   time scale. As a result, there is some focus on issues of the current and near future. For any

667   future repeats of this horizon scan, additional insight would be gained by specifying the future

668   period, but also by collecting perceptions of the solvability of challenges and priority of

669   solutions. We also appreciate there is a focus on the UK education system reflecting the

670   experiences of the participants. Investing additional effort to diversify respondents to the

671   surveys is recommended as more representation of students and employers, from a broader

672   geographical reach, would also likely provide further perspectives. Nevertheless, we anticipate

673   many of the main issues raised are likely to be global, that our findings will be thought-

674   provoking, and that this manuscript will incite further discussion.

675

676 Although horizon scanning has been applied to the environmental science discipline on

677 regional scales (e.g. Shackleton et al. 2011), and to ecology course planning using recent,

678 innovative teaching methods (Nordlund 2016), to our knowledge, this is the first time horizon

679 scanning techniques have been formally applied to the learning and teaching of ecology. The

680 issues raised in both the surveys and the workshop were raised by multiple respondents and

681 attendees, from different backgrounds, institutions, and countries in the case of the surveys,

682 adding confidence that challenges identified represent most people across the sector.

683

684 Ecologists worldwide are employing innovative strategies to encourage interest in ecology,

685 maximise student skills development, and improve collaboration across and between

686 educational institutions, and ecological, charitable, and governmental organisations. We have

687 identified ten solutions that addressed issues raised by the broader ecology teaching and

688 learning community, and are supported with evidence of their potential for adoption and further

689 development. In reporting the outcomes of the workshop, the resultant bibliography should

690 form a useful reference list for ecology teachers. We hope that our findings will ignite

691 discussion, and that together we can ensure the health - in all senses of the word - of the

692 future of ecology.

693

694

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1158

1159   **Tables and Figures**
1160
1161   **Figure 1. Schematic diagram of the horizon scan process and main outcomes.**
1162

Action

Outcome

Survey 1: Participants asked "What do you think are the most important challenges we are likely to face in teaching and learning in ecology, including those associated with the employment of ecology graduates in the future?"

700 issues from 98 respondents

Issues collated, separated into broad categories that reflected main emerging themes. Duplicates removed, except where appeared in different categories

298 issues across 17 categories

Survey 2: Participants asked to rank categories and issues within each of the categories.

45-62 people ranked issues and categories

Rankings prepared as histograms by category for workshop participants.

31 ecology students and teachers from 13 UK universities recruited for workshop

Small groups discussed each category for 60 minutes, with facilitators taking notes, determining:
1) main issues, grouping similar and similar ranked issues
2) possible future solutions or innovations that could address multiple issues
Workshop organisers attended part of all sessions and identified main perspectives discussed.

Issues considered from 3 perspectives: student, teacher, society

Workshop organisers collated notes from sessions and identified solutions highlighted in workshop as they addressed multiple issues and/or were continually brought up and developed across category discussions

9 solutions identified

Manuscript prepared with ranked issues presented from the 3 main perspectives, followed by the top forward-looking solutions, with workshop participants commenting further.

1163

1164   **Figure 2. Illustrated are the challenges, solutions, and opportunities identified in**
1165   **ecology teaching and learning for students, teachers, and society.** The main issues
1166   identified by the participants are shown on the left. The dominant solutions and opportunities
1167   identified in this study to address the challenges are on the right, with the linkages shown by
1168   blue dots on the where the relevant horizontal and vertical lines intersect.
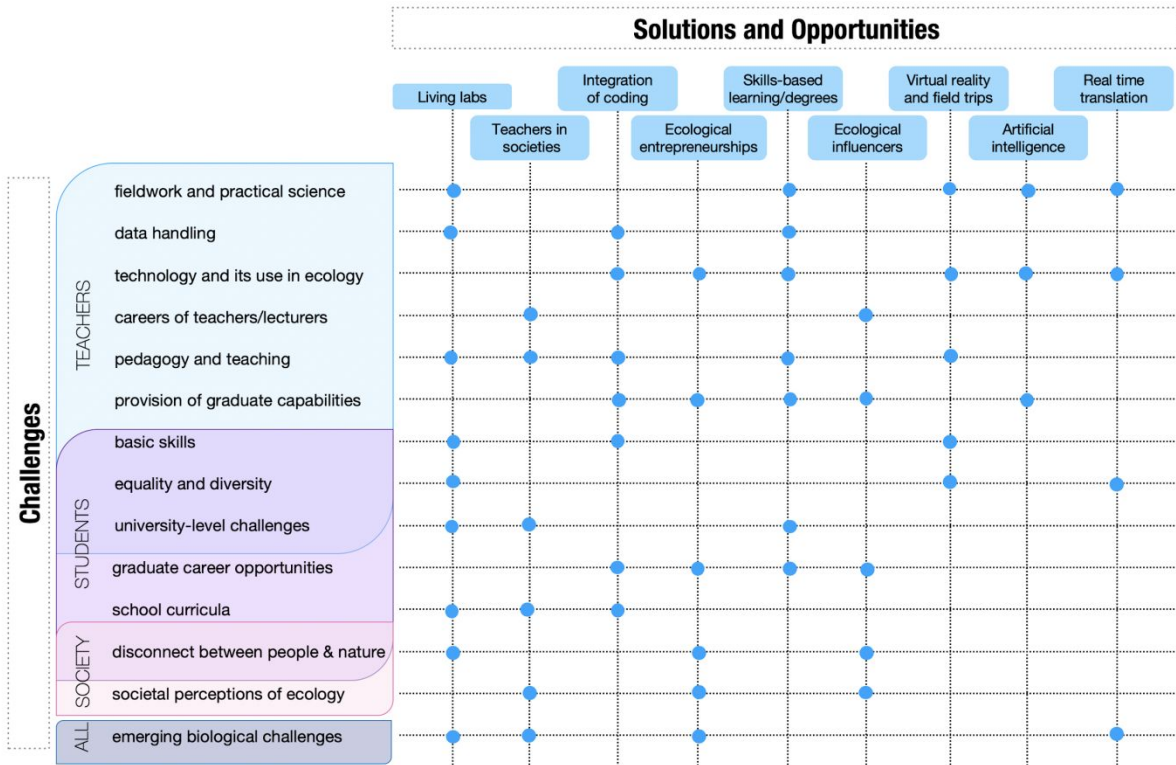
1169

1170 **Supplementary Information**

1171

1172 **Table S1. Locality of survey participants.** Due to rounding, the totals do not add up to 100%.

Respondent location	% respondents survey 1	% respondents survey 2
UK	84 %	83 %
Europe (but not UK)	6 %	4 %
Africa	0 %	0 %
Australasia	3 %	9 %
North America	4 %	2 %
South America	3 %	2 %
Asia	1 %	0 %
Total Respondents	97	46

1173

1174 **Table S2. Occupations of survey participants.** Due to rounding, the totals do not add up to
1175 100%.

Respondent Occupation	% respondents survey 1	% respondents survey 2
Higher Education	58 %	76 %
Secondary Education	14 %	4 %
Primary Education	8 %	2 %
Government	6 %	0 %
NGO	6 %	4 %
Policy Development	3 %	0 %
Consultancy	12 %	2 %

Industry	2 %	2 %
Research	18 %	24 %
Post graduate student	12 %	17 %
Undergraduate student	2 %	0 %
Other	10 %	0 %
Total Respondents	97	46

1176
1177

1178   **Figures S1-14. Rankings of main categories and subcategories.** Rankings were
1179   determined by first translating the ordering of issues, applied by each respondent, into
1180   numbers by assigning the highest ranked issue a score of n (where n = number of issues in
1181   the category), then second ranked allocated n-1 etc. For example, in the main categories,
1182   where there were 17 issues, if a respondent ranked "Disconnect between people and nature"
1183   first, it was given 17 points. The ***I don't want to rank below this line*** option was also given
1184   a score, even if ranked last and any issues ranked below the **I don't want to rank below this
1185   line** were automatically scored equal last. Scores were then summed for each issue across
1186   participants and these totals used to determine the overall ranking with highest scores
1187   representing the highest ranked issues. Here they are presented as relative rankings with the
1188   highest given a score of 100, and all other rankings listed in proportion to this. Rankings of
1189   subcategories not explicitly discussed at the workshop are not included.
1190
1191   Figure S1. Rankings of main categories
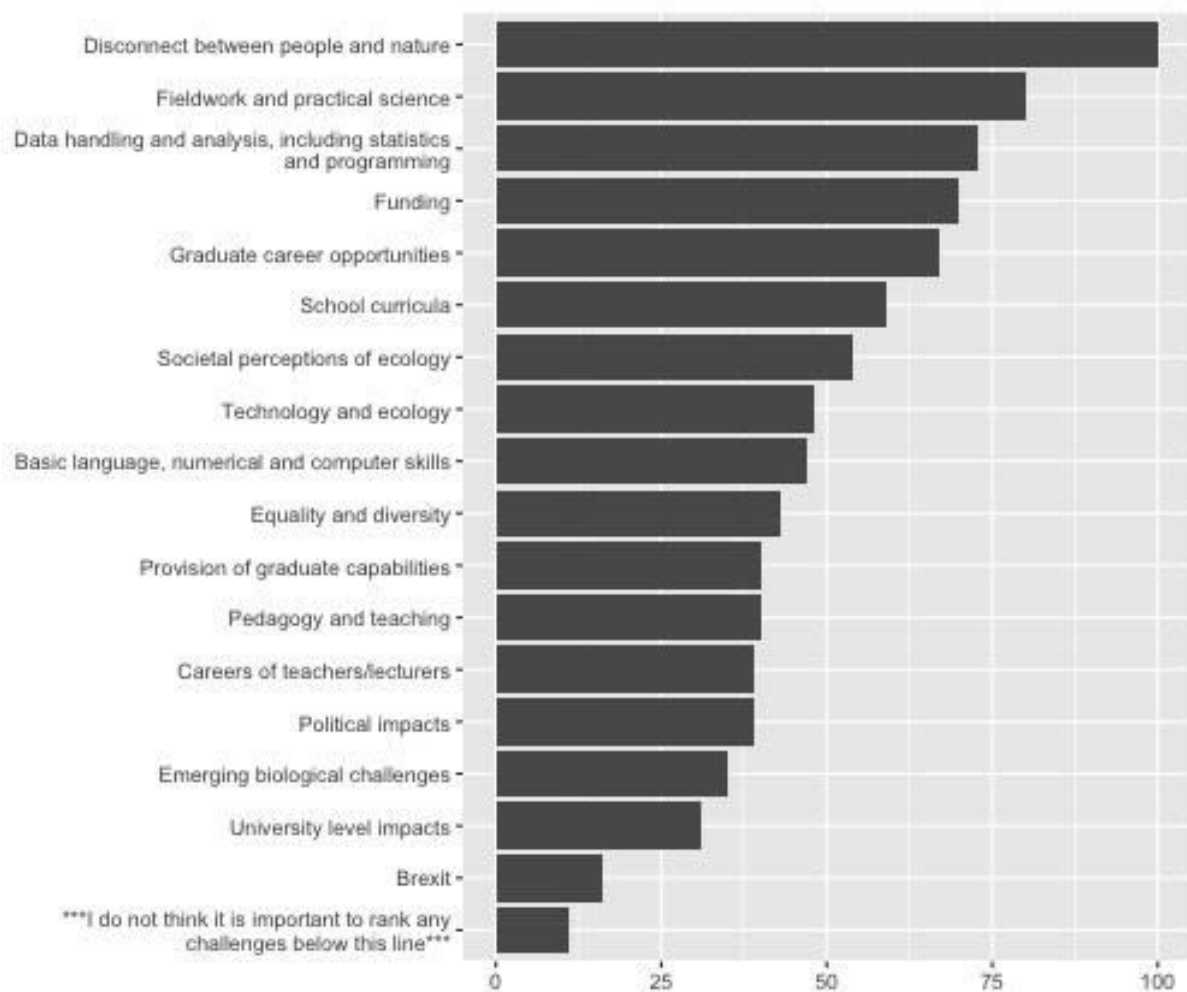
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1194   Figure S2. Rankings of issues associated with disconnect between people and nature
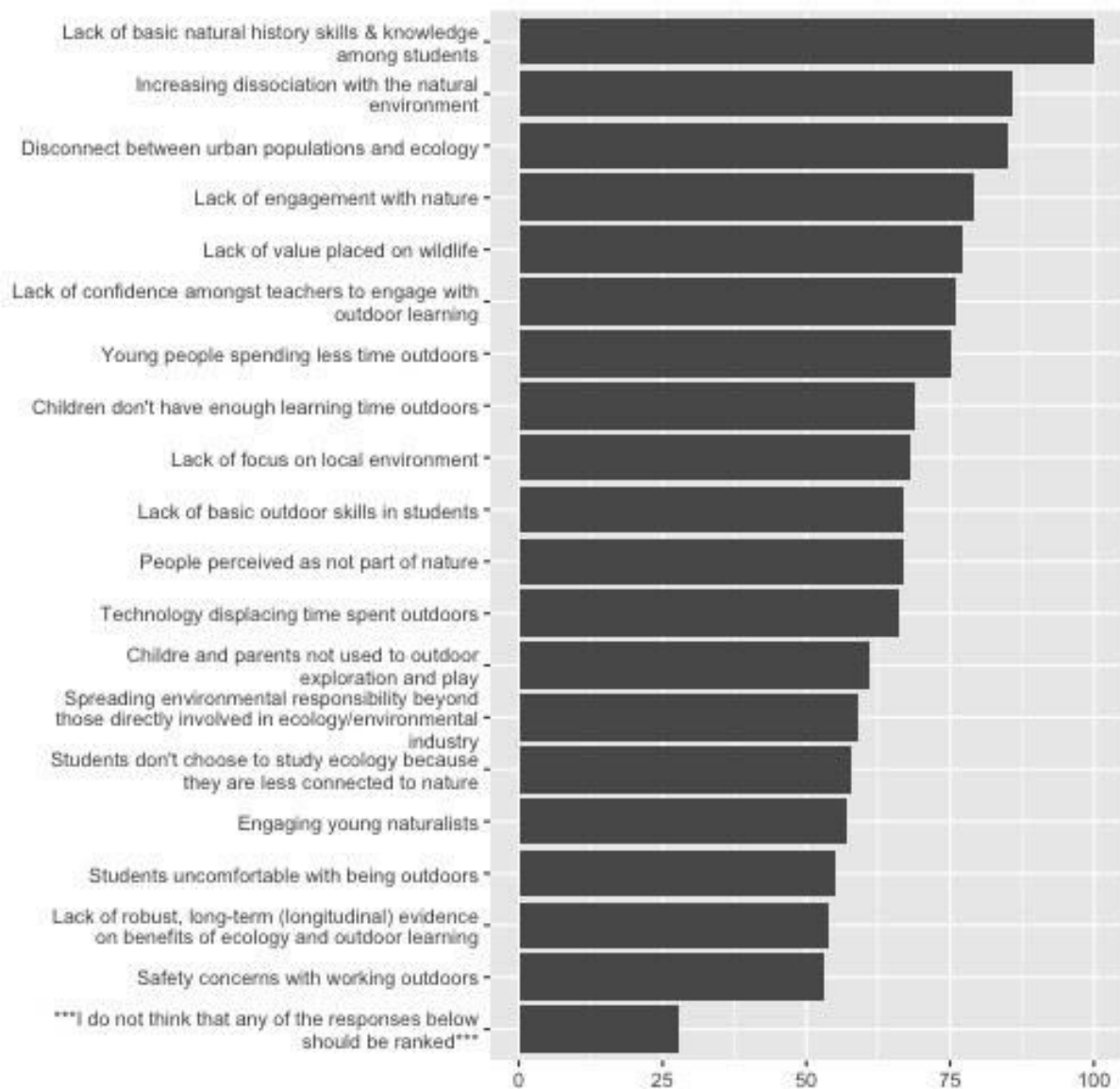
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1197   Figure S3. Rankings of issues associated with fieldwork and practical science
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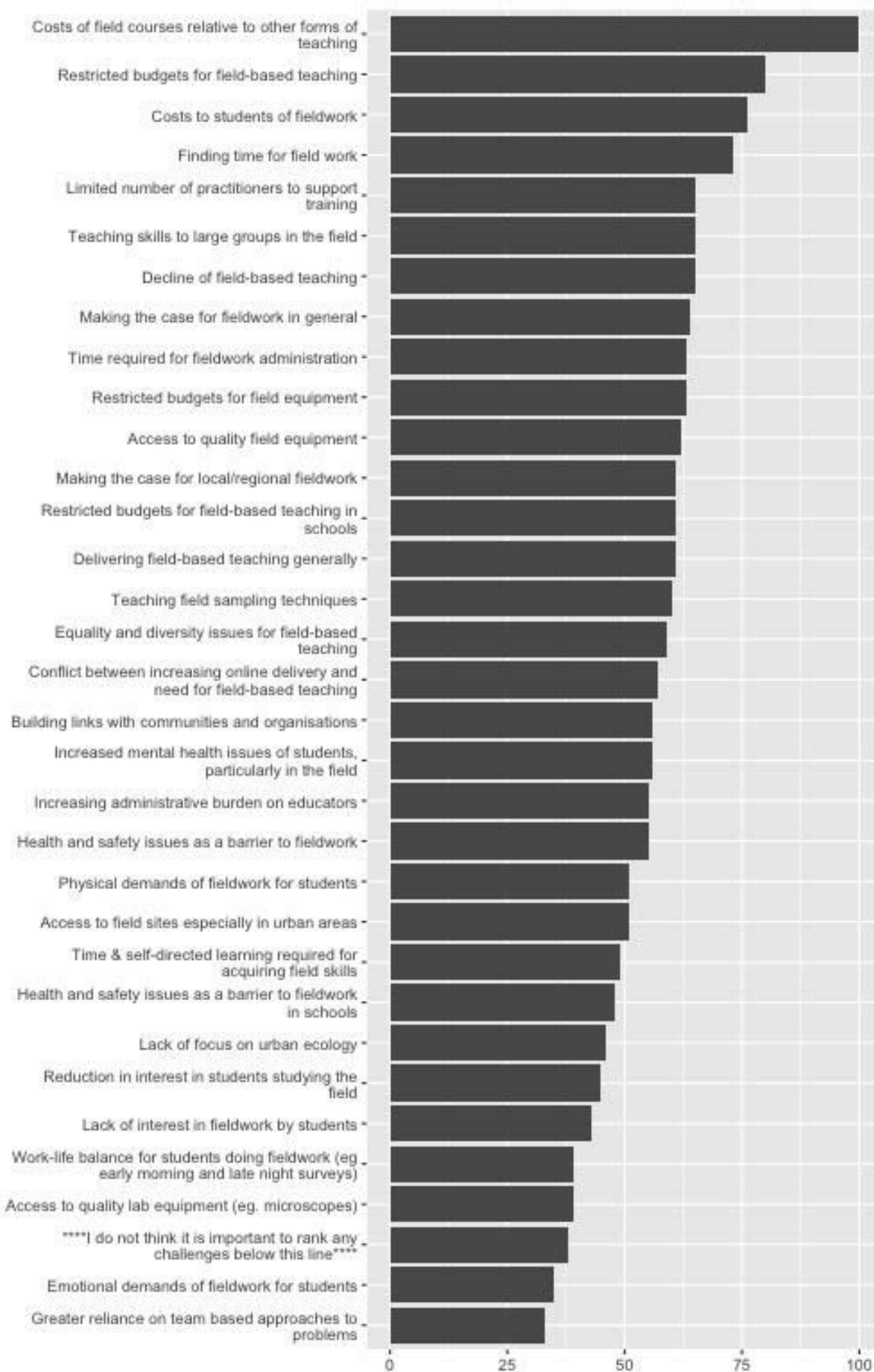
1200
1201   Figure S4. Rankings of issues associated with data handling and analysis, including statistics
1202   and programming

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1205   Figure S5. Rankings of issues associated with graduate career opportunities
1206
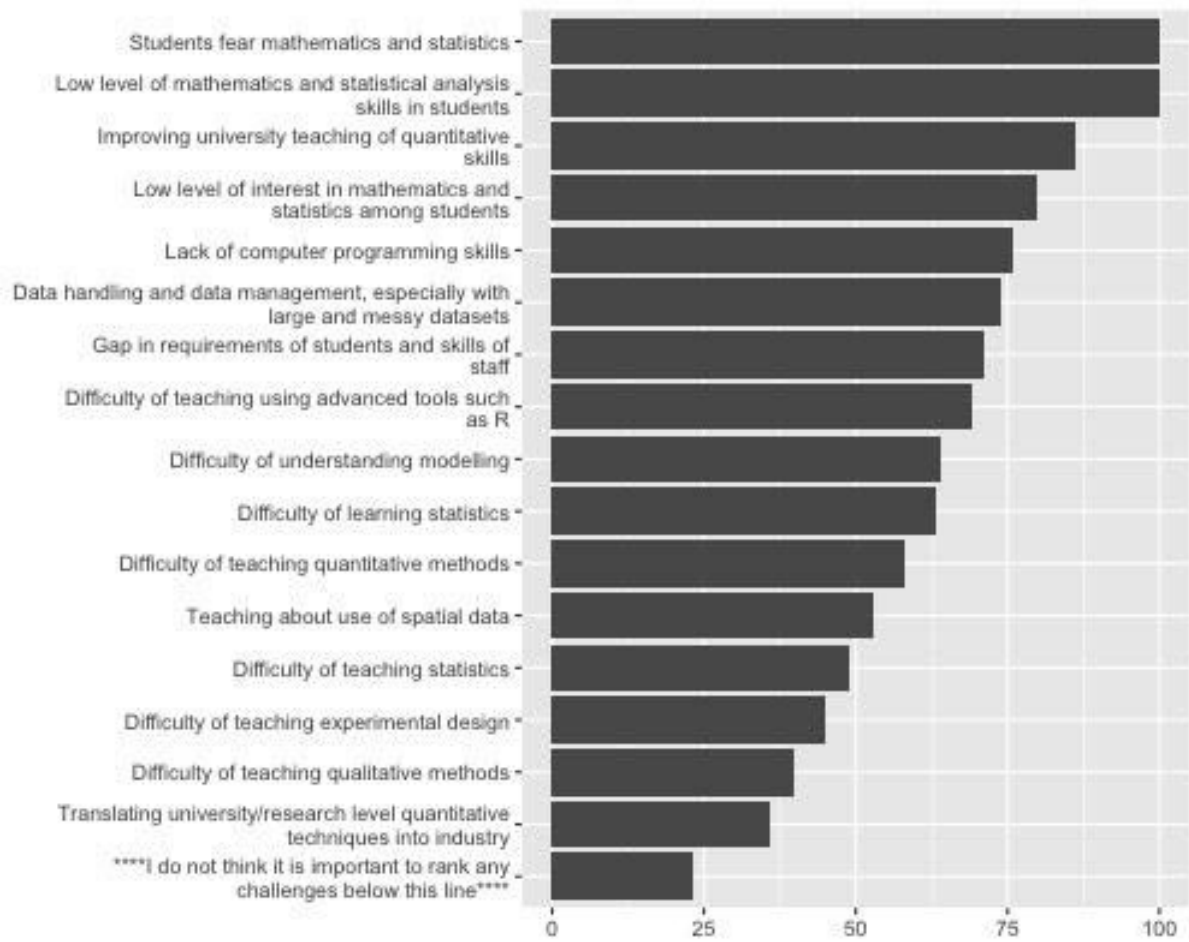
Lack of job availability
Few well paid jobs in ecology
Mismatch between cost of degrees and low salaries of ecology jobs
Possible exploitation - zero hour and short term contracts
Low paid status of sector
Diversity of careers poorly publicised
Ecology not valued as a career option by students
Lack of career progression
Lack of training opportunities
Ecology work involves long hours and large amounts of travel
Declining recruitment to ecology degrees
****I do not think it is important to rank any challenges below this line****
Too many ecology graduates
Graduates move overseas to pursue careers

1207

1208

1209   Figure S6. Rankings of issues associated with school curricula
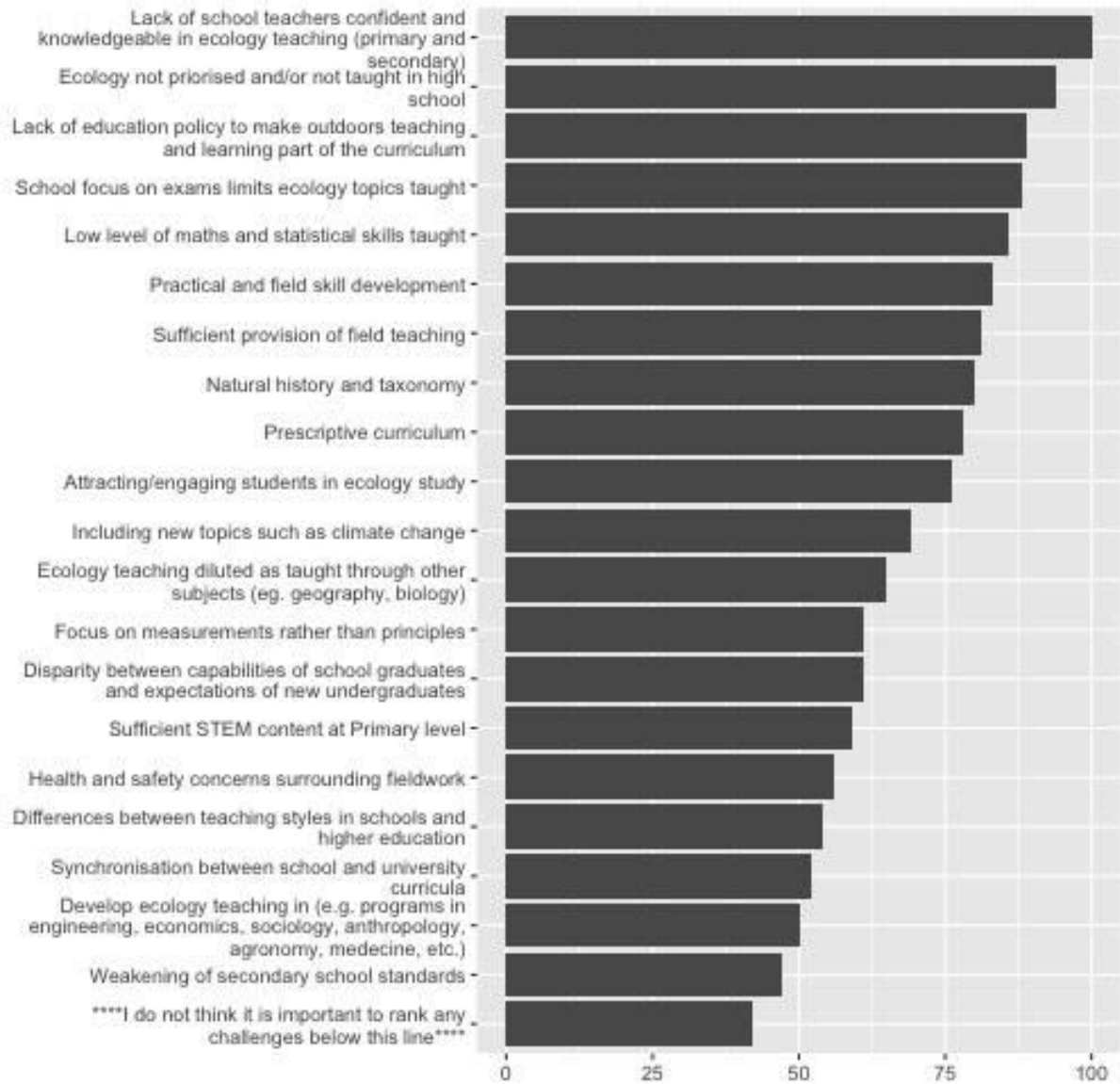
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1212   Figure S7. Rankings of issues associated with society perceptions
1213
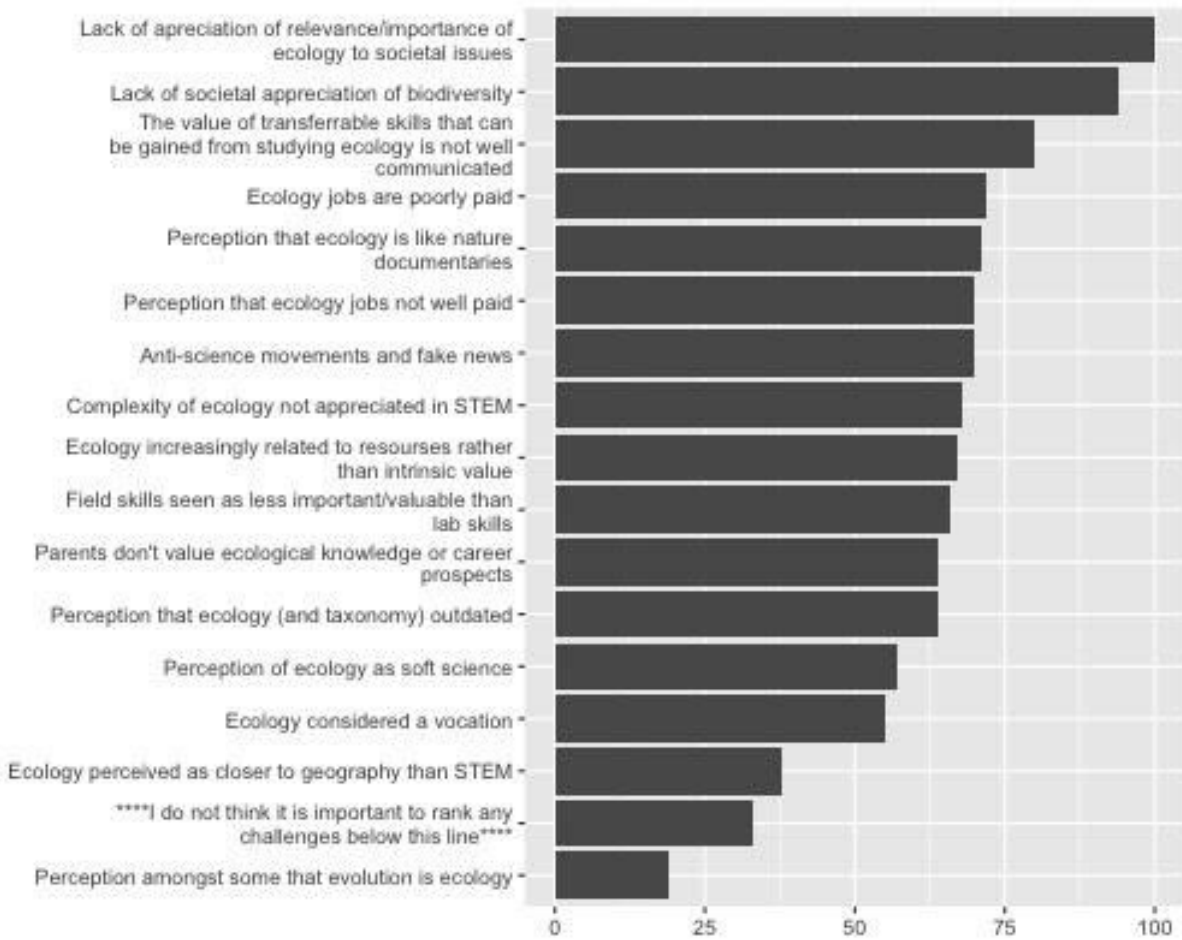
Figure S8. Rankings of issues associated with technology and ecology

Figure S9. Rankings of issues associated with basic language, numerical and computer skills

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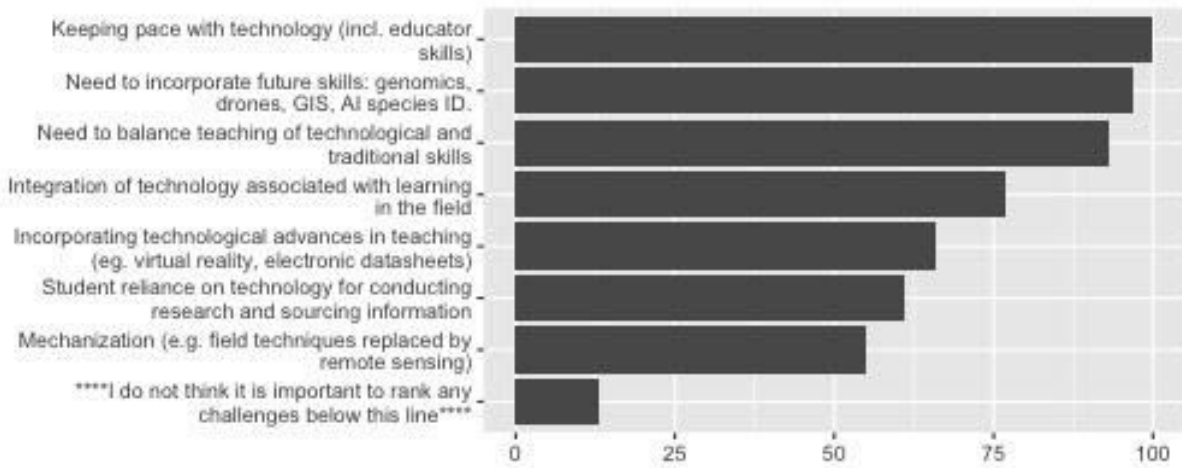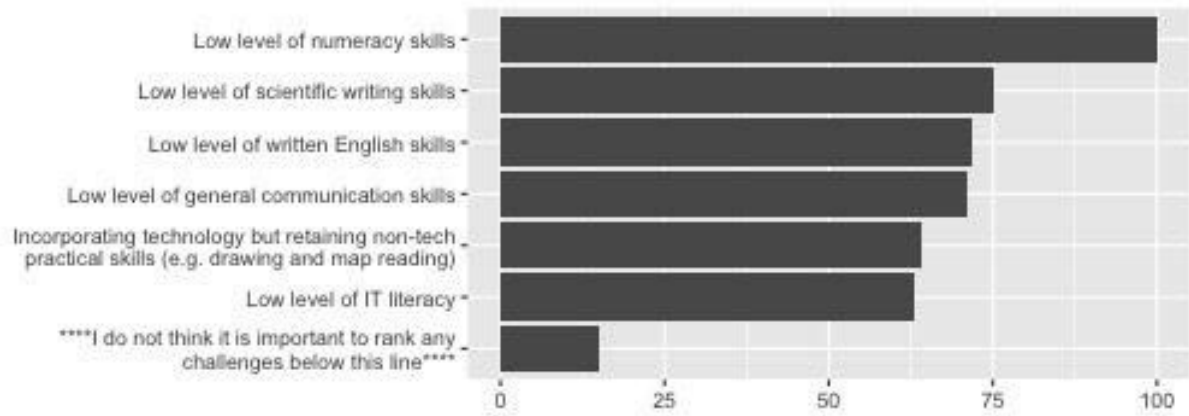
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1222   Figure S10. Rankings of issues associated with equality and diversity
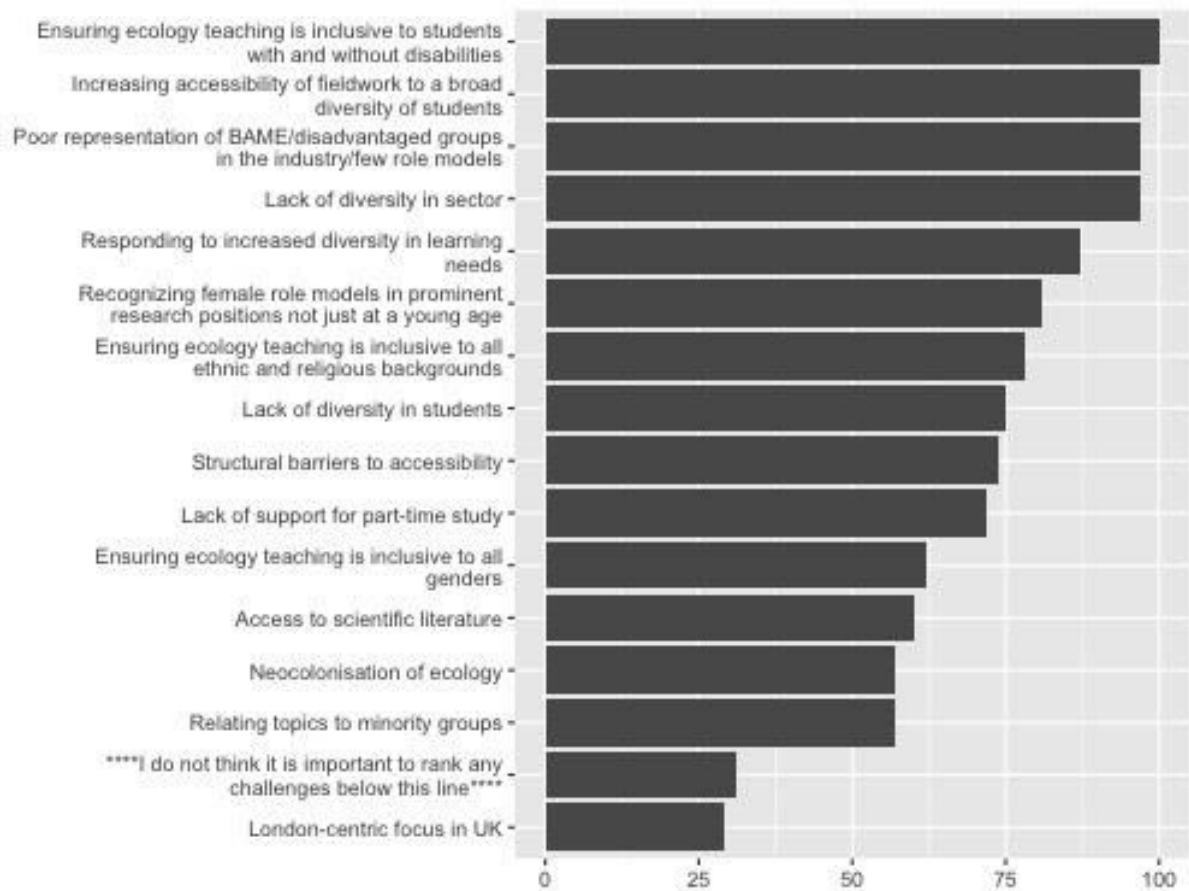
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1225   Figure S11. Rankings of issues associated with the provision of graduate capabilities
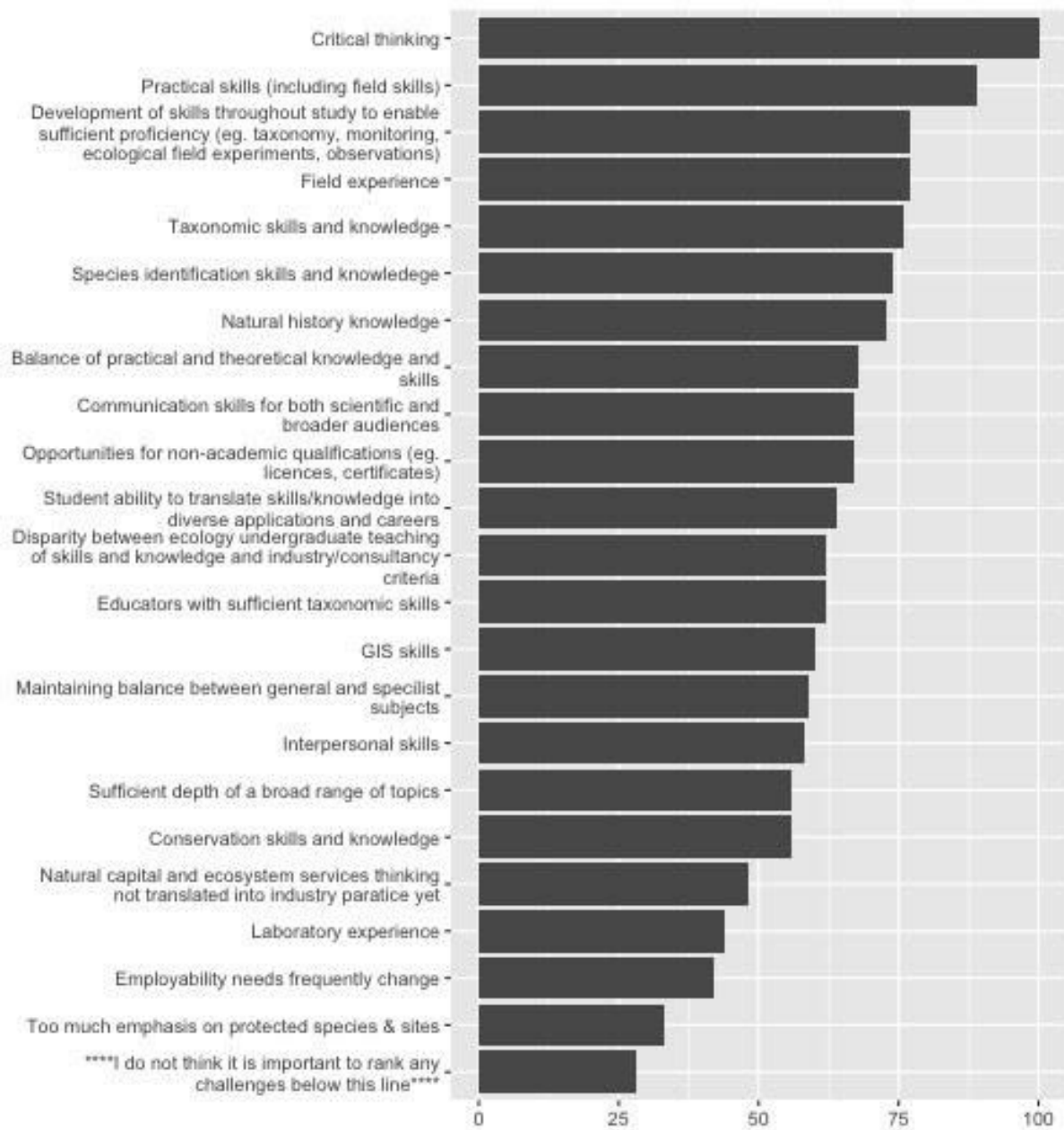
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1228   Figure S12. Rankings of issues associated with pedagogy and teaching
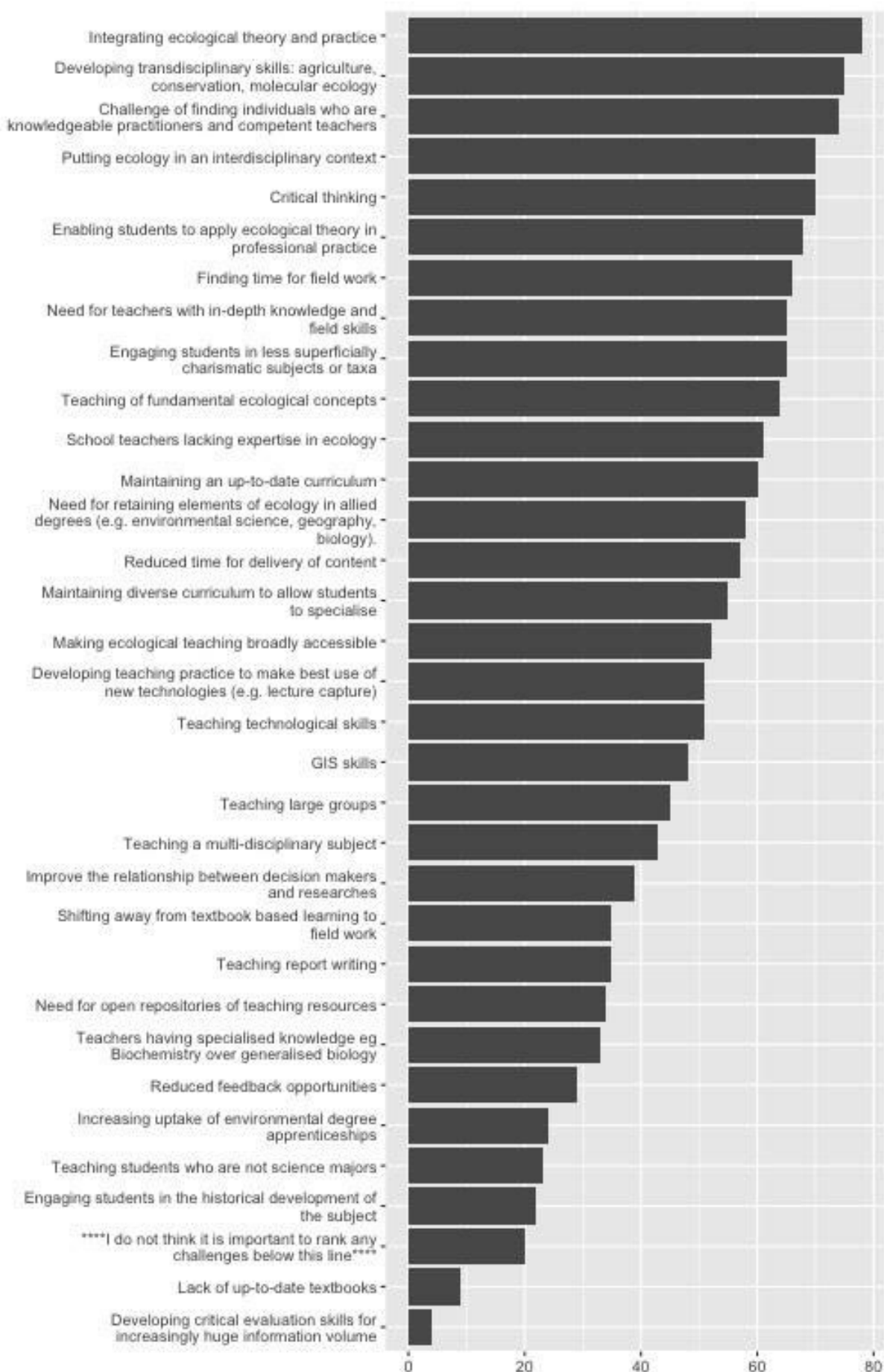
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1231   Figure S13. Rankings of issues associated with the careers of teachers/lecturers
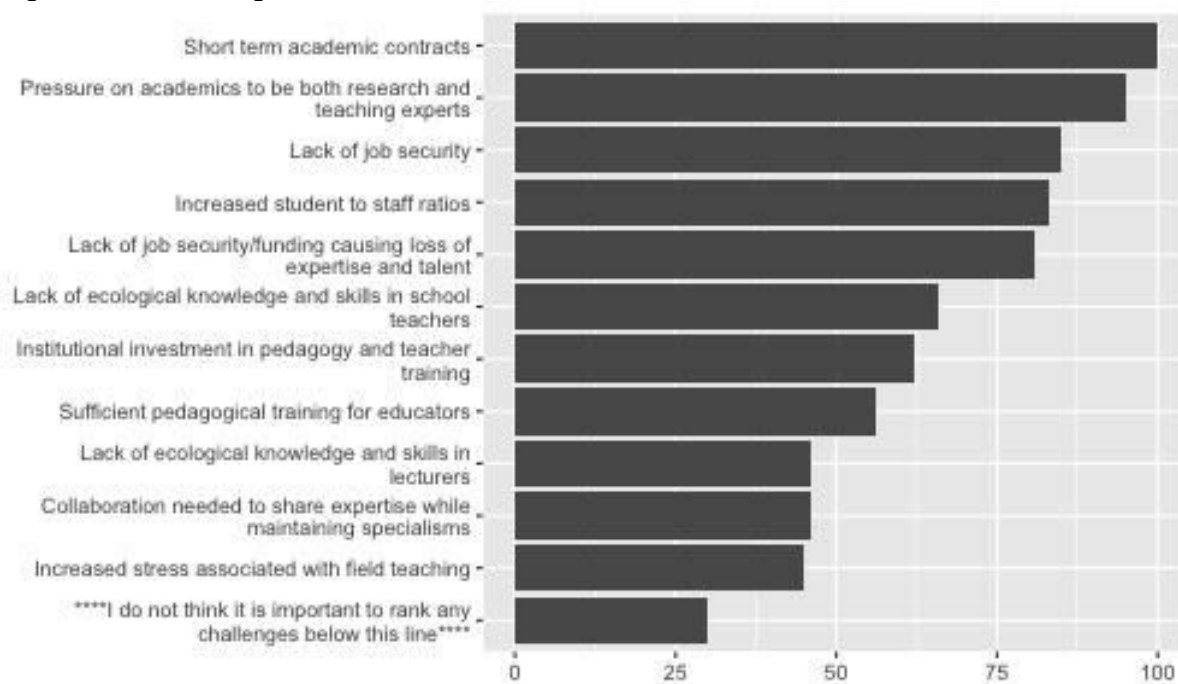
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1234   Figure S14. Rankings of issues associated with emerging biological challenges
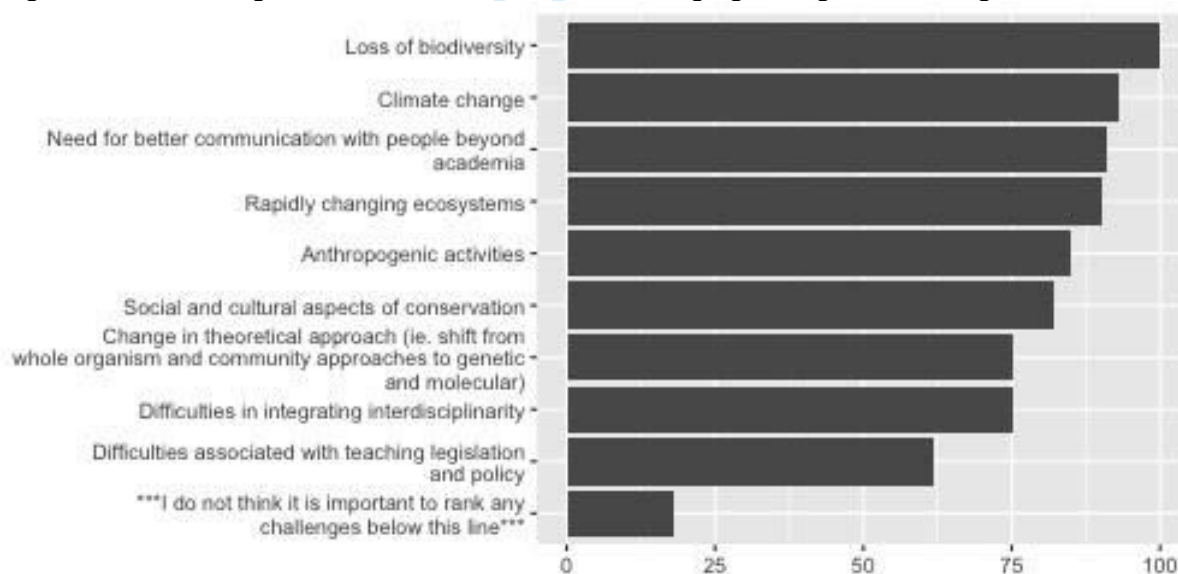
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Supplementary Information

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Figures S1-14. Rankings of main categories and subcategories. Rankings were determined by first translating the ordering of issues, applied by each respondent, into numbers by assigning the highest ranked issue a score of n (where n = number of issues in the category), then second ranked allocated n-1 etc. For example, in the main categories, where there were 17 issues, if a respondent ranked "Disconnect between people and nature" first, it was given 17 points. The ***I don't want to rank below this line*** option was also given a score, even if ranked last and any issues ranked below the **I don't want to rank below this line** were automatically scored equal last. Scores were then summed for each issue across participants and these totals used to determine the overall ranking with highest scores representing the highest ranked issues. Here they are presented as relative rankings with the highest given a score of 100, and all other rankings listed in proportion to this. Rankings of subcategories not explicitly discussed at the workshop are not included.

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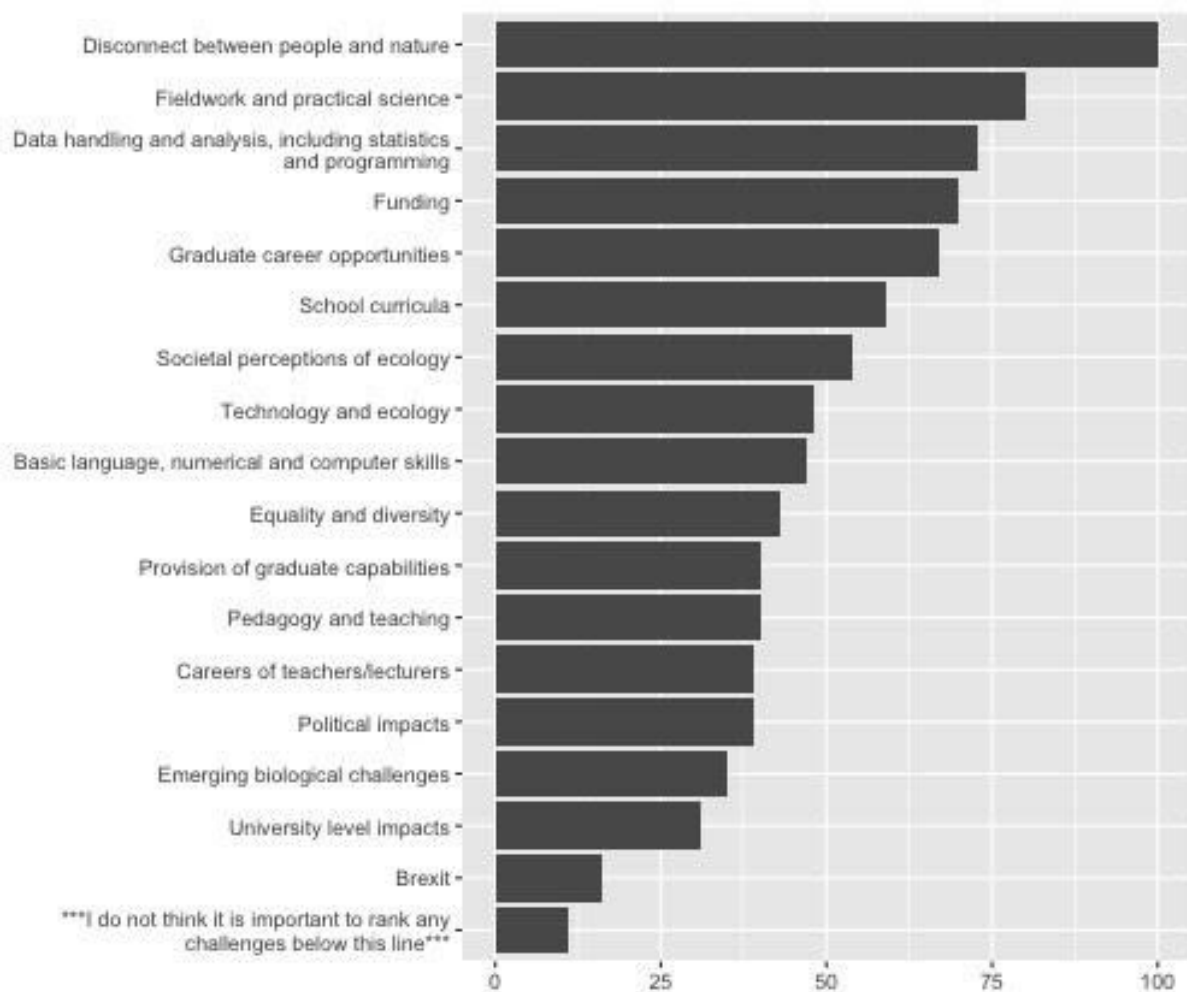
Figure S2. Rankings of issues associated with disconnect between people and nature
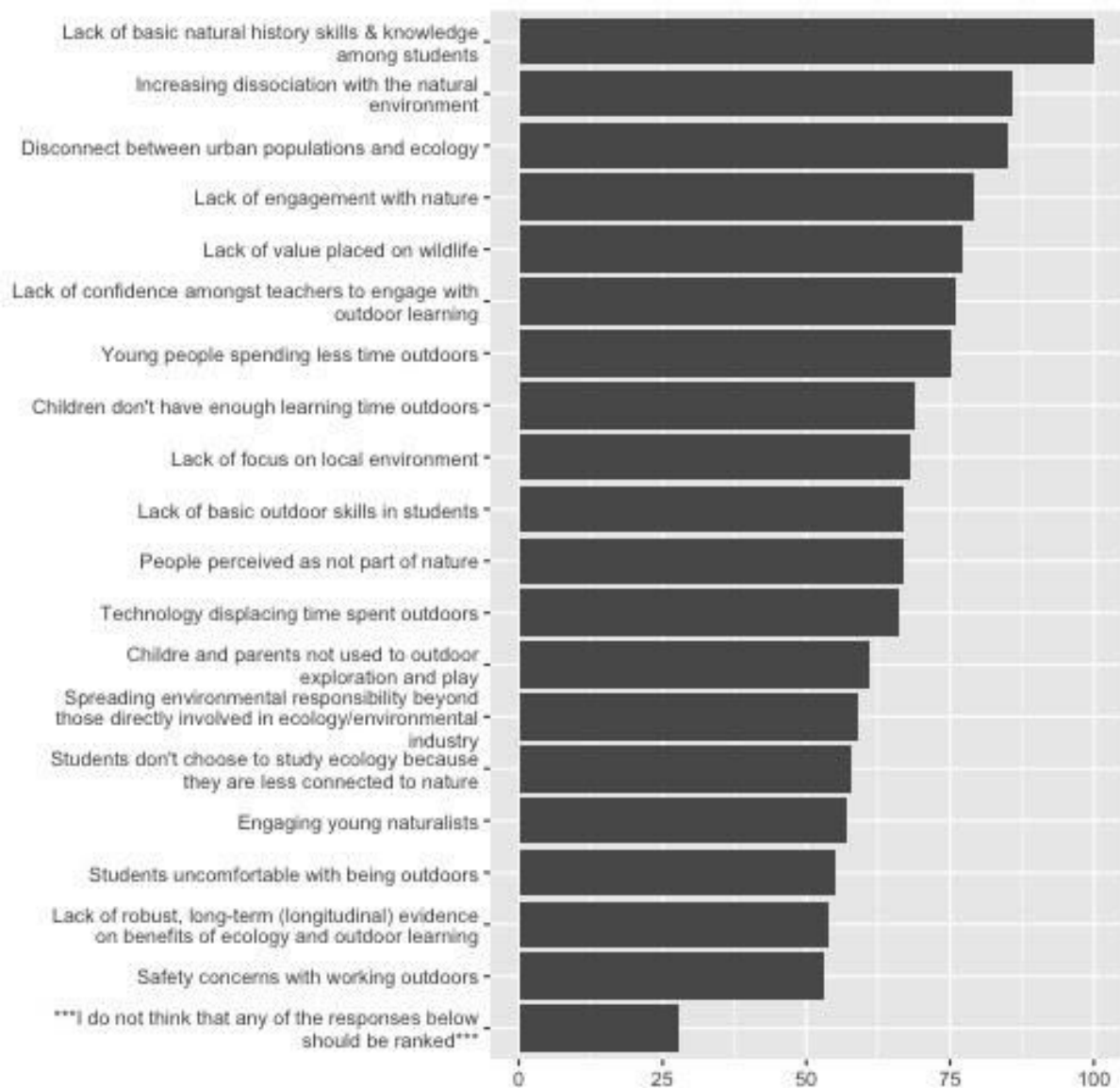
Figure S3. Rankings of issues associated with fieldwork and practical science
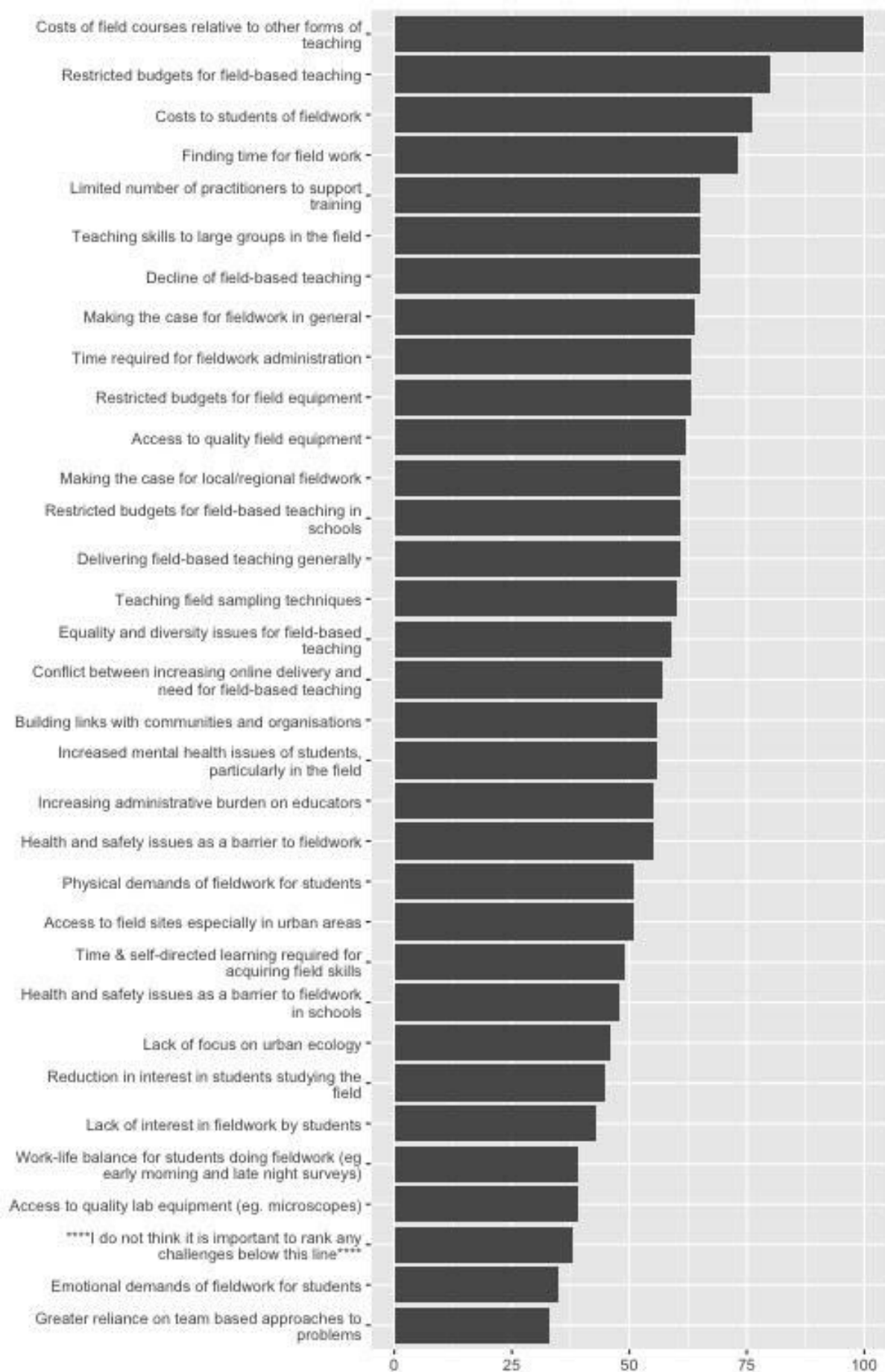
Figure S4. Rankings of issues associated with data handling and analysis, including statistics and programming
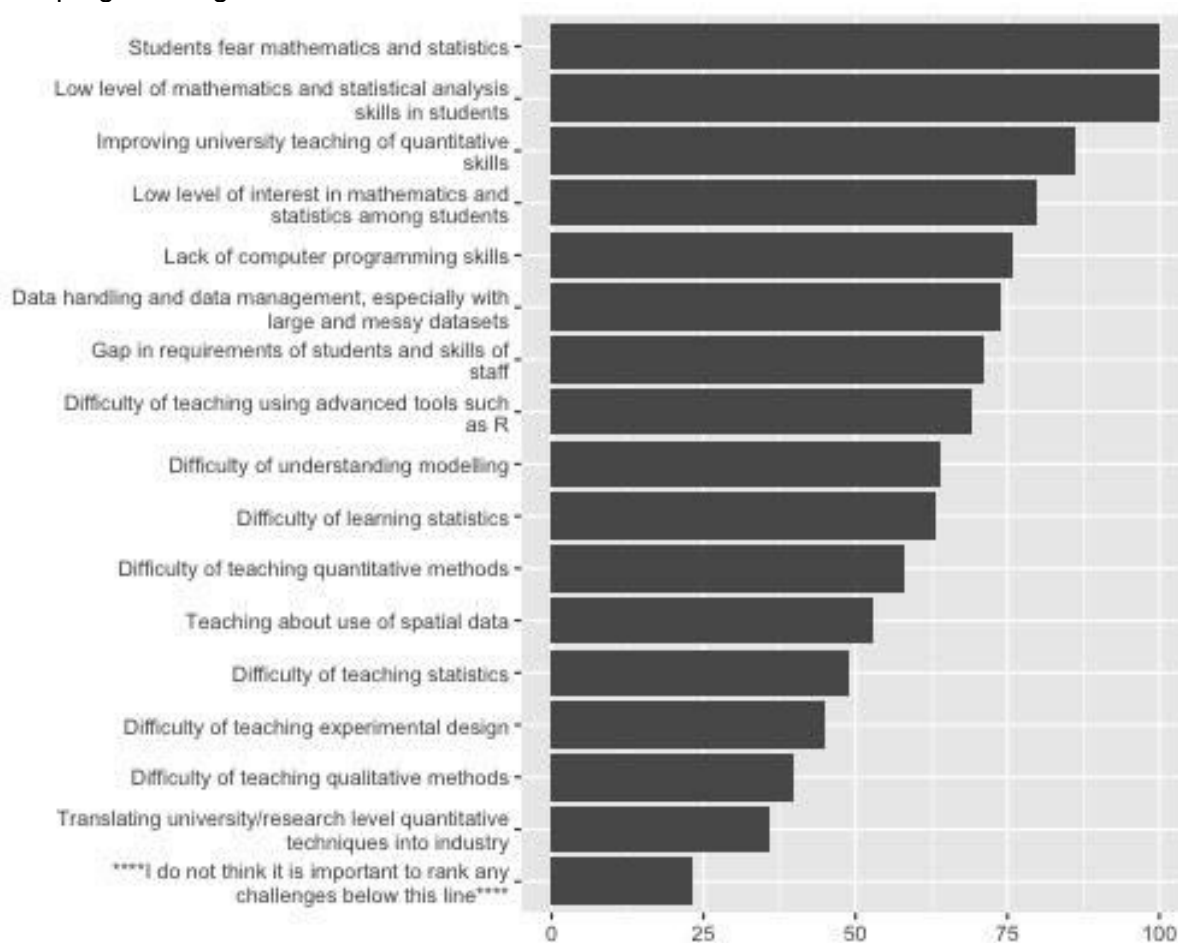
Figure S5. Rankings of issues associated with graduate career opportunities
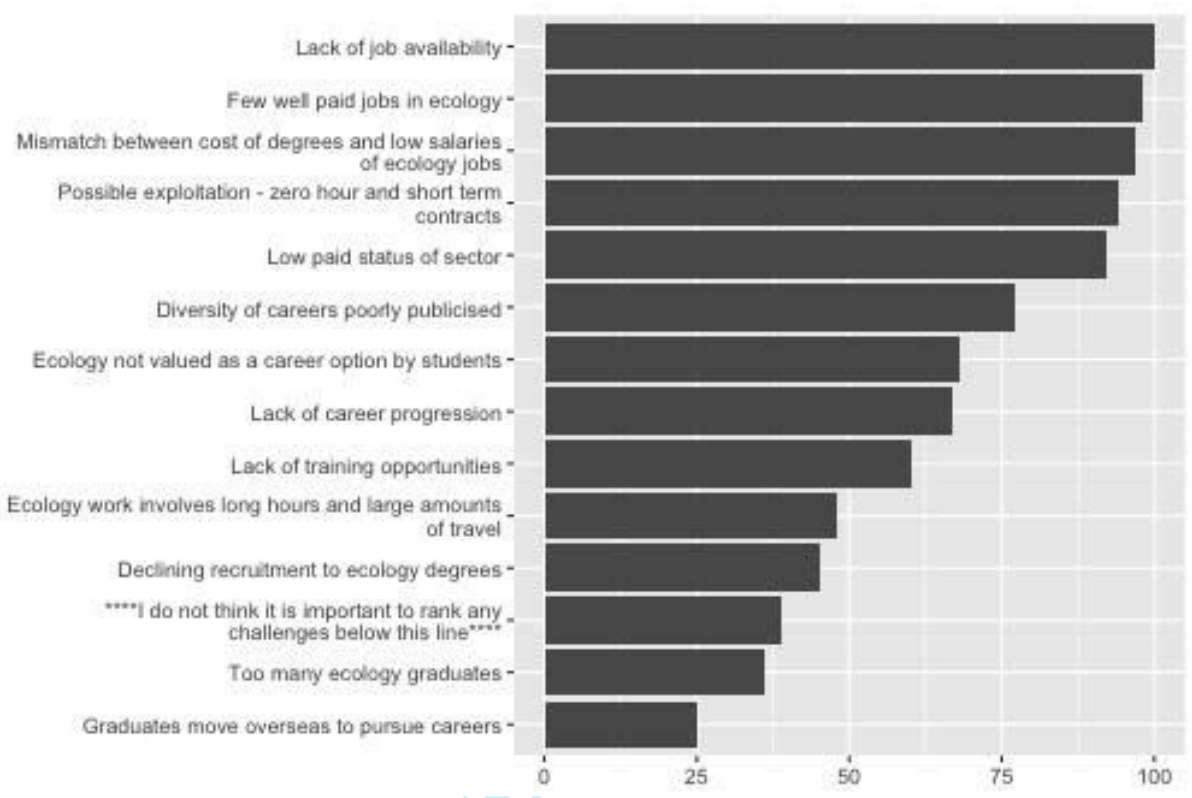
Figure S6. Rankings of issues associated with school curricula

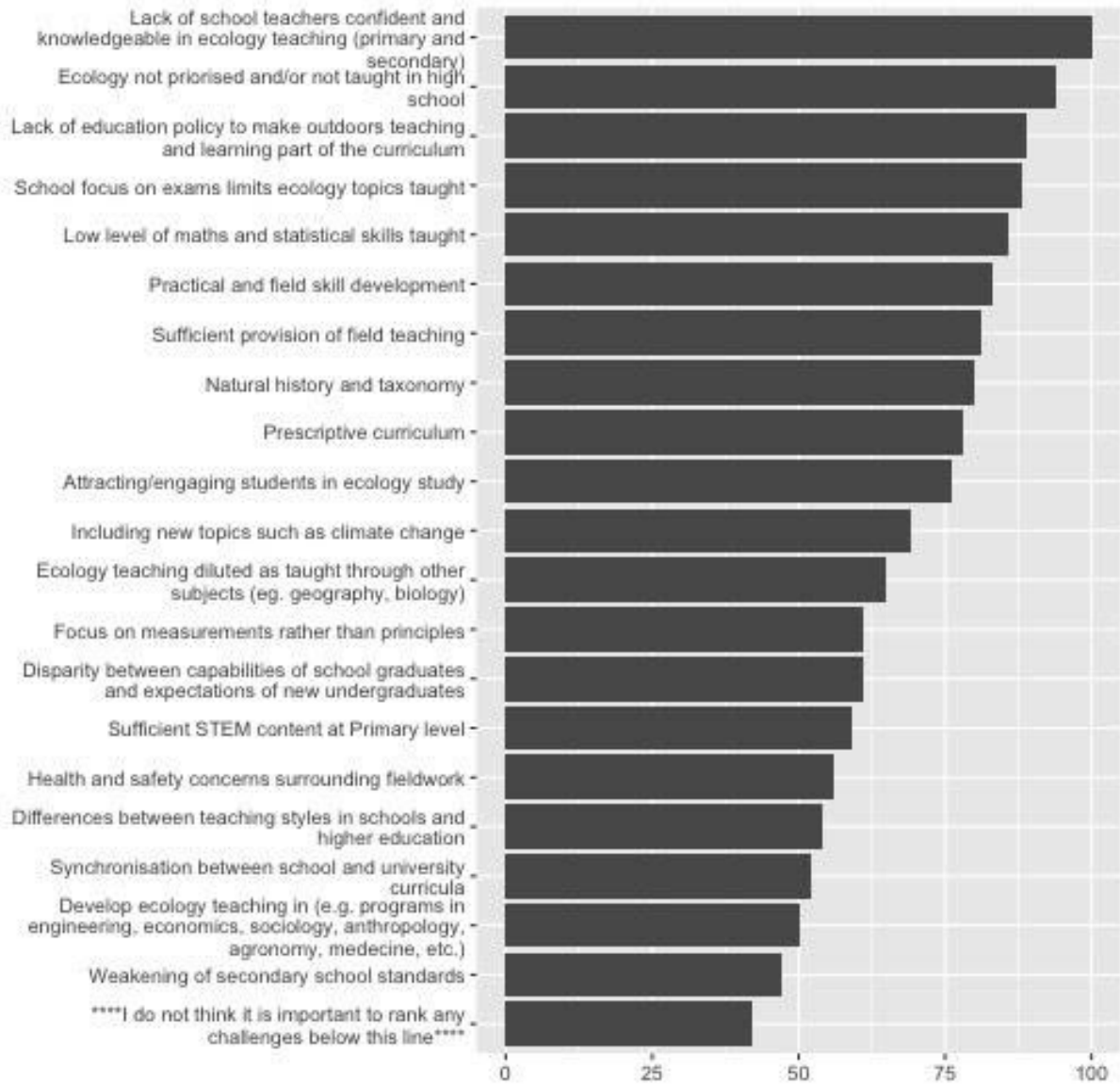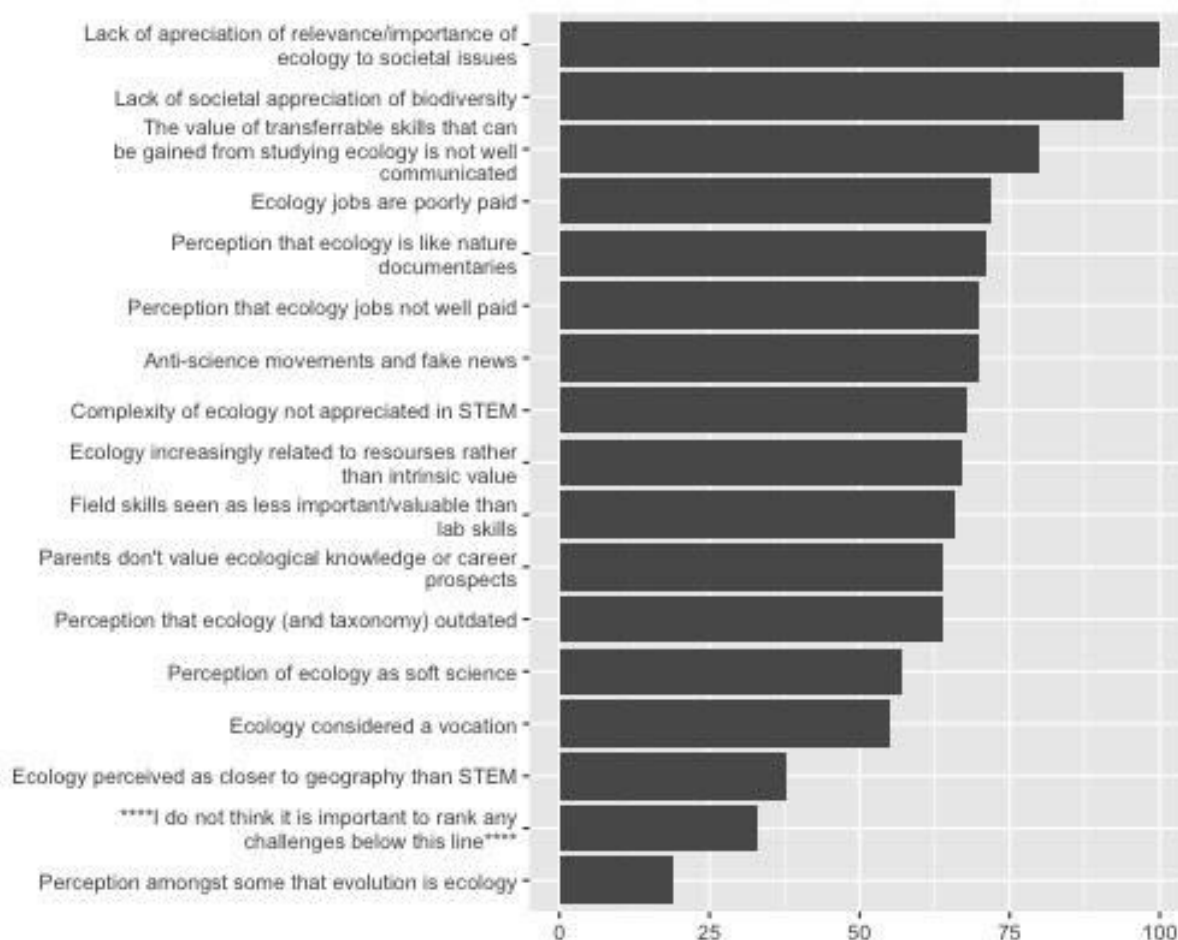Figure S7. Rankings of issues associated with society perceptions

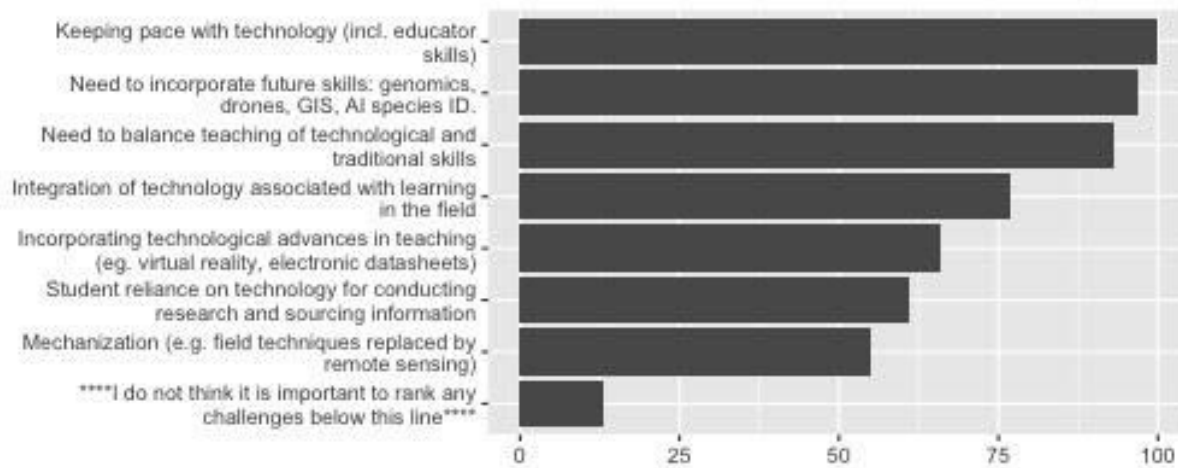Figure S8. Rankings of issues associated with technology and ecology

Figure S9. Rankings of issues associated with basic language, numerical and computer skills
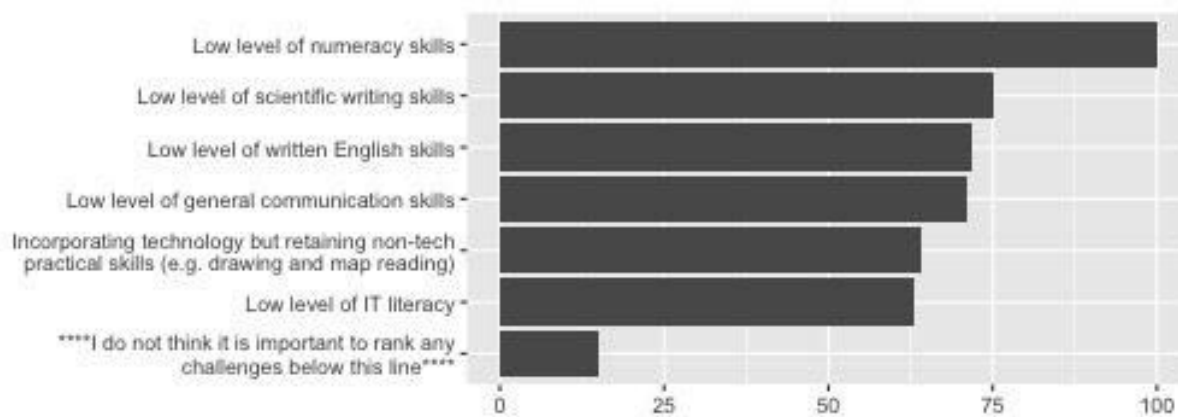
Figure S10. Rankings of issues associated with equality and diversity
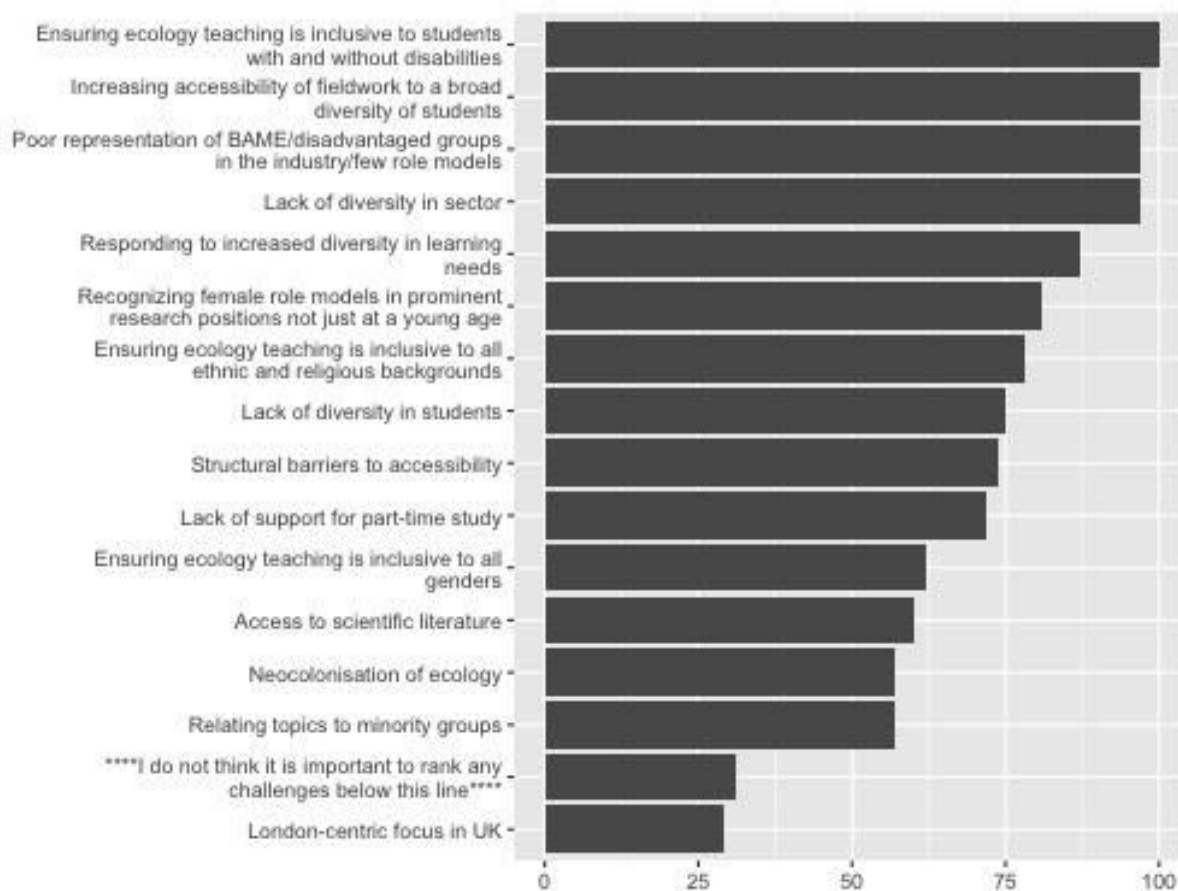
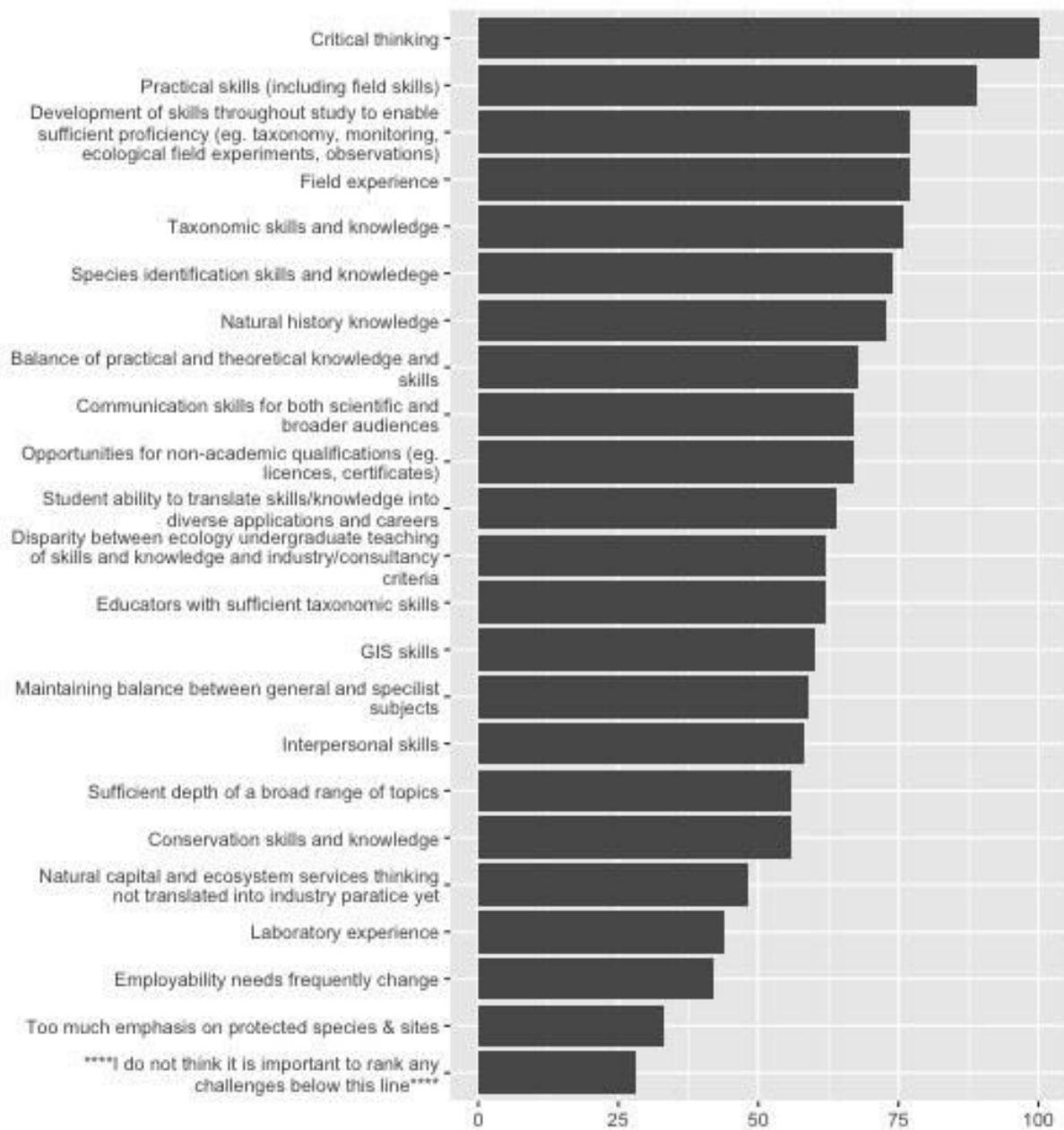Figure S11. Rankings of issues associated with the provision of graduate capabilities

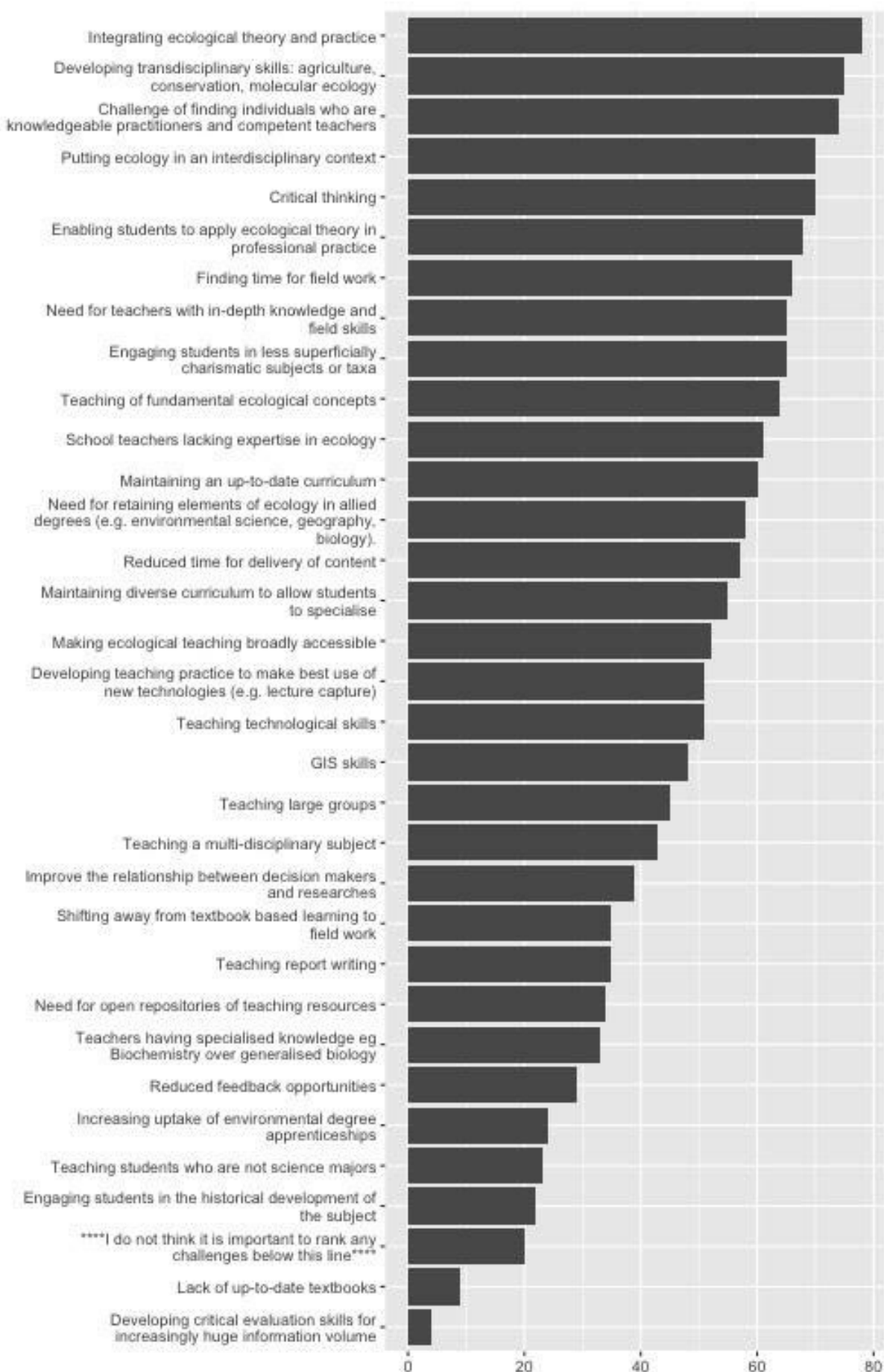Figure S12. Rankings of issues associated with pedagogy and teaching

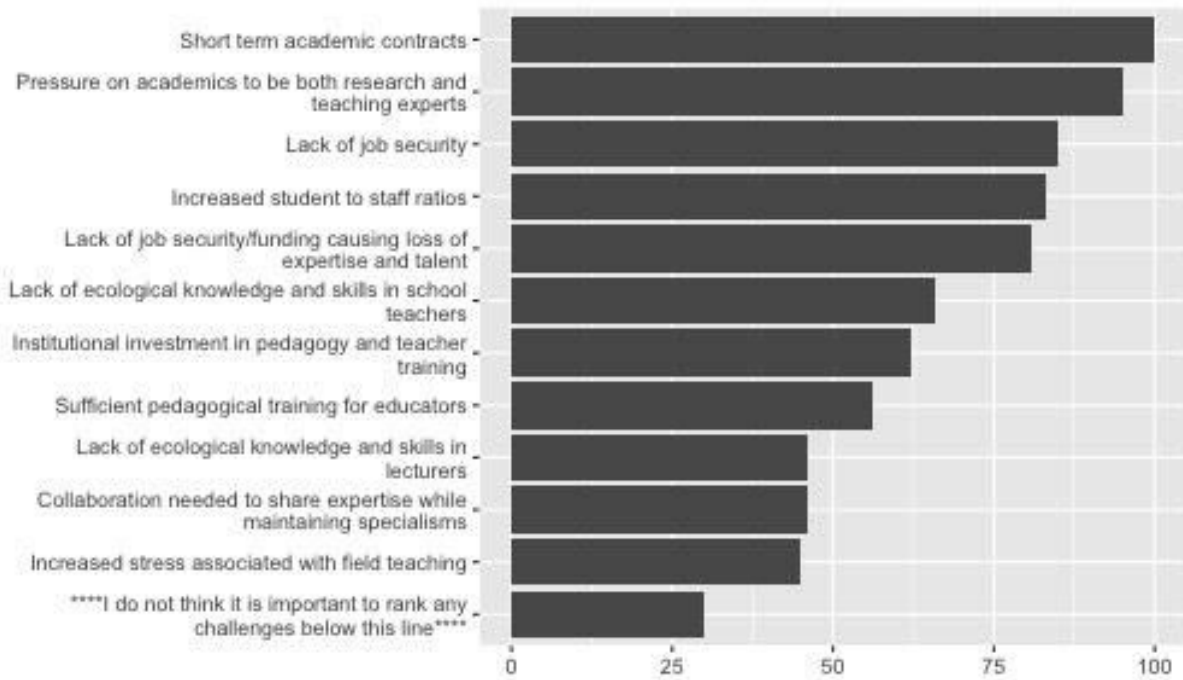Figure S13. Rankings of issues associated with the careers of teachers/lecturers

Figure S14. Rankings of issues associated with emerging biological challenges