

# Reproducible research and GIScience: an Evaluation using AGILE conference papers

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## ABSTRACT

The demand for reproducibility of research is on the rise in disciplines concerned with data analysis and computational methods. In this work existing recommendations for reproducible research are reviewed and translated into criteria for assessing reproducibility of articles in the field of geographic information science (GIScience). Using a sample of GIScience research from the Association of Geographic Information Laboratories in Europe (AGILE) conference series, we assess the current state of reproducibility of publications in this field. Feedback on the assessment was collected by surveying the authors of the sample papers. The results show the reproducibility levels are low. Although authors support the ideals, the incentives are too small. Therefore we propose concrete actions for individual researchers and GIScience conference series to improve transparency and reproducibility, such as imparting data and software skills, an award, paper badges, author guidelines for computational research, and Open Access publications.

## 1 INTRODUCTION

A "reproducibility crisis" has been observed and discussed in several scientific disciplines such as economics (Ioannidis, Stanley, and Doucouliagos, 2017), medical chemistry (Baker, 2017), or neuroscience (Button et al., 2013) and even across disciplines on scientific studies in general (Ioannidis, 2005). It stems from researchers facing challenges of understanding and re-creating results of others, a situation closely connected with data-driven and algorithm-based research. A reproducibility crisis has not yet been associated with geographic information science (GIScience) despite the fact that data and algorithms are becoming more relevant in the field. Although failures to reproduce are not a topic of broad and common interest in GIScience, the goal should be to prevent a crisis instead of reacting to one. Given this motivation, we aim to adapt the observations and

All links in this article were last accessed 23 November 2017.

38 challenges of reproducible research from other disciplines to the GIScience community, represented  
39 by AGILE conferences and the AGILE members. AGILE stands for Association of Geographic  
40 Information Laboratories in Europe; this association organises annual conferences on GIScience  
41 topics since 1998<sup>1</sup>. The conference series's broad topical scope and its wide acceptance in the  
42 respective community make it a reasonable starting point for our investigation of the level of  
43 reproducibility in GIScience. This publication continues a collaboration started at the AGILE 2017  
44 pre-conference workshop "Reproducible Geosciences Discussion Forum"<sup>2</sup>.

45 In this work, we first review papers from other disciplines, which provide recommendations  
46 on how to make research more transparent and reproducible. This literature study forms the basis  
47 for criteria to systematically evaluate a sample of 32 AGILE conference papers of the last eight  
48 years. From this evaluation and the lessons learned by others, we formulate recommendations for  
49 the AGILE community, ranging from individual researcher's practises to conference organisation.  
50 Because of its international reach, broad range of topics, and long-sustained community, we argue  
51 that AGILE is in a unique position to take a leading role to promote reproducibility in GIScience.  
52 The following research questions (RQs) structure the remainder of this article:

53 RQ 1 *What are general criteria for reproducible research?*

54 RQ 2 *What are key criteria for reproducible research in GIScience?*

55 RQ 3 *How do AGILE conference papers meet these reproducibility criteria?*

56 RQ 4 *What strategies could improve reproducibility in AGILE contributions and GIScience in  
57 general?*

## 58 2 RELATED WORK

59 Reproducible research is a frequently discussed topic in editorials and viewpoint articles in high-  
60 impact journals (cf. Section 3.2). Extensive studies on the state of reproducibility have been  
61 conducted in some domains, e.g. in computer systems research (Collberg and Proebsting, 2016)<sup>3</sup>  
62 or bioinformatics (Hothorn and Leisch, 2011). Brunsdon (2016) and Giraud and Lambert (2017)  
63 discuss the topic in quantitative geography and cartography respectively; Ostermann and Granell  
64 (2017) examine the domain of volunteered geographic information (VGI). No comprehensive study  
65 of reproducibility in the GIScience domain has been conducted.

66 Even though recent studies (Tenopir et al., 2011; Ioannidis, 2014) highlight an increased  
67 awareness of and willingness for open research, they also draw attention to persistent issues and  
68 perceived risks associated with data sharing and publication, such as the lack of rewards and the  
69 concern to lose recognition in a competitive academic environment. Beyond individual concerns,  
70 there are systematic impediments. Some (Stodden, McNutt, et al., 2016; McNutt, 2014; Ioannidis,  
71 2014) remark reproducible research is not an individual researcher's but a multi-actor endeavour,  
72 which requires a collective mind shift within the scientific community. Funding agencies, research  
73 institutions, publishers, journals, and conferences are all responsible to promote reproducible  
74 research practises. Existing examples<sup>4</sup> are remarkable yet in the big picture scarce and testimonial.

<sup>1</sup><https://agile-online.org/index.php/conference/past-agile-conferences>

<sup>2</sup><http://o2r.info/agile-2017/>

<sup>3</sup>See also project website <http://reproducibility.cs.arizona.edu/>

<sup>4</sup>Journals welcoming reproducible papers:

### 75 3 MATERIALS & METHODS

#### 76 3.1 What is Reproducibility?

77 Given the distinct nature and variety of research practises, the term reproducibility has been used  
78 with varying meanings and may stand for repeatability, robustness, reliability or generalisability of  
79 scientific results (Editorial, 2016). There has been some confusion about contradictory meanings in  
80 the literature (see for example Mark Liberman's "Replicability vs. reproducibility"<sup>5</sup>). Wikipedia's  
81 definition<sup>6</sup> is widely used to distinguish both terms:

82         Reproducibility is the ability to get the same research results using the raw data  
83         and computer programs provided by the researchers. A related concept is replicability,  
84         meaning the ability to independently achieve similar conclusions when differences in  
85         sampling, research procedures and data analysis methods may exist.

86         Leek and Peng (2015) similarly define reproducibility as the ability to compute exactly the same  
87         results of a study based on original input data and details of the analysis workflow. They refer to  
88         replicability as obtaining similar conclusions about a research question derived from an independent  
89         study or experiment. A Editorial (2016) defines reproducibility as achieved when "another scientist  
90         using the same methods gets similar results and can draw the same conclusions". Stodden, McNutt,  
91         et al. (2016, p. 1240) base their reproducibility enhancement principles on "the ability to rerun the  
92         same computational steps on the same data the original authors used".

93         While most literature shares a common understanding of what these two concepts are, the  
94         application by the scientific communities is still inconsistent and leads to different methods and  
95         dissemination conventions, which both influence and are shaped by particular interpretations of  
96         reproducibility and replicability. In the field of GIScience, Ostermann and Granell (2017, p. 226)  
97         argue that "a reproduction is always an exact copy or duplicate, with exactly the same features and  
98         scale, while a replication resembles the original but allows for variations in scale for example".  
99         Hence, reproducibility is exact whereas replicability means confirming the original conclusions,  
100         though not necessarily with the same input data, methods, or results.

101         This paper focuses on reproducibility in the context of conference publications and adopts the  
102         described consensus in the following definition:

103         A reproducible paper ensures a reviewer or reader can recreate the computational  
104         workflow of a study or experiment, including the prerequisite knowledge and the compu-  
105         tational environment. The former implies the scientific argument to be understandable  
106         and sound. The latter requires a detailed description of used software and data, and both  
107         being openly available.

#### 108 3.2 Recommendations and Suggestions in Literature

109 Scientists from various disciplines suggest guidelines for open and reproducible research considering  
110 the specific characteristics of their field, e.g. Sandve et al. (2013) for life sciences, McNutt (2014)

Information Systems (<https://www.elsevier.com/journals/information-systems/0306-4379>), Vadose Zone  
Journal (<https://dl.sciencesocieties.org/publications/vzj/articles/14/10/vzj2015.06.0088>), GigaScience  
([https://academic.oup.com/gigascience/pages/instructions\\_to\\_authors](https://academic.oup.com/gigascience/pages/instructions_to_authors)), JASA (<http://www.sph.umn.edu/news/wolfson-named-reproducibility-editor-asa-statistics-journal/>)

<sup>5</sup><http://languageelog ldc.upenn.edu/nll/?p=21956>

<sup>6</sup><https://en.wikipedia.org/wiki/Reproducibility>

111 for field sciences, and Gil et al. (2016) for the geoscientific paper of the future. Our goal is to  
112 identify common recommendations applicable across research fields, including GIScience.

113 Suggestions in the investigated papers were categorised according to four aspects: data concerns  
114 all inputs; methods cover everything on the analysis of data, e.g. algorithms, parameters, and source  
115 code; results include (intermediate) data and parameters as well as outcomes such as statistics, maps,  
116 figures, or new datasets; structure considers the organisation and integration of the other aspects.  
117 While some of the publications focus on specific aspects such as data (Gewin, 2016), code (Stodden  
118 and Miguez, 2014), workflow semantics (Scheider, Ostermann, and Adams, 2017), and results  
119 (Sandve et al., 2013), others provide an all-embracing set of research instructions (Stodden, McNutt,  
120 et al., 2016; Nosek et al., 2015; Gil et al., 2016).

### 121 **3.2.1 Data**

122 A recurrent aspect is making data accessible for other researchers (cf. Reichman, M. B. Jones,  
123 and Schildhauer, 2011), ideally as archived assets having a Digital Object Identifier (DOI) and  
124 supplemented by structured metadata (Gewin, 2016). Stodden, McNutt, et al. (2016) consider  
125 legal aspects, such as sharing data publicly under an open license to clarify reusability. Further  
126 recommendations refer to scientific practises, for example, citation standards to ensure proper  
127 acknowledgement (Nosek et al., 2015), fostering data transparency (McNutt, 2014), and open data  
128 formats to mitigate potentially disappearing proprietary software (Gewin, 2016). According to  
129 Reichman, M. B. Jones, and Schildhauer (2011), journals and funders should include data sharing in  
130 their guidelines.

### 131 **3.2.2 Methods**

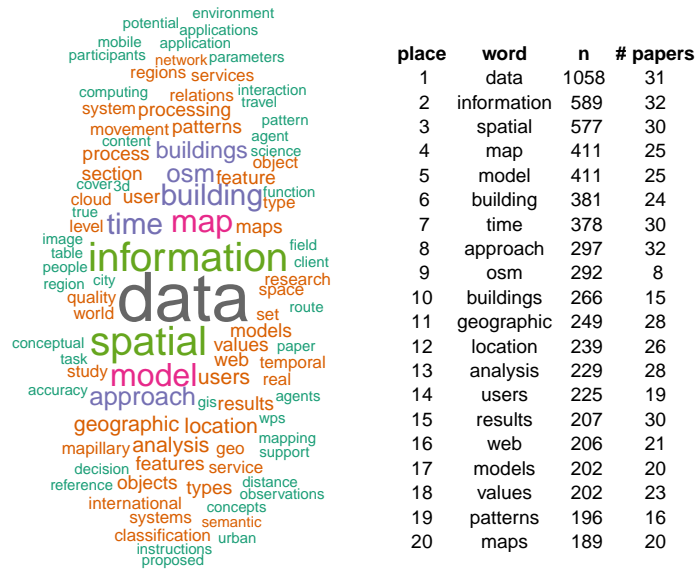
132 Sharing used or developed software is a key requirement (Sandve et al., 2013) concerning methods.  
133 It should be published by using persistent links (Stodden, McNutt, et al., 2016; Gil et al., 2016)  
134 and descriptive metadata (Reichman, M. B. Jones, and Schildhauer, 2011). Similar to data, open  
135 licensing (Barba, 2016) and proper credits (Stodden, McNutt, et al., 2016) are important. Researchers  
136 can accomplish software transparency by using version control systems (cf. Sandve et al., 2013).  
137 Transparency mandates using open source instead of proprietary software (Steiniger and Hay, 2009).  
138 Since full computational reproducibility can depend on exact software versions (Gronenschild et al.,  
139 2012), the computational environment needs to be reported (cf. Stodden, McNutt, et al., 2016;  
140 Gil et al., 2016). Further software-specific recommendations are workflow tracking (Stodden and  
141 Miguez, 2014) and keeping a record analysis parameters (Gil et al., 2016). Sandve et al. (2013)  
142 suggest avoiding manual data manipulation steps, instead using scripts to increase transparency in  
143 data preprocessing.

### 144 **3.2.3 Results**

145 Sandve et al. (2013) focuses on results-related guidelines such as storing intermediate results and  
146 noting seeds if computations include randomness. Journals should conduct a reproducibility check  
147 prior to publication (Stodden, McNutt, et al., 2016). Collberg and Proebsting (2016) propose funding  
148 explicitly for making research results repeatable. Barba (2016) describes the contents and benefits  
149 of a "reproducibility package" to preserve results.

### 150 **3.2.4 Structure**

151 An overarching structure for all aspects of research provides additional context, but none of the  
152 suggestions is widely established, for example Gentleman and Lang (2007) using programming



**Figure 1.** Word cloud of test corpus papers (left), scaled and coloured by number of occurrence, based on 96 unique words with at least 100 occurrences; top words based on overall occurrence and number of papers including the word at least once (right)

153 language packaging mechanisms, Bechhofer et al. (2013) using Linked Data, or Nüst et al. (2017)  
 154 using nested containers.

### 155 3.2.5 Summary

156 Most recommendations and suggestions to foster open research address data and methods. Particu-  
 157 larly methods cover a broad range of aspects including recommendations on data preprocessing, the  
 158 actual analysis, and the computational environment. Results receive less attention, possibly because  
 159 they are strongly connected with other aspects. While most of the recommendations address authors,  
 160 only few target journals and research institutions.

## 161 3.3 The Paper Corpus

162 We consider the AGILE conference series publications to be a representative sample of GIScience  
 163 research because of the conference's broad topical scope. Since 2007, the AGILE conference has a  
 164 full paper track (cf. Pundt and Toppen, 2017) and a short paper track with blind peer review. The  
 165 latter is published for free on the AGILE website. Legal issues (full paper copyrights lie with the  
 166 publisher<sup>7</sup>) and practical considerations (assessment of reproducibility is a manual time-consuming  
 167 process; old publications introduce bias because of software unavailability) led to the restriction of  
 168 our evaluation to nominees for the "best full and short paper" awards for 2010, and 2012 to 2017 (no  
 169 records for a best paper award could be found for 2011). Typically, there are three full paper and two  
 170 short paper candidates per year<sup>8</sup>. Exceptions are 2013 with only two full papers and 2010 without  
 171 any short papers. The corpus contains 32 documents: 20 full papers (7.9% of 253 full papers since  
 172 2007) and 12 short papers<sup>9</sup>.

<sup>7</sup><https://agile-online.org/index.php/conference/springer-series>

<sup>8</sup><https://agile-online.org/index.php/conference/proceedings>

<sup>9</sup>Full number of short papers cannot be derived automatically, see supplemental material.

**Table 1.** Reproducibility-related keywords in the corpus, ordered by sum of matches per paper

citation	reproduc..	replc..	repeatab..	code	software	algorithm(s)	(pre)process..	data	result(s)	all
Foerster et al. (2012)	0	0	0	2	3	11	140	129	41	326
Wiemann & Bernard (2014)	0	0	0	0	0	0	20	98	3	123
Mazimpaka & Timpf (2015)	0	0	0	3	0	4	4	97	10	118
Steuer et al. (2015)	0	0	0	0	0	25	12	64	17	118
Schäffer et al. (2010)	0	0	0	0	10	1	26	65	6	108
Rosser et al. (2016)	0	0	0	0	2	1	42	51	6	105
Gröchening et al. (2014)	0	0	0	0	0	3	2	69	27	101
Almer et al. (2016)	0	0	0	1	1	1	22	53	22	100
Magalhães et al. (2012)	0	0	0	2	1	20	52	9	1	85
Juhász & Hochmair (2016)	0	0	0	0	1	1	2	55	11	70
Wiemann (2016)	0	0	0	0	3	0	8	55	1	69
Fan et al. (2014)	0	0	0	0	0	3	8	44	12	67
Merki & Laube (2012)	0	0	0	0	0	9	6	40	6	62
Zhu et al. (2017)	2	2	0	2	0	10	7	32	6	61
Kuhn & Ballatore (2015)	0	0	1	2	14	1	5	26	8	58
Soleymani et al. (2014)	1	0	0	0	0	0	4	39	9	56
Fogliaroni & Hobel (2015)	0	0	0	0	0	3	14	30	5	52
Osaragi & Hoshino (2012)	0	0	0	0	0	0	5	36	7	48
Stein & Schlieder (2013)	0	0	0	0	0	0	3	42	3	48
Körner et al. (2010)	0	0	0	0	0	6	5	30	4	45
Knoth et al. (2017)	0	0	0	3	2	1	6	25	7	44
Raubal & Winter (2010)	0	0	0	1	1	1	18	0	13	34
Konkol et al. (2017)	1	0	0	3	1	1	2	4	19	31
Kiefer et al. (2012)	1	0	0	0	2	1	9	10	8	31
Haumann et al. (2017)	0	0	0	0	0	6	8	10	2	26
Josselin et al. (2016)	0	0	0	0	2	1	9	5	8	25
Heinz & Schlieder (2015)	1	0	0	2	1	3	2	14	2	25
Osaragi & Tsuda (2013)	0	0	0	1	1	0	3	16	2	23
Baglatzi & Kuhn (2013)	1	0	0	0	0	0	6	12	3	22
Scheider et al. (2014)	0	0	0	0	1	0	0	13	4	19
Brinkhoff (2017)	0	0	0	0	1	9	2	3	2	17
Schwering et al. (2013)	0	0	0	0	0	4	2	3	5	14
<b>Total</b>	<b>7</b>	<b>2</b>	<b>1</b>	<b>22</b>	<b>47</b>	<b>126</b>	<b>454</b>	<b>1179</b>	<b>280</b>	<b>2131</b>

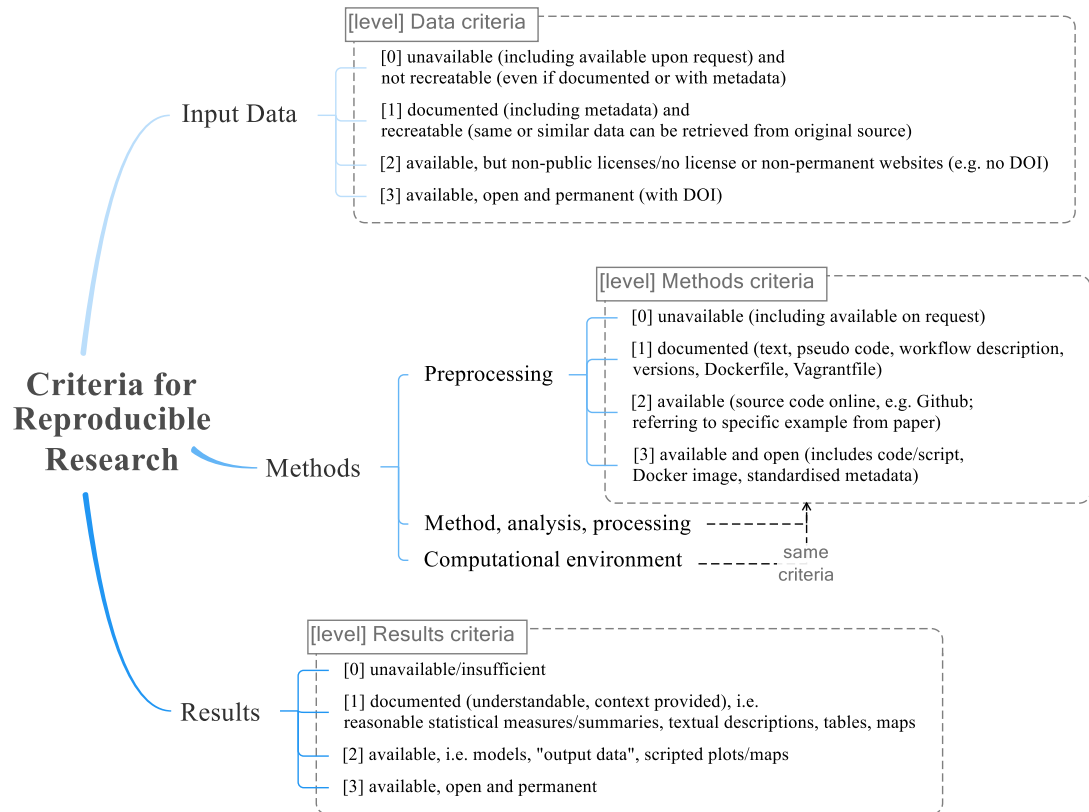
173 An exploratory text analysis of the paper corpus investigates the occurrence of keywords related  
 174 to reproducibility, data, and software. The code is published as an executable document in R  
 175 Markdown<sup>10</sup> (see supplemental material).

176 Most frequent terms mentioned are illustrated by Figure 1 and Table 1 shows keyword occurrence  
 177 per paper and in the entire corpus (bottom row "Total"). Keyword identification uses word stems, e.g.  
 178 `reproduc` includes reproducible, reproduce and reproduction. Few papers mention reproducibility,  
 179 some mention code and software, and many mention processes, algorithms, and data. This points to  
 180 data and analysis being generally discussed in the publications, while their reproducibility is not  
 181 deliberated.

### 182 3.4 Criteria for Assessing Reproducibility

183 In this section, we address RQ 2 and define criteria for assessing the reproducibility of GIScience  
 184 research articles. We build on the recommendations from Section 3.2 and differentiate data, methods,  
 185 and results as separate dimensions with concrete levels. These address specifics of GIScience  
 186 research and allow a fine-grained assessment of reproducibility.

<sup>10</sup><http://rmarkdown.rstudio.com/>



**Figure 2.** The final reproducible research criteria used for the evaluation. The categories *data*, *methods* (sub-categories: preprocessing, method/analysis/processing, and computational environment), and *results* each have four levels ranging from 0 = unavailable to 3 = fully reproducible

187 The assessed papers showed great variation. Data varies from spatial data to qualitative results  
 188 from surveys. Methods have an especially wide range from the application of spatial analysis  
 189 operations to statistical approaches or simulations. Therefore, we split methods up into three sub-  
 190 criteria addressing the distinct phases and respective software tools: data preprocessing, methods  
 191 and workflows, and computational environment. Results are maps, formulas, models or diagrams.

192 Figure 2 shows the criteria and their levels, which range from not applicable (NA) via no (value  
 193 of 0) to full (3) reproducibility. The latter requires the publication to have permanent links to  
 194 open repositories containing data, relevant elements of methods and workflows (such as software  
 195 versions, hardware specifications, scripts), and all results. The intermediate levels (1 and 2) allow a  
 196 differentiated evaluation, e.g. for data: at level 1 it is not accessible but documented sufficiently, so  
 197 others can recreate it; at level 2 it is available yet in a non-persistent way or with a restrictive license.

198 On purpose, our criteria cannot be applied to conceptual research publications, i.e. without data  
 199 or code. Their evaluation is covered by an editorial peer review process (see for example Ferreira  
 200 et al. (2016) for history and future of peer review), and assessing the merit of an argument is beyond  
 201 the scope of this work.

**Table 2.** Survey questions (except for paper identification questions; for full questionnaire see supplemental material)

Question	Possible answers
1. Have you considered the reproducibility of research published in your nominated paper?	<ul style="list-style-type: none"> <li>• Yes, it is important to me that my research is fully reproducible</li> <li>• Yes, I have somewhat considered reproducibility</li> <li>• No, I was not concerned with it</li> <li>• Other (please add)</li> </ul>
2. Do you agree with our rating of your publication? Please comment.	<i>Open answer</i>
3a. Please rate how strongly the following circumstances have hindered you from providing all data, methods and results used/developed during your research?	<ul style="list-style-type: none"> <li>• The need to invest more time into the publication</li> <li>• Lack of knowledge how to include data/methods/results into the publication</li> <li>• Lack of tools that would help to attach data/methods/results to the publication</li> <li>• Lack of motivation or incentive</li> <li>• Legal restrictions</li> </ul> <p>Available ratings:</p> <ul style="list-style-type: none"> <li>• Not at all</li> <li>• Slightly hindered</li> <li>• Moderately hindered</li> <li>• Strongly hindered</li> <li>• Main reason</li> </ul>
3b. Please add here if there were any other hindering circumstances	<i>Open answer</i>
4. What would you suggest to AG-ILE community to encourage publishing fully reproducible papers?	<i>Open answer</i>

### 3.5 Survey: Author Feedback on Assessment of Reproducibility

To understand better the reasons behind the low scores and to give the authors an opportunity to respond, we conducted a survey among authors using Google Forms<sup>11</sup> (see Table 2, cf. Baker (2016a) for a large scale survey on the topic). The full survey and responses are included in the supplemental material. The survey was sent to authors via e-mail and was open from 23 October to 24 November 2017. In case of obsolete e-mail addresses, we searched updated ones and resent the form. Out of a total of 82 authors, 22 filled in the survey resulting in responses for 17 papers, because six participants did not give consent to use their answers, two authors participated twice for different papers, and some papers had more than one individual response.

<sup>11</sup><https://www.google.com/forms/about/>



**Table 3.** Reproducibility levels for paper corpus; '-' is category not available

author	short paper	input data	preprocessing	method/analysis/processing	computational environment	results
Zhu et al. (2017)		0	1	1	1	1
Knoth et al. (2017)		0	-	0	1	1
Konkol et al. (2017)		2	2	1	1	1
Haumann et al. (2017)	X	0	1	1	0	1
Brinkhoff (2017)	X	0	-	1	0	0
Almer et al. (2016)		0	-	1	1	1
Wiemann (2016)		2	-	1	1	1
Juhász & Hochmair (2016)		0	1	1	0	0
Josselin et al. (2016)	X	1	-	0	0	1
Rosser et al. (2016)	X	0	-	1	0	0
Kuhn & Ballatore (2015)		-	-	-	-	-
Mazimpaka & Timpf (2015)		2	1	1	1	1
Steuer et al. (2015)		2	0	1	1	1
Fogliaroni & Hobel (2015)	X	-	-	-	-	-
Heinz & Schlieder (2015)	X	0	0	1	1	1
Scheider et al. (2014)		1	1	2	1	1
Gröchening et al. (2014)		2	0	1	0	1
Fan et al. (2014)		0	1	1	0	1
Soleymani et al. (2014)	X	0	0	1	0	0
Wiemann & Bernard (2014)	X	0	0	1	0	0
Osaragi & Tsuda (2013)		0	1	1	0	1
Baglatzi & Kuhn (2013)		-	-	-	-	-
Li et al. (2013)	X	0	0	1	-	1
Stein & Schlieder (2013)	X	0	-	1	0	1
Osaragi & Hoshino (2012)		0	0	1	0	1
Magalhães et al. (2012)		0	0	1	0	0
Foerster et al. (2012)		1	-	1	1	1
Merki & Laube (2012)	X	0	-	1	1	1
Kiefer et al. (2012)	X	0	1	1	0	1
Raubal & Winter (2010)		-	-	-	-	-
Schäffer et al. (2010)		0	0	1	1	1
Körner et al. (2010)		-	-	-	-	-

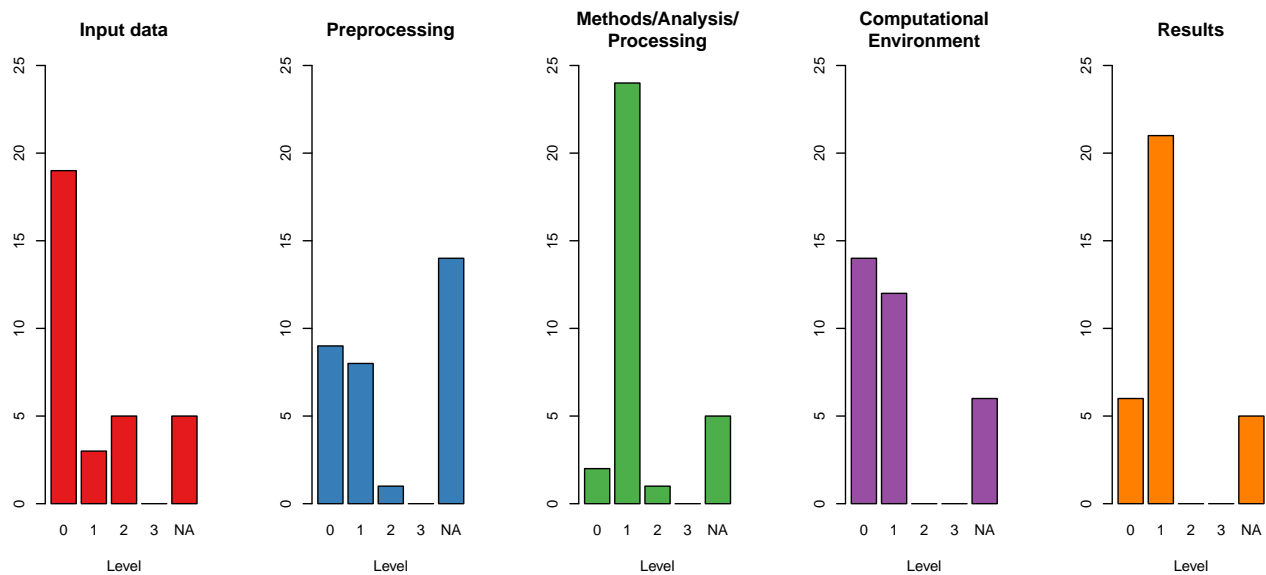
## 211 4 RESULTS

### 212 4.1 Reproducibility Assessment of Paper Corpus

213 To address RQ 3, we reviewed the papers in the corpus with the introduced criteria. Our objective  
 214 in publishing the full evaluation results is not to criticise or rank individual papers, but to identify  
 215 the current overall state of reproducibility in GIScience research in a reproducible manner. The  
 216 scientific merit of all papers was already proven by their nomination for the best paper award.

217 Evaluators chose to review papers without conflict of interest until two reviewers from different  
 218 research groups were assigned per paper. A general guideline was to apply the lower of two  
 219 possible levels in cases of doubt, such as partial fulfilment of a criterion or disagreement between  
 220 the evaluators. The assessment focuses on algorithmic and data-driven research papers. Thus, 5  
 221 fully conceptual papers were not assessed, while 15 partly conceptual ones were included. Notably  
 222 the data preprocessing criterion did not apply to 14 research papers. Table 3 shows the assessment's  
 223 results.

224 Figure 3 shows the distribution of reproducibility levels for each criterion. None of the papers  
 225 reaches the highest level of reproducibility in any category. Only five papers reach level 2 in  
 226 the data criterion, which is still the highest number of that level across all categories. Especially



**Figure 3.** Results of reproducibility assessment: level of reproducibility ranges from 0 (not reproducible) to 3 (fully reproducible); NAs include 5 conceptual papers (all categories are NA)

227 problematic is the high number (19 papers) with level 0 for data, meaning that the specific data is  
 228 not only unavailable but it is not re-createable from the information in the paper. Data preprocessing  
 229 applies to 18 publications and the levels are low. Only one publication has level 2. Concerning the  
 230 methods and results criteria, 19 out of 32 papers have level 1 in both, meaning an understandable  
 231 documentation is provided in the text.

232 Figure 4 shows average reproducibility levels are low and do not change significantly over time,  
 233 with the average being below level 1 for all categories. Tables 4 and 5 contain summary statistics  
 234 per criterion and means<sup>12</sup> for full and short papers. For each criterion, full papers reach higher levels  
 235 than short papers (see Table 5).

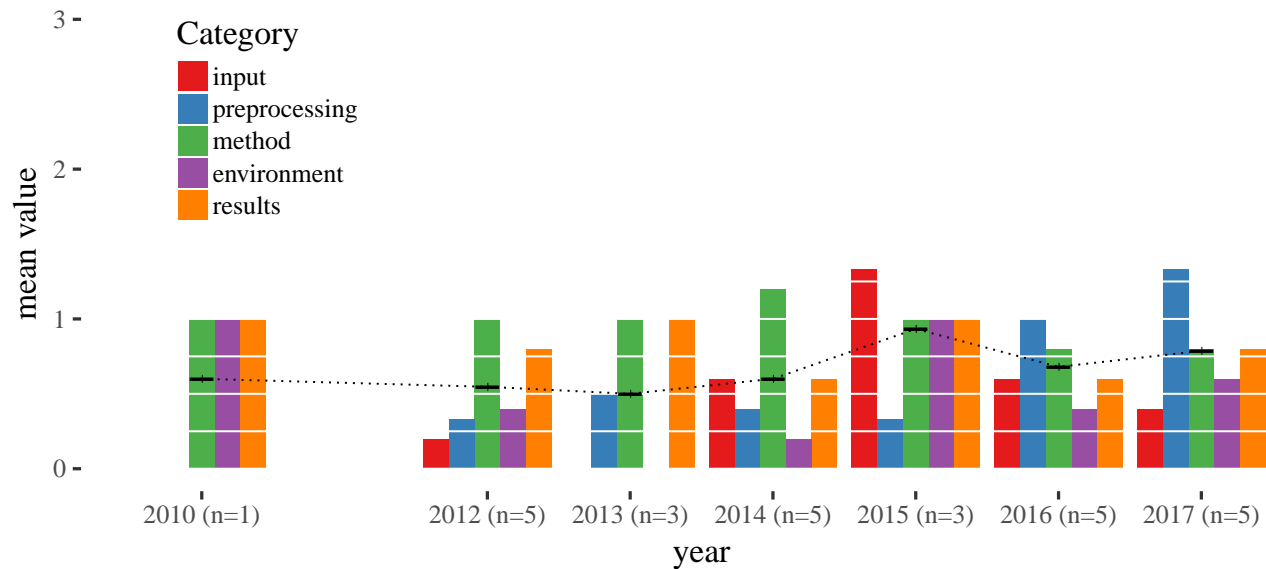
**Table 4.** Statistics of reproducibility levels per criterion

	input data	preproc.	method/analysis/proc.	comp. env.	results
Min.	0.00	0.00	0.00	0.00	0.00
Median	0.00	0.50	1.00	0.00	1.00
Mean	0.48	0.56	0.96	0.46	0.78
Max.	2.00	2.00	2.00	1.00	1.00
NA's	5.00	14.00	5.00	6.00	5.00

**Table 5.** Mean levels per criterion for full and short papers

	input data	preproc.	method/analysis/proc.	comp. env.	results
Full papers	0.75	0.67	1.00	0.62	0.88
Short papers	0.09	0.33	0.91	0.20	0.64

<sup>12</sup>The few data points and categorical variable type require cautious interpretation of the mean.



**Figure 4.** Mean reproducibility levels per category over time; black dotted line connects the mean per year over all categories (in 2010 only one of three papers could be assessed, reaching level 1 for methods)

## 4.2 Survey Results

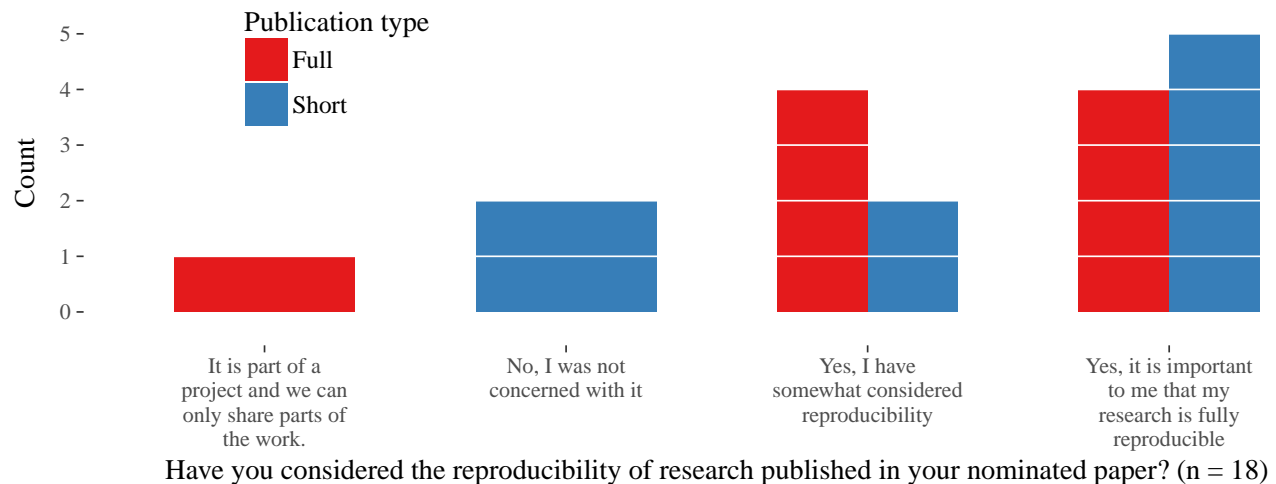
Authors were asked to comment on their agreement or disagreement with our evaluations of their specific paper. Seven responses fully agreed with the evaluation, five agreed partly, two expressed disagreement, and one did not answer the question. Most disagreement addresses the definition of criteria. Multiple authors argued that such requirements should not be applicable for short papers, and that specific data is not always necessary for reproducibility. Others disagreed on treating "availability upon request" as "unavailable". One argued that OpenStreetMap data is by default "open and permanent", while our criteria miss direct links to specific versioned subsets of data.

The answers suggest that authors are generally aware of the need of reproducibility and in principle know how to improve it in their work. However, many do not consider it a priority, giving as reasons the lack of motivation (eight respondents) or the required extra efforts. They say these are disproportionately large in comparison to the added value.

According to the survey results, reproducibility was important to more than half of the respondents (see Figure 5). Only two respondents claim they were not at all concerned about it (both short papers). Further comments revealed some authors consider short papers as introductions of new concepts and generally too short for reproducibility concerns. The paper corpus supports this opinion because short papers reach overall lower levels.

In contrast, we argue that transparency should depend on the publication type but is a feature of the entire scientific process. Especially at early stages, the potential for external review and collaboration can be beneficial for authors. Further, putting supplementary materials in online repositories addresses the problem of word count limits (for full and short papers) that many authors struggle with.

To identify barriers to reproducibility, the authors were asked to rate how strongly five predefined barriers (Table 2) impacted their work's reproducibility. They could also add their own reasons, for which they mentioned limited length of paper, and required additional financial resources. Table 6



**Figure 5.** Author survey results on the importance of reproducibility

261 shows legal restrictions and lack of time were mentioned most frequently, with only one respondent  
 262 indicating that they played no role. Although lack of knowledge on how to include data, methods  
 263 and results was not considered by many as a barrier, several respondents noted a lack of supporting  
 264 tools as main impediment for reproducibility.

265 Respondents also shared their ideas for encouraging reproducibility of AGILE publications. Four  
 266 suggested Open Access publishing and asked for solutions for sensitive data. A few suggested en-  
 267 couraging and promoting collaboration across research institutes and countries to mitigate ephemeral  
 268 storage and organisations. Some respondents proposed an award for reproducible papers, requiring  
 269 reproducibility for the best paper nomination, or conference fee waivers for reproducible papers. In  
 270 summary, almost all authors agreed on the importance of the topic and its relevance for AGILE.

### 271 4.3 A critical review of this paper's reproducibility

272 We acknowledge this paper has its own shortcomings with respect to reproducibility. The *input data*  
 273 (i.e. the paper corpus) for the text analysis cannot be re-published due to copyright restrictions. Our  
 274 sample is biased (although probably positively) as we only considered award nominees. Access to all  
 275 papers would have allowed a random sample from the population. Regarding the *methodology*, the  
 276 created criteria and their assignment by humans cannot honour all details and variety of individual  
 277 research contributions and is inherently subjective. We tried to mitigate this by applying a four  
 278 eyes principle, and transparently sharing internal comments and discussion on the matter in the  
 279 supplemental material. The material comprises an anonymised table with the survey results and a  
 280 literate programming document, which combines data preprocessing, analysis, and visualisations.  
 281 Using our own classification, we critically assign ourselves level 0 for data and target level 3 for  
 282 methods and results.

## 283 5 DISCUSSION & CONCLUSIONS

### 284 5.1 Improving day-to-day Research in GIScience

285 Our evaluation clearly identifies issues of reproducibility in GIScience. Many of the evaluated papers  
 286 use data and computer-based analysis. All have been nominated for the best paper award within  
 287 a double-blind peer review and represent the upper end of the quality spectrum at an established

**Table 6.** Hindering circumstances for reproducibility for each survey response (n = 17)

Legal restrictions	Lack of time	Lack of tools	Lack of knowledge	Lack of incentive
Main reason	Strongly hindered	Not at all	Not at all	Strongly hindered
Main reason	Not at all	Not at all	Not at all	Moderately hindered
Main reason	Slightly hindered	Strongly hindered	Moderately hindered	Strongly hindered
Main reason	Not at all	Slightly hindered	Not at all	Not at all
Strongly hindered	Strongly hindered	Strongly hindered	Moderately hindered	Strongly hindered
Moderately hindered	Main reason	Not at all	Not at all	Not at all
Slightly hindered	Moderately hindered	Slightly hindered	Slightly hindered	Moderately hindered
Slightly hindered	Not at all	Main reason	Strongly hindered	Not at all
Not at all	Moderately hindered	Not at all	Moderately hindered	Not at all
Not at all	Strongly hindered	Strongly hindered	Strongly hindered	Slightly hindered
Not at all	Moderately hindered	Not at all	Not at all	Not at all
Not at all	Slightly hindered	Main reason	Not at all	Strongly hindered
Not at all	Main reason	Not at all	Not at all	Not at all
Not at all	Main reason	Not at all	Not at all	Not at all
Not at all	Moderately hindered	Moderately hindered	Not at all	Strongly hindered
Not at all	Not at all	Not at all	Not at all	Not at all
Not at all	Slightly hindered	Not at all	Slightly hindered	Not at all

288 conference. Yet overall reproducibility is low and no positive trend is perceivable. It seems current  
 289 practises in scientific publications lack full access to data and code. Instead only methods and results  
 290 are documented in writing.

291 A lasting impact on the reproducibility of research requires changes in educational curricula,  
 292 lab processes, universities, journal publishing, and funding agencies (“Reproducible Research”  
 293 2010; McKiernan, 2017) as well as reward mechanisms that go beyond paper citations (cf. term  
 294 “altmetrics” in Priem et al., 2010). This is a major and long-term endeavour. Here, we focus on  
 295 recommendations and suggestions for individual researchers and a specific organisation: AGILE. A  
 296 snowball effect may lead to a change in practises in the GIScience community. The remainder of  
 297 this paper addresses RQ 4 by formulating suggestions to researchers and the AGILE conference  
 298 organisers.

## 299 5.2 Suggestions to Authors

300 Regarding habits and workflows, the Carpentries (the union<sup>13</sup> of Data Carpentry (Teal et al.,  
 301 2015) and Software Carpentry (Wilson, 2006)) offer lessons on tools to support research, such  
 302 as programming and data management, across disciplines. Further resources are available from  
 303 programming language and software communities, research domains, and online universities. Often  
 304 these are for free because the software is Free and Open Source Software (FOSS) and driven by  
 305 a mixed community of users and developers. Ultimately, proprietary software is a deal-breaker  
 306 for reproducibility (cf. Ince, Hatton, and Graham-Cumming, 2012; Baker, 2016b). OSGeo-Live<sup>14</sup>  
 307 provides a simple environment to test open alternatives from the geospatial domain, and several

<sup>13</sup><http://www.datacarpentry.org/blog/merger/>

<sup>14</sup><https://live.osgeo.org/>

308 websites offer help in finding FOSS comparable to commercial products<sup>15</sup>. But it is not only about  
309 the software. It can be as simple as "naming things" sensibly<sup>16</sup>, as realistic as not striving for  
310 perfection but following "Good enough practices in scientific computing" (Wilson et al., 2017), as  
311 egoistic as "selfish reasons to work reproducibly" (Markowitz, 2015), and as FAIR<sup>17</sup> as "structuring  
312 supplemental material" (Greenbaum et al., 2017).

### 313 5.3 Recommendations to Conferences in GIScience and Organisations like AGILE

314 *What can conferences and scientific associations do to encourage reproducibility?* The crucial step is  
315 acknowledging the important role organisations like AGILE can play in the adoption of reproducible  
316 research practises, building upon a large body of guidelines, documentation and software. In the  
317 remainder of this section we propose concrete actions using AGILE as the leading example.

318 Recognising the importance of reproducibility could take the form of an **award for reproducible**  
319 **papers**. This is already done by other communities, e.g. the ACM SIGMOD 2017 Most Reproducible  
320 Paper Award<sup>18</sup>. At AGILE reviewers suggest submissions to be nominated for best (short) papers  
321 and could also briefly check for reproducibility. A detailed reproduction could be the responsibility  
322 of a new Scientific Reproducibility Committee led by a Reproducibility Chair, working alongside  
323 the existing committees and their chairs. Committee membership would be publicly recognised.  
324 The "most reproducible paper" could be prominently presented in the conference's closing session.

325 Kidwell et al. (2016) demonstrate open data **badges** had a positive effect on actual publishing  
326 of data in the journal Psychological Science. They use badges and corresponding criteria by the  
327 Center for Open Science<sup>19</sup> (COS). Further examples are the "kite marks" by the journal Biostatistics  
328 (Peng, 2011), the Association for Computing Machinery's (ACM) common standards and terms for  
329 artifacts<sup>20</sup>, and the Graphics Replicability Stamp Initiative (GRSI)<sup>21</sup>. While AGILE could invent own  
330 badges, re-using existing approaches has practical (no need to design new badges), organisational  
331 (no need to reinvent criteria), and marketing (higher memorability) advantages. Author guidelines  
332 would include instructions on how to receive badges for a submission. The evaluation of badge  
333 criteria would be integrated in the review and could inform the reproducible paper award.

334 **Author guidelines** are the essential means to set the scene for a reproducible conference<sup>22</sup>.  
335 Independently of advertising awards and badges, they should include clear guidelines on when,  
336 how, and where to publish supplemental material (data, code). Authors must be made aware to  
337 highlight reproducibility-related information for reviewers and readers with *author guidelines for*  
338 *computational research*. These should comprise practical advice, such as code and data licenses<sup>23</sup>,  
339 and instructions on how to work reproducibly, e.g. in form of a space for sharing tools and data,  
340 which is the most popular suggestion from the survey (seven respondents).

341 While the established peer-review process works well for conceptual papers, an extra **track or**

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<sup>15</sup>E.g. <https://opensource.com/alternatives> or <https://alternativeto.net>

<sup>16</sup><https://speakerdeck.com/jennybc/how-to-name-files> by Jennifer Bryan

<sup>17</sup>Force11.org. Guiding principles for findable, accessible, interoperable and re-usable data publishing: version B1.0.  
<https://www.force11.org/node/6062>

<sup>18</sup><http://db-reproducibility.seas.harvard.edu/> and <https://sigmod.org/2017-reproducibility-award/>

<sup>19</sup><https://osf.io/tvyxz/wiki/home/>

<sup>20</sup><https://www.acm.org/publications/policies/artifact-review-badging>

<sup>21</sup><http://www.replicabilitystamp.org/>

<sup>22</sup>Cf. SIGMOD 2018 CFP, [https://sigmod2018.org/calls\\_papers\\_sigmod\\_research.shtml](https://sigmod2018.org/calls_papers_sigmod_research.shtml)

<sup>23</sup>E.g. OSI compliant for code and Open Definition compliant for data, see <http://licenses.opendefinition.org/>

342 **submission type**<sup>24</sup> allows a special process (e.g. public peer review) and can accommodate submis-  
343 sions focussing on reproducibility without an original scientific contribution. Such publications can  
344 include different authors, e.g. technical staff, or even reviewers as practised by Elsevier's Information  
345 Systems journal. They also mitigate limitations on research paper lengths. Unfortunately, they can  
346 also convey the counterproductive message of reproducibility being cumbersome and uncommon.

347 Such a special track as well as the regular conference proceedings should be published as **Open**  
348 **Access**<sup>25</sup> in the future. It might even be possible to re-publish short papers and abstracts of previous  
349 conferences after solving juridical concerns (e.g. if author consent is required). AGILE could utilise  
350 existing repositories or operate its own. Using third party repositories<sup>26</sup> for supplements, reduces  
351 the burden on the AGILE organisation. Choosing **one repository** allows collecting all AGILE  
352 submissions under one tag or community<sup>27</sup>. An AGILE-specific repository allows more control yet  
353 requires more work and might have lower visibility, since the large repositories are well indexed  
354 by search engines. Both approaches can support a double-blind review by providing anonymous  
355 view-only copies of supplemental material<sup>28</sup>.

356 *What skills related to reproducibility are desirable for authors at the 30th AGILE conference?*  
357 Predicting 10 years ahead might not be scientific, but it allows formulating a vision. We assume  
358 there will be hardly any paper not utilising digital methods, such as software for analysis, interactive  
359 visualisations, or open data. Ever more academics will meet a competitive selection process, where  
360 quality of research will be measured by its transparency and novelty. To achieve novelty in a setting  
361 where all research is saved, findable and potentially interpreted by artificial intelligence (N. Jones,  
362 2016), a new contribution must be traceable. Thus, the trend towards Open Science will be reinforced  
363 until using and publishing open source code and open data as well as alternative metrics beyond  
364 citations will be natural. As of now, AGILE is not ready for such research. It has identifiers (DOIs)  
365 only for full publications and lacks open licenses for posters and (short) papers. Statements on  
366 preprints (publication before submission) and postprints ("green" Open Access<sup>25</sup>) are missing.

367 We see AGILE, carried by its member labs and mission<sup>29</sup>, in a unique position to establish a  
368 common understanding and practise of reproducible research. Firstly, member labs can influence  
369 education, especially at graduate level, and ideally collaborate on **open educational material**.  
370 Completing a Ph.D. in an AGILE member lab and participating in AGILE conferences should  
371 qualify early career scientists to publish and review reproducible scholarly works. Secondly, the  
372 conference can take a leading role to set up new norms for conference review and publication but  
373 at the same time cooperate with other conferences (e.g. ACM SIGMOD). At first AGILE would  
374 encourage but eventually demand the highest level of reproducibility for all submissions. This  
375 process certainly will take several years to complete.

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<sup>24</sup>See IEEE's CiSE magazine's Reproducible Research Track <https://www.computer.org/cise/2017/07/26/reproducible-research-track-call-for-papers/>, and Elsevier journal Information Systems' section for invited reproducibility papers, <https://www.elsevier.com/journals/information-systems/0306-4379/guide-for-authors>

<sup>25</sup>See <https://open-access.net/DE-EN/information-on-open-access/open-access-strategies/>

<sup>26</sup>Beside the incumbents Figshare (<https://figshare.com/>), Open Science Framework (OSF) (<https://osf.io/>, community-driven) and Zenodo (<https://zenodo.org/>, potentially preferable given AGILE's origin because it is funded by EU), a large number of Open Access repositories exists, see <http://roar.eprints.org/> and <http://opendoar.org/>, including platforms by publishers, e.g. Springer (<https://www.springer.com/gp/open-access>), or independent organisations, e.g. LIPIcs proceedings (<https://www.dagstuhl.de/en/publications/lipics>).

<sup>27</sup>Cf. <http://help.osf.io/m/sharing/1/524053-tags> and <https://zenodo.org/communities/>

<sup>28</sup>See [http://help.osf.io/m/links\\_forks/1/524049-create-a-view-only-link-for-a-project](http://help.osf.io/m/links_forks/1/524049-create-a-view-only-link-for-a-project)

<sup>29</sup><https://agile-online.org/index.php/about-agile>

376 Researchers will have to leave their comfort zone and change the way they work. They also have  
377 to see benefits immediately to overcome old habits (Wilson et al., 2017). The evidence for benefits  
378 of Open Science are strong (McKiernan et al., 2016), but to succeed the community must embrace  
379 the idea of a reproducible conference. We acknowledge that fully reproducible GIScience papers are  
380 no small step for both authors and reviewers, but making them the standard would certainly be a  
381 giant leap for AGILE conferences. We are convinced AGILE can provide the required critical mass  
382 and openness and hope the experiences and information in this work contribute a starting point.

## 383 ACKNOWLEDGMENTS

384 We thank all authors who participated in the survey.

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