Article

Status of and Perspectives on River Restoration in Europe: 310 000 EUR per Hectare of Restored River

Ewelina Szałkiewicz[1], Szymon Jusik[2] and Mateusz Grygoruk[3,4*]

[1]   Poznań University of Life Sciences, Department of Hydraulic and Sanitary Engineering, ul. Piątkowska 94A, 60-649 Poznań, Poland; ewelszal@up.poznan.pl
[2]   Poznań University of Life Sciences, Department of Ecology and Environmental Protection, ul. Piątkowska 94 C, 60-649 Poznań, Poland; jusz@up.poznan.pl
[3]   Warsaw University of Life Sciences – SGGW, Faculty of Civil and Environmental Engineering, Department of Hydraulic Engineering, ul. Nowoursynowska 166, 02-787 Warsaw, Poland.
[4]   European Centre for River Restoration, Polish National Centre.
*   Correspondence: m.grygoruk@levis.sggw.pl; Tel.: +48 22 593-53-09

Abstract: The purpose of the present research was to analyze the available data on river restoration projects. As the framework of our study, we conducted a structured international survey. We asked selected entities and experts from among those responsible for river restoration in European countries about the details and costs of European Union river restoration projects. We examined 119 river restoration projects that were implemented in Europe between 1989 and 2016; some of the projects were still ongoing. We observed that the number of river restoration projects has been increasing since 1989, which expresses society's growing interest in improving the quality of aquatic environments. We revealed that 56% of these European river restoration projects have been implemented by dedicated entities and stakeholders, not as part of any structured, larger-scale river restoration policy; this indicates that most European countries do not have integrated plans for river restoration. Our analysis showed that 52% of the projects analyzed have been designed and implemented without the participation of local stakeholders. It also showed that the budgets for river restoration projects did not differ significantly across various time horizons from 1981 to 2016. In our study, the average cost of restoring 1 ha of an average European river was 310 000 EUR (or 195 000 EUR if 4 outlying values are excluded). Considering these projects' permanent assets and including their amortization, for European river systems, we calculated the average unit price of a river restoration's value in terms of ecosystem meta-service to be 7 757 EUR · ha^{-1} · year^{-1} (4 875 EUR · ha^{-1} · year^{-1} if 4 outlying values were excluded).

Keywords: river; restoration; ecosystem; management; water framework directive; ecosystem services

1. Introduction

The development of societies is expressed through increasing indices for growth, level of education and communication efficiency, as well as through a growing demand for a high-quality surrounding environment. Many suspect the latter to be the main driver of environmental restoration [1-3]. Some even deem the classic approaches such as process- and species-based conservation paradigms to lack resilience on a long time horizon, arguing that environmental restoration is the only way to reach sustainability goals [4]. As Suding stated, this situation and the increasing priorities on environmental issues provide exponentially more opportunities for the improvement of environmental quality and sustainable development than at any time before [1].

As synergies in environmental restoration result in measurable economic gains that follow restoration-induced improvements of ecosystems' statuses [5-7], one may suspect that the scientific and political implementation consortia that are restoring various ecosystems worldwide are finally

able to provide comprehensive ecosystem restoration and to positively stimulate local economies and societies. However, the societal demand for high-quality environments remains spatially heterogeneous, as does the growth in environmental consciousness, education and emotions regarding nature [8-10]. That is why there are specific groups of interest, including people with various objectives and profiles who are responsible for the design and implementation of environmental restoration projects [11].

Unlike for other ecosystems, the restoration of rivers and wetlands remains a global issue [12-14]. These azonal ecosystems occur in every latitude of every continent. The problems related to riverine environments – including modifications in hydromorphology, flow velocities, and both longitudinal (upstream-downstream) and vertical (channel-floodplain lakes) connectivity – remain unrelated to climatic zones and thus are cited and reported on a universal basis [15]. Restoration of rivers and riparian wetlands still has great economic potential; the ecosystem services that these mesobiomes provide have been estimated to retain high economic value [16]. When well-planned, -designed and -managed, restored river-wetland systems can mitigate the negative consequences of changing land uses and of climate extremes such as floods and droughts and can also help to sustain biodiversity [17-21]. Restoration of these systems is even more critical due to the fact that, among the ecosystems that Costanza et al. [22] evaluated, only two had decreasing economic unit values for the services they provide: namely freshwater wetlands and estuaries, both of which are related to – and dependent on – rivers and their valleys maintaining good status. Moreover, Costanza et al. also reported that the area of these ecosystems is decreasing on a global scale. Hence, the restoration of rivers and related riparian ecosystems may soon become an element of (inter)national strategy that is inherently included in water policies.

In the European Union (EU), the Water Framework Directive (WFD) [23] has regulated actions related to rivers and their ecosystems since 2000. This regulation promotes integrated water management. The WFD's meta-goal is to maintain rivers' good ecological states or at least achieve their good ecological potential. As riverine systems face existing pressures and most are in a deteriorating state, large-scale river restoration strategies seem to be the ultimate measure for fulfilling both the WFD's requirements and the goals of other environmental regulations [24-25]. Therefore, especially from the EU's perspective, the revision and general assessment of past and present river restoration projects – which so far has not been done – would (1) provide important information about these projects' costs, results and future prospects and (2) help determine whether contemporary river restoration tends to involve strategic action or be reduced to the costly hobby of certain groups of stakeholders.

Our paper addresses the following research goals: (1) to quantify and assess the scale of particular river restoration projects in the EU; (2) to identify whether the reviewed river restoration projects remain individual, spontaneous actions or if they are now elements of more widely planned river restoration strategies; (3) to reveal the scale and share of EU and national funding spent on river restoration; and (4) to assess the approximate average cost of river restoration, as this reveals the value that societies are willing to pay to maintain healthy rivers.

2. Materials and Methods

Our study was based on a questionnaire (Tab. 1) that contained both open- and closed-ended questions. The open-ended queries focused on basic information (river, country, project's start year and completion year) as well as on more detailed information such as budget and share of funding (if any) from the EU. If the budget for a given restoration project was not known or if the respondent did not wish to provide a detailed budget, he or she could select from ranges of costs. The questionnaire also included questions that addressed the issues of which entities were responsible for particular projects, the size and scope of those projects, the technical solutions applied in them, the level of the local communities' participation, the monitoring of project results, and information regarding whether the project was part of a large-scale strategy or plan. The questionnaire was distributed to more than 300 European specialists involved in the implementation of or research on restoration for rivers and riparian ecosystems. Additionally, to obtain the broadest set of data

98 possible, we carried out a structured review of river restoration databases such as River Wiki [26]
99 and Onema [27]. The River Wiki database is funded by the Environmental Agency (England) and
100 administered by the River Restoration Centre (UK).

101 **Table 1.** Closed questions asked in the questionnaire.

Question	Answers
Entity responsible for the project*	a. nationwide authorities b. provincial/regional authorities c. association (NGO) d. private investors e. others
Scope of the project*	a. works within channel b. works within floodplain c. works within catchment
Size of the project	a. river reach length < 2 km b. river reach length > 2 km c. whole river d. more than one watercourse
Solutions which were used*	a. removal of hydrotechnic structures b. deflectors c. threshold d. introducing of logs or other wood elements e. biological strengthening of the banks f. preparing the spawning grounds g. constructing the fish ladders h. crosscut of the channel or other diggings i. introducing of macrophytes j. others
Source of the project funding*	a. government budget b. EU funding c. association or foundation funds d. private funds e. others
Did the local community participate in the project?	Yes / No
Have the monitoring of the restoration project been performed?	Yes / No
Was the project a part of the larger restoration plan (national, international)?	Yes / No

102   * Questions with possibility to choose multiple answers.

103   The general analysis of the questionnaire consisted of summing up the answers for each query
104 and conducting standard statistical analyses. The collected structured data allowed for rough
105 calculations of the unit cost for river restoration in Europe, expressed in kEUR/ha. Although this
106 information provides only a very general approximation, we found it critical, as it is the most accurate
107 economic measure of a river's aggregated ecosystem services. This cost refers to the amount of funds
108 that stakeholders will pay to bring back a functioning riverine ecosystem that provides aesthetic
109 value as well as services such as biodiversity, self-purification, and sustainable flood/drought
110 mitigation.

111 **3. Results**

112   We obtained 105 questionnaire responses from 19 countries, of which 102 were reliable sources
113 of data for the analysis. This is response rate of 36%, which we considered sufficient for purposes of
114 our study. Altogether, we analyzed 119 river restoration projects in detail (Fig. 1). The collected

115   information about these projects is provided in the Supplementary Material. We are aware that other
116   countries have implemented river restoration projects, but to ensure that the results correspond to
117   the methodology, we did not count these countries' projects in our analysis.
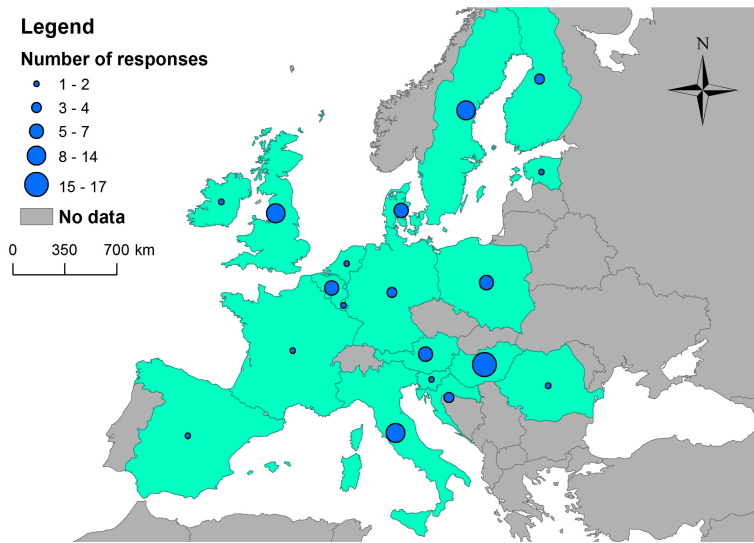118

119

120   **Figure 1.** Number of surveys collected from each country.
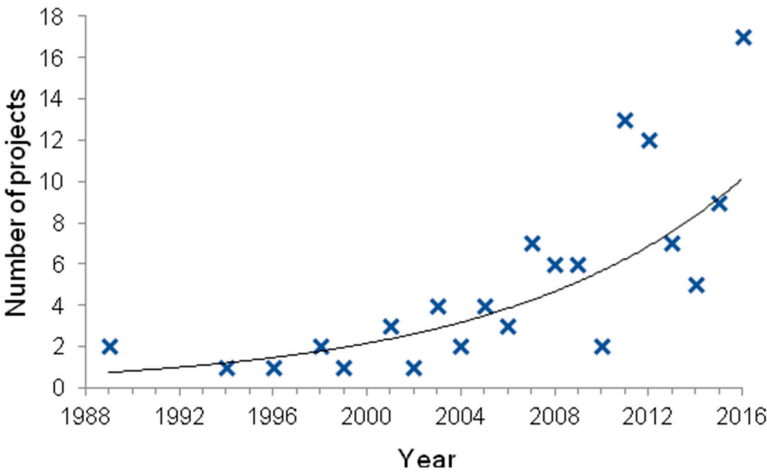

121

122   **Figure 2.** Number of river restoration projects finalized in particular years analyzed.

123   We collated projects by the year when they were finished. The earliest project for which we have
124   data is from 1989. The most recent year we considered was 2016, but some of the projects were still
125   running and the end of that year. However, to keep the analysis clear, we assumed that, in such cases,
126   2016 was the terminal year for these restoration projects. Either way, the number of European river
127   restoration projects in the countries for which we have data has clearly increased since the last two
128   decades of the 20th century (Fig. 2).

129   In the next step, we analyzed the setup of the river restoration projects. We attempted to
130   determine whether these projects analyzed were planned and implemented with the active
131   participation of the local authorities; whether their results were monitored to allow for adaptive
132   management; and whether the river restoration initiatives belonged to or result from any structured,
133   large-scale river restoration strategy (e.g., a national river restoration plan). Less than a half of the
134   projects included the active participation of local communities. Approximately 80% of initiatives
135   included the monitoring of project efficiency (e.g., water level monitoring, river discharge
136   measurements or ecological monitoring). Surprisingly, only approximately 44% of the projects were

137 part of large-scale (e.g., nationwide) river restoration policies, meaning that the majority of the EU
138 river restoration projects comprised the individually planned actions of interested entities (Fig. 3).

139

Figure 3. Share of the projects analyzed with participation of local communities in project
design/implementation, share of the projects which results were methodologically monitored and
projects that remained a part of a larger (e.g. country-wide) river restoration strategy.
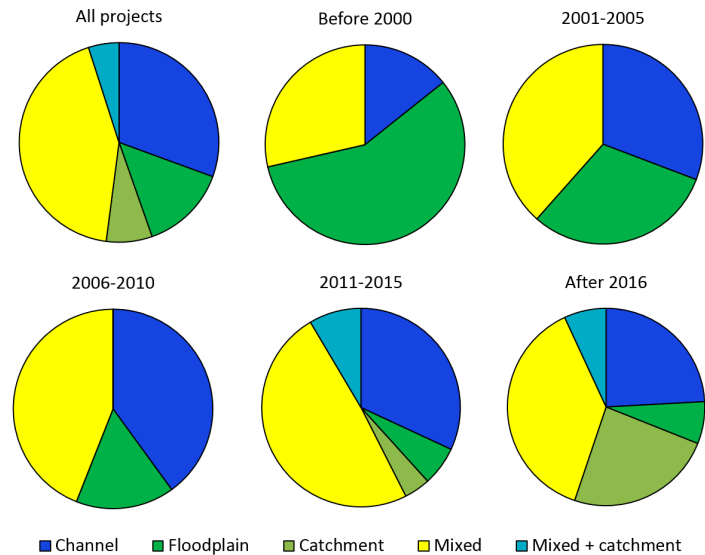

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Figure 4. Share of the projects in selected time frames oriented at restoration measures in river
channel, floodplain, whole catchment and complex projects including catchment-scale measures.

146 Regarding the main goals of the river restoration projects, we revealed that an increasing number
147 of projects are oriented beyond the river channel (to include the floodplain and the whole catchment;
148 Fig. 4). By time frame, the most comprehensive and abundant projects, including actions in the river
149 channel, floodplain and catchment (or a mixture of these measures), occurred in 2016, the most recent
150 time period (Fig. 4). This indicates that river restoration managers account for systematic solutions
151 and address ecohydrological process at the catchment scale. The projects in the oldest time frame
152 considered (1989-2000) did not include any actions oriented toward catchment-scale processes and
153 instead concentrated mainly on the river itself, although a few floodplain-related measures were
154 implemented (Fig. 4).

155 Among the river restoration projects analyzed, the majority (51%) were designed and
156 implemented by regional authorities or by other entities working on a regional scale (Fig. 5).
157 Nongovernmental organizations (NGOs) were reported to have participated in 13% of the projects
158 (7% with the aid of national-scale institutions such as National Environmental Directorates and 6%
159 run by NGOs on their own). The remaining projects were run by either national-scale entities or by
160 other consortia (19% and 18%, respectively; Fig. 5). When analyzing the survey results, we observed
161 that the numbers of projects designed and implemented by regional-scale authorities increased
162 significantly from 1989 through 2015. The number of NGOs and national consortia implementing

163   river restoration projects did not increase in that time. No project run solely by NGOs were present
164   before 2011 (Fig. 5), but they started to occur after hat year. Because the time frame after 2016 was not
165   fully reported, we do not draw conclusions about which authorities were implementing river
166   restoration projects in this period. However, based upon the results of the survey, we observed that
167   the number of NGO-run projects has increased, even as the number of projects implemented by
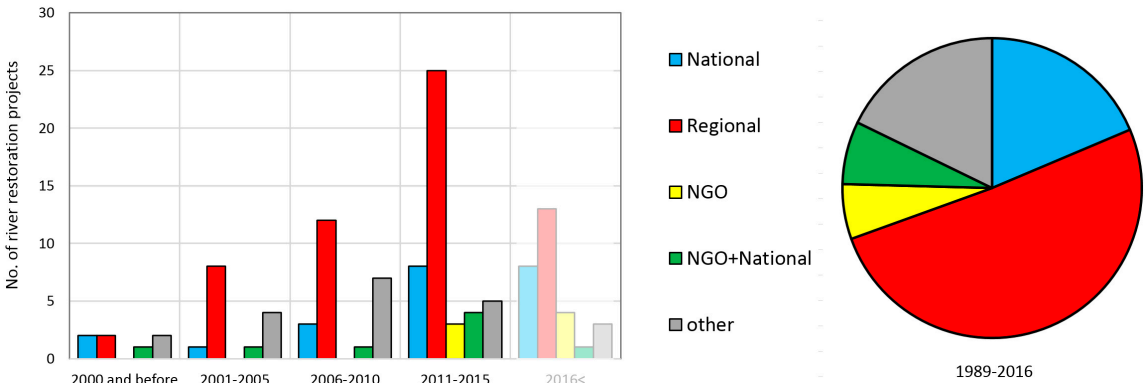168   national- or regional-scale entities remained the same or declined.

Figure 5. Types of entities responsible for the implementation of particular river restoration projects in particular time frames analyzed. The last time frame is shielded as it is still running and the results present only partial view.
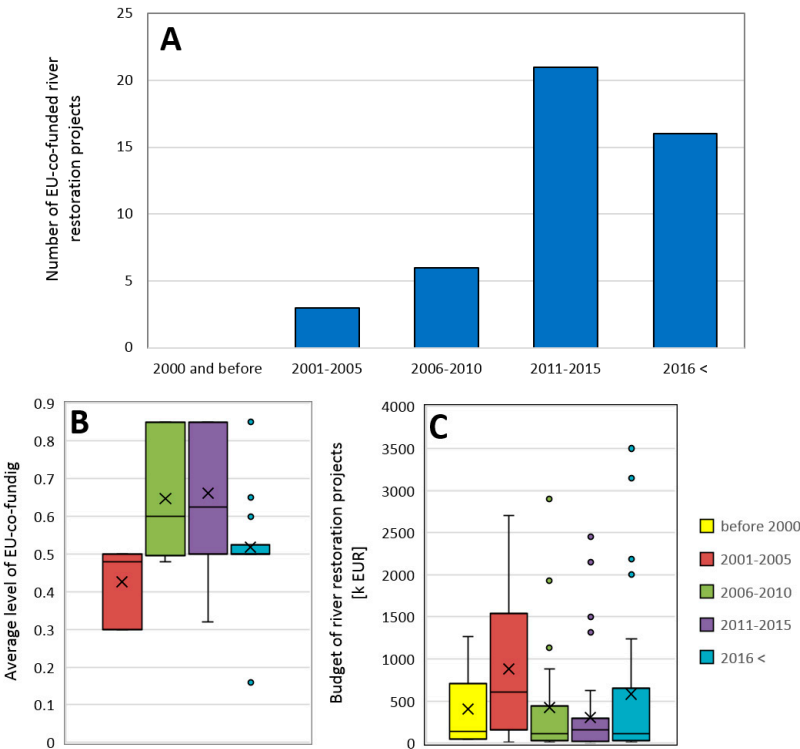

Figure 6. Selected characteristics of river restoration projects analyzed: A – number of projects co-funded by the EU, B – average level of EU funding, C – average cost of river restoration project (kEUR per project). Box-plot charts (B and C): box represents the range from 25 to 75 percentile, x – average value, vertical line in the box – median, whiskers represent maximum and minimum values, dots represent outlying values.

179   Analysis of the funding sources for the river restoration projects revealed that approximately
180   half of initiatives analyzed across all time frames were cofinanced, with the funds originating directly

181   from EU subsidies (Fig. 6B). Moreover, 22.2% of the projects had nongovernmental funding, which
182   proves that associations and groups of enthusiasts play an important role in river restoration in
183   Europe. We observed (Fig. 6B) that the number of partially EU-funded river restoration projects has
184   been continuously increasing (Fig. 6A). Among the projects in the 1989-2000 period, none were
185   supported by EU funds (Fig. 6A and B).

186   The level of EU co-funding for river restoration projects has increased from 43% (in 2000-2005)
187   to 65% (in 2010-2015). In the last time frame analyzed (2016 onward), the rate of EU co-funding
188   decreased to 52%. However, the last time frame analyzed is still not complete, as it does not cover a
189   full 5-year period. In the years analyzed, the total budgets for river restoration projects did not differ
190   significantly (Fig. 6C and Tab. 2). There was only a significant difference between two periods, as
191   the projects implemented in 2001-2005 were significantly more costly than those implemented in
192   2011-2015 (Tab. 2).

193   **Table 2.** *p*-values of the T-Test of the differences between total budgets of river restoration projects in
194   different time frames analyzed. * - differences significant at the level of 0.05.

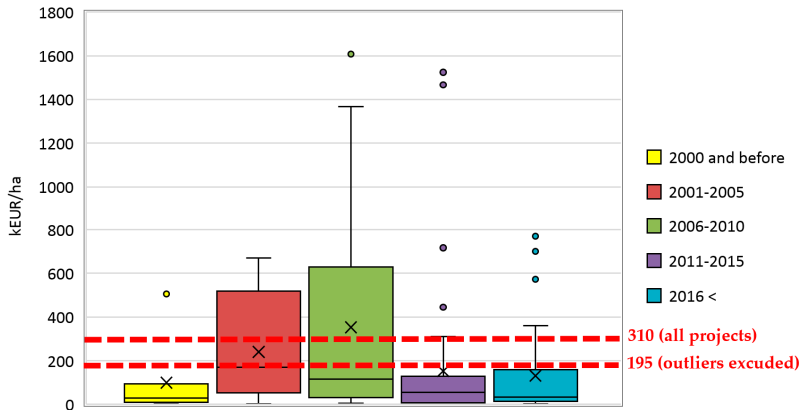| *p (T-Test)*	2000 and before	2001-2005	2006-2010	2011-2015	2016 <
2000 and before	-	0.108	0.934	0.631	0.473
2001-2005	0.108	-	0.096	*0.028**	0.303
2006-2010	0.934	0.096	-	0.490	0.477
2011-2015	0.631	*0.028**	0.490	-	0.159
2016 <	0.473	0.303	0.477	0.159	-

195

196   **Figure 7.** Distributions of unit costs of river restoration projects (kEUR/ha) in selected time frames.
197   Box represents the range from 25 to 75 percentile, x – average value, vertical line in the box – median,
198   whiskers represent maximum and minimum values, dots represent outlying values. kEUR stands for
199   thousand of Euro.

200   Once considering the total budgets of the river restoration projects and the areas of their
201   influence (lengths and widths restored), we calculated these projects' average unit value per hectare
202   of restored river (Fig. 7). We revealed that, on average, the cost of restoring 1 ha of river was 310 000
203   EUR (310 kEUR), with a range from 99 kEUR/ha (in 2000 and before) to 353 kEUR/ha (in 2006-2010;
204   Fig. 7). After excluding 4 extremely outlying values (two Italian projects on the Draganziolo and
205   Marzenego rivers, with unit restoration costs of 2000 and 4500 kEUR/ha, respectively; and two
206   French projects on the Bievre and Petersbach rivers with unit restoration costs of 2600 and 5680
207   kEUR/ha, respectively), the average unit restoration cost was only 195 kEUR/ha (Fig. 7). Despite
208   these outlying values, the differences in the unit river restoration costs across the time frames
209   analyzed were not statistically significant (Tab. 3). This observation leads to the conclusion that the

210   unit cost of river restoration, although strongly variable from site to site and highly dependent on
211   the measures applied, remained at a similar level throughout the period from 1989 to 2016

212   **Table 3.** *p*-values of the T-Test of the differences between unit costs of river restoration projects
213   (kEUR/ha) in different time frames analyzed.

p	2000 and before	2001-2005	2006-2010	2011-2015	2016 <
2000 and before	-	0.057	0.068	0.533	0.693
2001-2005	0.057	-	0.542	0.074	0.066
2006-2010	0.068	0.542	-	0.117	0.080
2011-2015	0.533	0.074	0.117	-	0.727
2016 <	0.693	0.066	0.080	0.727	-

214   Analyzing the unit costs of river restoration projects with respect to their spatial scales
215   (catchment; channel; floodplain; channel and floodplain together; or channel, floodplain and
216   catchment together; again, excluding the 4 outlying Italian and French restoration projects), we
217   found that the differences among these groups were more significant than those between the time
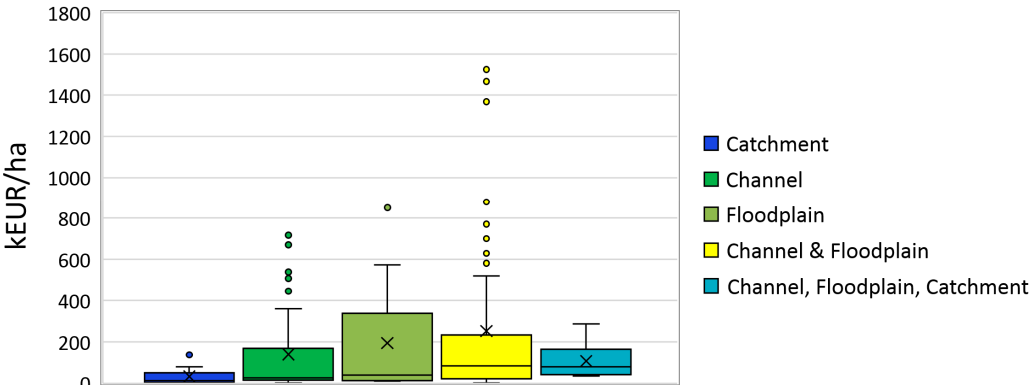218   frames (Fig. 8.; Tab. 4).

219

220   **Figure 8.** Distribution of unit costs of river restoration projects (kEUR/ha) with respect to different
221   spatial scales. Box represents the range from 25 to 75 percentile, x – average value, vertical line in the
222   box – median, whiskers represent maximum and minimum values, dots represent outlying values.

223   **Table 4.** *p*-values of the T-Test of the differences between unit costs of river restoration projects'
224   oriented at different spatial scales. * - differences statistically significant at the level of significance
225   0.05.

p	Catchment	Channel	Floodplain	Channel & Floodplain	Catchment & Channel & Floodplain
Catchment	-	*0.007**	*0.018**	*0.0001**	0.083
Channel	*0.007**	-	0.660	0.095	0.327
Floodplain	*0.018**	0.660	-	0.260	0.220
Channel & Floodplain	*0.0001**	0.095	0.260	-	*0.016**
Catchment & Channel & Floodplain	0.083	0.327	0.220	*0.016**	-

226   In general, the unit costs of the catchment-scale river restoration projects (average: 32 kEUR/ha)
227   were significantly lower than for other types of projects. The highest statistical significance was
228   recorded for the difference between the catchment-scale projects and the joint channel- and
229   floodplain-oriented actions (average: 280 kEUR/ha). This observation is based on the types of actions

230 implemented at the catchment-scale projects, which mostly involve planting trees and other low-
231 cost actions (see Supplementary Material). The most expensive actions were implemented in the
232 channel-floodplain and floodplain-only scales, and they included floodplain-lake reconnections and
233 dyke relocations. As the number of projects varied strongly across the 19 countries (from 1 to 17), we
234 decided not to differentiate the unit cost of river restoration at the country level.

235 **4.   Discussion**

236 First and foremost, we are aware that the analyzed sample covers only a portion of river
237 restoration projects implemented in European countries. The RiverWiki [26] and Onema [27]
238 databases contain many more records. These databases showed that, of the countries in Europe, only
239 the UK has hundreds of river restoration projects [28]. However, most of these projects lacked
240 information about river lengths and project budgets, which prevented us from considering these data
241 reliable enough for use in our study. Many projects related to the restoration of floodplain
242 environments were also reported; they were oriented mainly at wetlands (e.g., ditch blocking) and as
243 such, could not be analyzed. Bearing this issue in mind, however, the results presented in our
244 analysis, which are based on 119 projects from 19 countries, reflected the most relevant, general
245 advances in EU river restoration's progress at the end of the 20th and start of the 21st century.

246 Our survey results tended to mirror the conclusions provided by Palmer et al. [15] and Wohl et
247 al. [29]; for instance, the number of river restoration projects implemented in Europe continues to
248 increase. In our analysis of the structure of river restoration projects, we noted that less than half of
249 all the projects (42%) were part of a larger restoration strategy. Therefore, the majority of river
250 restoration projects were designed and implemented on a site basis, driven by the river managers'
251 and stakeholders' desire to improve the rivers. On the one hand, this can be considered a good
252 prerequisite for river restoration in the future, as the pattern revealed shows that managers and
253 stakeholders do not need special strategies or plans for their rivers. Their actions in the design and
254 implementation of river restoration projects tend to reflect the growing societal demand for high-
255 quality ecosystems, which Suding [1] foresaw as the main driver for environmental restoration in the
256 21st century. On the other hand, the lack of the comprehensive river restoration strategies in particular
257 countries could remain an obstacle for certain projects that should be structurally implemented and
258 that should not depend on the fluctuations of societal moods. One might expect that, if the availability
259 of external funds for river restoration projects were to decline (e.g., due to the EU shifting its priorities
260 away from environment and toward agriculture), then the lack of structured, national river
261 restoration plans would inhibit the design of new projects. The number of EU-co-funded river
262 restoration projects is increasing, and the cofinancing rate has reached 50-65% in most countries (or,
263 in some cases, 95%; Fig. 6), which has led to enhanced cooperation between NGOs and regional (or
264 national) official entities (Fig. 5). However, without structured strategies and planned cooperation
265 between NGOs and national (or regional) authorities, river restoration projects will likely remain
266 hobbyists' activities rather than comprehensive country-level actions that would produce measurable
267 improvements in degraded rivers' statuses.

268 Although Wohl et al. [29] reported that most river restoration projects are oriented at one river
269 only and that the measures applied remain limited to a single action (e.g., changing
270 hydromorphology or opening migration barriers), we found this status to be changing. Starting in
271 2000, we observed an increasing heterogeneity of measures. These measures were formerly limited
272 to the river channel and floodplain, but the set of actions that were undertaken in the most recent
273 time frame had expanded to include the catchment and its integrated actions. The most significant
274 shift in this manner occurred in 2011-2015 and from 2016 onward (Fig. 4). The growing scientific
275 interest in river restoration meant that the vast majority (78%) of projects included structured before-
276 and-after control-impact monitoring. Sadly, less than a half of the projects were designed and
277 implemented with the active participation of local communities (Fig. 4). This status frequently led to
278 conflicts between local stakeholders and implementing authorities [30]. Conflicts predominantly
279 arose when the communication process began too late in a project's life or failed to put the restoration
280 project in a local context [31]. A higher level of participation from local communities and other

281 relevant stakeholders has already been determined to have a positive impact on environmental
282 management projects, and a special emphasis on ecological restoration has resulted in more
283 comprehensive measures, longer project life and longer-lasting results [32-33]. However, ensuring a
284 high level of stakeholder participation in a restoration project requires targeted communication, and
285 it is efficient only if the gaps related to the science-practice interface have been narrowed [31]. Either
286 way, those who wish to implement successful river restoration projects should foster the wider
287 involvement of stakeholders in the project's design and implementation and in measures that ensure
288 the sustainability of the projects' results.

289   We estimated the average unit costs for EU river restoration projects, expressed in EUR · ha^{-1},
290 and although we calculated these values with a relatively small sample, there were few statistically
291 significant differences across temporal, spatial or technical scales (Tab. 2, Tab. 3 and Tab. 4). The lack
292 of information about some projects' longevity prevented us from defining the direct economic value
293 of the actions in each year, for comparison with the value of the ecosystem services for riparian and
294 riverine ecosystems, as other authors have calculated. Based on the collected answers from the
295 participants, we could not estimate the desirable persistence of the projects' ecological results over a
296 certain duration. Although the goal of a restoration project should be to enhance the existence of
297 resilient river systems, regardless of the duration [3,9,14-15,29], most restoration-related actions are
298 technical interventions (fish-ladder construction, floodplain-lake reconnection, etc.). Hence, these
299 projects could be considered permanent assets that undergo amortization (depreciation over time).
300 The annual depreciation (amortization) rate applied to the calculations made it feasible for us to
301 calculate the annual value of each river restoration per hectare. According to Poland's legal
302 regulations [34], the amortization rate of permanent assets (hydrotechnical constructions, land
303 reclamation or drainage systems, weirs, spillways, etc.) is 2.5% per annum. This means that
304 permanent assets are designed and constructed to function for 40 years (1 year/2.5%). Assuming that,
305 due to legal accordance, similar levels of amortization apply to such assets throughout the EU, the
306 average cost of river restoration projects per hectare per annum would be 7 757 EUR · ha^{-1} · year^{-1} (310
307 kEUR · ha^{-1} · 40 years^{-1}), which is equal to roughly 8 920 USD · ha^{-1} · year^{-1}. Excluding the four outlying
308 values referred to above, the unit costs of river restoration were 4 875 EUR · ha^{-1} · year^{-1} (5 606 USD ·
309 ha^{-1} · year^{-1}).

310   These values represent the price that European society wishes to pay (technically, has already
311 paid) to restore river functions. Hence, we consider this value to be the monetary dimension of
312 healthy rivers' ecosystem meta-service. Due to each river restoration project's complex aims and
313 measures, it is difficult to calculate the elementary values of a particular ecosystem's services (e.g., a
314 restored river as a new habitat for fish), but the given annual unit cost of restoring 1 hectare of a river
315 system is likely to represent the average long-term value of that river's services.

316   Interestingly, the calculated unit cost of river restoration may now be referred to as the value of
317 riverine ecosystem meta-service and is similar to the average worldwide unit value of ecosystem
318 services that de Groot et al. calculated for rivers and lakes combined [35] (4 247 USD · ha^{-1} · year^{-1};
319 ranging from 1 446 USD · ha^{-1} · year^{-1} to 7 757 USD · ha^{-1} · year^{-1}). At the same time, the calculated
320 value is a bit higher than the quantities for some single-ecosystem services calculated in individual
321 studies (such as flood retention, as calculated by Grygoruk et al. [21] and priced at approximately 500
322 EUR · ha^{-1} · year^{-1} or 590 USD · ha^{-1} · year^{-1}), but lower than the ones calculated by Costanza et al. (11
323 727 USD · ha^{-1} · year^{-1} for calculations published in 1997 [16] and 12 512 USD · ha^{-1} · year^{-1} for
324 calculations published in 2014 [36]). One might suspect that the differences shown above result from
325 the fact that both de Groot et al. [35] and Costanza et al. [16,36] used different calculation algorithms
326 and also dealt with lakes in addition to rivers. However, the river restoration projects that we
327 analyzed also referred to floodplains, which de Groot et al. [35] and Costanza et al. [16,36] listed in a
328 different category; the floodplain projects in these studies were priced much higher than average.
329 Despite these differences, all of the cited values have the same order of magnitude. This allows us to
330 hypothesize that the methodology we used to assess the unit value of the riverine ecosystems' meta-
331 service (on the basis of river restoration costs), thus expressing societies' willingness to pay for
332 healthy rivers, is a novel, comprehensive and reliable approach. One should be aware that every river

333 restoration project is strongly site-specific in terms of the river's proportions (width, depth and
334 stretch length), the project's spatial scale (channel, floodplain or catchment) and the measures applied
335 (from planting trees to heavy mechanical works in the channel). Moreover, labor and investment
336 costs also were strongly variable across the set of countries analyzed. However, the general lack of
337 statistical significance in the differences between the projects' budgets across the 19 countries and the
338 time frames analyzed (Tab. 2), with respect to the unit costs (Tab. 3), allow us to state that the
339 calculated unit value of river ecosystems' meta-service is reliable. As such, our results could be
340 carefully applied in EU-scale studies and policies regarding the value of rivers.

341 Among the projects analyzed, relatively few dam-removal initiatives were reported. Some new
342 initiatives are, however, being planned [37] and implemented [38], mainly in Western European
343 countries; this allows us to suspect that the number of removed dams will increase across the
344 continent. Similarly, observing advances in dam removal around the world, including the best
345 documented dam removals in the U.S. [39], we foresee that the 21st century will include more
346 ecosystem-economy-based discussions; our results, which are oriented at the calculation of healthy
347 rivers' services, may contribute to these discussions. The results of the research on dams' downstream
348 effects provides sufficient evidence that dam-reservoir-induced flow-regime changes and the related
349 negative responses of humans and of riverine and riparian ecosystems must be addressed through
350 (costly) mitigation measures [40-43].

351 On the other hand, even though the need for diverse, well-developed and resilient riverine
352 ecosystems has been agreed upon for quite some time [44], in recent discussions, scholars have
353 documented and even promoted ideas related to hard technical interventions (including the
354 construction of new dams and hydrotechnical infrastructure) as a *sine qua non* for growth [45]. Muller
355 et al. [45] hypothesized that humanity – for its own sake and benefit – is likely to continue degrading
356 rivers by introducing newly built infrastructure than to restore the rivers' environmental features.
357 However, along with increases in sustainable growth and outstanding recent advances in ecological
358 engineering, the awareness of the need for a high-quality environment will also rise [46-47], so we
359 believe this negative scenario will not come to pass.

5. Conclusions

361 We analyzed 119 river restoration project from 19 EU countries, revealing that the number of
362 river restoration projects has been increasing over the time frame analyzed (1989-2016). We also
363 observed that the complexity of these river restoration projects has increased; in addition to the
364 restoration measures in river channels and floodplains, more catchment-scale initiatives are now
365 being implemented. We also revealed that majority of river restoration projects were not done in the
366 framework of any larger (e.g., country-scale) policy, meaning that most are individual actions
367 implemented by groups such as regional authorities. We also observed an increasing involvement of
368 NGOs across the time frames. By analyzing the projects implemented in a variety of countries across
369 multiple spatial and temporal scales, we revealed that the unit cost of river restoration does not
370 change significantly across these scales. The average cost of restoring 1 ha of a river system was 310
371 kEUR (195 kEUR excluding four outlying values) and did not significantly change with respect to the
372 scale of the project, the country of implementation or the measures applied. The EU's average
373 contribution to these projects' budgets has also increased, reached a typical range of 50 to 60%. We
374 concluded that the EU's contributions and the implementation of the WFD significantly increased the
375 number of river restoration projects. On the basis of the obtained data and our subsequent
376 calculations, we estimated the average unit cost of river restoration per hectare to be 7 757 EUR · ha^{-1}
377 · year^{-1} (8 920 USD · ha^{-1} · year^{-1}). We stated that this value reflects society's willingness to pay for a
378 healthy river. Therefore, the calculated value can be referred to as monetary expression of river
379 systems' ecosystem meta-service, encompassing a range of individual services. This measure can be
380 applied to European environmental policy to address the sustainable management of riverine
381 ecosystems.

382 Based on our study's results, we suggest that, to ensure thee sustainable management of
383 Europe's rivers, certain countries should implement financial mechanisms that allow local

384 stakeholders (e.g., NGOs) to apply for external funds to pay for local river restoration initiatives. Such
385 programs would broaden the involvement of local stakeholders and decentralize river restoration
386 initiatives, thus enhancing local stakeholders' responsibility for their rivers. At the same time,
387 countries should implement national programs to address river restoration on nationwide scales to
388 provide planned and structured catchment-scale actions.

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