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Impact of Point Polluters on Terrestrial Ecosystems: Presentation of Results in Publications[1]

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Abstract—In the present paper we briefly outline the principles of meta-analysis, which gradually substitutes narrative reviews in modern ecology and becomes a standard for generalization of the results of independent studies. We demonstrate that a substantial part of publications reporting effects of industrial pollution on terrestrial biota cannot be used in meta-analyses due to incomplete presentation of the results. To overcome this problem, we suggest a protocol for the description of the results that includes necessary and desirable characteristics of a polluter, an impact region, study objects and sampling design. We stress the need to always report mean value, its corresponding variance and sample size. Failure to comply with the simplest requirements to the presentation of research results in publications leads to the loss of valuable information.

Keywords: industrial pollution, point polluter, impact region, terrestrial ecosystems, meta-analysis, scientific publications, protocol for the description of the results

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In the first part of our paper (Vorobeichik, Kozlov, 2012) we discussed methodology of studying impact regions and outlined the typical errors made by researchers while harvesting the outcomes of passive experiments. The other tasks of equal importance are correct data analysis and accurate presentation of the results in publications. Keeping in mind the urgent need of quantitative research synthesis in the field of impact ecology, in this paper we discuss the basic requirements to the presentation of the information in scientific publications.

META-ANALYSIS AS AN EFFECTIVE TOOL FOR INTEGRATING THE RESULTS OF INDEPENDENT STUDIES

Search for regularities by generalization of particular results is the most challenging goal of any scientific research, which is however difficult to achieve. While the statistical analysis is widely used in ecology since the first quarter of the XX century, no formalized methods for the quantitative analysis of the accumulated information existed until the late 1970's. As the result, narrative reviews suffered from inevitable, sometimes unconscious, subjectivity: their conclusions were non-repeatable due to the absence of strict criteria for both selection of publications for the review and evaluation of the quality of the published data.

This problem has been solved with the development of meta-analysis. This relatively modern statistical method allows to quantitatively combine the results of several independent studies addressing the same problem (Shitikov et al., 2008; Borenstein et al., 2009). The core of the meta-analysis is the transformation of the diverse data extracted from publications (selected by clearly defined criteria) into a common measure of effect size. These effect sizes are then analysed to find common trends and identify factors explaining differences between the outcomes of individual studies (Gurevitch, Hedges, 2001). Importantly, meta-analysis explicitly accounts for the representativeness of each case study, giving larger weight to the studies based on a larger number of replicates.

Not every problem deserves application of meta-analysis. Meta-analysis is most effective when the amount of accumulated information is large, and the preliminary analysis has demonstrated that, in an average, effect sizes are minor, results of case studies are contradictory, and/or there is the reason to suspect research or publication bias. Impacts of industrial pollution on biota obviously belong to this kind of problem.

Objectivity of the meta-analysis is achieved through the combination of precisely formulated criteria for selection of primary studies with the use of the statistical approach for integration of their outcomes. Therefore, in theory, conclusions of meta-analysis are reproducible: any scientist, by using the described cri-

[1] The article was translated by the authors.

teria of selection and methods of publication search, will collect the same set of primary studies, extract the same data and come to the same conclusions as his/her predecessors.

It should be admitted that the meta-analysis has some shortcomings. One of the basic problems is associated with the extreme difficulties in accounting for the hierarchy of the investigated factors and in analyzing their interactions. Moreover, the usefulness of meta-analysis is still criticized by some skeptics (though this criticism, as a rule, is directed towards the particular poorly conducted studies, not towards the method in general). Nevertheless, meta-analysis is widely used in many areas of science, especially in medicine; it is increasingly applied in modern ecology, gradually substituting narrative reviews and becoming a standard for generalization of the results of independent studies (Gates, 2002; Stewart, 2010). It can be expected that the prestigious international journals will soon cease to publish narrative reviews, and all research syntheses will be based on the meta-analytical approach.

In the first part of our paper (Vorobeichik, Kozlov, 2012) we described the database of publications reporting impacts of point polluters on terrestrial ecosystems. To date, this database served the basis for meta-analyses of the pollution effects on the abundance and diversity of bryophytes (Zvereva, Kozlov, 2011), soil micromycetes (Ruotsalainen, Kozlov, 2006) and terrestrial arthropods (Zvereva, Kozlov, 2010), as well as on the diversity (Zvereva et al., 2008), growth and reproduction (Zvereva et al., 2010), abundance (Zvereva, Kozlov, 2010) and fluctuating asymmetry (Kozlov et al., 2009) of vascular plants. The meta-analyses of studies addressing pollution impacts on the abundance and diversity of birds and annelids, as well as on litter decomposition, are under preparation. Regional effects of pollution have also been considered in several meta-analyses, e.g., those addressing effects of ozone on crops (Feng, Kobayashi, 2009) and trees (Wittig et al., 2009), development of parasitic invasion (Vidal-Martinez et al., 2010) and oxidizing stress (Isaksson, 2010) with environmental contamination, and accumulation of cadmium by mammals (Veltman et al., 2007).

The simplest meta-analysis aims at identifying the common trend in primary studies addressing the same problem, when these studies report diverse, sometimes contradictory, results. For example, some researchers did not find correlation between the level of pollution and the diversity of plant communities; moreover, some studies reported an increase of diversity with pollution. Nevertheless, meta-analysis of all published studies demonstrated that, in general, diversity of vascular plants decreased with pollution (Zvereva et al., 2008).

At the same time the meta-analysis is not equivalent to simple summation of the published data. The most important and interesting task of meta-analysis is to understand why outcomes of individual studies differ from each other. Search for sources of variation often yields new information that is absent in primary studies. For example, meta-analysis of studies addressing pollution-induced changes in the diversity of vascular plants (mentioned above) demonstrated that effect sizes depended on climate: adverse effects were less expressed at high latitudes (Zvereva et al., 2008). Another meta-analysis discovered that adverse effects on the abundance of several groups of biota became stronger with time from the beginning of the pollution impact, while adverse effects on individual performance of the same groups (measured as body size or survival) decreased (Kozlov, Zvereva, 2011).

Importantly, meta-analysis allows revealing gaps in knowledge, thus facilitating development of the strategy of the further research. This is achieved through (1) visualization of the amount of data available for different study objects and (2) identification of regularities that are considered trivial but lack the empirical support.

Meta-analysis can only be implemented when primary studies report sufficient information to allow calculation of effect sizes. For this purpose, several simple requirements must be fulfilled. As a rule, effect size can be calculated from (a) sample size and coefficient of correlation between the pollution level (or the distance to the polluter) and characteristic under study or (b) means, variances (or standard errors) and sample sizes for both "treatment" (data collected within the impact region) and "control" (outside of it, i.e., representing regional background). If one of these values is missing, or there exists uncertainty in the identity of some values (e.g., it is not stated explicitly whether the value placed after a "±" sign is the standard error or the standard deviation), then the study cannot be used in any meta-analysis. In fact, this means the loss of valuable information, collection and analysis of which had required substantial efforts. Besides obvious negative consequences for the author of the primary study (which, most likely, will be simply forgotten), exclusion of incompletely reported results from the meta-analysis can potentially bias its conclusions.

RUSSIAN PUBLICATIONS ON THE ECOLOGY OF IMPACT REGIONS

The larger part of studies addressing impacts of point polluters on biota was conducted by the Russian researchers (the proportion of their publications in the database described above is ca. 65%). First of all, this is explained by location of the substantial part of large sources of industrial emissions on the territory of Russia. At the same time many works published in Russian are lacking the information needed to calculate effect sizes and therefore they cannot be used in meta-analyses. To some extent this is caused by a tendency to split the results into the smallest publishable units, which is typical for the Russian ecologists. This tendency results

Table 1. Comparison between studies published in Russian and in English (random samples of 50 publications in each language) in frequencies of reporting the data that are critically important for conducting meta-analysis, and in characteristics reflecting the quality of the research

Characteristics of the study	Language		χ^2/P
	Russian	English	
Presence of information:			
time of data collection	30	46	14.0/0.0002
number of study sites	49	49	0.0/1.00
spatial distribution of study sites	14	43	34.3/<0.0001
number of samples	24	19	1.02/0.31
mean(s) and corresponding variance(s)	14	34	16.0/<0.0001
Quality of research:			
results of statistical analysis reported	16	48	44.4/<0.0001
number of study sites (per publication)	10.5	17.1	14.3/0.0002
number of effect sizes that can be calculated (per publication)	3.8	9.0	7.61/0.006
number of verbal conclusions (per publication)	5.5	10.6	2.82/0.09

in predominance of publications consisting of one to three pages, the volume that does not allow describing either methods or results in sufficient details.

To corroborate this statement, we compared two random samples from our database consisting of 50 publications by the Russian researchers and 50 publications by the researchers from the Western Europe, USA and Canada. In the first sample 72% of publications were not suitable for meta-analysis, because they did not report either mean values or measures of their variability, while in the second sample the proportion of unsuitable publications was 32% (Table 1). Similarly, 46% of papers published in Russian appeared unsuitable for the meta-analysis of pollution impact on soil micromycetes, while among studies published in other languages the proportion of unsuitable papers was 10% only (Ruotsalainen, Kozlov, 2006). Thus, although incomplete reporting of study results is a problem of international magnitude, the peculiarity of publications by Russian scientists is indeed obvious. Moreover, the Russian authors rarely use statistical analysis to substantiate their conclusions (Table 1). They also report timing of data collection and spatial distribution of study sites relative to the polluter (i.e., information that is vital to explore sources of variation in outcomes of individual studies) much less frequently than their Western counterparts (Table 1).

A detailed analysis of the reasons behind the detected pattern is beyond the scope of the present work because this topic belongs to the history of science. However, we can point out two major causes. First, the negligence of the Russian researchers in statistically analyzing their data dates back to the times when Russian biology was undergoing a gloomy period (Leonov, 1999). As a result, Russian authors lacked the "statistical traditions" prompting them to report sample sizes and/or standard errors. Second, censorial restrictions of the Soviet era against publishing even minor details about industrial enterprises and their impacts on nature had created a tradition of "safe" representation of information among the Russian ecologists. Unsolvable "geographical puzzles" had substantially decreased the value of data published during the 1970's and 80's. Even nowadays, some publications mention just "a factory" (of unknown type), the geographical position of which cannot be ascertained more precisely than at the level of the continent. Since the size of pollution effects can depend on many characteristics of both polluter and the local environment, papers lacking information on the polluter can only be used for calculating an average effect size, but not in the analysis of the sources of variation in the outcomes of primary studies.

One of the obvious consequences of insufficient attention to the correct presentation of research materials is the low frequency of citations of papers, which have been originally published in Russian, in international journals. Using Web of Science, we have selected a sample of 630 papers describing effects of industrial pollution on different groups of biota. All these papers were authored or co-authored by the Russian researchers and published during 1980 to 2010 both in Russian (257 papers) and international (373 papers) journals. To exclude effect of language, we accounted only for those Russian journals that are also published in English. The average numbers of citations were 0.92 for papers originally published in Russian (and then translated to English) and 9.10 for papers originally published in English. We are certain that these striking differences in citation frequency are primarily related not to the topic of the research, but to the accuracy of the description of both methods and results of the study.

A logical and easy action to tackle this problem is to change the attitudes of editorial boards of Russian ecological journals to the completeness and the level of detalization required for the presentation of research results. First of all, this suggestion concerns the "Materials and methods" section, to which the Russian journals pay much less attention than international journals. To corroborate this statement, we compared 81 papers from three Russian journals (Russian Journal of Ecology, Eurasian Soil Science, Biological Bulletin) and 81 papers from three international journals publishing studies on the same topics (Oikos, Applied Soil Ecology, Environmental Pollution). The samples were created as follows: we selected three first papers (only those reporting original empirical data) from each of three first journal issues for each of three years of publication (2006-2008). This protocol, to our opinion, assures representativeness of our samples, allowing for the comparison between Russian and international ecological journals. In the selected papers we counted the total number of characters (excluding abstract, tables, figures and references) and the number of characters in the "Materials and methods" section. To avoid effects of language, we used English translations of the papers originally published in Russian. We found that in an average the "Materials and methods" section in Russian journals contained 2800 characters (95% confidence interval: 2500–3200), while in international journals—7000 characters (6400–7700). We doubt that this substantial (the 2.5 times!) difference is due to the "supernatural" ability of the Russian authors to compress the information more than their Western counterparts do. The difference persists when we account for the publication volume (papers in international journals are on average 1.5 times longer): the proportion of the "Materials and methods" section in Russian journals was 18.5%, while in international journals—29.4%. All arguments given above justify the need to change, to a certain extent, the editorial policy of the Russian journals that publish ecological research.

PROTOCOL FOR THE DESCRIPTION OF THE RESULTS IN PUBLICATIONS

The problem of uniform requirements to presentation of the results of experimental research is topical not only for the Russian ecological journals. It could be reminded that a similar problem was recognized in medicine a few decades ago. The problem was solved in 1978 when a group of editors of the leading medical journals (recently known as the Vancouver Group) developed uniform requirements to the structure of publications, description of experimental methods and equipment, data analysis and presentation of the results. Later on, these requirements were substantially improved and extended (Uniform requirements..., 2010). Unfortunately, a similar standard for ecological publications does not exist at either international or national levels. In Russia the situation is aggravated by the absence of teaching of scientific writing in most Russian universities, in contrast to the Western ones. Textbooks on communicating scientific information (Marjanovich, Knjazkin, 2009; Councils ..., 2011) and manuals for describing the outcomes of statistical analysis (Lang, Sesik, 2011) were published in Russian only recently. Besides, instructions for authors of many Russian journals (in contrast to the international ones) do not provide detailed recommendations concerning the style of writing and completeness of the reported information.

On the basis of our experience we have compiled the list of characteristics which should be reported in primary studies addressing impacts of point polluters on terrestrial ecosystems (Table 2). All these characteristics are necessary to allow the efficient use of published data in the search for general regularities by means of meta-analysis. And though the list appeared to be large enough, we are certain that it is possible to report crucial data on the polluter, impacted area and study objects on one page of manuscript. Descriptions of the sampling protocol and of the processing of samples can also fit to one page. We would like to emphasize that the description of materials and methods should contain sufficient details to allow replication of the research by a qualified scientist, i.e., allow this scientist to locate study sites and repeat sampling and processing of materials using of the same (unequivocally defined) methods.

It is worth reminding that information which is trivial for the author can be far from trivial for many

Table 2. Protocol for the description of the results of studies addressing impacts of point polluters on terrestrial ecosystems

Component of description	Part of description	Characteristics	
		Necessary	Desirable
Polluter	Reference data	Name and type of *PP* (e.g., copper smelter)	Basic products
	Geographical data	Location of *PP*: political or administrative unit, village/town/city	Geographical coordinates of *PP* with highest possible accuracy
	Historical data	Year of putting *PP* into operation	Years when major changes in structure and/or amount of production occurred
	Chemical data	List of principal pollutants, years when major changes in amount and/or composition of emissions occurred	Amounts of emissions during the study years and in the past
Impact region	Geographical data	Position of studied *PP* relative to other *PP* with comparable amounts of emissions	Presence or absence of overlap between the impact region of the study *PP* and impact regions of other *PPs*
	Landscape data	Biome (e.g., southern taiga or forest-steppe) and landscape characteristics (e.g., low mountains or plain)	Short description of vegetation changes and estimates of the size of the impact region
	Ecological information	Original state of vegetation and soils (including pH of upper soil horizons)	Physical and chemical characteristics of upper soil horizons (including granulometric composition, concentrations of N, C, exchangeable Ca, Mg, K, Al, etc.)
	Historical data	Brief history of the development of most important environmental changes caused by emissions	Brief review of earlier research conducted in the impact region
	Chemical data	References to publications describing spatial distribution of pollutants around *PP*	
Study object*	Taxonomical information	The lowest hierarchical category; Latin name (for living beings)	Accepted classification (e.g., for landscapes, soils, plant communities). For taxa identification of which requires specific skills: who identified the material and where the vouchers are deposited
	Ecological information	Characteristics of the study object that are important for understanding the results of the study	Brief characteristic necessary to visualize the object for those not familiar with it
Sampling design: larger scale	Reference data	Number of *SS*, their labeling in the text. Size and shape of sampling plots. Dates of sampling	References to other studies that used the same *SSs*. Relationships between timing of data collection and phenology of the study object

Table 2. (Contd.)

Component of description	Part of description	Characteristics	
		Necessary	Desirable
Sampling design: larger scale (Contd.)	Geographical data	Direction (compass point) and distance from *PP* to each *SS*. Landscape position of *SS* (e.g., lower third of a slope). Altitude (for the mountain areas)	Geographical coordinates of *SSs* with highest possible accuracy. Map showing positions of *SSs*. Altitude (for plains)
	Methodological approach	Method used to select *SSs* (random choice, selection based on some criteria, etc.). Criteria used to assure comparability between *SS* located outside (control) and inside (treatment) impact region	Justification of the method used to select *SSs*
	Chemical data	Concentration of one of the principal pollutants and pH of soil (forest litter) at each *SS*	Concentrations of several more pollutants at each *SS*
Sampling design: smaller scale	Reference data	Definition of evaluation unit (e.g., tree, plot 25 × 25 cm, composite sample prepared from multiple individual samples). Number of evaluation units and method of their selection within *SS* (e.g., random or regular distribution). Distance between evaluation units. Positions of evaluation units in microrelief or relative to other objects (e.g., tree trunks)	Justification of the applied sampling design
	Protocol of sampling and processing materials	Detailed description of the protocol that is sufficient to repeat sampling, or reference to standard protocol (if it has not been modified). Accuracy of measurements	Control of repeatability; standards used in comparisons
	Equipment	Key characteristics (e.g., detection limit and accuracy of measurements)	Type and manufacturer
Results	Values (of each character at each *SS*)**	Mean value, its corresponding variance or standard error or confidence interval, and sample size	Other characteristics of empirical distribution (median, mode, quartiles, deciles, maximal and minimal values, coefficient of variation, asymmetry, and kurtosis) whenever necessary
	Statistical analysis	Selected statistical test, along with information justifying correctness of its application. Value of test statistic, degrees of freedom and the achieved probability level	Justification for selection of the statistical test

Note: *PP*—point polluter, *SS*—study site. *—In the case of multiple study objects this information is provided for each object; **—reported in tabular form or shown on graphs; can be published in electronic appendices.

readers. A widespread mistake is to guess that readers are well informed about details of regional importance, and skip, on the basis of this guess, characteristics of study area and the polluter. In our opinion, the author should always address to the reader who is not aware of local environment and has no practical possibility to receive additional information (e.g., because of linguistic problems or limited access to proceedings of national conferences). Attention paid to the reader is not only a principle of scientific ethics; this is also a prerequisite for reading and correct understanding of the publication by other researchers who will then be able to correctly use the reported results, giving credits to the author by referring to his/her work.

META-ANALYSIS AND QUESTIONS OF SCIENTIFIC ETHICS

While searching the data for several meta-analyses we often had to request additional information from authors of published studies. Results of this communication prompted us to express our opinion on some topics related to the scientific ethics. We believe that authors are responsible for presenting their materials in such a way that the outcomes of the study could be unequivocally interpreted, and subsequently used without having to request for additional information. If the author fails in this task and the reader seeks clarification, the standard principles of scientific ethics allow hoping for a prompt and detailed response. Unfortunately, these hopes were proved wrong.

To corroborate this statement, we report the results of a sociological research conducted in 2006–2009. Out of 100 requests sent to Russian authors, more than half remained unanswered. Importantly, repeated requests and phone calls showed that the requests had been received, but many authors did not consider it necessary to bother to respond. Prompt and unequivocal answers were received for only 10% of the requests; and these 10% included, among others, "negative results", e.g., information that the primary data are lost or details of sampling protocol are forgotten with time. In approximately 20% of the cases, authors provided "formal responses" (e.g., "All data were analyzed statistically" in response to the question "What is published in the specific table—standard error or variance?"). In the remaining 20% of the cases, authors did not refuse to answer our questions, but put forth some conditions for providing the requested information. We were especially impressed by the "commercial" offers, such as the request of payment for providing us with standard errors (three cases) or promise to collect "the same" material if this procedure is paid in full (two cases). Against this background, offers to provide information on sample sizes in exchange for the co-authorship of a review paper (two cases) or new publication based on the same material (one case) do not seem outrageous any more.

CONCLUSIONS

Modern methods of research synthesis impose strict requirements to the presentation of research results in publications. We provided arguments for the acceptance of uniform protocol for the description of the results of studies addressing impacts of industrial pollution on terrestrial biota, and suggested the first version of it. We believe that compliance with this protocol can substantially increase the quality of scientific publications. Efforts needed for adequate description of study area, study objects and research results, are negligible in comparison with losses that will be experienced by scientists due to impossibility to use valuable but improperly reported information.

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