Landscape Ecol (2016) 31:469–479
DOI 10.1007/s10980-015-0296-z

PERSPECTIVE

Advancing landscape ecology as a science: the need for consistent reporting guidelines

Daniela Vetter · Ilse Storch · John A. Bissonette

Received: 20 January 2015 / Accepted: 6 October 2015 / Published online: 30 October 2015

Abstract
Context In the face of global change, evidence-based information for policy development and political action is needed. Research syntheses have the potential to produce more reliable and generalizable results than are possible from small and regional extent primary studies. Data-sharing and detailed reporting are indispensable prerequisites for syntheses, however syntheses often are seriously hindered by insufficient reporting of primary data.
Objectives Since many ecological processes are strongly influenced by spatial pattern, we suggest reporting guidelines for landscape-ecological studies. Better data reporting will not only benefit the quality of primary research studies, and allow replication, but also facilitate research syntheses.
Methods We evaluated how landscape context information was reported in primary research articles including recently published articles in the journal *Landscape Ecology*. We further looked at the author guidelines for several journals to check what authors are expected to report.
Results Specifically, we found that the existing reporting of landscape context information was insufficient to evaluate the effects of tropical forest edges on bird nest predation risk. More generally, exact study locations were not provided in any evaluated article. No journal gave detailed instructions to authors on how to report study characteristics.
Conclusions We argue that consideration of the following reporting guidelines could substantially facilitate research syntheses: (1.1) detailed map of study area, (1.2) spatial location of sampling points; (2.1) land-use types; (2.2) vegetation, key resources, soil, geology, and disturbance history; (2.3) additional site parameters; (3) results for each sampling point.

Keywords Research synthesis · Reporting guidelines · Data availability · Landscape context

Electronic supplementary material The online version of this article (doi:10.1007/s10980-015-0296-z) contains supplementary material, which is available to authorized users.

D. Vetter (✉) · I. Storch
Chair of Wildlife Ecology and Management, Faculty of Environment and Natural Resources, University of Freiburg, Tennenbacher Str. 4, 79106 Freiburg, Germany
e-mail: daniela.vetter@wildlife.uni-freiburg.de

I. Storch
e-mail: ilse.storch@wildlife.uni-freiburg.de

J. A. Bissonette
Department of Wildland Resources, Quinney College of Natural Resources, Utah State University, Logan, UT 84320, USA

Introduction

In the face of global change, research needs to provide evidence-based information for political actions. Unfortunately, most ecological studies are conducted at smaller spatial extents so that the possibility of reaching more general conclusions is limited (Hillebrand and Gurevitch 2013). At the same time, large numbers of primary research studies are available. Modern research synthesis techniques offer an exciting potential to compare results across studies and arrive to more reliable results and to detect important generalities (Thompson et al. 2000; Stewart 2010; Hillebrand and Gurevitch 2013). A prerequisite for substantial research syntheses is a "data-sharing culture" (Pullin and Salafsky 2010) and detailed reporting (Hillebrand and Gurevitch 2013). Today, digital data depositories allow storage of huge amounts of data (Pullin and Salafsky 2010; DRYAD 2014) and make the importance of documentation even more important. As one reviewer of this ms reminded us "raw data and specific coordinates provide (the) potential for re-analysis at later dates even generations from now that will be extremely important in these times of global change". Nevertheless, research synthesis is seriously hindered by insufficient reporting of primary data.

In ecology, Hillebrand and Gurevitch (2013) have recently drawn attention to the importance of extensive reporting, commenting on the lack of "basic and essential details" in ecological studies and advocating a standardized reporting. The journal *Ecology Letters* has added a new checklist for reporting standards in experimental studies to their author guidelines (Hillebrand and Gurevitch 2013). Reporting guidelines are important tools for ensuring the applicability of research results. In health research, more than 200 reporting guidelines are listed and promoted by The EQUATOR Network (2014). Authors, reviewers, and editors commonly apply these guidelines and are aware of their value and benefit for high-quality research.

The delayed development in reporting guidelines for ecological studies might be due to the extreme variability in study subjects, conditions, and designs. Estimates of the world's number of species vary between 5 and 30 million and only about 1.8 million species have been described so far (Vié et al. 2009). Health researchers, in comparison, only have to deal with one focal, albeit complex, study subject: humans. Ecological studies commonly have to deal with a number of largely uncontrollable and mostly unmodifiable conditions; e.g., species interactions, climatic influences, and anthropogenic disturbances. Because many ecological processes are strongly influenced by spatial pattern, the landscape context necessarily needs to be considered (Turner 1989; Pickett and Cadenasso 1995; Thompson et al. 2000). Manipulation of landscapes is either impossible or extremely costly and laborious. Health research, in contrast, benefits from powerful designs that allow for secure inferences, e.g., randomized controlled trials (Sibbald and Roland 1998). In addition, parameters that possibly influence study results can more easily be sampled and are consistently applied, e.g., sex, age, weight, or medication.

Manipulative experiments are not often practical or possible in many ecological studies carried out in real landscapes, so inferences need to be drawn from different data designs. More often than not, data collection is influenced by a variety of possibly moderating effects (Thompson et al. 2000; Shaffer and Johnson 2008; Sagarin and Pauchard 2010), e.g., climatic conditions, different land-use types, or human attitudes and activities. These conditions further drive the need to report information about landscape context in such detail that research syntheses become possible. Better data reporting will not only benefit the quality of primary research studies, but also facilitate research syntheses (Thompson et al. 2000; Nichols et al. 2007; Hillebrand and Gurevitch 2013). We therefore argue that reporting guidelines for studies carried out in real landscapes are urgently needed.

In the following, we present evidence of insufficient reporting of landscape context information from two literature searches and suggest a list of reporting guidelines for landscape-ecological studies.

Methods

We here refer to an already published meta-analysis (Example 1), where we aimed to analyze the influence of edge effects on avian nest predation (Vetter et al. 2013a). This meta-analysis has a strong biological focus and thus only reflects one aspect of landscape ecology (Bastian 2001; Wu 2006). We present it here because it nicely highlights the problem of insufficient reporting of landscape context information for a focused research synthesis. To also consider a broader variety of landscape ecological studies, we additionally evaluated reporting in recently published articles in *Landscape Ecology* (Example 2).

Example 1: reporting for a concrete case of research synthesis

For our meta-analysis, we searched for articles that evaluated the effects of tropical forest edges on bird nest predation risk (Vetter et al. 2013a). We found 20 articles on artificial nest predation studies that fulfilled our study inclusion criteria and tested for an influence of edge distance on nest predation risk. Moreover, we were interested in analyzing the influence of the landscape context. In particular, matrix type (here defined as land-use types other than native forest) (Angelstam 1986; Andrén 1995; Marzluff and Restani 1999; Lahti 2001), forest fragment sizes (Hanski et al. 1996; Marzluff and Restani 1999) and forest cover (Donovan et al. 1997; Hartley and Hunter 1998; Lahti 2001; Thompson et al. 2002) were hypothesized to have an influence on nest predation rates. We therefore extracted available information on matrix types adjacent to studied forest, forest fragment sizes, and forest cover from the Methods sections of the 20 evaluated studies.

Example 2: reporting in current articles of *Landscape Ecology*

We perused the most recently published articles in *Landscape Ecology*. We chose the journal because it traditionally publishes studies with a focus on landscape pattern and spatial heterogeneity. On April 23rd 2015, we searched all recently published articles and discarded those which had not conducted their own field work (Table S1). We searched the Methods sections of the articles not for specific parameters, as in Example 1, but for general information on the location of the study area and sampling points. We considered reporting of the precise sampling point locations as important, because respective information would allow generating desired landscape parameters for research synthesis (see "Discussion"). We documented if the following information was provided: coordinates of the study site(s), coordinate precision, a map with coordinates or distinct reference points, and precise locations of sampling points. We further documented if the authors had recorded and reported additional site parameters that were of interest for their specific study, e.g., canopy cover, number of snags, stem density, vegetation height, or distance to edge.

Journal instructions on reporting

We additionally looked at the Author Guidelines of various journals in order to check what they expected authors to report. We selected the five highest ranked journals in the Journal Citation Report 2012 (5-year IF) for the category "Biodiversity Conservation" in the Web of Knowledge. We looked for specific instructions on how to describe study sites and landscape parameters.

Results

Example 1: reporting for a concrete case of research synthesis

Matrix types

Although all 20 articles gave some information on the matrix types present in the study area, descriptions mostly offered little detail (Table S2). Twelve articles mentioned the presence of one matrix type in their study areas (e.g., pasture or farmland). Of the other eight articles that reported more than one matrix type, seven did not clearly relate matrix types to studied forest (fragments), although two reported results by matrix type. Only one article that reported different matrix types clearly related them to the studied fragments.

Fragment sizes

Seven articles reported sizes of studied fragments, but in only three articles could results be related to fragments. Four articles did not provide information on fragment sizes. Of the remaining nine articles, two had conducted research in continuous forest and seven in a forest block, although the sizes of the forest blocks were not always reported.

Forest cover

Six articles did not give information on forest cover in the study area. The reporting in the remaining articles had little detail and was diverse so that no useful information could be derived for analysis.

As a consequence, we could only test for an influence of matrix types in coarse categories and were unable to test for an influence of forest fragment sizes. Regarding forest cover, we used the location of the study area and generated the desired data ourselves via satellite images and GIS software. Yet, the exact positions and extents of the study areas were not available (Table S3). Mostly, coordinates were not precise (e.g., 17°45′N, 89°W) or represented only a delineation of the study area (e.g., 19°06′–19°18′S and 39°45′–40°19′W). We therefore calculated forest cover at three radii around the study area center which we defined by either the given coordinate pair or by averaging the provided delineation.

Example 2: reporting in current articles of Landscape Ecology

After excluding all articles that had not reported field work, we evaluated 20 articles (Tables S1, S4). Sixteen articles did not report coordinates. One article reported coordinates in degrees and three articles in minutes. The problem of different resolutions is evident when one realizes that (assuming a position at the equator) 1° latitude = 110.6 km = 60 min, 1 min = 1842.9 m = 60 s, and 1 s = 30.7 m. Similarly, 1° longitude = 111.3 km = 60 min, 1 min = 1855.3 m = 60 s, and 1 s = 30.9 m (calculated at http://msi.nga.mil/MSISiteContent/StaticFiles/Calculators/degree.html). Of the 20 articles, 18 articles presented maps, of which three articles displayed maps with coordinates (degrees/minutes) and two articles with other distinct reference points. No article reported precise locations of sampling points, although two articles stated that they had recorded each sampling point by GPS. Additional site parameters had been measured in 16 articles, but were not reported.

Journal instructions on reporting

No journal gave detailed instructions to authors on how to report study characteristics (Table S5). Only two journals (*Global Change Biology* and *Conservation Letters*) instructed authors to report sufficient detail to allow replication. One journal (*Diversity and Distributions*) offered authors the possibility to refer to outside data repositories where data used in their paper can be accessed by other scientists. All journals offered online supplementary material space to the authors. The lack of instructions for reporting important landscape context information in sufficient detail is obvious. We suggest that history probably has played a part in this problem. When journals were only printed, space was a fiscal constraint. Now that many journals are almost exclusively electronic, the constraint is relaxed. We now have the opportunity to rethink how to describe study sites and landscape parameters and to improve reporting.

Discussion

In our meta-analysis (Example 1) research synthesis was hindered by insufficient reporting of landscape context information. Analyzing the influence of matrix type, forest fragment sizes, and forest cover would have been relevant to explain variation across studies. Yet, analysis was only possible with little detail (matrix type, forest cover) or none at all (forest fragment sizes). The problem of insufficient reporting of the landscape context for research synthesis has been recognized repeatedly (Thompson et al. 2000; Parker et al. 2005; Nichols et al. 2007; Gardner et al. 2008; Mortelliti et al. 2010; Batáry et al. 2011; Vetter et al. 2011; García-Morales et al. 2013; Hillebrand and Gurevitch 2013; Vetter et al. 2013a). Landscape context matters (Ritchie 1997; Lindenmayer et al. 2002) as do scale and resolution (Bissonette 2013), and yet are not referenced consistently in primary research papers.

A variety of metrics and tools to quantify landscape pattern, e.g., landscape patchiness, edge density, landscape richness, or landscape shape index have been developed (Turner 1989; Turner 2005). The value of such metrics for reporting guidelines is however problematic, since metrics change with the resolution and extent of sampling and return different results depending on the classification of habitats or definition of a patch (Hargis et al. 1998; Turner 2005). Consider the simple measure of % forest cover: If primary studies provided % forest cover for their study area, but differed in extents or definition of 'forest', comparability would be problematic. Another issue is the amount of work for the primary authors. A hydrological study measuring nitrate concentration for a certain catchment area (Arvola et al. 2015) could be of interest for research synthesis on the impact of landscape patchiness on water quality (expressed by nitrate concentration). Yet, reporting landscape patchiness for their study area may be beyond the original purpose of the primary authors. The requirements of reporting guidelines will certainly create additional work for the primary authors. We argue that, considering the advantages and benefits of better reporting and facilitated research synthesis, a certain additional amount of work may be justifiable. It may be possible to distribute the additional workload appropriately between primary authors and scientists conducting research synthesis.

Below, we propose guidelines that do not require the primary authors to report a compulsory list of landscape metrics, but rather to provide the necessary information that allow scientists synthesizing studies to generate the desired landscape parameters themselves. For example, precise coordinate locations of *sampling points* would enable access to available land cover data and satellite images of known resolution and date, e.g., Corine Land Cover data (Copernicus Programme 2014), Landsat data (U.S. Geological Survey 2015), National Land Cover Database (NLCD) (Multi-Resolution Land Characteristics (MRLC) Consortium 2015) and allow re-generation of the desired data (for examples see Parker et al. 2005; Batáry et al. 2011; Vetter et al. 2013a). If primary authors in our meta-analysis (Example 1) had provided precise coordinate locations of *sampling points*, we would have been able to generate and analyze data on matrix types adjacent to studied forest, forest fragment sizes, and a more precise estimate on % forest cover of the study area. Yet, information on locations of sampling points was not given and information on study locations was imprecise. Example 2 suggests that insufficient reporting of landscape context information, including precise locations of study areas and sampling points, is not an occasional, but a common problem in most landscape-ecological studies.

Reporting guidelines for landscape-ecological studies

We suggest that the following basic data be provided for every paper:

Where was the study conducted? Where were the samples taken?

1.1. A detailed map of the study area, and/or a shapefile
1.2. Spatial location of sampling points with a clear description of the sampling protocol

Which conditions were present at sampling points?

2.1. Land-use types present in the study area and at the location of each sampling point
2.2. Vegetation, key resources, soil, geology, and disturbance history at sampling points
2.3. Author-provided additional site parameters

What results were found?

3. Results, i.e., associations or raw data, in relation to each sampling point

1. 1 A detailed map of the study area, and/or a shapefile

A detailed map provides a reference for the land cover data and/or satellite images. Coordinates, resolution and extent, lines of latitude and longitude, and map generation details (map source, projection, time/date, for satellite images: sensor, spectral bands) allow for referencing the map to a GIS-environment. Ideally, the map could be detailed enough to allow distinct sampling points to be recognized (Fig. 1).

Preferably, a shapefile containing the sampling points of the study area could be provided and stored in an online archive (see Shapefile files 1-6 in supplementary material). Additional information connected to the sampling points (e.g., date and time of sampling, investigator) could also be reported (in attribute table).

1.2 Spatial location of sampling points with a clear description of the sampling protocol

Providing precise locations of sampling points is essential, because by knowing the sampling point locations, most landscape parameters can be generated via land cover data or satellite images. Data on sampling point locations enable, for example, the consideration and analysis of fragment sizes, adjacent matrix types, edge distance, or fragment isolation. Ideally, coordinates in table format (see Table S6) or a shapefile (see above) containing the sampling points could be provided. In any case, we suggest coordinates

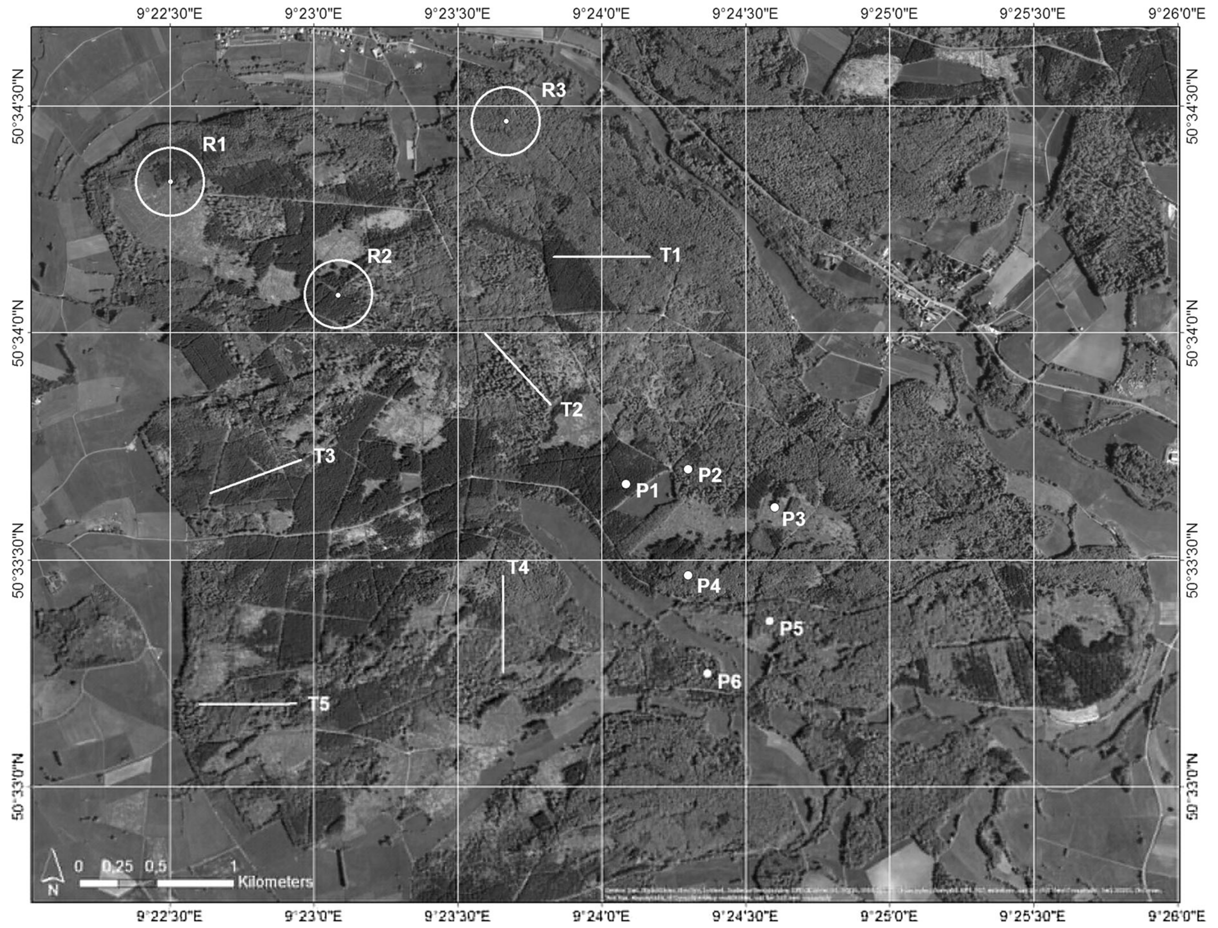

Fig. 1 Map of a hypothetical study site. Coordinates, extent and resolution, scale, and projection are given. Additional *lines* of latitude and longitude facilitate referencing the map to a GIS-environment. Sampling points are shown as *circles* (e.g., areas where stem density was sampled), *transects* (e.g., sampling of vegetation height), and *points* (e.g., bird point counts). *Projection* Web Mercator Auxiliary Sphere. *Map source* World Imagery (ArcMap Basemap: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS user community: Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community). Date: May 14th 2012, Resolution: 0.3 m, Provider: DigitalGlobe, Aerial Imagery (Common sensor usage)

be reported with a precision of seconds (e.g., 47°34′18″N; 7°40′25″E) or of ca. 30 m resolution (see above) (Table 1). Detailed reporting on sampling point locations already covers information on extent and resolution of the sampling. However, a clear description of the sampling protocol could be given, including information on where, why, when, and how data were sampled. Considering endangered species or privacy issues, reporting precise locations of sampling points might not always be possible or feasible. Primary authors may then instruct scientists aiming for research synthesis how and from whom they could get permission to access restrained data.

2.1 Land-use types present in the study area and at the location of each sampling point

The type of the land-use in a study area can have far-reaching influences on numerous ecological processes and conditions (Foley et al. 2005), such as ecosystem services (Kremen et al. 2007), soil quality (Islam and Weil 2000), species diversity (Blair 1996), or river ecosystems (Allan et al. 1997). Generating land-use types for research synthesis on basis of sampling point locations may not be possible, if no detailed land-cover data are available for the studied region. We therefore ask primary authors to either cite a reference

Table 1 Recorded data and parameters presented by sampling point to facilitate cross study comparisons

	Sampling point P 1	Sampling point P 2	Sampling point P 3
Where sampled?			
1.2 Coordinates	50°33′42″N, 9°24′18″E	50°33′37″, 9°24′36″E	50°33′28″N, 9°24′18″E
Which conditions?			
2.1 Land-use type	Forest	Pasture	Forest
2.2 Vegetation	80-year-old beech (*Fagus sylvatica* L.) forest; little ground cover, natural regeneration of beech (ca. 10 % cover)	Grass	Succession after wind throw; extensive blackberry (*Rubus* spec.) cover; single young trees [beech, spruce (*Picea abies*, L.)]
2.2 Soil	Cambisol	Gleysol	Cambisol
2.2 Geology	Basaltic bedrock	Basaltic bedrock	Basaltic bedrock
2.2 Disturbance	Forest management (no clear-cuts, single tree harvest)	Cattle grazing	Wind throw (5 years ago)
2.3 No. of tree cavities (20 m radius)	2	n.a.	n.a.
2.3 Mean tree diameter (20 m radius)	50 cm	n.a.	n.a.
What found?[a]			
3. Correlation between ground vegetation height and insect richness			
20 samples (see text for sampling protocol)	0.31	0.78	0.54
3. No. of recorded bird species			
Sample 1 (April 15th 2013)	5	4	10
Sample 2 (May 20th 2013)	3	5	12
3. NO_3 concentration in stream (mg m^{-3})			
Sample 1 (March 29th 2013)	458	1020	584
Sample 2 (August 13th 2014)	612	1179	657

[a] Results are shown as associations (here: correlations) or raw data (here: number of recorded birds, nitrate concentrations)

of a land-cover database where data on land-use types of their study region can be found or to report land-use types present in the study area and at each sampling point. In the latter case, land-use types could be reported in table form (Table 1) or as a detailed map (for examples see Vergara et al. 2013; Loos et al. 2015).

2.2 Vegetation, key resources, soil and (if any) disturbance history at sampling points

For some studies, finer-resolution parameters going beyond the information derivable from satellite images or land-cover databases might be relevant. Vegetation structure and composition can impact species presence, abundance, movements, and fitness (Wiens 1969; Rotenberry 1985; Patterson and Best 1996; Bakker et al. 2002; Sekercioglu 2002; Mueller et al. 2011). For large frugivorous bats, for example, mature forest trees with big fruits represent important food resources (Schulze et al. 2000; Vleut et al. 2013). Orangutans (*Pongo abelii*, Lesson) find important food trees in riverine lowland forests (Kelle et al. 2014). For the capercaillie (*Tetrao urogallus*, L.), blueberry cover (*Vaccinium myrtillus*, L.) is essential (Storch 1997). Studies on species responses could therefore provide a description of vegetation structure and composition at sampling points (Table 1). In addition, for specialized species key resources may need to be reported (e.g., deciduous dead wood for the white-backed woodpecker (*Dendrocopos leucotos*, Bechstein), Angelstam and Mikusinski 1994).

Soil characteristics influence plant growth and vegetation composition (Huenneke et al. 1990; van Breemen et al. 1997). Hydrological processes might be impacted as much by geologic as by soil characteristics (Leland and Porter 2000; Tague and Grant 2004; Western et al. 2004). Soil types could therefore be reported for vegetation studies and geologic characteristics and soil types for hydrological studies.

Anthropogenic disturbances, e.g., agriculture, forestry, hunting, tourism, or cattle grazing, as well as natural disturbances, e.g., strong wind and fire events, can affect ecological processes and conditions (Connell 1978; Pickett and White 1985; Peres 2000; Laurance et al. 2006; Thiel et al. 2008; Vleut et al. 2013; Hao et al. 2014; Liu et al. 2015). Information on the date, type, extent, frequency, and intensity of disturbances will be valuable for cross study analyses. Because frequency and intensity are confounded variables (Benedetti-Cecchi 2003), a qualitative assessment of intensity could suffice, e.g., return to bare mineral soil, wind throw, or an earlier successional stage. Because of potential legacy effects, the reporting of past land-use activities can be important for research synthesis. For example, current vegetation composition and structure can be strongly influenced by past agricultural practices (Bellemare et al. 2002; Flinn and Marks 2007).

2.3 Author-provided additional site parameters

Frequently, authors may record additional (site) parameters of interest that are not included in this list of reporting guidelines. For example, Campbell et al. (2015) also estimated canopy cover while studying flow regime impacts on meta-communities, Galitsky and Lawler (2015) also sampled the number of snags and presence of water while studying bird community composition, and Lu et al. (2014) recorded tree height and diameter while studying the ecosystem services of plantations. We argue that all recorded information is valuable for research synthesis and should not be lost (see also Thompson et al. 2000), but made available. Additional parameters, such as key resources, forest stand characteristics, topography, and climatic characteristics or soil type, could be presented for each sampling point in online appendices. Since primary authors will usually have data on additional parameters ready and prepared for analysis, publishing as online appendices normally would require little extra effort. Our evaluation of current reporting in 20 articles published in *Landscape Ecology* (Example 2) showed that 16 articles had recorded or estimated additional parameters, but none reported them (Table S4).

3. Results, i.e., associations or raw data for each sampling point

Most primary studies in landscape ecology sample data with replicated, spatially distinct sampling designs. Yet, in almost all cases authors report results combined for the entire study area. Due to this practice, results are only available at broader resolution and existent scientific evidence is lost for research synthesis. In our Example 1, seven articles reported sizes of studied fragments, but only three articles reported results separated per fragment. We could easily have analyzed the influence of fragment size on nest predation for at least seven articles if the other four articles had presented results separated per fragment. Another four articles did not give information on fragment size nor on results per fragment. If all articles had given information on *sampling point location plus results per sampling point*, we could have included all articles in an analysis of fragment size effects on nest predation. The reporting of sampling point location therefore inevitably needs to be linked to the reporting of results, i.e., associations (between stressor, driver, condition, and observed response) (Ziegler et al. 2015) or raw data per sampling point (Table 1). As a consequence, many landscape parameters could be considered in research synthesis, improving our ability to draw general conclusions (Hillebrand and Gurevitch 2013).

Publishing raw data has additional benefits, because the recurring challenge of finding an appropriate effect size for a meta-analysis (Lajeunesse 2013) would greatly be facilitated (Mengersen et al. 2013). Meta-analysis is a powerful statistical summary method used to combine results from primary research studies (Borenstein et al. 2009; Koricheva et al. 2013; Vetter et al. 2013b). The great variation in primary studies is also expressed in the variety of measurements that are used to present results and effect sizes. For meta-analysis, a variety of measurements needs to be transformed into a common effect size, a process that frequently leads to the exclusion of articles which did not present results in a usable or transformable format (Lajeunesse 2013; Mengersen et al. 2013). Technical storage conditions are no longer a viable reason for excluding raw data, since data can quite easily be stored in online archives, e.g. DRYAD (2014).

Conclusion

Research syntheses in ecology offer the great advantage of combining results across mostly small and regional studies, improving the reliability of results and generality of conclusions. We have shown that insufficient reporting of the landscape context (including study area and sampling point locations) substantially hinders research syntheses. We presented a list of Reporting Guidelines for landscape-ecological studies that focused on the reporting of precise sampling point locations (item 1) in connection with the reporting of results per sampling point (item 3). We argue that by reporting the where (location) and what (results) of future ecological studies, research synthesis can be facilitated considerably. We explicitly address these concerns not only to authors, but primarily to editors and reviewers. We argue that reporting guidelines will help with drawing inferences "founded on solid empirical information" and thus make a significant contribution to the advancement of landscape ecological research (Wiens 1996).

Acknowledgments D.V. was supported by a grant from the ''Landesgraduiertenförderung Baden-Württemberg''. Support for J.A.B. was provided by the Department of Wildland Resources and the USGS Utah Cooperative Fish and Wildlife Research Unit at Utah State University. We are grateful to all our colleagues from the Chair of Wildlife Ecology and Wildlife Management for providing input and ideas. We thank T. Ludwig for help and advice with all GIS-related questions. Three anonymous reviewers made valuable comments on earlier versions and helped to improve the manuscript.

References

Allan JD, Erickson DL, Fay J (1997) The influence of catchment land use on stream integrity across multiple spatial scales. Freshw Biol 37:149–161

Andrén H (1995) Effects of landscape composition on predation rates at habitat edges. In: Hansson L, Fahrig L, Merriam G (eds) Mosaic landscapes and ecological processes. Chapman & Hall, London, pp 225–255

Angelstam P (1986) Predation on ground-nesting birds' nests in relation to predator densities and habitat edge. Oikos 47(3):365–373

Angelstam P, Mikusinski G (1994) Woodpecker assemblages in natural and managed boreal and hemiboreal forest—a review. Ann Zool Fenn 31(1):157–172

Arvola L, Einola E, Järvinen M (2015) Landscape properties and precipitation as determinants for high summer nitrogen load from boreal catchments. Landscape Ecol 30(3):429–442

Bakker KK, Naugle DE, Higgins KF (2002) Incorporating landscape attributes into models for migratory grassland bird conservation. Conserv Biol 16(6):1638–1646

Bastian O (2001) Landscape ecology—towards a unified discipline? Landscape Ecol 16:757–766

Batáry P, Báldi A, Kleijn D, Tscharntke T (2011) Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proc R Soc B 278(1713): 1894–1902

Bellemare J, Motzkin G, Foster DR (2002) Legacies of the agricultural past in the forested present: an assessment of historical land-use effects on rich mesic forests. J Biogeogr 29(10–11):1401–1420

Benedetti-Cecchi L (2003) The importance of the variance around the mean effect size of ecological processes. Ecology 84(9):2335–2346

Bissonette JA (2013) Scale in wildlife management: the difficulty with extrapolation. In: Krausman PR, Cain JW (eds) Wildlife management and conservation: contemporary principles and practices. The Johns Hopkins University Press, Baltimore, pp 73–83

Blair RB (1996) Land use and avian species diversity along an urban gradient. Ecol Appl 6(2):506–519

Borenstein M, Hedges LV, Higgins JPT, Rothstein HR (2009) Introduction to meta-analysis. Wiley, West Sussex

Campbell RE, Winterbourn MJ, Cochrane TA, McIntosh AR (2015) Flow-related disturbance creates a gradient of metacommunity types within stream networks. Landscape Ecol 30(4):667–680

Connell JH (1978) Diversity in tropical rain forests and coral reefs. Science 199(4335):1302–1310

Copernicus Programme (2014) Corine land cover. http://land.copernicus.eu/pan-european/corine-land-cover. Accessed June 2014

Donovan TM, Jones PW, Annand EM, Thompson FR III (1997) Variation in local-scale edge effects: mechanisms and landscape context. Ecology 78(7):2064–2075

DRYAD (2014) Dryad digital repository. http://www.datadryad.org. Accessed June 2014

Flinn KM, Marks PL (2007) Agricultural legacies in forest environments: tree communities, soil properties, and light availability. Ecol Appl 17(2):452–463

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309(5734): 570–574

Galitsky C, Lawler JJ (2015) Relative influence of local and landscape factors on bird communities vary by species and functional group. Landscape Ecol 30(2):287–299

García-Morales R, Badano EI, Moreno CE (2013) Response of Neotropical bat assemblages to human land use. Conserv Biol 27(5):1096–1106

Gardner TA, Hernández MI, Barlow J, Peres CA (2008) Understanding the biodiversity consequences of habitat change: the value of secondary and plantation forests for Neotropical dung beetles. J Appl Ecol 45(3):883–893

Hanski IK, Fenske TJ, Niemi GJ (1996) Lack of edge effect in nesting success of breeding birds in managed forest landscapes. Auk 113:578–585

Hao L, Sun G, Liu Y, Gao Z, He J, Shi T, Wu B (2014) Effects of precipitation on grassland ecosystem restoration under grazing exclusion in Inner Mongolia, China. Landscape Ecol 29(10):1657–1673

Hargis CD, Bissonette JA, David JL (1998) The behavior of landscape metrics commonly used in the study of habitat fragmentation. Landscape Ecol 13(3):167–186

Hartley MJ, Hunter ML (1998) A meta-analysis of forest cover, edge effects, and artificial nest predation rates. Conserv Biol 12(2):465–469

Hillebrand H, Gurevitch J (2013) Reporting standards in experimental studies. Ecol Lett 16(12):1419–1420

Huenneke LF, Hamburg SP, Koide R, Mooney HA, Vitousek PM (1990) Effects of soil resources on plant invasion and community structure in californian serpentine grassland. Ecology 71(2):478

Islam K, Weil R (2000) Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. Agric Ecosyst Environ 79(1):9–16

Kelle D, Gärtner S, Pratje PH, Storch I (2014) Reintroduced Sumatran orangutans (*Pongo abelii*): using major food tree species as indicators of habitat suitability. Folia Primatol 85(2):90–108

Koricheva J, Gurevitch J, Mengersen K (eds) (2013) Handbook of meta-analysis in ecology and evolution. Princeton University Press, Princeton

Kremen C, Williams NM, Aizen MA, Gemmill-Herren B, LeBuhn G, Minckley R, Packer L, Potts SG, Roulston T, Steffan-Dewenter I, Vázquez DP, Winfree R, Adams L, Crone EE, Greenleaf SS, Keitt TH, Klein A, Regetz J, Ricketts TH (2007) Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecol Lett 10(4):299–314

Lahti D (2001) The "edge effect on nest predation" hypothesis after twenty years. Biol Conserv 99(3):365–374

Lajeunesse MJ (2013) Recovering missing or partial data from studies: a survey of conversions and imputations for meta-analysis. In: Koricheva J, Gurevitch J, Mengersen K (eds) Handbook of meta-analysis in ecology and evolution. Princeton University Press, Princeton, pp 195–206

Laurance WF, Croes BM, Tchignoumba L, Lahm SA, Alonso A, Lee ME, Campbell P, Ondzeano C (2006) Impacts of roads and hunting on Central African Rainforest mammals. Conserv Biol 20(4):1251–1261

Leland HV, Porter SD (2000) Distribution of benthic algae in the upper Illinois River basin in relation to geology and land use. Freshw Biol 44(2):279–301

Lindenmayer DB, Cunningham RB, Donnelly CF, Nix H, Lindenmayer BD (2002) Effects of forest fragmentation on bird assemblages in a novel landscape context. Ecol Monogr 72(1):1–18

Liu M, Liu G, Zheng X (2015) Spatial pattern changes of biomass, litterfall and coverage with environmental factors across temperate grassland subjected to various management practices. Landscape Ecol 30(3):477–486

Loos J, Kuussaari M, Ekroos J, Hanspach J, Fust P, Jackson L, Fischer J (2015) Changes in butterfly movements along a gradient of land use in farmlands of Transylvania (Romania). Landscape Ecol 30(4):625–635

Lu N, Fu B, Jin T, Chang R (2014) Trade-off analyses of multiple ecosystem services by plantations along a precipitation gradient across Loess Plateau landscapes. Landscape Ecol 29(10):1697–1708

Marzluff JM, Restani M (1999) The effects of forest fragmentation on avian nest predation. In: Rochelle JA, Lehmann L, Wisniewski J (eds) Forest fragmentation: wildlife and management implications. Brill, Leiden, pp 155–169

Mengersen K, Gurevitch J, Schmid CH (2013) Meta-analysis of primary data. In: Koricheva J, Gurevitch J, Mengersen K (eds) Handbook of meta-analysis in ecology and evolution. Princeton University Press, Princeton, pp 300–312

Mortelliti A, Amori G, Capizzi D, Rondinini C, Boitani L (2010) Experimental design and taxonomic scope of fragmentation studies on European mammals: current status and future priorities. Mamm Rev 40(2):125–154

Mueller T, Olson KA, Dressler G, Leimgruber P, Fuller TK, Nicolson C, Novaro AJ, Bolgeri MJ, Wattles D, DeStefano S, Calabrese JM, Fagan WF (2011) How landscape dynamics link individual- to population-level movement patterns: a multispecies comparison of ungulate relocation data. Glob Ecol Biogeogr 20(5):683–694

Multi-Resolution Land Characteristics (MRLC) Consortium (2015) National land cover database (NLCD). http://www.mrlc.gov/. Accessed May 2015

Nichols E, Larsen T, Spector S, Davis AL, Escobar F, Favila M, Vulinec K (2007) Global dung beetle response to tropical forest modification and fragmentation: a quantitative literature review and meta-analysis. Biol Conserv 137(1):1–19

Parker TH, Stansberry BM, Becker CD, Gipson PS (2005) Edge and area effects on the occurrence of migrant forest songbirds. Conserv Biol 19(4):1157–1167

Patterson MP, Best LB (1996) Bird abundance and nesting success in Iowa CRP fields: the importance of vegetation structure and composition. Am Midl Nat 135(1):153–167
Peres CA (2000) Effects of subsistence hunting on vertebrate community structure in Amazonian forests. Conserv Biol 14(1):240–253
Pickett STA, Cadenasso ML (1995) Landscape ecology: spatial heterogeneity in ecological systems. Science 269(5222): 331–334
Pickett STA, White PS (eds) (1985) The ecology of natural disturbance and patch dynamics. Academic Press, San Diego
Pullin AS, Salafsky N (2010) Save the whales? Save the rainforest? Save the data!. Conserv Biol 24(4):915–917
Ritchie ME (1997) Populations in a landscape context: sources, sinks, and metapopulations. In: Bissonette JA (ed) Wildlife and landscape ecology: effects of pattern and scale. Springer, New York, pp 160–184
Rotenberry JT (1985) The role of habitat in avian community composition: physiognomy or floristics? Oecologia 67(2): 213–217
Sagarin R, Pauchard A (2010) Observational approaches in ecology open new ground in a changing world. Front Ecol Environ 8(7):379–386
Schulze MD, Seavy NE, Whitacre DF (2000) A comparison of the phyllostomid bat assemblages in undisturbed Neotropical forest and in forest fragments of a slash-and-burn farming mosaic in Peten, Guatemala. Biotropica 32(1):174–184
Sekercioglu CH (2002) Effects of forestry practices on vegetation structure and bird community of Kibale National Park, Uganda. Biol Conserv 107(2):229–240
Shaffer TL, Johnson DH (2008) Ways of learning: observational studies versus experiments. J Wildl Manag 72(1):4–13
Sibbald B, Roland M (1998) Understanding controlled trials: why are randomised controlled trials important? BMJ 316(7126):201
Stewart G (2010) Meta-analysis in applied ecology. Biol Lett 6(1):78–81
Storch I (1997) The importance of scale in habitat conservation for an endangered species: the capercaillie in Central Europe. In: Bissonette JA (ed) Wildlife and landscape ecology: effects of pattern and scale. Springer, New York, pp 310–330
Tague C, Grant GE (2004) A geological framework for interpreting the low-flow regimes of Cascade streams, Willamette River Basin, Oregon. Water Resour Res 40(4):W04303
The EQUATOR Network (2014) The EQUATOR network—enhancing the quality and transparency of health research. www.equator-network.org. Accessed May 2014
Thiel D, Jenni-Eiermann S, Braunisch V, Palme R, Jenni L (2008) Ski tourism affects habitat use and evokes a physiological stress response in capercaillie *Tetrao urogallus*: a new methodological approach. J Appl Ecol 45(3):845–853
Thompson FR, Brawn JD, Robinson S, Faaborg J, Clawson RL (2000) Approaches to investigate effects of forest management on birds in eastern deciduous forests: how reliable is our knowledge? Wildl Soc Bull 28(4):1111–1122
Thompson FR III, Donovan TM, DeGraaf RM, Faaborg J, Robinson SK (2002) A multi-scale perspective of the effects of forest fragmentation on birds in Eastern forests. Stud Avian Biol 25:8–19
Turner MG (1989) Landscape ecology: the effect of pattern on process. Annu Rev Ecol Syst 20(1):171–197
Turner MG (2005) Landscape ecology: what is the state of the science? Annu Rev Ecol Evol Syst 36(1):319–344
U.S. Geological Survey (2015) Earth resources observation and science (EROS) center. http://eros.usgs.gov/. Accessed May 2015
van Breemen N, Finzi AC, Canham CD (1997) Canopy tree-soil interactions within temperate forests: effects of soil elemental composition and texture on species distributions. Can J For Res 27(7):1110–1116
Vergara PM, Pérez-Hernández CG, Hahn IJ, Jiménez JE (2013) Matrix composition and corridor function for austral thrushes in a fragmented temperate forest. Landscape Ecol 28(1):121–133
Vetter D, Hansbauer MM, Végvári Z, Storch I (2011) Predictors of forest fragmentation sensitivity in Neotropical vertebrates: a quantitative review. Ecography 34(1):1–8
Vetter D, Rücker G, Storch I (2013a) A meta-analysis of tropical forest edge effects on bird nest predation risk. Biol Conserv 159:382–395
Vetter D, Rücker G, Storch I (2013b) Meta-analysis: a need for well-defined usage in ecology and conservation biology. Ecosphere 4(6):art74
Vié J, Hilton-Taylor C, Stuart SN (eds) (2009) Wildlife in a changing world—an analysis of the 2008 IUCN red list of threatened species. IUCN, Gland
Vleut I, Levy-Tacher SI, de Boer Willem, Frederik Galindo-González J, Vazquez L (2013) Tropical secondary forest management influences frugivorous bat composition, abundance and fruit consumption in Chiapas, Mexico. PLoS One 8(10):e77584
Western AW, Zhou S, Grayson RB, McMahon TA, Blöschl G, Wilson DJ (2004) Spatial correlation of soil moisture in small catchments and its relationship to dominant spatial hydrological processes. J Hydrol 286(1–4):113–134
Wiens JA (1969) An approach to the study of ecological relationships among grassland birds. Ornithol Monogr 8:1–93
Wiens JA (1996) Challenges for the future. IALE Bull 14(1):1
Wu J (2006) Landscape ecology, cross-disciplinarity, and sustainability science. Landscape Ecol 21(1):1–4
Ziegler CR, Webb JA, Norton SB, Pullin AS, Melcher AH (2015) Digital repository of associations between environmental variables: a new resource to facilitate knowledge synthesis. Ecol Ind 53:61–69