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Commentary

Should Invertebrates Receive Greater Inclusion in Wildlife Research Journals?

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ABSTRACT Invertebrates are among the most diverse organisms on Earth, significantly contribute to ecosystem function and integrity, and possess high potential as bioindicators. By definition, invertebrates also are wildlife. Yet, inclusion of invertebrates in peer-reviewed wildlife journals has not been investigated. As such, our objective was to assess inclusion of invertebrates in prominent wildlife journals published in the last decade. Based on our review and first-hand experience, we also aimed to provide recommendations for integration of invertebrates into wildlife science, education, and peer-reviewed literature. We performed a systematic literature review by manually searching all issues and articles from 2003–2013 of the following journals: *European Journal of Wildlife Research*, *Journal of Wildlife Management*, *South African Journal of Wildlife Research*, *Wildlife Biology*, *Wildlife Research*, and *Wildlife Society Bulletin*. We analyzed data derived from our review to elucidate trends in the inclusion of invertebrates in these journals. We identified 4,916 articles that involved animal taxa, of which 122 (2.5%) included invertebrates and <1% included invertebrates as focal taxa. Our results indicated invertebrates are included in a minute portion of articles in top wildlife journals. We recommend a paradigm shift to a less taxonomically homogenized and vertebrate-centric approach to wildlife science and education, integrating invertebrates into wildlife studies, and publishing results of those studies in wildlife journals to facilitate effective management of all wildlife species.

KEY WORDS insects, invertebrates, literature inclusion, systematic review, wildlife science.

Invertebrates comprise most animal biodiversity and biomass on Earth and dominate all ecosystems (Wilson 1988, Gaston 1991). Insects (Phylum Arthropoda, Class Insecta) alone comprise approximately 57% of all metazoan species (Stork 1997). The sheer number and diversity of invertebrate species influence their global ecological importance, as illustrated by E. O. Wilson's (1987) designation of invertebrates as "The Little Things that Run the World."

Invertebrates occupy the greatest breadth of ecosystems, microhabitats, and niches among animals and assume key ecological functions among myriad trophic levels, affecting soils, plants, and vertebrates (Collins and Thomas 1991). Some invertebrates are ecosystem engineers, affecting soil properties and releasing soil resources for use by other organisms, including plants (Lavelle et al. 1997, Jouquet et al. 2006). Curry (1994) observed increased plant growth in grassland ecosystems as a direct result of invertebrate influences on soil function and fertility. Other invertebrates serve as primary pollinators of numerous plants that directly and indirectly contribute to habitat for vertebrates (Potts et al. 2010, Gilgert and Vaughan 2011). Invertebrates are consumed by a plethora of vertebrates (and other invertebrates), including most land birds, bats, rodents, amphibians, and reptiles (Greenberg 1995). Young, developing vertebrates often depend on protein-rich invertebrates, especially gamebirds (Healy 1985, Hill 1985, Palmer et al. 2001, Park et al. 2001, Potts 2012) and songbirds (Duguay et al. 2000). Invertebrates also can provide pivotal food sources during food-stress periods (e.g., red knot [*Calidris canutus*] and horseshoe crab eggs [*Limulus polyphemus*]; Baker et al. 2004, Karpanty et al. 2006). Invertebrates are often the most important primary consumers by biomass in ecosystems, including deciduous forests (Strong et al. 2000), tropical forests (e.g., leafcutter ants [*Atta* spp. and *Acromyrmex* spp.]; Wilson 1987), and grasslands (Joern 1979). In addition, some invertebrates serve as disease vectors and parasites, in turn influencing vertebrate mortality rates (e.g., West Nile virus; Kilpatrick et al. 2007) and individual fitness via additive stress (e.g., ticks; Del Giudice et al. 1997).

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Complementing their vast ecological significance, many invertebrates can be valuable bioindicators for assessing the efficacy of wildlife management. Because invertebrates exhibit great ecological plasticity, invertebrate communities are representative of a wide range of ecosystems and environmental gradients (Kremen et al. 1993). From soils to streams (Paoletti et al. 1991, Cain et al. 1992) and forests to rangelands (Pearce and Venier 2006, Hoffmann 2010, Iglay et al. 2012), invertebrate responses can indicate ecosystem-wide impacts of anthropogenic and natural disturbances. Invertebrates occupy habitats of vertebrates. Therefore, trophic interactions within ecosystems can be traced up from invertebrates to vertebrates (i.e., bottom-up) rather than top-down, with the former being a primary driver of ecosystem function in many cases (Loreau et al. 2001). Finally, invertebrates' sensitivity to environmental conditions, response to micro-scale changes, and diverse body sizes, vagilities, and physiologies make them suitable study organisms for assessing fine- and large-scale response to local and landscape-level changes (Triplehorn and Johnson 2005, Arribas et al. 2012).

Given their value as indicators of land use change and many integral roles in ecosystems (e.g., as food for other wildlife), invertebrates have the capacity to enhance our understanding of wildlife science. For example, wildlife studies aiming to reveal relationships between invertebrate and vertebrate wildlife may lead to better informed, bottom-up habitat management that ensures invertebrates are available to the vertebrates that depend on them for food. Invertebrates are by definition wildlife (e.g., The Wildlife Society Strategic Plan 2008–2013; The Wildlife Society 2008), and, as such, inclusion of invertebrates in wildlife research, management, and policy is justifiable. We suggest that the degree to which invertebrates are included in wildlife research publications and how they are included (i.e., as the focal species or indirectly as food for wildlife) are metrics that indicate how well invertebrates are being integrated into wildlife science.

Representation of invertebrates in peer-reviewed wildlife research journals has not been investigated, and consequently, the role invertebrates play in wildlife science is not fully understood. Quantification of invertebrate occurrence in wildlife research could help direct future efforts to study and conserve invertebrate and vertebrate wildlife alike. Indeed, Cardoso et al. (2011) already noted limited use of invertebrates in the development of conservation policy. We assessed inclusion of invertebrates in 6 wildlife journals during the past 10 years of publication (2003–2013), with the goal of understanding the current state of invertebrate representation in these journals. We also elucidated trends in representation of invertebrates in wildlife journals by documenting the prevalence of focal (invertebrate = primary study organism) or non-focal (invertebrate ≠ primary study organism) invertebrate articles, characteristics of both focal and non-focal invertebrate articles, and how invertebrates were used in the estimation of vertebrate populations. We wanted to generate data for inclusion in a formal meta-analysis on representation of invertebrates in wildlife journals to assess prospective applications of invertebrates in wildlife science. By conducting a meta-analysis rather than simply expressing our opinion on the subject at hand, we were able to provide a review of the current status of invertebrate representation in wildlife journals and, in conjunction with first-hand experience, provide recommendations for their future inclusion in wildlife science and journal publications.

METHODS

We selected journals based on relevancy and accessibility to wildlife professionals, including journals most likely read by wildlife managers, researchers, and educators (see Christoffel and Lepczyk 2012). Key word searches in search engines, including Web of Science, yielded too few invertebrate articles, whereas Google Scholar yielded too many. Hence, we employed a systematic review (as defined in Vetter et al. 2013) of invertebrates in wildlife journals by manually searching all issues and articles of: *European Journal of Wildlife Research* (formally *Zeitschrift fur Jagdwissenschaft*), *Journal of Wildlife Management* (published by The Wildlife Society), *South African Journal of Wildlife Research* (published by the South African Wildlife Management Association), *Wildlife Biology* (published by the Nordic Council for Wildlife Research), *Wildlife Research* (published by the Commonwealth Scientific and Industrial Research Organisation), and *Wildlife Society Bulletin* (published by The Wildlife Society) from 2003–2013. We limited the review to a 10-year period because manually searching through articles was time- and labor-intensive, and we believed 10 years was a sufficient time period to elucidate trends. We excluded articles from 2003 for *European Journal of Wildlife Management* and 2007–2010 for *Wildlife Society Bulletin* because of a language discrepancy and publication lapse, respectively.

We isolated articles involving animal taxa based on titles, key words, and abstract content. We excluded analysis-, philosophy-, and plant-related articles that made no mention of animal taxa. For each article involving animal taxa, we recorded general bibliographical information and characteristics, including topic (categories = conservation, dietary, disease ecology, ecology, habitat management, method, and parasitology), publication type (categories = note, research article, review, and short communication), geographic region, taxonomy of vertebrates and invertebrates used (categories = class, order, and family), and whether articles included focal (invertebrate = primary study organism) or non-focal (invertebrate ≠ primary study organism) invertebrate taxa. From each isolated article's Methods and Results sections, we recorded invertebrate taxonomic categories (categories = Arachnids, Community [i.e., guilds, multiple families, or orders], Crustacea, Helminths [flukes, roundworms, tapeworms], Insects, Mollusks, Nematodes, and Other), insect orders, and taxonomic resolution used for invertebrate specimen identification. We also recorded the number of articles that incorporated invertebrate metrics (e.g., biomass, abundance, diversity) into vertebrate population models. We included all of these data in our meta-analysis.

We used several analyses in program R version 3.0.1 (R Core Development Team 2013) to elucidate trends in the representation of invertebrates in the examined journals. We compared given proportions per journal among reviewed journals using a test of given proportions (R function prop. test; Newcombe 1998) of all invertebrate articles (i.e., count of total invertebrate articles/total number of articles), focal invertebrate articles (i.e., count of focal invertebrate articles/ total number of articles), and non-focal invertebrate articles (i.e., count of non-focal invertebrate articles/total number of articles).

We also examined whether invertebrate article characteristics (see list earlier in Methods) differed between focal and non-focal invertebrate articles to determine if applications to wildlife management depended on whether invertebrates were primary study organisms or not. We calculated proportions for each characteristic by category (i.e., dividing counts in each category by the total count of all categories for a given characteristic). We compared these proportions between focal and non-focal invertebrate articles using a Pearson's χ^2 test of independence and generated P-values with a Monte Carlo simulation of 2,000 replicates (Patefield 1981). We used a Monte Carlo simulation to generate P-values because expected frequencies in the χ^2 procedure fell below 5. We used $\alpha = 0.05$ for all tests and summarized remaining information using descriptive statistics similar to a review on herpetofauna by Christoffel and Lepczyk (2012).

RESULTS

Of the 4,916 total animal articles, 122 (2.5%) included invertebrates (see Supporting Information for a complete list). Most invertebrate articles were non-focal ($n = 97$, 80%). Focal invertebrate articles comprised only <1% of all reviewed articles (Table 1). Proportion of total invertebrate articles and non-focal invertebrate articles differed among journals ($\chi^2_5 = 76.54$, $P < 0.001$ and $\chi^2_5 = 91.71$, $P < 0.001$, respectively). *European Journal of Wildlife Research* published the most invertebrate articles ($n = 43$, 6% of articles published in journal; Table 1).

Overall, focal and non-focal invertebrate articles differed in the following article characteristics: geographic region ($\chi^2 = 18.35$, $P = 0.002$), invertebrate taxonomic categories ($\chi^2 = 36.68$, $P \leq 0.001$), invertebrate taxonomic resolution ($\chi^2 = 16.28$, $P = 0.004$), and topic ($\chi^2 = 62.55$, $P \leq 0.001$). We also documented several specific differences in article characteristics between focal and non-focal invertebrate articles (Table 2). Insects (31%) and invertebrate communities (23%) dominated the invertebrate taxonomic categories in focal invertebrate articles. Various parasite groups (approx. 46%), including ticks (Arachnida: Acari; 18%), helminths (flukes, tapeworms, and roundworms; 18%), and nematodes (10%), dominated non-focal invertebrate articles. Coleoptera, Diptera, and Lepidoptera were most frequently included among all invertebrate articles ($n = 26$ articles; Fig. 1). About a third of focal (28%) and non-focal (29%) invertebrate studies identified specimens to species. Percent of article topics was relatively evenly distributed among focal invertebrate articles ($\bar{x} = 14.29\%$, SD $= 1.98$) but varied among non-focal invertebrate articles ($\bar{x} = 14.14\%$, SD $= 17.75$). Parasitology was the primary topic of non-focal invertebrate articles (54%). Of these, over 75% ($n = 44$) involved parasites ($n = 39$) or vectored diseases of mammals ($n = 5$), predominantly of Artiodactyla and Carnivora, with most parasitological studies published as short communications. Dietary studies also were common among non-focal invertebrate studies (25%). Most dietary studies involved birds (Galliformes and Passeriformes; $n = 12$, 48%) and bats (Chiroptera; $n = 9$, 36%). Most focal invertebrate studies occurred in North America (40%), and non-focal studies in Europe (44%). Research articles and short communications were the first and second most common publication types for both focal and non-focal invertebrate articles. Of the articles including both invertebrates and vertebrates, most (71%) did not use invertebrate metrics (e.g., biomass, abundance, diversity) in modeling vertebrate population metrics. Articles that used invertebrate metrics as predictors of indirect measures of vertebrate populations, including habitat selection or use (9%) and activity budgets or feeding rates (10%), outnumbered those that used invertebrate metrics as predictors of more direct measures, including survival or fecundity (5%), abundance (3%), and density (2%).

DISCUSSION

Our results indicated a severe underrepresentation of invertebrates in wildlife journals. In comparison, prevalence of herpetofauna in wildlife journals, another traditionally

Table 1. Number of articles and percent of all published articles using animal taxa including invertebrates. Data are from a systematic literature review of 6 wildlife research journals from 2003–2013, with exceptions for European Journal of Wildlife Research and Wildlife Society Bulletin[a]. Focal invertebrate articles included a primary invertebrate study organism; non-focal invertebrate articles included a secondary invertebrate study organism.

Journal	Continent	Total articles	Invertebrate use	
			Focal	Non-focal
European Journal of Wildlife Research	Europe	677	2 (0.30%)	41 (6.06%)
Journal of Wildlife Management	North America	1,817	7 (0.39%)	17 (0.94%)
South African Journal of Wildlife Research	Africa	209	3 (1.44%)	12 (5.74%)
Wildlife Biology	Europe	377	0 (0%)	7 (1.86%)
Wildlife Research	Australia	736	7 (0.95%)	10 (1.36%)
Wildlife Society Bulletin	North America	1,100	6 (0.55%)	10 (0.91%)
Total		4,916	25 (0.51%)	97 (1.97%)

[a] We excluded 2003 for *European Journal of Wildlife Research* and 2007–2010 for *Wildlife Society Bulletin* because of a language discrepancy and publication lapse, respectively.

Table 2. Percentage of categories present in focal and non-focal invertebrate articles for each characteristic we examined. Data are from a systematic literature review of 6 wildlife research journals from 2003–2013, with exceptions for *European Journal of Wildlife Research* and *Wildlife Society Bulletin*[a]. Focal invertebrate articles included a primary invertebrate study organism; non-focal invertebrate articles included a secondary invertebrate study organism.

	Percentage of articles within each category	
Category	**Focal**	**Non-focal**
Invertebrate group diversity		
Arachnida	7.69	18.63
Community	23.08	25.49
Crustacea	7.69	0.00
Helminthes	3.85	17.60
Insecta	30.77	23.53
Mollusca	11.54	2.94
Nematoda	3.85	9.80
Other	11.54	1.96
Topic		
Conservation	16.00	1.03
Dietary	16.00	24.74
Disease ecology	12.00	8.25
Ecology	16.00	3.09
Habit management	16.00	8.25
Methods	12.00	1.03
Parasitology	12.00	53.61
Invertebrate taxonomic resolution		
Phylum or guild	4.00	7.22
Order	8.00	12.37
Family (1)	8.00	2.06
Family (>1)	4.00	10.31
Species (1)	44.00	19.59
Species (>1)	28.00	28.87
n/a	4.00	19.59
Geographic region		
Africa	12.00	14.43
Australia/Oceana	20.00	8.25
Europe	24.00	44.33
North America	40.00	25.77
South America	0.00	4.12
Other	4.00	3.10
Publication type		
Note	8.00	3.09
Research article	68.00	63.92
Review	0.00	3.09
Short communication	24.00	29.90

[a] We excluded 2003 for *European Journal of Wildlife Research* and 2007–2010 for *Wildlife Society Bulletin* because of a language discrepancy and publication lapse, respectively.

underrepresented taxa in wildlife science, increased over the last 30 years (Christofell and Lepczyk 2012). Given that global invertebrate biodiversity is estimated to be 7 times that of vertebrates collectively (Wilson 1987) and invertebrates serve multiple functional roles (Wilson 1988, Gaston 1991), exclusion of invertebrates in wildlife journals indicates wildlife managers are acquiring information on a minority of ecologically significant wildlife species and not the overwhelming majority.

Several potential reasons may explain why invertebrates rarely were included in wildlife journals. We suggest a primary reason for their exclusion is that some wildlife professionals may believe the accepted norm is that "wildlife journals publish on vertebrate matters and invertebrate journals publish on invertebrate matters" (Anonymous wildlife journal reviewer, personal communication). The fact that some authors of invertebrate articles may have this view would not be surprising, given the traditional prominence of certain vertebrate taxa (e.g., charismatic mega-fauna and utilitarian game animals) in wildlife journals (see Powell et al. 2010). We emphasize that the general mission of wildlife journals is to promote wildlife conservation, including invertebrates and vertebrates alike. For example, The Wildlife Society (TWS) defines wildlife as "living organisms that are not humans, domesticated animals, or plants. This includes, insects and other invertebrates, fish, amphibians, reptiles, birds, mammals…" (The Wildlife Society 2008). The TWS Strategic Plan (The Wildlife Society 2008) goes on to allocate the study of fish to the sister organization of TWS, The American Fisheries Society, but makes no such allocation of invertebrates to other professional societies outside of TWS. By embracing wildlife's diversity in wildlife journals and recognizing that invertebrates are indeed considered wildlife, we can begin to shift from restrictive accepted norms and pursue solutions to complex conservation and management issues.

Of the few articles that included invertebrates, 5 times as many non-focal invertebrate articles were published than focal. Although non-focal invertebrate articles can play a major role in informing wildlife science (see Moving Forward section below), most non-focal invertebrate article topics did not span the diverse sub-disciplines of wildlife management. For instance, parasitology was the focus of approximately half of non-focal invertebrate articles; this topic emphasizes negative impacts of invertebrates on vertebrate wildlife and arguably belongs in an alternative outlet such as the *Journal of Wildlife Diseases*. Dietary studies also were the topic of a relatively large portion of non-focal invertebrate articles, which certainly sheds light on an important aspect of wildlife management. However, non-focal invertebrate articles that focused on core topics in wildlife science such as habitat management were still few, indicating that the full potential of indirect use of invertebrates in wildlife studies has not been met.

Most invertebrate studies were conducted in Europe and North America and focused on insects, suggesting regional and taxonomic biases. Despite the fact that tropical regions harbor the greatest invertebrate diversity, particularly of insects (Erwin 1988, Stork 1993), studies in tropical climates were rare in our review of wildlife journals. Invertebrate studies from temperate climates may be more common in wildlife journals than other climatic regions because most wildlife journals are published in temperate regions of the world. Similarly, wildlife journals typically publish few articles on tropical studies in general, regardless of the taxa included. Despite common use of Coleoptera (the most diverse order among animals), Diptera, Hymenoptera, and Lepidoptera, these 4 insect orders barely capture the true diversity of insects. The prominent inclusion of the "Big Four"—Coleoptera, Diptera, Hymenoptera, and Lepidoptera—in wildlife journals may simply be because they are represented in proportion to their abundance and

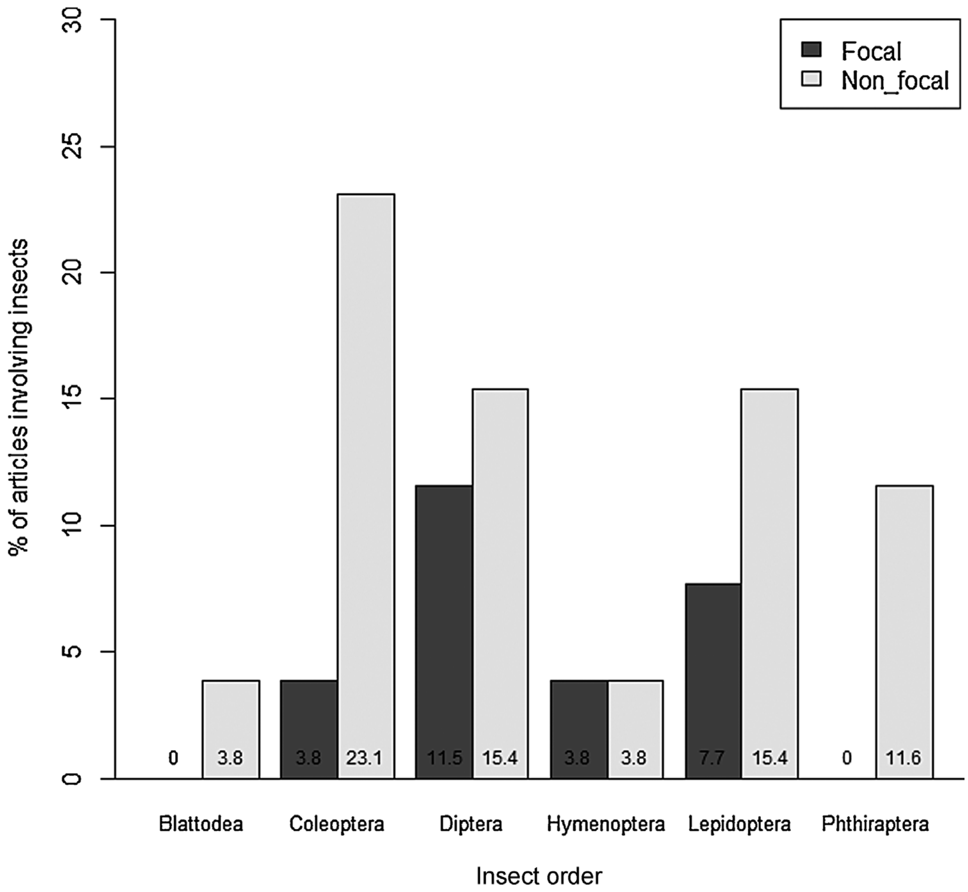

Figure 1. Percentage of orders included amongst focal and non-focal invertebrate articles that included insects from 6 wildlife research journals, 2003–2013. We excluded other invertebrate groups in this figure because insects dominated invertebrate articles.

diversity (approx. 80% of all insects are in these 4 orders; Grimaldi and Engel 2005).

Although invertebrates largely are ignored in prominent wildlife journals, we do not suggest that invertebrates are underrepresented in the scientific literature. Indeed, our meta-analysis and review only focused on wildlife journals. Additionally, publication and research interests can change. Recent publications of The Wildlife Society (e.g., Morrison 2006, Ellison 2013) suggest a possible increased interest in invertebrate inclusion in wildlife science that could contrast the observed paucity of invertebrate articles. However, based on our analysis, Morrison's (2006) call for inclusion of invertebrate articles in the *Journal of Wildlife Management* did not appear to stimulate an increase in invertebrate articles in any future issues of wildlife journals, and, in fact, we saw a decline in the numbers of invertebrate articles after 2006.

Moving Forward

We make the following recommendations for integration of invertebrates into wildlife science, based on the results of our review and our first-hand experience.

Appropriateness of content.—Studies integrating invertebrate and vertebrate ecology could have the greatest potential for increasing invertebrate inclusion in wildlife journals. Indeed, this notion was recognized early on in wildlife management, when Bennitt et al. (1937) suggested "Wildlife management is not restricted to game management…It embraces the practical ecology of all vertebrates and their plant and animal associates." Furthermore, the first issue of the *Journal of Wildlife Management* included a study entitled "Worm parasites in their relations to wildlife investigations" (van Cleave 1937); the publication was 1 of 6 articles in the issue.

However, approximately 70% of studies involving both vertebrates and invertebrates did not use invertebrate metrics in measures of vertebrate populations, indicating that most studies including both taxonomic groups failed to link the influence of invertebrates on vertebrate populations or vice versa. Yet, good examples of wildlife research exist, particularly in the United Kingdom, that incorporated invertebrate metrics (i.e., covariates) into vertebrate population models (see Potts 2012 for examples), mechanistically linking invertebrates to vertebrate populations. However, much of this work is published in broader ecological journals (e.g., *Journal of Applied Ecology*) rather than wildlife journals. As such, we recommend that wildlife researchers better address potential bottom-up effects on vertebrate populations and incorporate invertebrate metrics into vertebrate population models. Even so, wildlife studies that document only invertebrate response to management actions may prove to be informative for managing vertebrate populations that depend on them for food, independent of testing for direct mechanistic links between the 2 taxonomic groups. Thus, incorporation of any invertebrate data in wildlife studies is better than none at all.

Focal invertebrate articles were few but most had indirect implications for vertebrate conservation and management. Many of these articles explained interactions between vertebrates and their invertebrate food sources, such as the influence of horseshoe crab eggs on red knot distributions (Karpanty et al. 2006), Florida applesnail (*Pomacea paludosa*) activity on snail kite (*Rostrhamus sociabilis*) distributions (Stevens et al. 2002), and mosquitoes on bat activity in coastal habitats (Gonsalves et al. 2013). In a few cases, focal invertebrate articles documented invertebrate response to habitat management, including prescribed burning (Croft et al. 2011), disking (Benson et al. 2007), timber harvest (Duguay et al. 2000), and landscape implications of the Conservation Reserve Program (Davros et al. 2006). We believe these and similar articles illustrate how including invertebrates in wildlife journals may lead to increased recognition of ecosystem responses from the bottom-up (e.g., plant community influencing invertebrate community influencing vertebrate community; Hunter 1990, Hunter and Price 1992, Power 1992), at the same time addressing topics that are appropriate for wildlife journals.

Harnessing the power of invertebrate bioindicators.—Invertebrate bioindicators remain severely underrepresented in wildlife studies but could greatly benefit wildlife researchers. Including bioindicators can improve the resolution and scale of inventory and monitoring programs and inform adaptive management in terrestrial systems, in the same way bioindicators have benefited stream biology (e.g., stream health indicators such as Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies]; Karr 1991). Invertebrate assemblages that are sensitive to land use change and are easy to sample (Kremen et al. 1993) are ideal for incorporating into studies that inform habitat management, affecting vertebrate and invertebrate wildlife alike. Specifically, studies can focus on well-known, taxonomically diverse assemblages that respond to land use changes of interest (e.g., vegetation structure, decreasing plant diversity; Pearce and Venier 2006). For example, ground-dwelling beetles are sensitive to land use change in forest systems, providing wildlife managers unique insights into ecosystem response (Iglay et al. 2012). Also, focusing on well-known invertebrate bioindicators may decrease operational limitations like sorting time and provision of taxonomic keys necessary for accurate biological classification (e.g., pitfall trapping for ground-dwelling beetles [Coleoptera: Carabidae]; Kremen et al. 1993, Pearce and Venier 2006). Furthermore, refining sampling efforts to focus exclusively on key invertebrate bioindicator groups may facilitate more efficient invertebrate identification without extensive observer training (Kremen et al. 1993).

Invertebrate monitoring already has influenced land management in several regions worldwide. Therefore, wildlife researchers need not develop their own bioindicators but rather take advantage of well-established, invertebrate bioindicator groups previously tested by researchers in closely related fields (e.g., ecology, applied entomology) conducive to their particular research questions. Simplified ant (Formicidae) monitoring protocols in Australia essentially reproduced all of the key findings of an intensive survey, enabling land managers to use citizen science to inform land management (Anderson et al. 2002). Similar invertebrate monitoring efforts have supported environmental assessments (reviewed by Anderson and Majer 2004), and informed management of rangelands (Anderson et al. 2004) and rehabilitated mine sites (Majer 1983). Several common invertebrate bioindicators are applicable to wildlife studies, including ants and carabid beetles for the ground layer of forests, and ants, Orthopterans, and Lepidopterans for open habitats types like prairie or grasslands (reviewed in Gerlach et al. 2013). McGeouch (1998) and Hodkinson and Jackson (2005) provided in-depth reviews of selection, testing, and application of terrestrial insects as bioindicators.

Proliferating invertebrate exclusion through education.—As stated earlier, invertebrates are by definition wildlife, but many current undergraduate and graduate students studying wildlife science likely have limited exposure to entomology. These educational trends in wildlife science may lead to continued lack of invertebrate inclusion in future wildlife studies. We suggest university wildlife programs consider integrating entomology courses into wildlife curricula. The University of Delaware's College of Agriculture and Natural Resources' Department of Entomology and Wildlife Ecology is a good example (and as far as we know the only example) of this type of movement at an institutional level. Their program initially focused on entomology and applied ecology and then transitioned to a wildlife and entomology department. Similarly, wildlife journals could educate their readership on the important roles invertebrates play in wildlife management by defying taxonomic stereotypes and accepting worthy invertebrate papers or soliciting papers for a special section on invertebrate research in their respective publications. Professional wildlife societies can play an educational role in redefining wildlife science to include invertebrates by encouraging symposia on invertebrate research influencing wildlife management, for instance.

Collaborate.—Collaboration with entomologists and entomological systematists at academic and other public institutions can alleviate many of the operational limitations, including invertebrate identification, that potentially discourage inclusion of invertebrates in wildlife studies. Invertebrate systematists and entomologists often are familiar with not only the classification of invertebrate groups but also their ecology and evolution (Danks 1988). Non-entomologist wildlife professionals could find experts on invertebrate taxa potentially willing to aid in identification and verification of invertebrate specimens that also may help inform assessment of ecological responses in invertebrates. Local museums and land-grant institutions usually harbor invertebrate reference collections and informed curators, both of which can aid in the identification and inclusion of invertebrates in applied wildlife management (Suarez and Tsutsui 2004). Furthermore, museum invertebrate collections are becoming more accessible to wildlife researchers and managers as digitized, online reference collections (Bertone et al. 2012).

MANAGEMENT IMPLICATIONS

Following Guthery (2011), we summarized the broader implications of our findings on the discipline of wildlife science rather than explicitly on management. Given invertebrates' astounding diversity and impact on ecosystem function, coupled with the highly endemic readership of wildlife journals, lack of inclusion of invertebrates in wildlife journals likely indicates that wildlife managers have access to little information on invertebrate wildlife relative to their capacity to influence wildlife conservation and management. As such, wildlife management may be prone to disproportionately focusing on top-down influences on ecosystems, when terrestrial ecosystem structure and function is driven primarily by those that are bottom-up (Loreau et al. 2001). We recommend a paradigm shift to a less taxonomically homogenized and vertebrate-centric approach to wildlife research, management, and education by integrating invertebrates into wildlife studies and publishing results in wildlife journals to support effective on-the-ground management of all wildlife species.

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