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Long-Term Studies Contribute Disproportionately to Ecology and Policy

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As the contribution for long-term ecological and environmental studies (LTEES) to our understanding of how species and ecosystems respond to a changing global climate becomes more urgent, the relative number and investment in LTEES are declining. To assess the value of LTEES to advancing the field of ecology, we evaluated relationships between citation rates and study duration, as well as the representation of LTEES with the impact factors of 15 ecological journals. We found that the proportionate representation of LTEES increases with journal impact factor and that the positive relationship between citation rate and study duration is stronger as journal impact factor increases. We also found that the representation of LTEES in reports written to inform policy was greater than their representation in the ecological literature and that their authors particularly valued LTEES. We conclude that the relative investment in LTEES by ecologists and funders should be seriously reconsidered for advancing ecology and its contribution to informing environmental policy.

Keywords: climate change, impact factor, citation rate, National Research Council, study duration

Never in the history of scientific inquiry has it been so crucial to understand how species and entire ecosystems respond to environmental change and an ever-growing human population. Long-term ecological and environmental studies (LTEES) hold great promise for identifying and understanding these ecological consequences and for informing management and policy responses. Such knowledge underpins effective approaches to mitigate and adapt to these changes, including the protection of biodiversity, ecosystem functions, and the many ecosystem services relied on by humans. Long-term ecological and environmental studies (LTEES) are essential to characterizing how and why nature is changing, providing a means to understand the regulation and functioning of ecological communities, linking biological patterns to environmental variability, and informing the management of human influences on ecosystems and the services they provide (Likens 1989, McGowan 1990, Cody and Smallwood 1996, Ducklow et al. 2009, Clutton-Brock and Sheldon 2010, Magurran et al. 2010, Nelson et al. 2011, Lindenmayer et al. 2012, Hofmann et al. 2013).

LTEES have contributed profoundly to the development of a multitude of foundational advances in ecology across a diversity of natural ecosystems (figure 1). The inextricable relationship between temperate forest and stream ecosystems emerged from long-term forest manipulations and monitoring at the Hubbard Brook Experimental Forest (figure 1a; Likens et al. 1970). Such studies provided strong evidence of the importance of ecosystem connectivity and how human activities in one ecosystem are transmitted to and influence the biogeochemical processes and the structure, dynamics, and functions (e.g., productivity) of adjacent ecosystems. A theory for the maintenance of species diversity (e.g., unified neutral theory; Hubbell 2001) evolved from the long-term patterns of species dynamics in tropical rainforests, such as those revealed at Barro Colorado Island (figure 1b). Relationships between biodiversity and ecosystem function (e.g., productivity and nutrient cycling) and the ecological

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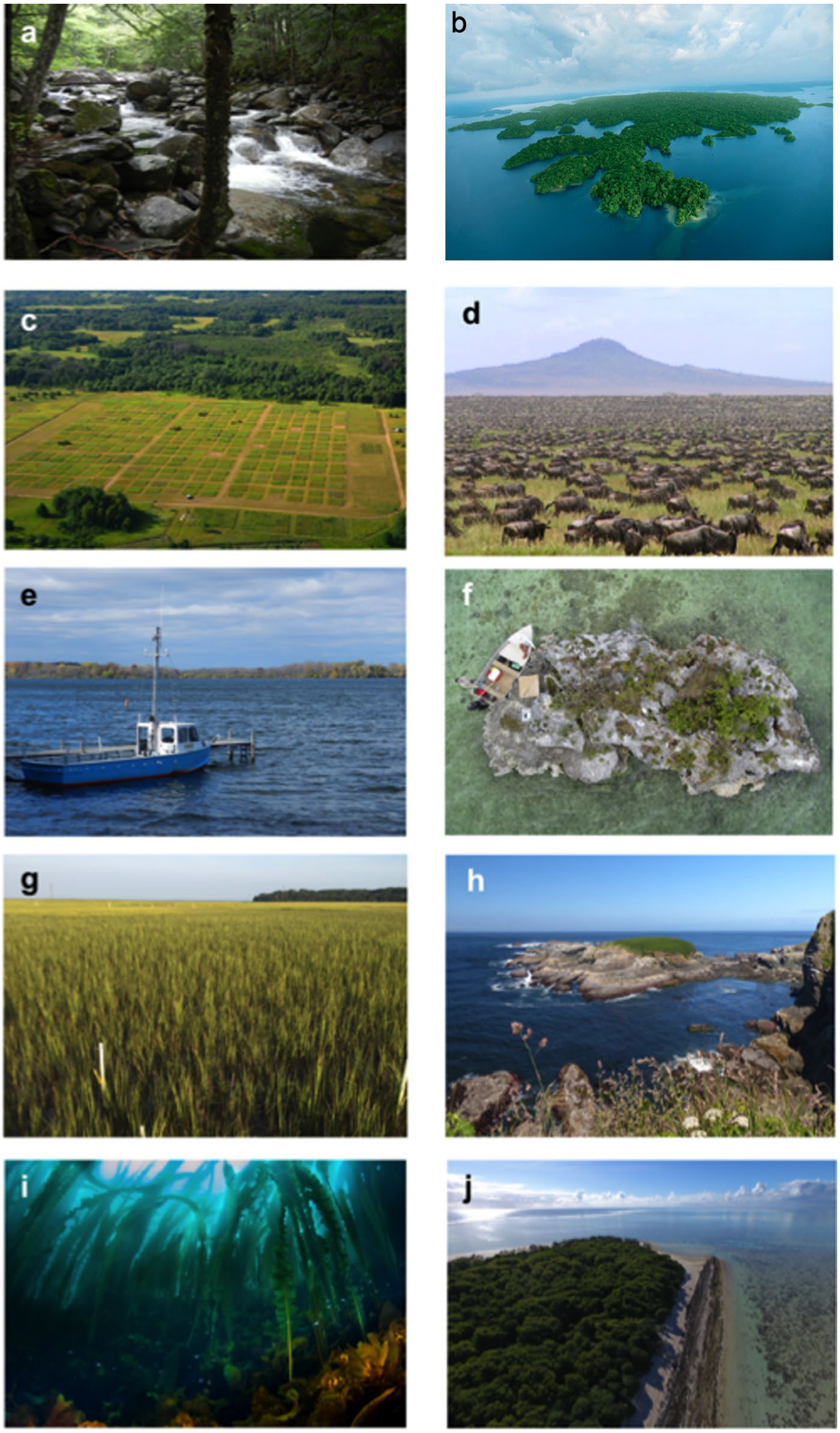

Figure 1. Examples of long-term ecological research sites, which have contributed significantly to advancing ecology and informing environmental policy: (a) temperate forest, Hubbard Brook Experimental Forest (Photograph: Claire Nemes); (b) tropical forest, Barro Colorado Island (Photograph: Christian Ziegler); (c) temperate grassland, Cedar Creek (Photograph: Jacob Miller); (d) tropical savannah, Serengeti (Photograph: Anthony Sinclair); (e) temperate lake, Lake Mendota (Photograph: Stephen Carpenter); (f) tropical islands, Staniel Island (Photograph: Louie Yang); (g) subtropical estuary, Sapelo Island (Photograph: Christine Angelini); (h) temperate rocky intertidal, Tatoosh Island (Photograph: Timothy Wootton); (i) temperate kelp forest, Aleutian Islands (Photograph: Joe Tomoleoni); (j) tropical coral reef, Heron Island (Photograph: Sam Chapman).

mechanisms underpinning those relationships (e.g., competition, life-history traits, functional complementarity, and redundancy) were revealed by long-term manipulations and monitoring of a temperate grassland ecosystem at the Cedar Creek Ecosystem Science Reserve (figure 1c; Tilman 1988, Tilman et al. 2002). Only long-term studies of predator–prey interactions in the tropical savannah ecosystem of the Serengeti revealed how the consequence of these interactions is greatly influenced by the diversity of both predators and prey and their relative body sizes (figure 1d; Sinclair et al. 2003). Long-term studies of community structure in the temperate freshwater lakes of Wisconsin (figure 1e) advanced understanding of the interactions between environmental drivers and trophic cascades (e.g., Carpenter et al. 2001) and revealed rapid shifts in ecosystem states that informed the theory of alternative stable states of ecosystems (Sheffer et al. 2001), spawning research on warning signs of these transitional "tipping points" (Scheffer 2001, Carpenter et al. 2011). Decades of study of lizard and spider assemblages on Caribbean Islands (figure 1f) have shaped our understanding of the concept of niches, resource partitioning, and the interplay between ecological processes (e.g., predation and competition) and environmental conditions for species coexistence and the structure of ecological communities (e.g., Spiller and Schoener 1995, 2008, Schoener and Spiller 1996, Losos et al. 2001). Continued long-term studies building on the seminal works of Odum, Teal, and others (e.g., Odum and Smalley 1959, Teal 1962) on energy and nutrient dynamics in the Sapelo Island saltmarsh (figure 1g) have advanced our understanding of how species interactions affect ecosystem processes. Long-term studies of how species interactions influenced spatial patterns of community structure and species diversity in the rocky intertidal of Tatoosh Island, Washington (figure 1h), inspired the concept of keystone species (Paine 1966). Decadal time series of the abundance of kelp forests (figure 1i), sea urchins, and sea otters across the Aleutian archipelago created one of the best-documented examples of trophic cascades, the crucial role of higher-level predators exerting "top-down" control of community structure (Estes and Palmisano 1974), and links between offshore and onshore ecosystems (Estes et al. 1998). Similarly, multiyear monitoring of the relative abundances of corals on tidal flats of Heron Island, Australia (figure 1j), ultimately revealed outcomes of competitive interactions and the consequences of episodic hurricanes that provided evidence for nonequilibrial mechanisms of the maintenance of diversity in the form of intermediate disturbances (Connell 1978, Connell et al. 2004). Collectively, LTEES have conceived and critically evaluated many of the key conceptual developments in ecology.

LTEES have also proven to be essential for supporting societal and political decisionmaking (Nichols and Williams 2006, Willis et al. 2007, Lindenmayer and Likens 2010, Rohani and King 2010, Schindler and Hilborn 2015). For example, consider where the discussion on global climate change would be in the absence of the Keeling curve, which quantifies the multidecadal rise of atmospheric carbon dioxide levels (Keeling 2008). This study in particular nicely illustrates how very small incremental environmental changes can be detected only because the phenomenon is studied over long periods. Another example is how the characterization of the long-term dynamics of wolf and moose populations on Isle Royale helped establish a nonintervention management policy by the US National Park Service but later identified the potential need of intervention to restoring the integrity of natural ecological processes (Peterson 1999). Ranges of natural variation are identified and temporal trends emerge with prolonged observation. Therefore, LTEES allow us to better understand the inherent variability of natural systems, to discern trends and shifting baselines (Lovett et al. 2007), and to witness rare events and unanticipated ecological surprises (Magnuson 1990, Doak et al. 2008, Lindenmayer et al. 2010). One exemplary case study of these unanticipated discoveries is the classic work of Gene Likens and colleagues at Hubbard Brook Experimental Forest in the northeast United States. Associated with their long-term environmental monitoring program, Likens and colleagues (1996) serendipitously discovered "acid rain" deposition, spawning a series of important publications (Likens et al. 1972, Likens and Bormann 1974) that ultimately influenced the 1990 Clean Air Act Amendment. Another way long-term monitoring studies have influenced environmental policy is their impact on pollution regulations, such as the termination of tributyltin (TBT) in antifouling paints, and how the recovery of species is quantified in order to evaluate the efficacy of these regulations (Hawkins et al. 2010). Other examples include the many cases in which long time series of fisheries stock assessments and fisheries independent surveys, in conjunction with environmental observations, have provided strong evidence of ocean ecosystems responding to climate change and also moving fisheries policy from single-species management to ecosystem-based fisheries management (Edwards et al. 2010). We cannot hope to understand such fundamental ecological phenomena such as forest succession or crucial environmental processes such as climatic interactions and oceanic circulation without long-term studies because they simply operate on longer time frames. Furthermore, because LTEES can capture processes at multiple timescales, conclusions may complement or be more robust and even different from those of studies of shorter durations (Wiens 1981, Brown et al. 2001).

Ironically, as the need for LTEES becomes ever more imperative, the persistence of many existing LTEES has become more precarious, and few new LTEES are being established. For example, although overall funding of ecological studies by the premier funding source for ecological research in the United States, the National Science Foundation (NSF), stagnated over the past decade (2004–2015; figure 2; $R^2(1,10) = .133$, $p = .244$), funding allocated to short-term studies (4 years or fewer) has increased ($R^2(1,10) = .473$, $p = .013$), funding allocated to long-term studies (4 years or longer) has decreased ($R^2(1,10) = .496$,

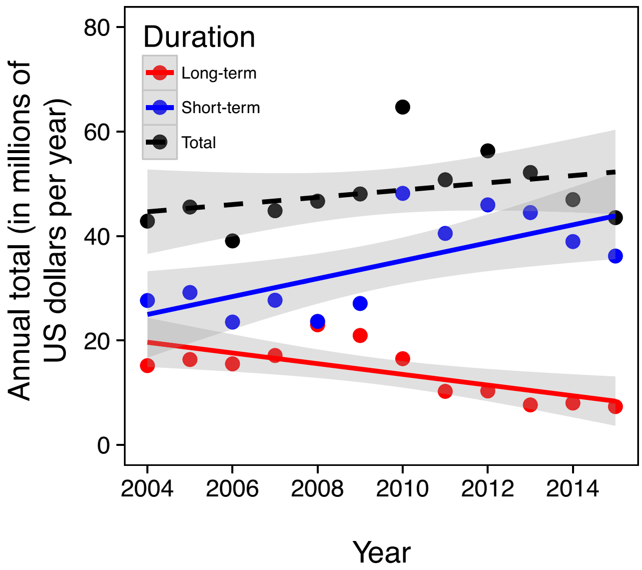

Figure 2. Trends in NSF funding for short- (4 years or shorter) and long-term (longer than 4 years) LTEES studies, as well as total funding, for DEB and Biological Oceanography programs. The solid lines are significant (p < .05) trends, and the dashed lines are nonsignificant (p > .05) trends. The gray areas represent 95% CI.

p = .011), and the trends in overall funding of long-term and short-term studies over this period have deviated significantly (ANCOVA: $F(1) = 4.157$, $p < .0005$; see "Trends in NSF funding of LTEES" in the supplemental materials for detailed methods and analyses). Similarly, during this period, the number of awards allocated to short-term studies have not changed ($R^2(1,10) = .102$, $p = .311$), but the number of awards allocated to long-term studies has significantly decreased ($R^2(1,10) = .547$, $p = .006$), resulting again in a significant deviation in the number of awards allocated to long-term versus short-term studies over the last decade (ANCOVA: $F(1) = 6.951$, $p = .016$; see "Trends in NSF funding of LTEES" in the supplemental materials). Moreover, the average award amount for individual long-term (longer than 4 years) studies has not significantly increased ($R^2(1,10) = .001$, $p = .921$), whereas the average award amount for individual short-term (4 years or fewer) has significantly increased ($R^2(1,10) = .426$, $p = .0215$). Although these award amounts are converging, typical long-term studies continue to include many more co-investigators (e.g., the NSF's Long-Term Ecological Research, LTER, programs).

Whereas this evaluation of LTEES funding by the US National Science Foundation is illustrative, other important examples include the precarious support of some of the most important LTEES in Canada as well. Perhaps the most disconcerting example is the recent funding dynamics of the Experimental Lakes Area (ELA), a premier ecological research institution in Canada, involving both ecosystem experiments and long-term monitoring. Established in 1968, funding by the federal government was terminated in 2012. Fortunately, a privately funded organization, the International Institute for Sustainable Development, agreed to assume operation of the facility, and provincial governments stepped in to bridge the funding gap. In 2014, the federal government once again provided some partial support for ELA. Similarly, the Department of Fisheries and Oceans (DFO), Canada, maintained among the finest and most valuable long-term records of Sockeye salmon population dynamics throughout British Columbia, Canada. However, recently, these time series, some of them spanning over 45 years, have been terminated, including the only Sockeye salmon stocks along a 1000-kilometer coastline for which freshwater and marine survival could be partitioned. Such examples of the discontinuation of highly invested, extremely valuable LTEES are not confined to the governmental funding and research institutions of the United States or Canada but are instead symptomatic of trends in many parts of the world as these organizations face difficult funding decisions.

In general, the declining support for LTEES by funding organizations such as the NSF reflects several contributing factors. Historically, support for LTEES in the scientific community has been contentious (Legg and Nagy 2006, Lindenmayer and Likens 2009, Fancy and Bennetts 2012). Critics have noted poorly defined questions and hypotheses and the inflexibility of sampling designs for addressing emerging environmental problems. Funders are hesitant to invest in LTEES that largely support the same investigators repeatedly for prolonged periods and prefer distributing funds across a greater number of researchers whose short-term studies can more rapidly address pressing and emerging ecological and policy issues. Moreover, in academia, young scientists are rewarded for frequent publications and may be increasingly hesitant to initiate and invest in studies whose publishable products will be delayed. Nonetheless, we suggest that funding decisions should reflect the relative value of short- and long-term ecological studies as perceived by the science community, including those involved in the process of informing policy.

Here, we demonstrate the disproportionate value of LTEES to science and for informing policy relative to funding allocations that favor short-term studies. To evaluate the perceived value of LTEES to both science and policy, we tested the following hypotheses: (a) The representation of LTEES (the percentage of LTEES of all ecological studies) increases in journals that publish peer-reviewed articles of greater perceived value to the scientific community (as is judged by a journal's impact factor). (b) LTEES contribute disproportionately to a journal's higher impact factor (i.e., the citation rates of LTEES increases with study duration, and this relationship increases with the impact factor of a journal). To determine whether LTEES are more highly valued in reports whose purpose is to inform decisionmakers, we also tested the hypotheses that (c) the representation of LTEES in US National Research Council (NRC) reports was

Table 1. A list of journals used to test for relationships between the citation rate and the study duration (2006 only) and between the study duration and the impact factor of the journal (2006 and 2010).

	Impact factor		
Number	2006	2010	Journal
1	1.92	1.91	*Journal of Experimental Marine Biology and Ecology*
2	2.29	2.48	*Marine Ecology Progress Series*
3	3.33	3.52	*Oecologia*
4	3.38	3.39	*Oikos*
5	NA	4.41	*PLOS One*
6	3.47	4.28	*Ecological Applications*
7	3.76	4.89	*Conservation Biology*
8	4.53	4.97	*Journal of Applied Ecology*
9	4.78	5.07	*Ecology*
10	7.10	5.93	*Ecological Monographs*
11	7.61	15.25	*Ecology Letters*
12	9.64	9.77	*Proceedings of the National Academy of Sciences (PNAS)*
13	10.99	10.26	*Current Biology*
14	26.68	36.10	*Nature*
15	30.03	31.38	*Science*

Note: Most journals are exclusively ecological, and others frequently publish ecological articles (Science, Nature, Current Biology, PNAS, PLOS ONE). The journals were selected to encompass a range of impact factors. NA indicates that the journal did not exist that year.

greater than their representation in the general scientific literature and that (d) the authors of those NRC reports particularly valued LTEES in their analyses and reports. For our tests of these hypotheses, we restricted our analyses to the ecological subset of NRC reports.

Perceived value of LTEES to advancing the field of ecology

We used two approaches to test our first hypothesis that the representation of long-term studies increases with the perceived importance of a journal, applying a categorical definition of LTEES (longer than 4 years) and applying study duration as a continuous variable. We used a linear regression to test the relationship between the percentage of published studies categorized as long term (longer than 4 years, hereafter "percent long-term studies") and journal impact factor (IF) for journals reviewed in both 2006 and 2010. We then used ANCOVA to test for any differences in this relationship between 2006 and 2010 (see "Percent long-term studies and journal impact factor" in the supplemental materials). We also used a linear regression to test for a relationship between mean study duration (in years) and a journal's impact factor for both 2006 and 2010.

To test our second hypothesis that LTEES contribute disproportionately to the impact factor of a journal, we used a two-factor ANOVA to test for an interaction between study duration and journal impact factor on the citation rate of articles in each of the journals reviewed in 2006 and 2010 (see "Contribution of LTEES to citation rates of higher impact journals" in the supplemental materials). We determined the study duration of all articles published by 15 representative ecological journals in 2 years (2006 and 2010; table 1). We chose these 2 years for our analyses because our review was initiated in late (September–December) 2012 for 2006 studies and September 2016 for 2010 studies, and citation rates tend to peak well beyond 2 years after publication (Glånzel and Moed 2002).

Study duration was evaluated as both a continuous and a categorical (LTEES longer than 4 years in duration) variable using a minimum resolution of 1 year (see "Estimate of study durations in the ecological literature" in the supplemental materials). Four years is a meaningful delineation between long- and short-term studies because it represents a typical maximum length of many NSF grants and graduate research studies. Nonetheless, we assessed the sensitivity of our results to this categorization by comparing the slope of relationships between journal impact factor and the percentage of LTEES using LTEES definitions of durations longer than 4 to longer than 9 years and found no difference in these relationships (see "Categorization of LTEES" in the supplemental materials). Our analyses of articles from both 2006 and 2010 allowed us to determine the repeatability of the observed relationships between duration and both citation rate and journal impact factor.

Although study duration can be defined and quantified in various ways and applied to various ecological approaches (e.g., field, modeling, reviews, meta-analyses, and paleoecological), we were interested in the perceived value of the temporal and financial investment in prolonged research programs. Not all ecological studies are pertinent to this evaluation. For example, paleoecological studies were excluded to avoid outliers that would create a bias toward longer study durations and because of great differences in the financial investment related to methods used in these studies and modern ecological studies. We therefore considered only empirical experimental and observational studies either in the lab or field and quantified their duration by the total number of years in which sampling was actually conducted (e.g., 5 years of data collection in sequential years and five intermittent annual samples over a 20-year study duration were both categorized as a 5-year study). Nonetheless, study duration and study span (beginning to end of overall study period) were tightly correlated (see "Estimate of study durations in the ecological literature" in the supplemental materials). We also estimated the error among journal reviewers in their estimates of study duration. Of the total 18% error in estimates of study duration between observers, 48% was error by a single year and therefore had little influence on comparisons of long- and short-duration studies (see "Categorization of LTEES" in the supplemental materials).

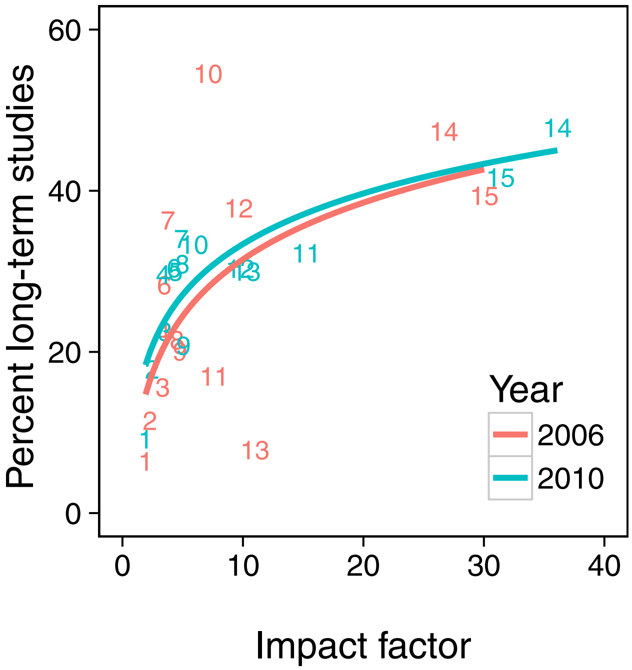

Figure 3. The relationship between a journal's impact factor and the percentage of its articles whose studies exceeded a duration of 4 years, averaged over 2 years (2006 and 2010). The numbers indicate individual journals (table 1).

Impact factors (equation 1) are commonly used to assess the relative importance of journals in relation to others and are commonly calculated as the following:

$$IF_t = (A_{t-1} + A_{t-2}) * (B_{t-1} + B_{t-2})^{-1} \qquad \text{Equation 1}$$

where the impact factor, IF, reflects the ratio of the number of citations, A, from previous years and the number of citable items, B, in those years (Journal Citation Reports, Thomson Reuters, New York City, United States). Journal impact scores were obtained from the Web of Science in 2012 for 2006 and in September 2016 for 2010.

The percentage of articles (2006 and 2010 combined) in a journal consisting of LTEES increased with journal impact factor (figure 3; $R^2(1,27) = .483$, $p < .0001$; see "Percent long-term studies and journal impact factor" in the supplemental materials). Similarly, we detected a positive relationship between a journal's impact factor and the mean duration of its published studies (2006: $R^2(1,13) = .454$, $p = .008$; 2010: $R^2(1,14) = .615$, $p = .0005$). Moreover, with respect to our second hypothesis that LTEES contribute disproportionately to a journal's impact factor, we found that the positive relationship between citation rate and study duration was stronger as journal impact factor increased (figure 4a–b; two-factor ANOVA, impact factor*study duration interaction; 2006: $F(1) = 21.627$, $p < .0001$; 2010: $F(1) = 3.968$, $p = .0465$; see "Contribution of LTEES to citation rates of higher-impact journals" in the supplemental materials). This relationship was consistent for both years of journals reviewed. These analyses revealed that LTEES therefore contribute disproportionately to the perceived value of articles in higher impact journals (2006), however, the pattern was not consistent between the two years sampled.

Perceived value of LTEES for informing environmental policy

We used NRC reports to evaluate the importance of LTEES for informing environmental policy by testing the hypotheses that (a) the duration of studies cited in reports is greater than those of studies published in the general ecological literature and that (b) LTEES are represented disproportionately in NRC reports relative to their frequency in the scientific literature. NRC reports are considered among the most influential sources of scientific synthesis for informing US environmental policy. Each NRC report serves as a topic-specific synthesis of the scientific literature and is conducted for the specific purpose of informing policymakers. We restricted our analyses to all 44 ecologically relevant NRC reports published in 2010. All studies cited within each NRC report that met the same criteria we used in our consideration of journal impact factors were considered, representing publications from the years 1951–2010 from 333 different journals. To directly compare the durations of NRC-cited studies with those published in the sampled ecological literature, we accounted for a positive relationship among study duration and publication year, ecosystem-specific differences, and random-effect differences between NRC reports. We did so by using the duration residuals of a linear mixed model including these covariates and standardizing these to the year 2006 (see "Evaluation of LTEES contribution to policy-informing literature" in the supplemental materials).

Each NRC report was reviewed by two individuals. Each reviewer independently counted the total number of references cited in the report and identified all the peer-reviewed ecological studies. The two reviewers then reconciled the differences between their tallies. For a subset of interdisciplinary papers for which ecological classification by a reviewer pair proved difficult, a larger number of reviewers were consulted to reach a consensus. Similar to the approach we used for the ecological journals, error in the assignment of study durations among reviewers was evaluated by having all reviewers assign durations from the same set of 20 references. Overall, the pooled standard deviation of study duration from these references was 0.722 years, which is less than the defined minimum duration of 1 year.

The NRC reports and ecological literature cited studies conducted over different time periods and across a diversity of ecosystems, so we tested for relationships between study year or ecosystem and the duration of cited studies to determine whether differences in the range of years and the proportionate representation of ecosystems (freshwater, marine, terrestrial, or "multiple") in studies cited in the

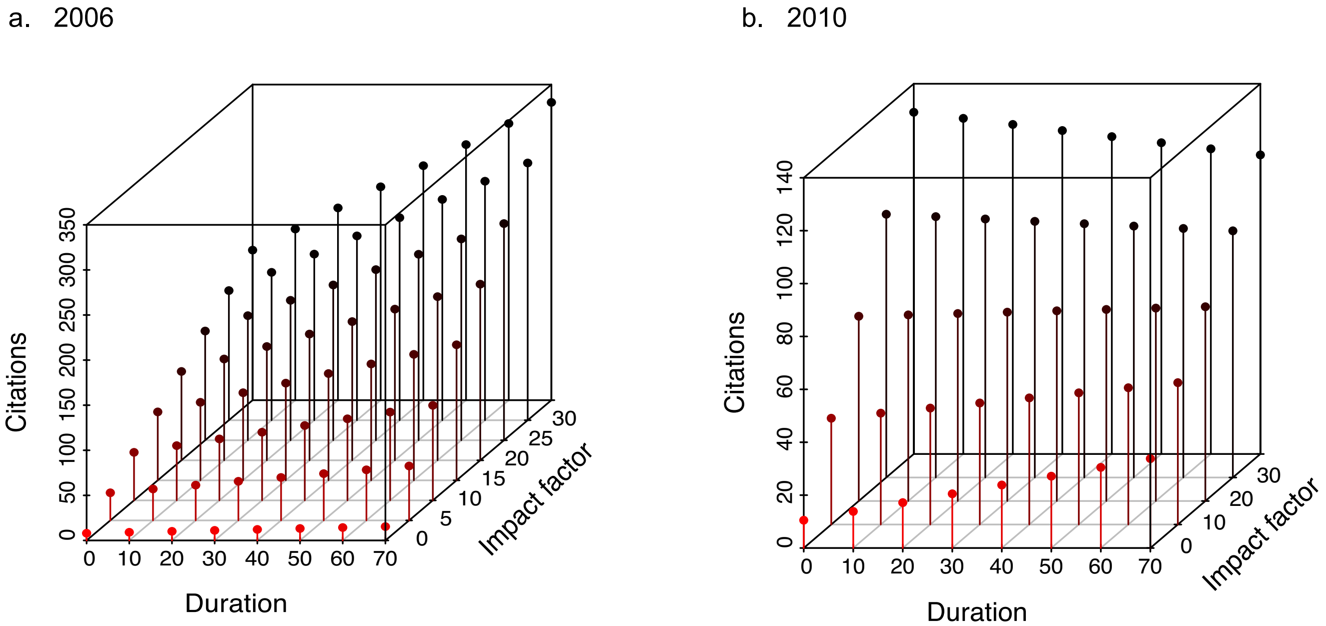

Figure 4. Modeled relationship between a journal's impact factor and the rate at which the number of citations of an article published in (a) 2006 and (b) 2010 increased with study duration (supplemental table s1). The lines under the model points serve as references for the orientation of axes.

ecological literature and the NRC reports might confound our comparisons. Study duration differed with both year and ecosystem, and study duration was related to both year and ecosystem type in the general ecological literature. However, there was little indication that study duration varied by year or ecosystem in studies cited in NRC reports (see "Relationship between year of publication, ecosystem, and study duration" in the supplemental materials). To account for the differences in study duration by ecosystem and publication year, the residuals from these models were used as the response variables. We used a two-sided t-test to assess the difference between mean residual durations of the two data sets. Our null hypothesis was that the means of the residual study durations from the general literature and the literature extracted from the NRC reports would be the same.

The median duration of NRC-cited studies was only 1.30 years longer than studies in the scientific literature (t-test, $t(4780) = 7.22$, $p < .001$, 95% confidence intervals [CI] = 1.21–1.39). However, this seemingly small difference in median study durations belie a far greater difference in the representation of LTEES in NRC reports because the frequency distributions of study durations were highly skewed and heavy tailed. A second analysis considering the difference in the cumulative frequency distributions of study durations in NRC-cited studies and the scientific literature illustrates how NRC reports disproportionately cited studies of greater duration (figure 5). The longest-duration studies (greater than the 75th percentile) from NRC reports were 5 to 40 years longer in duration than the same percentile in the general scientific literature.

To gain further insight into the process by which short- versus long-term ecological studies were selected by NRC report authors, we surveyed all authors of the 44 NRC reports considered (see "NRC author survey methods" in the supplemental materials). NRC reports are written by experts representing academia, government, industry, and non-profit organizations, whose perception of LTEES may differ (National Academies 2015). Of the 480 authors contacted, 114 (23.75%) responded anonymously to a series of questions (Likert scale and rank style) assessing their opinions on (a) the value of long-term ecological research and its contribution to scientific knowledge and policy decisions, (b) the importance of study durations for informing NRC report recommendations, and (c) the importance of a study's duration for citation in a report. We used these answers to assess whether a disproportionate number of authors expressed preference for LTEES and whether self-reported ecologists versus nonecologists differed in their opinions regarding the relative importance of LTEES.

Our survey revealed that NRC report authors agreed that (a) study duration was an important criterion for citation more frequently than expected under the null hypothesis (null = 0, 95% CI = 0.32–0.60, $n = 62$, $p < .0001$), (b) authors were more inclined to cite long-term studies than short-term studies (null = 0, 95% CI = 0.15–0.32, $n = 109$, $p < .0001$), (c) long-term ecological data sets provide information that short-term studies cannot (null = 0, 95% CI = 0.59–0.73, $n = 109$, $p < .0001$), and (d) long-term studies are important for informing policy (null = 0, 95% CI = 0.65–0.77, $n = 109$, $p < .0001$). For more detailed results, see "NRC author survey results" in the supplemental materials. When we

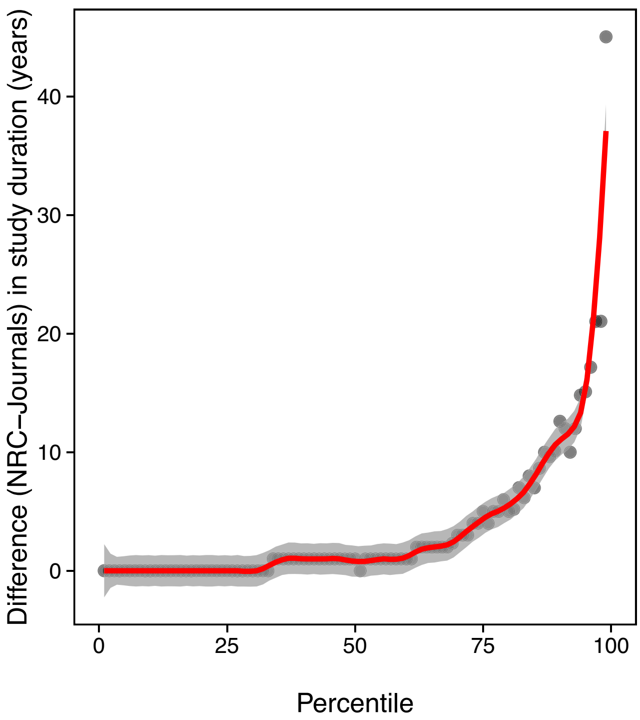

Figure 5. The difference in the cumulative frequency distribution of study durations between studies cited in NRC reports and the scientific ecological literature. The line was fitted using a loess smoother function. The relationship illustrates the disproportionate frequency with which LTEES are used to inform policymaking decisions; 25% of NRC-cited studies had durations of 5 to more than 40 years greater than the equivalent percentile of studies in the scientific literature.

compare responses between ecologist versus nonecologists, there was a general, albeit nonsignificant (all $p > .05$), trend of ecologists viewing the importance of long-term ecological data sets more favorably.

These same NRC authors also ranked studies of more than 1 year as more important to the recommendations of their report relative to studies with shorter durations based on ranked analyses of increasing study duration ($\chi^2(3) = 38.08$, $p < .0001$, all pairwise comparisons with "less than 1 year" differed at $p < .0001$). When these values were broken down by ecologists versus nonecologists, there was a tendency for ecologists to cite fewer short-term (1-year study duration; $p = .0166$) and more long-term (6- to 10-year study duration; $p = .0018$) studies compared with nonecologists. However, when authors were asked how often they cited studies with different durations, they reported citing studies of 2–5 years' duration most frequently. This mismatch between citation frequency and preference for study duration suggests a relative scarcity of long-term ecological studies in the literature. This was also supported by the fact that the majority (56%) of ecologists who reported infrequent citation of long-duration studies of 6 or more years explained that doing so was because of the lower availability of long-term studies in the literature. For more detailed results of these analyses, see "NRC author survey results" in the supplemental materials.

Conclusions

As was indicated by the disproportionate frequency with which LTEES are cited and their disproportionate occurrence and contributions in the more highly regarded scientific journals, our results indicate that the scientific community values LTEES more highly than shorter-term ecological studies. Within the scientific community, there is growing appreciation and demand for time series with durations well beyond those generated by the typical study currently being funded. The rapidly expanding capacity to forecast system dynamics, detect causality between variables, and forewarn of impending tipping points when longer time series are available underpins this growing interest (Scheffer 2010, Ye et al. 2015). Indeed, even among the long time series that do exist, most are still limited to single or paired species, with very few representing the community-wide studies necessary to advance our understanding of the complex dynamics of multispecies assemblages and ecosystems. However, in recognition of the importance of data sets generated by LTEES, the science community is exploring the unique nuances of archiving and sharing these valuable data sets (Mills et al. 2015, Mills et al. 2016, Whitlock et al. 2016).

Our review of NRC reports further indicates that LTEES play a vital role in informing environmental policy, with NRC reports disproportionately citing LTEES relative to their frequency of citation in the ecological literature and NRC authors agreeing that LTEES contribute unique information to the recommendations of their reports. Notably, the survey of NRC authors also highlighted a mismatch between the demand and availability of LTEES. This suggests that the paucity of LTEES in the scientific literature comes at a significant cost to not only the scientific advancement of ecology and its related fields but also the capacity of science to inform policymakers. Together, these results support the assertion that both private and governmental funding sources should reverse their declining allocations of funds to long-term ecological studies.

Past critiques of LTEES have spurred much thought by the ecological community of the key elements of productive, sustainable LTEES (box 1; Lindenmayer and Likens 2009, McDonald-Madden et al. 2010, Peters 2010). These studies are designed to address questions or hypotheses that pertain to issues of significant societal interest (i.e., that inform management and policy decisions) and that require long-term ecological and environmental time series. They are multidisciplinary, especially those that span multiple ecosystems or explore the complexity of coupled social–ecological systems. They integrate short- and long-term experimental, observational, and modeling components. They are initiated with well-designed data-management, -archiving, and -dissemination systems. Core time series maintain consistent sampling designs and protocols that ensure the integrity of

Box 1. A recommended attributes of sustainable, productive LTEES largely drawn from the ecological literature (see text for citations).

Question/hypothesis-based purpose

Ensure that the purpose and design of a LTEES is motivated by well-defined questions and associated hypotheses.

Both basic and applied purposes

Include both basic and applied purposes (questions) to increase the value of an LTEES and breadth of interested participants and funding sources.

Consistent core sampling design and protocols

Ensure that core sampling design criteria (spatial and temporal) and protocols are consistent through time to maintain the integrity of a time series. Any new designs and methods should be gradually transitioned to with calibration to evaluate comparability and compatibility of the time series.

Consistency and quality of data collection

Establish a rigorous system for maintaining consistency and reliability of data collection and quality control over the long term that is robust to turnover of project personnel. This includes the training and evaluation of data collectors.

Adaptability of sampling design and protocols

Ensure capacity to adopt additional designs and protocols to enhance its relevance by addressing emergent and topical questions and hypotheses.

Documentation

Maintain rigorous and detailed documentation of sampling designs, data collection methods, instrumentation, calibrations, environmental conditions and other metadata to inform the proper use and interpretation of data.

Data management and dissemination

Design and support a well-developed and adaptable data management and data dissemination program throughout the lifetime of the LTEES. This includes a strong online presence.

Attractive and inclusive participation by the scientific community and others

Develop means (e.g., workshops, website, outreach) for engaging others in the research community, managers, stakeholders, citizen science and others with emphasis on recruiting new young researchers.

Management structure

Implement an adaptable and functional management and governance structure that is responsible for strategic research planning, resource allocation, administrative policies, and staffing throughout the lifetime of the LTEES.

Rigorous funding structure

Identify and establish long-term reliable and resilient funding sources in advance of initiating an LTEES. Establish mechanisms for identifying and pursuing additional sources of funding throughout the lifetime of the LTEES (e.g., outreach products and efforts).

Complementary research programs

Foster and integrate a diversity of multi- and interdisciplinary research approaches (e.g., short and long-term experiments, modeling, coupled biological and physical observations, coupled socio-ecological investigations).

Educational component

Create educational components that expose future generations of scientists and others to the value of LTEES at several levels (visiting researchers and teachers, post-doctoral fellows, graduate students, undergraduates, K-12).

the long-term data sets. These and other design elements enable LTEES to simultaneously address those questions that require long time series but are flexible enough to address emerging and timely issues that draw on insights generated by the long time series. They attract young investigators with the opportunity to contribute to and quickly benefit from the intuitive understanding of systems that only long time series generate. Creative designs that leverage and integrate short- and long-term studies can resolve past concerns raised by critics of poorly designed long-term studies.

Not surprisingly, all of these elements of continuously informative LTEES have become crucial components of the NSF's LTER (*www.lternet.edu/lter-sites*) program (Callahan 1984, Franklin et al. 1990) and have contributed importantly to our understanding of the ecological consequences of a changing global climate. However, across the 28 LTER sites, the majority confined to the United States, there is representation of only a fraction of earth's ecosystems and they do not capture the large-scale geographic variation typical of ecosystems. Therefore, the inferences generated by this small sample size of long-term research programs are constrained by the limited funding provided by governmental and nongovernmental funding sources. The conclusions generated by our analyses argue strongly for greater funding for a larger global network of LTEES modeled on many of the attributes of the NSF's LTER program. Fortunately, the more recent establishment of Long-Term Ecosystem Research in Europe (LTER-Europe; *www.lter-europe.net*) and the International Long Term Ecological Research (iLTER; *www.ilternet.edu*) programs will provide a more global characterization of long-term ecosystem dynamics.

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Supplemental material

Supplementary data are available at *BIOSCI* online.

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SUPPLEMENTARY MATERIALS

Trends in NSF funding of LTEES

To evaluate trends in the relative investment (awards) in long-term ecological and environmental studies (LTEES) by NSF, we compared the trajectories of the total amount awarded for ecological research (including LTER, excluding workshops, instrumentation and REU) and funding allocated to short-term (≤ 4 year) and long-term (> 4 year) research projects by the Divisions of Environmental Biology (DEB) and Oceanography (OCE) by year from 2004 to 2015. Funding (awards) data were downloaded from http://www.nsf.gov/awardsearch/. Temporal trajectories of the award total, number of awards, and average award size for short-term and long-term studies were compared with an analysis of covariance (ANCOVA).

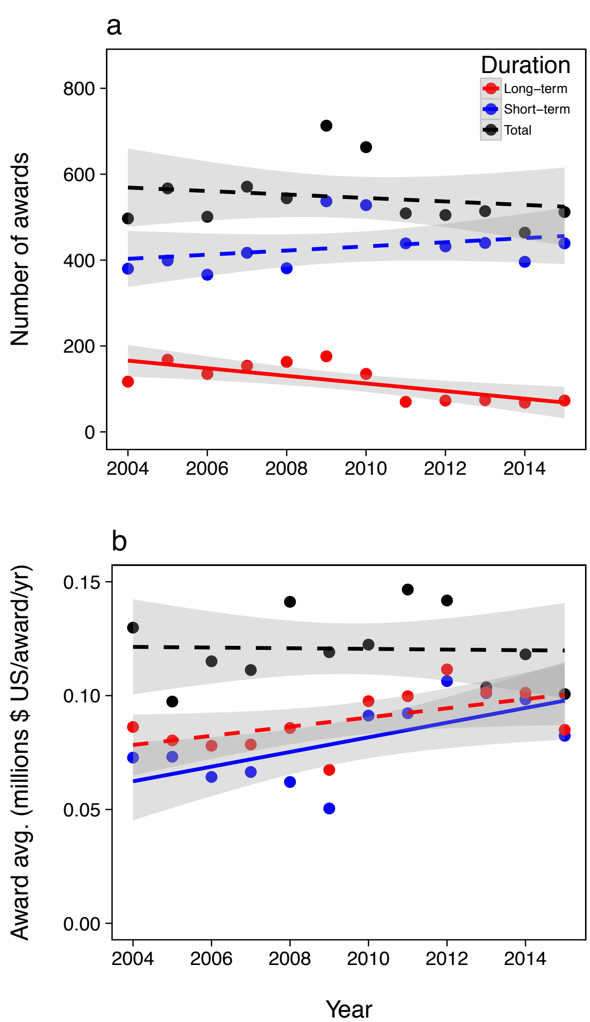


Figure s1. Trends in NSF funding for DEB and Biological Oceanography for (a) number of awards and (b) average award size for short (≤ 4 year) and long-term (> 4 year) study duration, respectively. Solid lines indicate significant trends ($P < 0.05$), dashed lines indicate non-significant trends ($P > 0.05$). Grey areas represent 95% CI.

Error in of study duration estimates: ecological literature

Sixteen individuals reviewed an entire year of publications in 14 and 15 journals from 2006 and 2010, respectively. We determined the error in estimates of study duration among reviewers by comparing duration estimates by two independent observers of a subsample of articles (5%; n = 142) selected at random from both years of the journals. Of the total 18% error in estimates of study duration between observers, 48% was error by a single year (supplementary materials figure s2).

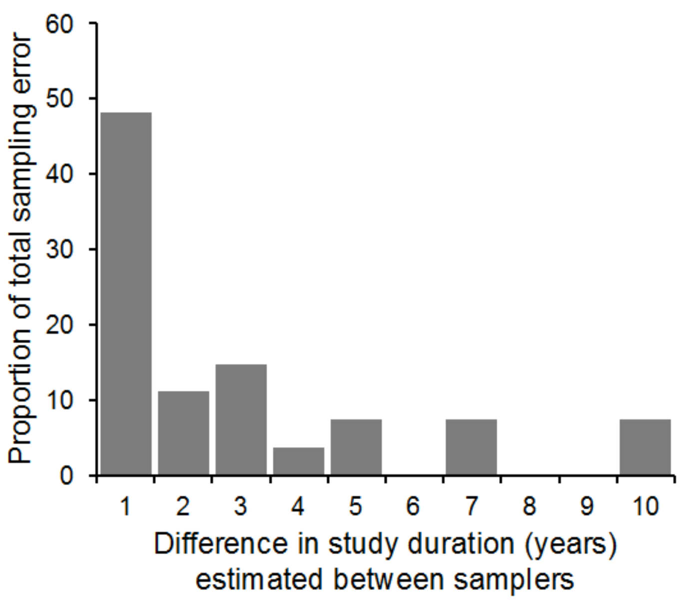


Figure s2. Results from a resampling estimate of reviewer error in estimates of study duration.

Categorization of LTEES

We assessed LTEES both as a continuous variable (e.g., mean study duration) and categorically by defining LTEES as study durations greater than 4 years. We chose this delineation to distinguish LTEES from study durations typical of both doctoral dissertations and individual NSF awards (typically four years or less). We evaluated the effect of this choice on the results of our analyses by comparing the slope of relationships between journal impact factor and percent LTEES using LTEES definitions of 5 to 10 year durations with an analysis of covariance (ANCOVA). Slopes of these relationships did not differ significantly for either 2006 (Duration * Impact Factor interaction: $F = 0.093$; $df = 5,72$; $P = 0.993$) or 2010 ($F = 0.442$, $df = 5,78$; $P = 0.818$).

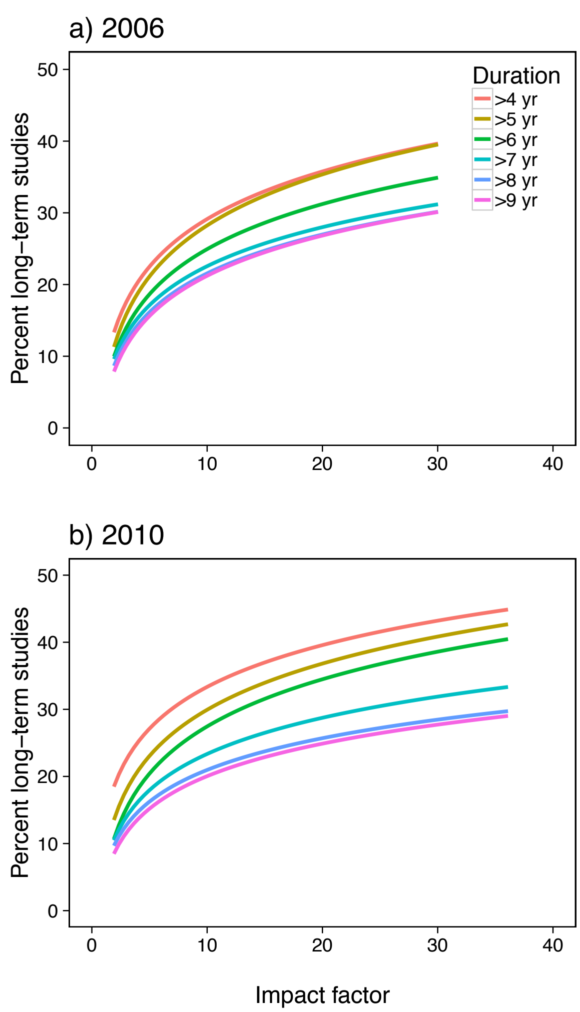


Figure s3. Evaluation of categorizing LTEES by > 4 to > 9 years on strength (slope) of the relationship between percent LTEES and journal impact factor. Impact factors ranged from 1 to 30 and 1 to 36 in 2006 and 2010, respectively.

Percent long-term studies and journal impact factor

We tested for relationships between the percent of studies published in a journal that were of durations greater than four years and the impact factor of that journal for each of 2006 and 2010. Journal impact factor was log10 transformed to linearize the relationships in the analysis. An ANCOVA was used to test for differences in intercept and slope of the relationships between years. There was no significant difference in slopes of the two years (ANCOVA full model interaction term: $F = 0.0617$; $df = 1$; $P = 0.806$) (figure 3). There was no significant difference in intercept (ANCOVA reduced model without interaction term: $P = 0.0525$. However, the relationship between percent long-term studies and (log) journal impact factor was significant (journal impact factor effect: $F = 25.18$; $R^2 = 0.483$; $df = 1,27$; $P < 0.0005$). Therefore, we averaged the percent long-term studies and log journal impact factor between years and tested for a relationship across these averages with simple linear regression.

Contribution of LTEES to citation rates of higher impact journals

To determine whether LTEES contributed to the higher citation rates of higher impact journals, we used all 1,800 articles published in the 14 journals in 2006 and 1,734 articles published in 2010 and tested for an interaction between journal impact factor and study duration on the number of citations per article with a two-factor analysis of variance. 2006 and 2010 were analyzed separately. Both journal impact factor and study duration were modeled as fixed effects. The rate of increase of the relationship between study duration and number of citations increased with impact factor of the journal.

Table s1. Results of two-factor analysis of variance to test for the interaction between study duration and journal impact factor on the number of citations of articles published in a) 2006 and b) 2010.

a) 2006

Source	***df***	***Sum of Squares***	***F***	***P***
Duration	1	1051432	800.23	< 0.0001
Impact Factor	1	30905	23.52	< 0.0001
Impact Factor*Duration	1	28416	21.627	< 0.0001

b) 2010

Source	***df***	***Sum of Squares***	***F***	***P***
Duration	1	354020	996.93	< 0.0001
Impact Factor	1	8658	24.38	< 0.0001
Impact Factor*Duration	1	1409	3.9682	0.04652

Evaluation of LTEES contribution to policy-informing literature

We restricted our analyses to National Research Council (NRC) reports published in 2010 in the Division of Earth and Life Studies, excluding the following subtopics: Chemical Sciences and Technology, Laboratory Animals, and Nuclear and Radiation Studies. As in our review of the scientific journals, ecological studies were defined as those that examined the relationship between living organisms or organisms and their environments. Similarly, NRC-cited ecological papers lacking empirical data sets were excluded (e.g., reviews, meta-analyses, and purely theoretical papers), as were paleoecological studies. Based on these criteria we reviewed 44 NRC reports (supplementary materials table s2) and all the ecologically-relevant citations. NRC reports cited a much greater range of years than the scientific literature of our first analyses (1951-2010 versus 2006 and 2010) and ecosystems than the ecological literature.

Table s2. Committee members of 44 NRC reports were surveyed. All reports were conducted under the Division of Earth and Life Sciences of the NRC and published in 2010.

NRC Report Title
A Review of the Proposed Revisions to the Federal Principles and Guidelines Water Resources Planning Document
A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta
Adapting to the Impacts of Climate Change
Advancing the Science of Climate Change
An Evaluation of the Food Safety Requirements of the Federal Purchase Ground Beef Program
Assessment of Intraseasonal to Interannual Climate Prediction and Predictability
Assessment of Sea-Turtle Status and Trends: Integrating Demography and Abundance
BioWatch and Public Health Surveillance: Evaluating Systems for the Early Detection of Biological Threats: Abbreviated Version
Building Community Disaster Resilience through Private-Public Collaboration
Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences
Climate Stabilization Targets: Emissions, Concentrations, and Impacts Over Decades to Millennia
Continuing Assistance to the National Institutes of Health on Preparation of Additional Risk Assessments for the Boston University NEIDL, Phase 2
Ecosystem Concepts for Sustainable Bivalve Mariculture
Eighteenth Interim Report of the Committee on Acute Exposure Guideline Levels
Evaluation of a Site-Specific Risk Assessment for the Department of Homeland Security's Planned National Bio- and Agro-Defense Facility in Manhattan, Kansas
Evaluation of the Health and Safety Risks of the New USAMRIID High Containment Facilities

at Fort Detrick, Maryland
Final Report of The National Academies Human Embryonic Stem Cell Research Advisory Committee and 2010 Amendments to the National Academies Guidelines for Human Embryonic Stem Cell Research
Impact of Genetically Engineered Crops on Farm Sustainability in the United States
Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico: Strategies and Priorities
Informing an Effective Response to Climate Change
Letter Report Assessing the USGS National Water Quality Assessment Program's Science Framework
Limiting the Magnitude of Climate Change
Management and Effects of Coalbed Methane Produced Water in the United States
Missouri River Planning: Recognizing and Incorporating Sediment Management
Monitoring Climate Change Impacts: Metrics at the Intersection of the Human and Earth Systems
Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean
Precise Geodetic Infrastructure: National Requirements for a Shared Resource
Progress Toward Restoring the Everglades: The Third Biennial Review--2010
Realizing the Energy Potential of Methane Hydrate for the United States
Review of the Department of Defense Enhanced Particulate Matter Surveillance Program Report
Review of the Department of Homeland Security's Approach to Risk Analysis
Review of the Environmental Protection Agency's Draft IRIS Assessment of Tetrachloroethylene
Review of the St. Johns River Water Supply Impact Study: Report 3
Review of the WATERS Network Science Plan
Sequence-Based Classification of Select Agents: A Brighter Line
Seventeenth Interim Report of the Committee on Acute Exposure Guideline Levels
Strategic Planning for the Florida Citrus Industry: Addressing Citrus Greening
The Use of Title 42 Authority at the U.S. Environmental Protection Agency: A Letter Report
Toward Sustainable Agricultural Systems in the 21st Century
Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts
Understanding Climate's Influence on Human Evolution
Understanding the Changing Planet: Strategic Directions for the Geographical Sciences
Verifying Greenhouse Gas Emissions: Methods to Support International Climate Agreements
When Weather Matters: Science and Service to Meet Critical Societal Needs

Relationship between year of publication, ecosystem and study duration

To determine whether differences in the range of years and the proportionate representation of ecosystems in studies cited in the ecological literature and the NRC reports might confound comparisons, we tested for relationships between study year or ecosystem and the duration of cited studies. Ecosystem was classified by freshwater, estuarine, marine, terrestrial, or "multiple" (if the study was cross-ecosystem or could not easily fit into one of the four primary categories). We used a generalized linear mixed effects model to examine the effect of study year and ecosystem on log-transformed study duration in NRC report citations, treating NRC report as a random effect (lme4 and lmerTest packages in R) (Bates 2014, Kuznetsova 2015). Study duration differed with both year and ecosystem for the general ecological literature (supplementary materials table s3a, figure s4a). However, the general linear mixed model indicated that study duration was slightly related to year with little indication of ecosystem differences for studies cited in NRC reports (supplementary materials table s3b, figure s4b).

To address whether publication journal affected our results, we analyzed a subset of the data that included only the focal journals from the general ecological literature analysis and found similar results. The magnitude of this difference in median study durations increased from 1.30 years to 1.34 years when considering only studies published in our focal set of 15 ecological journals (t-test, $t = 4.36$, $df = 3532$, $P < 0.001$, 95 % CI: 1.17 - 2.30).

Table s3. (a) Tests of relationships between year (2006 and 2010) and ecosystem (fixed factors) and journal (random factor) on study duration from studies in the general ecological literature using a general linear mixed effects model. **(b)** Tests of relationships between year and ecosystem (fixed factors) and journal (random factor) on study duration of publications in the reviewed NRC reports. Results from generalized linear mixed effects model show fixed effects only. Reference group for ecosystem is "multiple".

(a) General Ecological Literature

	Parameter Estimate	***Std. Error***	***t***	***P***
Intercept	-68.75	16.71	-4.115	< 0.0001
Year	0.035	0.008	4.212	< 0.0001
Ecosystem: freshwater	-0.807	0.202	-3.989	< 0.0001
Ecosystem: marine	-0.635	0.199	-3.185	0.0015
Ecosystem: terrestrial	-0.618	0.195	-3.176	0.0015

(b) NRC Cited Literature

	Parameter Estimate	***Std. Error***	***t***	***P***
Intercept	-14.66	8.158	-1.798	0.0725
Year	0.008	0.004	1.923	0.0547
Ecosystem: freshwater	-0.258	0.194	-1.331	0.1833
Ecosystem: marine	-0.009	0.134	0.703	0.4821
Ecosystem: terrestrial	-0.162	0.163	0.992	0.3216

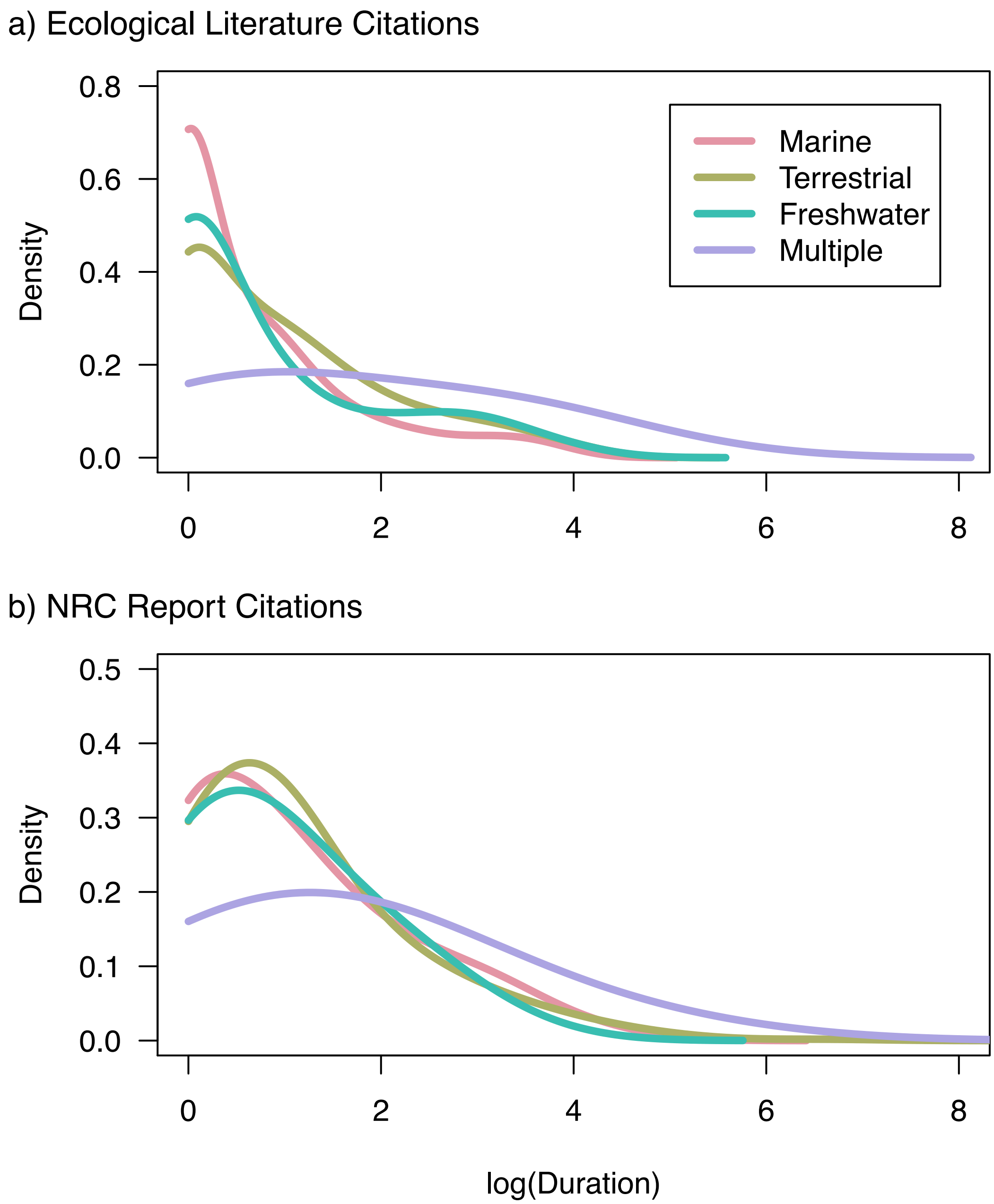


Figure s4. Density plot showing the distribution of log study durations from the (a) General Ecological Literature and (b) NRC citations by study ecosystem. Mean log-transformed durations by system for (a) are 0.632 (marine), 0.936 (terrestrial), 0.770 (freshwater), and 1.658 (multiple), and for (b) are 1.918 (marine), 2.171 (terrestrial), 1.421 (freshwater), and 1.897 (multiple).

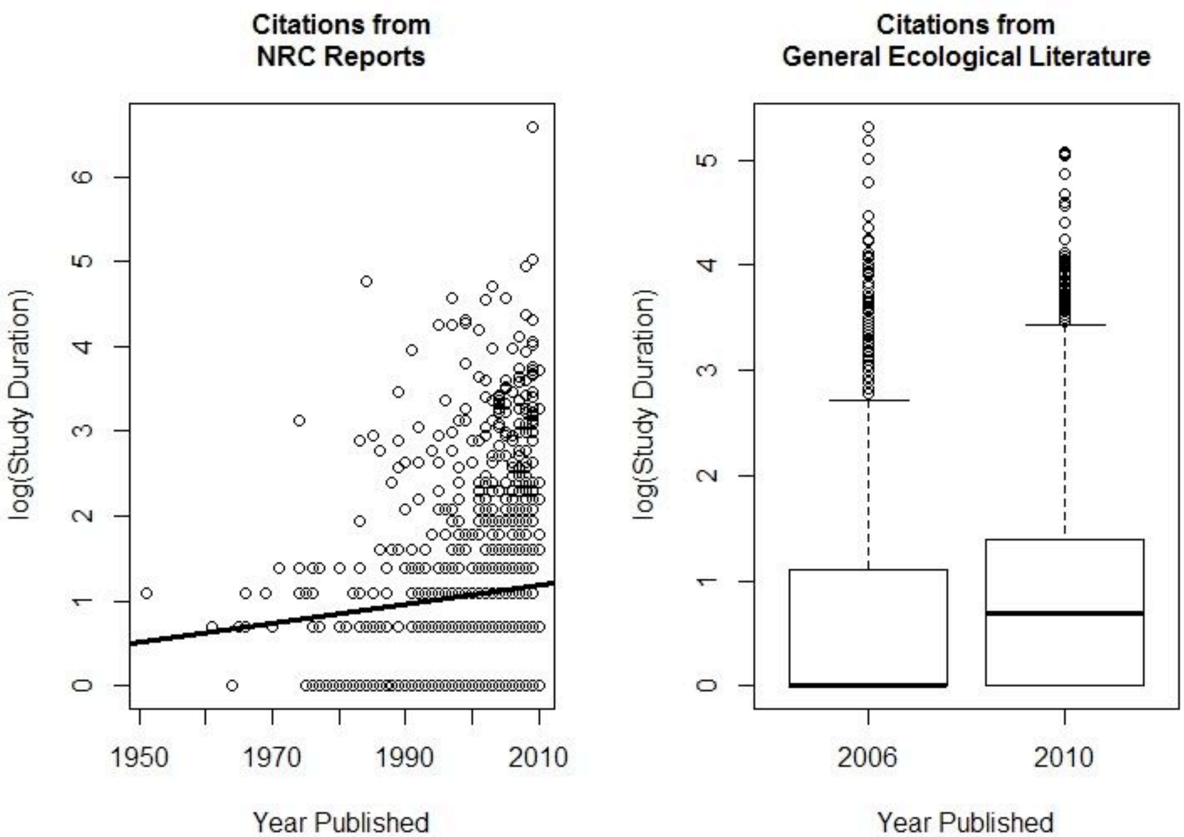


Figure s5. Relationship between year of publication and log-transformed study durations for citations from NRC reports (left) and the general ecological literature (15 journals; right). In both cases, study duration increased over time.

NRC author survey methods

The survey of NRC report authors was conducted with the approval of the Oregon State University Institutional Review Board (IRB) for inclusion of human subjects (IRB #5882).

Participants

The survey population was comprised of all authors for each of the 44 NRC reports that were analyzed in the NRC reference analysis. Names and email addresses of authors were obtained from publicly available data on the NRC website and through internet searches. The 480 resulting authors were emailed a link to the survey, which was hosted using the Qualtrics survey software (http://www.qualtrics.com/). Survey participants were given two months to complete the survey. All 114 respondents (23.75 % response rate) remained anonymous, and any identifying information was kept independent from responses.

Survey Questions

The survey first asked each report author to identify her/his sector of work (i.e., government, academia, non-governmental organization, and industry), field(s) of expertise, and the NRC report authored. Authors were then asked a series of question to determine: (1) the opinion of NRC authors on the value of long-term ecological research, and its contribution to scientific knowledge and policy decisions, (2) the importance of studies of different durations for the conclusions of the NRC report, (3) the importance of study duration in determining why a study was included, and (4) the difference in citation frequency of studies of different durations between ecologists and non-ecologists (see supplementary materials table s4). Note that while NRC report authors were asked questions regarding the "duration" of cited studies, we did not explicitly define duration in the survey questions. The strong correlation between span and duration as defined in our NRC citation analyses indicates the feasibility of comparisons between the literature citation duration analyses and survey results (supplementary materials figure s6).

Survey Analysis

We asked two types of questions, Likert-scale and rank-style, each requiring a different statistical analysis. Likert-scale questions asked respondents to choose the degree to which they agreed with a statement, or the degree to which they thought the statement was important. Respondents could choose one of five options: Strongly Agree (Very important), Agree (Important), Neither Agree nor Disagree (Neither Important or Unimportant), Disagree (Unimportant) or Strongly Disagree (Very Unimportant).

Likert-scale questions were analyzed using a non-parametric Wilcoxon signed rank test on the distribution of ranked answers where strongly agree = 1, agree = 0.5, neither agree nor disagree = 0, disagree = -0.5, and strongly disagree = -1. Our null hypothesis was that the mean rank was not statistically different from 0.

For rank-style questions, respondents were asked to order given statements from most to least important, or from most to least frequently cited. Rank-style questions were analyzed using non-parametric Wilcoxon signed rank test to assess whether studies of a given duration were ranked as "most important" (rank of first) more frequently than expected under the null hypothesis that the chance of any one of the statements being ranked as the most important (most frequently cited) was equal. With four options to rank, the probability of each statement being ranked as most important was thus 1 to 4. We then used the Wilcoxon non-parametric comparison test to determine significant differences between pairs of study duration. Finally, we compared differences in responses for each study duration category using a two-sample Wilcoxon rank sum test. Statistical analyses were performed using JMP (v. 12; SAS, U.K.).

Table s4. Comprehensive list of questions asked to survey participants, and the responses they had to choose from.

Question	**Response Options**
1. In total, on how many NRC report committees have you sat as a member or chair?	1, 2-3, 4+
2. Which of the following most closely describes your profession at the time you were an NRC report committee member or chair?	Agency scientist / resource management scientist; Environmental professional; Industry professional; Professor / academic researcher; Public policy or government official; Other (please specify) ___________
3. Which of the following describes your field(s) of expertise? (check all that apply)	Agriculture Food and Renewable Resources; Anthropology; Atmospheric and Hydrospheric Sciences; Biology; Chemistry; Education; Engineering; Geology and Geography; Mathematics; Medical Sciences; Natural Resources; Physics; Psychology; Social, Economic, and Political Sciences; Statistics
3.5. [Note: this question only appears if “Biology” is selected in Question 3.] Within the field of biology, which of the following describes your field(s) of expertise? (check all that apply)	Ecology; Evolution; Molecular Biology; Physiology
4. What was the most recent NRC report for which you served as committee member or chair? Please select the year and then the report title.	Year: 2009, 2010
5. Did the NRC committee on which you served include anyone with expertise in ecology?	Yes; No
6. Did you cite ecology-related references in your NRC report?	Yes; No; I don't know

[Note: If "No" or "I don't know" is selected, then the respondent is taken to Question 13.]	
7. How important was each factor for citing an ecology reference in your NRC report? Factors: Study authors Journal prestige/ impact factor Temporal extent of study Spatial extent of study Publication date Location of study Study conclusions	Very Unimportant; Somewhat Unimportant; Neither Important nor Unimportant; Somewhat Important; Very Important; Unable to Rate
8. For the same factors, how important was each factor for citing an ecology reference in your NRC report? Drag and drop the options in the order of their importance. (top = most important, bottom = least important)	Factors: Study authors; Journal prestige/ impact factor; Temporal extent of study; Spatial extent of study; Publication date; Location of study; Study conclusions
9. Of the ecology references, how important were studies of the following durations to the conclusions or recommendations of your report? Drag and drop the options in the order of their importance. (top = most important, bottom = least important)	Citation Frequency: 1 year or less; 2-5 years; 6-10 years; 10+ years
10. Of the ecology references, how often did you cite studies that included each of the following study types? Study Types: Theoretical, modeling Empirical, with primary data Review Meta-analysis	Never; Infrequently; Frequently; Always; Unable to Rate
11a. Of the ecology references, how often did you cite studies of the following durations?	Citation Frequency: 1 year or less; 2-5 years; 6-10 years; 10+

Drag and drop the options in the order of their frequency. (top = most frequent, bottom = least frequent)	years
11b. [Note: this question only appears if 6-10 years and 10+ years are ranked 3rd frequent in Question 11.] How would you best explain why you cited 6-10 and 10+ year studies least often?	We found that studies of 6+ years were less relevant to the topic of the NRC report. We found that studies of 6+ years were not as common in the literature as shorter-term studies. We were less familiar with studies that have a duration of 6+ years. We did not consider study duration in reference selection. Other (please specify) : ____________
12. To what level do you agree or disagree with the following statements? Statements: Our NRC committee was more inclined to cite a study if it used a long-term data set (6+ years). Our NRC committee was more inclined to cite a study if it used a short-term data set.	Strongly Disagree; Disagree; Neither Agree nor Disagree; Agree; Strongly Agree
13. To what level do you agree or disagree with the following statement? Long-term ecological data sets provide information that short-term studies cannot provide.	Strongly Disagree; Disagree; Neither Agree nor Disagree; Agree; Strongly Agree
14. To what level do you agree or disagree with the following statement? Long-term ecological data are important for informing policy.	Strongly Disagree; Disagree; Neither Agree nor Disagree; Agree; Strongly Agree
15. Please enter any other comments you'd	

like to share with us about ecology-related references in NRC reports.	

NRC author survey results

Table s5. Reasons why survey respondents did not rank studies of longer durations (10+ years or 6-10 years) as frequently cited (question 11b). The total number of respondents is 18. Survey respondents were only directed to question 11b if they ranked studies of 6-10 years and 10+ years as the least frequently cited (3rd or 4th place ranking).

Reason given for infrequent citation	***Number of respondents***	***Percentage of respondents***
We found that studies of 6+ years were less relevant to the topic of the NRC report.	2	11.1%
We found that studies of 6+ years were not as common in the literature as shorter-term studies.	10	55.6%
We were less familiar with studies that have a duration of 6+ years.	0	0.0%
We did not consider study duration in reference selection.	5	27.8%
Other	1	5.5%

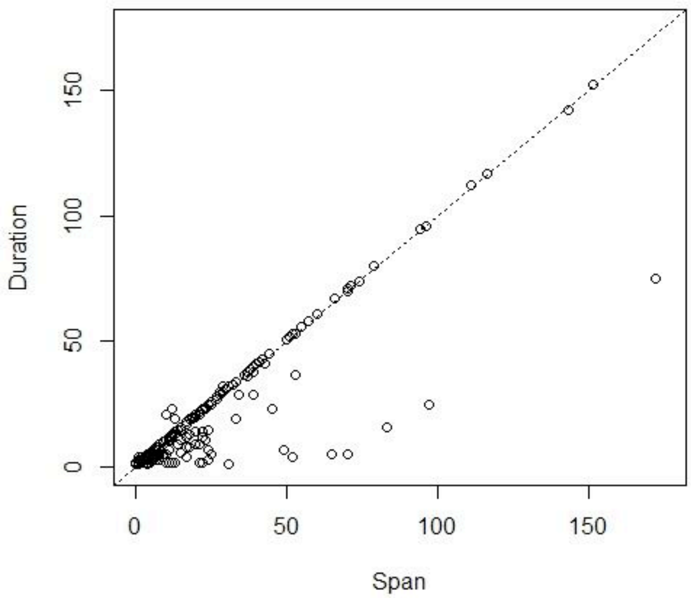
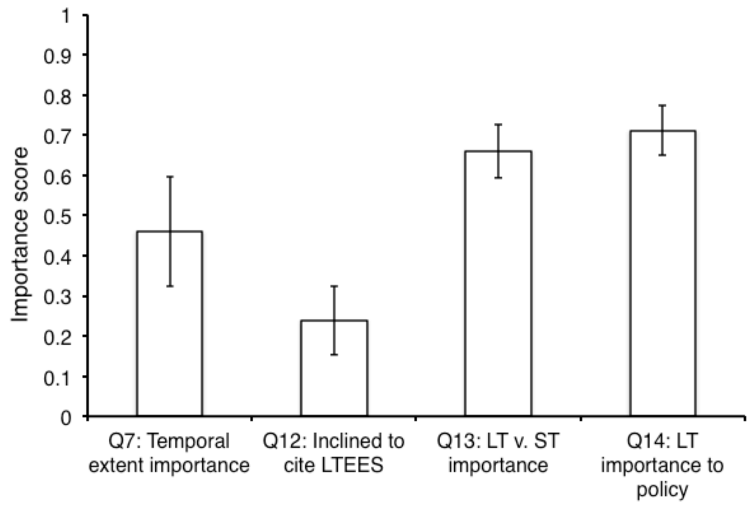


Figure s6. Relationship between span (study end year - study start year) and duration (number of years of "effort"; see methods) of all ecological studies cited in the reviewed NRC reports. Dotted line is the 1:1 ratio of span to duration. Pearson's correlation coefficient for this relationship, r = 0.9174.

a



b

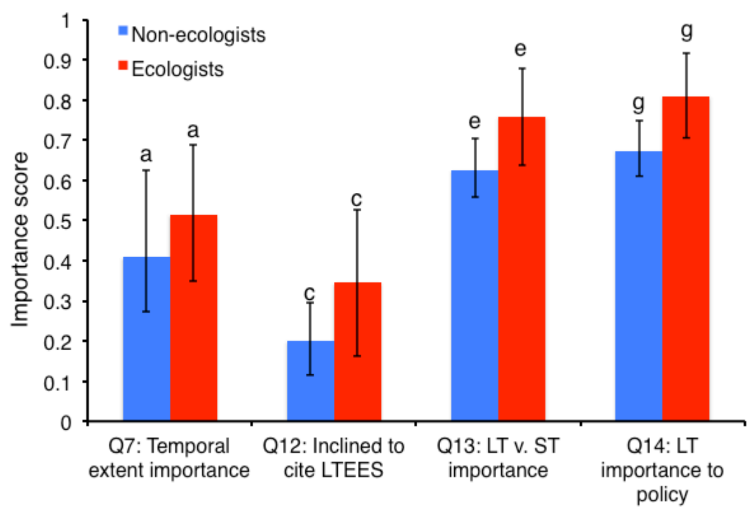


Figure s7. Results from survey of authors of NRC reports asking the overall importance from several survey questions (supplementary materials table s5) for both a) pooled respondents and b) testing for the difference in responses between non-ecologists v. ecologists. Importance scores range from -1 to 1 with positive values reflecting greater agreement for the importance of LTEES. Likert-scale questions were analyzed using a non-parametric Wilcoxon signed rank test on the distribution of ranked answers. The mean was compared to the null hypothesis (null = 0) for a) and b). Differences in lettering for b) indicate significant differences ($P < 0.05$) from paired comparisons between non-ecologists and ecologists for each question, using a Wilcoxon/Kriskal-Wallis test, P-values for questions 7, 12, 13, 14 were 0.81, 0.06, 0.08, and 0.06, respectively. Error bars are 95% CI.

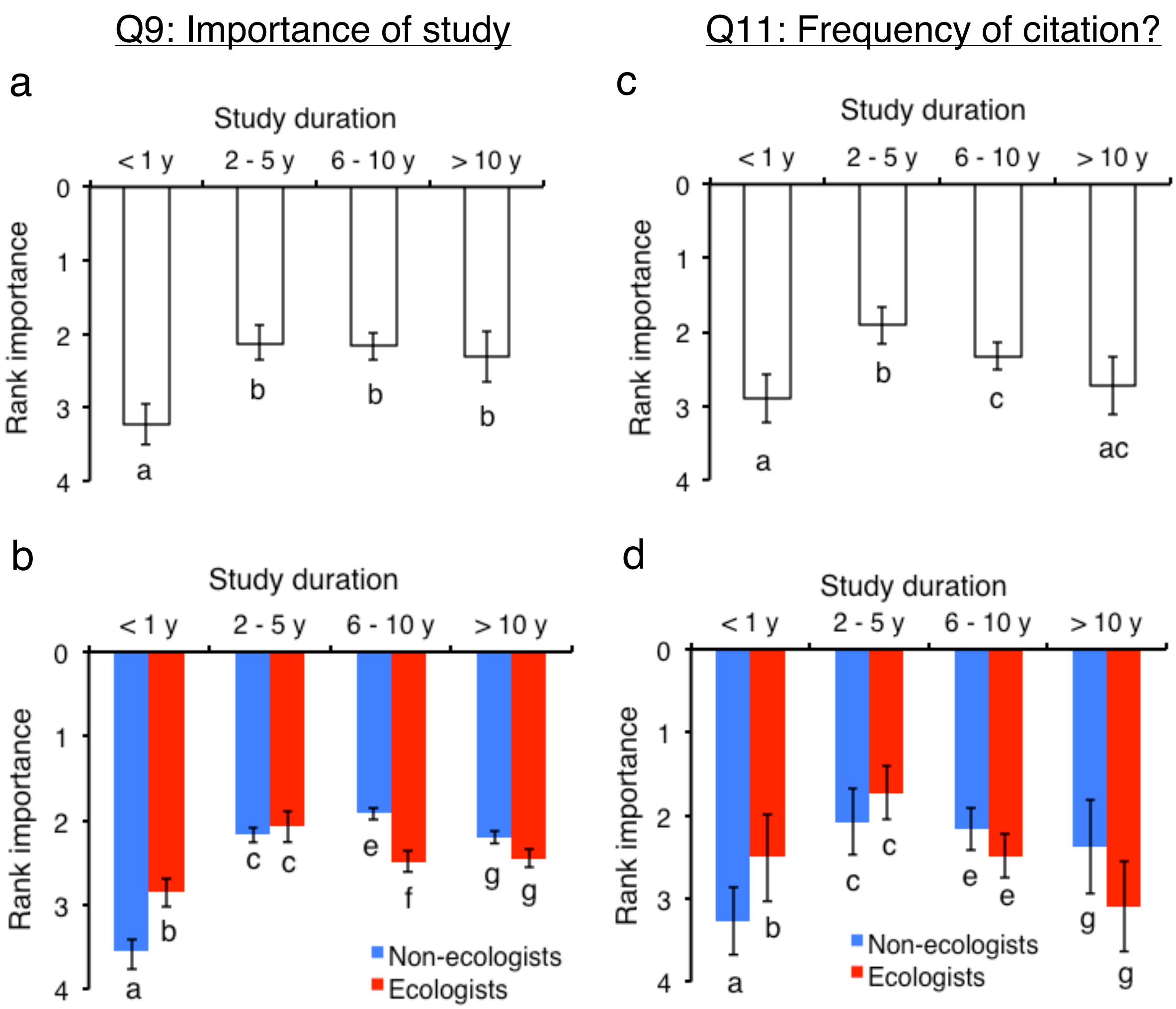


Figure s8. Results from survey of authors of NRC reports asking the rank importance (1 = very important to 4 = not important) for survey questions 9 and 11 (supplementary materials table s3) for both a) and c) pooled respondents, and b) and d) testing for the difference in responses between non-ecologists v. ecologists. Responses (ranks) were analyzed using a Wilcoxon/Kriskal-Wallis test. Differences in lettering indicate significant differences from paired comparisons ($P < 0.05$). For b) and d), differences in lettering compared the difference in response between non-ecologists and ecologists for each study duration category. Error bars are 95% CI.

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