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Aligning evidence generation and use across health, development, and environment

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Although health, development, and environment challenges are interconnected, evidence remains fractured across sectors due to methodological and conceptual differences in research and practice. Aligned methods are needed to support Sustainable Development Goal advances and similar agendas. The Bridge Collaborative, an emergent research-practice collaboration, presents principles and recommendations that help harmonize methods for evidence generation and use. Recommendations were generated in the context of designing and evaluating evidence of impact for interventions related to five global challenges (stabilizing the global climate, making food production sustainable, decreasing air pollution and respiratory disease, improving sanitation and water security, and solving hunger and malnutrition) and serve as a starting point for further iteration and testing in a broader set of contexts and disciplines. We adopted six principles and emphasize three methodological recommendations: (1) creation of compatible results chains, (2) consideration of all relevant types of evidence, and (3) evaluation of strength of evidence using a unified rubric. We provide detailed suggestions for how these recommendations can be applied in practice, streamlining efforts to apply multi-objective approaches and/or synthesize evidence in multidisciplinary or transdisciplinary teams. These recommendations advance the necessary process of reconciling existing evidence standards in health, development, and environment, and initiate a common basis for integrated evidence generation and use in research, practice, and policy design.

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Introduction

Numerous studies have shown the strong links among health, development, and environmental sustainability [e.g. 1•,2•]. Overlooking these links in research and management can lead to negative unintended consequences [3–7]; as well as missed synergies and a limited view of viable interventions to address a challenge [8•,9]. In response to increased awareness of these linkages and the perils of ignoring them, intergovernmental commitments (e.g. Sustainable Development Goals (SDGs), Paris climate agreement) [10•] increasingly recognize the fundamental importance of accounting for feedbacks and linkages among these sectors. Many efforts have called for integration [e.g. 1•,2•,8•,9,10•], yet agendas are dominated by narrowly defined goals [11], funding remains highly sector-specific [12], technical expertise and networks are largely isolated [9,13], professional incentives focus on in-sector advancement, and the training and evidence bases underpinning research advances, policies, and actions remain fragmented [14].

Here, we focus on describing and removing some barriers that reinforce a fragmented evidence base, stymieing joint research and action planning across the health, development, and environment sectors [2•]. Each sector already approaches problems by conducting evidence-based research, design, and planning. As the complexity of global challenges (such as climate change, large-scale human migration, food and water insecurity, air and water pollution, urbanization, desertification, and emerging infectious diseases) increases, multidisciplinary and transdisciplinary approaches expand and many relevant frameworks and methods have emerged (e.g. network analysis [15]; system integration [16]; ecosystem services [17]; planetary health [2•]; one health [18]; nexus approaches [19]; multi-objective planning [20], analysis [21] and decision-making [22]; and socio-ecological action situations [23]). However, their practical use by individuals or teams continues to be hampered by the fractured evidence available and the varying and sometimes conflicting methods used by different disciplines.

The kinds of multidisciplinary and transdisciplinary collaborations needed to solve today's global challenges [24] require time to align on terms, methods and standards before work can proceed. This need for alignment can slow progress and limit adoption of existing approaches [24]. In an effort to streamline alignment of methods and provide a practical starting point for further iteration, we present a set of principles and methodological recommendations for evidence generation and use across health, development, and environment sectors. We draw from review of the recent literature and consensus of a diverse set of experts from relevant disciplinary and practice backgrounds (see Supplementary material, Table S1). Our recommendations address three common methodological barriers to evidence use; (1) inconsistent design of logic models when developing or assessing interventions; (2) disagreement about admissible evidence for evaluating confidence; and (3) different standards for what constitutes high confidence in a given set of evidence for assessing intervention impacts. Each is described further below.

The first set of methodological challenges we address relates to understanding how an intervention is likely to contribute to change(s) in a system [25]. Within typical research and planning processes, the health, development, and environment sectors each employ some form of logical framework to explore the impacts of system changes or interventions. Frameworks can take the form of logic models, log frames, theories of change, or results chains in development [e.g. 26] and health evaluations [e.g. 27], a subset of social, physical or biological network models addressing causal interactions [e.g. 15], and mental models, results chains or means-ends diagrams in environmental planning and research [e.g. 28,29]. Here, we use the term 'results chain' for all logical frameworks that visually represent the causal logic of how interventions lead to consequences (positive and negative) through a series of expected changes [20,28].

There is an increasing emphasis on including and representing feedbacks and interactions within a system in results chains [30] and depicted causal relationships can be further expanded or translated into mathematical models (e.g. Bayesian network models, earth system models, or many other types). Relationships within models can be quantified with data drawn from an increasingly wide range of sources (e.g. survey data, direct observations, smart sensors, remote-sensing drones, satellites, big data processed by computer algorithms, etc. [31–35]).

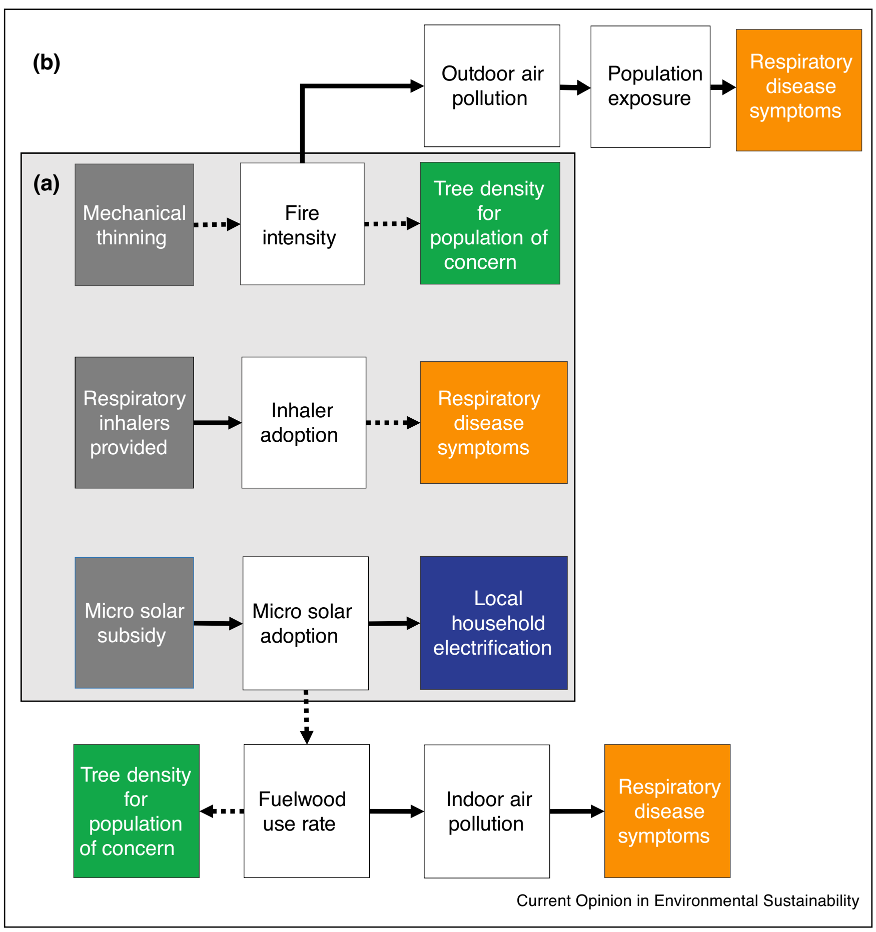
While results chains of some form are used by health, development, and environment sectors, methodological challenges and variations limit their effective use for cross-sector problems. The creation of results chains from single sector entry points can fail to identify negative unintended consequences that pose risks to project success or to other aspects of the system. Cases of unintended impacts from one sector on another are abundant. For example, expansion of biofuels to reduce fossil fuel use and stabilize the global climate can cause local food insecurity [3]. In other examples, nature conservation intended to save biodiversity can unintentionally worsen inequalities in local communities by reducing access to land or resources [4] or by driving inconsistent access to markets or resources [5]. Economic development programs aimed at improving irrigation can increase water depletion, environmental damage, and agricultural risk in some cases [6] and can increase malaria risk in others [7].

In addition, single sector results chains can overlook positive unintended consequences and synergies (also called co-benefits), leading to conservative expectations about total system impacts, miscalculation of total return in investment, and missed opportunities for implementation with other sectors [8•,9]. For example, reproductive health and conservation programs can have greater impacts on both health and the environment when implemented together compared to the same programs implemented in parallel [8•]. When research or practitioner groups do expand on single sector results chains, lack of knowledge can lead to generic representations of causal pathways and impacts (e.g. a conservation intervention leading directly to 'community resilience' or a development intervention leading to a 'healthier environment').

Planning for and evaluating interventions from a single sector perspective also leads to a myopic view of solutions, resulting in overlooked interventions and misinterpretations of what the most effective solution may be. For example, a hypothetical case of environment, development, and health results chains constructed for single-sector outcomes (Figure 1a) shows how this view can overlook the potential for the environment and development interventions to deliver on health benefits (Figure 1b). If sectors used consistent methods to create results chains, a systems view could more readily be taken, revealing both positive and negative unintended consequences in other sectors and identifying the full set of viable candidate interventions.

A second set of methodological challenge relates to differences in the types of evidence considered admissible for determining confidence in potential impacts. Results chains are commonly used as a basis for structured synthesis of evidence to evaluate the confidence in intervention effectiveness [20,26]. To improve consistency, sectors support efforts to standardize the interpretation of evidence within their own community so that researchers, practitioners, and policy makers can work from a consistent understanding (e.g. Cochrane, Campbell Collaboration, 3ie, Conservation Evidence, Environmental Evidence). Nascent efforts (e.g. Evidence Synthesis International,

Figure 1



Simplified single-sector **(a)** and cross-sector **(b)** views of three interventions.
Typical results chains, such as the highly simplified, hypothetical chains in (a), relate interventions (grey nodes) to expected sector-specific impacts on the environment (green node), development (blue node) or health (orange node). By expanding the view across sectors (b), results chains can help identify a broader set of solutions and a more complete understanding of consequences. Solid arrows represent positive relationships, dotted arrows represent negative relationships.

Global Evidence Synthesis Initiative) are emerging to more fully align existing evidence standards across sectors, but major challenges remain in harmonizing methods.

First, there are different views among (and sometimes within) disciplines on the types of information that are admissible as evidence for this use. For example, the health sector relies on a specific set of methods to inform the evidence base on interventions or treatments, with large, randomized controlled trials serving as the gold standard [36,37•]. Views in the medical field are expanding. For example, Cochrane Reviews now allow inclusion of non-randomized studies and other forms of quantitative studies, economic data, qualitative studies, and equity considerations [36], while methods for additional evidence types are under development. Large, randomized trials are often not feasible, nor sensible in the environment sector; hence alternative forms of evidence are commonly used [38•]. Economic and social development researchers hold diverse views, some aligning closely with health communities in pursuing experimental or quasi-experimental methods, while others adopt case studies, mixed and comparative methods, mathematical models, triangulation and causal mechanisms as viable evidence forms [39].

As each sector or discipline follows its own standards, different subsets of evidence are admitted for analyses, possibly leading to different levels of confidence in the same intervention. For example, consider forest fuel management (such as thinning and debris removal) as an intervention for reducing fires, smoke exposure and respiratory disease risk. Available evidence on effectiveness of this intervention consists of several large-scale pseudo-experiments and models [e.g. 40,41]. Some ecologists would readily admit this evidence, while some health experts would not, leading to evaluations of different subsets of evidence, and likely inconsistent conclusions.

Within these same standards, we find the third major methodological barrier we address; differences in how to assess the strength of admitted evidence. Evaluations of the strength of evidence are commonly done to create confidence statements, which can inform decisions about whether and how to proceed with an intervention. For example, if there is low confidence in a link in a chain (Figure 2) that is high risk and/or of importance to stakeholders, decision makers may choose not to go ahead with an action, identify additional interventions, modify the investment to mitigate risks, or invest in monitoring and evaluation to increase understanding. Many methods for establishing confidence statements have been advanced, some through standard setting bodies (e.g. GRADE [42], IPCS/WHO [43]). Efforts in the environment sector have been more diffuse (e.g. [44], IPCC [45•], IPBES [46], US National Climate Assessment [47]), and there is no accepted evidence standard-setting body.

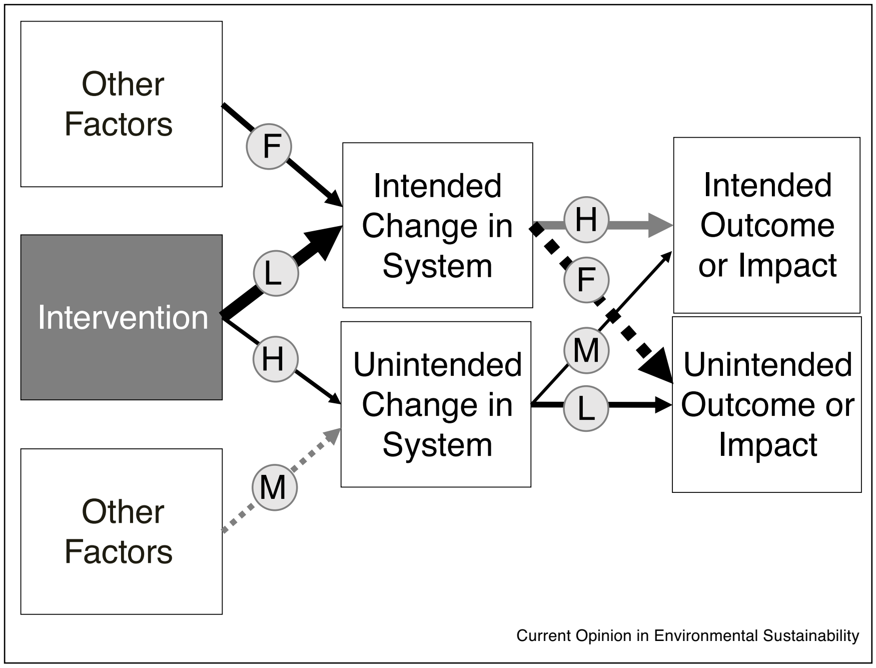
Differences in standards and lack of consensus make it challenging to use any one existing method for confidence statements when evidence is used from multiple sectors. Some methods are set up for multi-disciplinary application (like IPCC, IPBES, US NCA), but each is built for purpose rather than working from a consistent set of methods or assumptions. This can make their use incompatible across disciplines. For example, the IPCC and the International Agency for Research on Cancer rubrics have made some cross-sector considerations, but treat theory differently as a type of evidence [48]. Bespoke standards also limit the comparison of trends over time or the comparison of interventions across sectors (e.g. each topical IPBES report creates its own confidence statement method).

An emergent research-practice collaboration, called the Bridge Collaborative, was created and joined by the authors of this paper to address some of the noted challenges in evidence use across sectors. As we sought to find consensus across disciplines and streamline the alignment process for future efforts, three aspects of the Bridge Collaborative process made the findings here novel: (1) the breadth of global challenges, sectors and disciplinary perspectives included; (2) the focus on consensus across this broad range of disciplines and challenges rather than synthesis or discussion of differences; and (3) the use of iteration between specific challenges and generalizable agreements.

Through a rapid, iterative process, over 100 experts from 80 research, practice, private sector and multilateral organizations engaged in six multi-sector working groups. Collaborative members lead or engage in many existing networks and cross-sector efforts (e.g. Locus; Scaling up Nutrition; Agriculture-Nutrition Community of Practice (Ag2Nut); One Health; EAT; Future Earth; Global Evidence Synthesis Initiative; Planetary Health Alliance; Cochrane; Conservation Evidence; Food, Energy, Environment, and Water Network; CGIAR Agriculture for Nutrition and Health; CGIAR Water, Land, and Ecosystems; USAID's BRIDGE Project; others), providing an opportunity for groups to learn from, find generalities among, and amplify these initiatives.

The process focused on reaching consensus around methods that are relevant to a wide range of global challenges and acceptable across disciplines and sectors. The group did not focus on synthesis and summary but rather on agreement, elevating principles and methods that all participants endorsed from their various perspectives. Past efforts to find such consensus typically focused on a single challenge (e.g. climate change, food security), rather than looking broadly across a diverse set of global challenges. Working group foci included: stabilize the global climate; make food production sustainable; decrease air pollution and respiratory disease; improve

Figure 2



Generalized results chain constructed using recommendations for compatible results chains and evidence evaluation.
Arrows reflect an increase (solid arrow) or decrease (dotted arrow) in the endpoint node, arrow weight indicates effect size (thicker arrows show larger effect sizes, thinner arrows show weaker effect sizes), and arrow color indicates time scale of change (black arrows change quickly, grey arrows change slowly). Additional graphical symbols can be added to reflect the confidence in the assumption underlying an arrow given available evidence evaluated using the unified rubric. Confidence can be high (H), moderate (M), fair (F) or low (L).

sanitation and water security; and solve hunger and malnutrition (two groups).

The nine-month consensus process started with a workshop attended by the co-leads of all six working groups and the Bridge Collaborative Secretariat. Each working group then progressed independently to review recent relevant disciplinary literature and draw from their own experiences to generate recommendations for principles and methodological solutions. The six initial sets of recommendations were compiled and synthesized by the Bridge Collaborative Secretariat and used as the basis for discussions in an in-person meeting of all working group co-leads. Live line editing continued until consensus was reached on all recommendations. Additional feedback was incorporated from a round of review by all contributing authors, and a second round of review from working group co-leads. The process allowed for effective iteration between topical working group foci that grounded thinking in practical challenges and the creation of generalized recommendations that tested the applicability of suggestions across contexts and disciplines.

Although our framing and participants were diverse (see Supplementary material, Table S1), they were not representative of all disciplines, sectors or relevant challenges. We present the following principles and recommendations as a starting point for further iteration and testing in a broader set of contexts and disciplines.

Principles for effective cross-sector collaboration

Methodological solutions to the challenges reviewed above are likely to emerge from and be applied through some form of cross-sector collaboration. The Bridge Collaborative, as one such collaboration, adopted and reinforced six principles that were deemed valuable for advancing cross-sector interactions around evidence use [9]. These principles may aid transdisciplinary and cross-sector groups applying the methodological recommendations that follow.

Use evidence to inform decisions

The health, development, and environment sectors have long recognized the benefits of evidence-based decision making [49,50].

Act now and learn by doing

We acknowledge that intentional learning by doing can improve actions and impact even while there is incomplete understanding, evidence, or political or social alignment. This principle forms the basis of adaptive management, evidence-based management, and action research approaches championed extensively by the environment [51], development and health fields [52]. These approaches all emphasize the need to plan for learning, as it is not guaranteed to happen on its own.

Seek and respect other perspectives
Many barriers to multi-sectoral action will be reduced over time by adoption of the principle that goals in one sector may be met more effectively, efficiently or sustainably by embracing ideas, interventions, methods, or concepts from other sectors [12,14]. Preliminary experiences of the Bridge Collaborative suggest that even brief (<1 day) opportunities for people with expertise and experiences from different sectors to problem solve together can lead to rapid transformation in problem framing, strategic planning, and evidence use.

Be intentional about inclusion
The value of inclusion of people from diverse backgrounds (disciplinary, geographic, race, culture, gender, age, etc.) and information from diverse sectors and sources has been shown in many fields. Guidance and tools for increasing inclusion are well established for use within health, development, and environment sectors [e.g. 53,54]. Existing guidance may be equally useful in cross-sector engagements.

Strive to do no harm
Cross-sectoral efforts that fail to prevent or mitigate negative outcomes for other sectors, groups, or future generations are likely to be short-lived and ineffective at balancing multiple objectives. Tools and methods for identifying tradeoffs and synergies are available [55] and could be applied more widely. When negative impacts or inequitable outcomes are expected, they should be avoided or reduced and assistance should be provided to those who are harmed [55–57].

Share information openly and transparently
Lack of openness and transparency across sectors may lead to mistrust, misunderstandings, increased transaction costs, inefficiency, overlooked options, and short-lived partnerships [58]. We encourage all to share data, frameworks, concepts and software quickly, openly, and transparently (respecting anonymity, privacy, and security concerns), and to recognize, articulate, and challenge barriers to doing so.

Methodological recommendations for cross-sector evidence use
The Bridge Collaborative made methodological recommendations to advance three key challenges in the detailed practice of using evidence from multiple disciplines in intervention design: (1) create more compatible results chains; (2) agree on admissible evidence; and (3) use a consistent standard for confidence statements. These recommendations focus on removing remaining barriers to the use of evidence across multiple disciplines and challenges.

Creation of compatible results chains
While general guidance for use of results chains is abundant, it varies across and within sectors, often creating confusing or conflicting starting points for teams applying multi-objective methods or taking a multidisciplinary or transdisciplinary approach [20,26–28,59]. To streamline the use of evidence across sectors, we generated eight recommendations for harmonizing methods and improving the cross-sectoral compatibility of results chains (Box 1). In their simplest form, these recommendations suggest that results chains should be made up of nodes that represent drivers (including interventions), mediators or outcomes (intermediate or final), and arrows that represent hypothesized causal relationships (Figure 2). This aligns with some recommendations [e.g. 20,26] but differs from others that are more specialized for particular disciplinary uses (for example, directed acyclic graphs in epidemiology [60]).

While the recommendations may seem basic, the authors considered each one important to create enough consistency for comparison and integration across sectors, or to surface and address challenges that commonly arise when extending results chains from single-sector to cross-sector applications. For example, time scales of impacts may vary dramatically across sectors and commonly result in some unintended consequences (e.g. longer term environmental or equity impacts are commonly overlooked for nearer term development or health gains). As such, time scales should be represented when possible (Box 1, Recommendation 3). These temporal trade-offs can be demonstrated through the example of promoting women's husbandry of animals with lower environmental footprints (e.g. chickens instead of goats or cattle) that may have short-term effects on children's growth rates and other nutritional outcomes and longer-term impacts

Box 1 Guidance for compatible results chains

1 Arrows point from cause to effect for each link.
2 Arrows can graphically represent effect size and/or whether effect is positive or negative.
3 Arrows can graphically reflect expected time scale of change.
4 Each arrow reflects only one hypothesized and testable causal relationship.
5 Nodes capture drivers and/or consequences.
6 Nodes do not capture the direction of change, but arrows can (see #2).
7 Nodes do not represent actors, stakeholders, or context without being associated with a driver or consequence.
8 Impacts included in the chain are measurable or observable.

on income resiliency, women's empowerment, education attainment, and environmental conditions.

Several results chain recommendations support a consistent and useful level of sensitivity and specificity across sectors, helping to avoid the use of vague concepts such as 'human well-being', 'community resilience', or 'wildlife'. While useful to understand general connections, these terms are not sufficiently precise to guide hypothesis development, intervention selection, or metric development. We recommend avoiding these generalities by creating links in a chain that reflect only one hypothesized and testable causal relationship (Recommendation 4). In some instances, it may be useful to construct chains with links that do reflect more than one expected causal relationship when complexity underlying the link is expressed elsewhere (e.g. in a complex, dynamic model), evidence for specific links has been explored and found to be lacking, or when it is necessary to simplify for larger scale considerations or communication with stakeholders. We further recommend that nodes only reflect specific groups of people or elements of context if they are specified as a driver or consequence (Recommendation 7), and that posited impacts be measurable or observable (Recommendation 8). For example, an initial vague idea that conservation may impact 'local communities' on further probing may reveal that the expected impact is on gender equity in assets in local communities or diversity of food sources in local communities. The latter are much more specific and measurable elements. Graphical inclusion of all suggested types of information (Figure 2) may be more confusing than clarifying in some contexts. The intent of these recommendations is to spur thinking about critical elements for consideration and to encourage researchers and practitioners to explore and document each of these elements as useful.

Applying these recommendations would lead to the production of results chains able to consistently represent interventions and potentially quantify impacts for multiple sectors (Figure 2). Beyond the simplified, hypothetical examples provided here, the recommendations have been used to create results chains for more complex contexts with feedbacks and interactions that include; pesticide taxes and habitat subsidies as alternative interventions in sustainable agriculture [25], solar energy installation on public lands [25,61], oyster reef restoration investments in the Gulf of Mexico [62], and salt marsh habitat restoration [63]. These applications provide some suggestion that the recommendations are relevant to a broader set of challenges. The generalizability of these recommendations will be further improved through continued testing and iteration.

Admissible evidence: what can be included?

Once results chains are created, one can determine the strength of confidence in causal pathways and potential impacts. The first step in creating confidence statements is to determine what qualifies as admissible evidence. Recognizing the need for inclusive, cross-sector problem solving, we recommend drawing on all relevant types of evidence from involved sectors. We consider admissible evidence to include quantitative studies, qualitative studies, theory, model results, expert, and tacit knowledge (including local knowledge, traditional knowledge, subject matter expertise), and measurement results. Though some advocate for a more narrow definition of evidence, other groups support a similarly broad definition [44,64–66].

Ensuring coverage of all relevant and available evidence will require inclusion of perspectives from multiple disciplines, sectors, and sources. Relevant guidance exists for including local and traditional knowledge in climate change initiatives [67], health and economic or social development approaches [e.g. 68], and conservation assessments [e.g. 69]. Searches for evidence may be broadened by looking across multiple language sources as well as expanding keyword lists and expert and local networks.

Strength of evidence: what creates high confidence?

The second step in creating confidence statements is to assess the strength of admitted evidence. To address inconsistencies in this step across sectors, we recommend assessing confidence (Figure 2) by applying a common and consistent rubric (Table 1). Here we provide a rubric with confidence criteria that draw from multiple existing frameworks (e.g. [45•], IPCC [49], IPBES [46], US National Climate Assessment [47], GRADE [49], IPCS/WHO [43]), and were agreeable to Bridge Collaborative members spanning the health, development and environment sectors (Table 1). In this rubric, confidence is based on the diversity of types of evidence, consistency of results across evidence, status of methods used to generate evidence, and applicability of available evidence to the study context.

This rubric improves on some critiques of existing frames [43,70] but leaves others unaddressed [70]. One advance is to more clearly specify elements of high-quality evidence, here detailed as certainty of methods and applicability of evidence. In addition, our specification of confidence criteria may improve consistency of evidence interpretation by trans-disciplinary project teams and major assessment processes that do not have a standardized confidence rubric or alignment body (e.g. the environmental community, and environmental assessments such as those conducted by IPBES).

The proposed rubric includes four confidence levels (Table 1). High confidence can be stated when multiple types of evidence (e.g. randomized control trials, systematic reviews, model results, and qualitative focus group results) support a hypothesis, results are consistent across sources, types of evidence and contexts, methods used

Table 1

Evidence evaluation rubric. This rubric provides a consistent and acceptable set of criteria for identifying confidence in results chain links across health, development and environmental evidence. Types of evidence refers to the diversity of admissible evidence types found that address a hypothesis. We consider admissible evidence to include quantitative studies, qualitative studies, theory, model results, expert knowledge (including local knowledge, traditional knowledge, subject matter expertise), and measurement results. Consistency refers to the agreement across findings in a body of evidence, not the lack of variability in observed relationships. We define accepted methods as those that have been peer reviewed and broadly supported by a community of practice. Applicability refers to the similarity in ecological, social, political, cultural, temporal, spatial or economic context or other relevant conditions between those represented in the available evidence and those in the case to which the evidence is being applied

Confidence level	Criteria			
	Types of evidence	Consistency of results	Methods	Applicability
High	Multiple	AND consistent across sources, types of evidence and contexts	AND well documented and accepted	AND high
Moderate	Several	Some consistency	Not fully accepted, some documentation	Some
Fair	Few	Limited consistency	Emerging, limited documentation	Limited
Low	Limited, extrapolations	Inconsistent	Poor documentation or untested	Limited to none

across evidence types are well documented and accepted by the relevant field(s) and available evidence is highly applicable to the study or practice context.

Applicability is a critical consideration when relating a body of evidence to a specific case. We define applicability broadly as the similarity in ecological, social, political, cultural, economic, spatial or temporal context, or other relevant conditions between those represented in the available evidence and those in the case to which the evidence is being applied.

Any application of the rubric should be accompanied by a clear account of the evidence examined and interpretation of the criteria [70]. Moving beyond the conceptual example here (Figure 2), this rubric has been used to evaluate evidence for solar energy installation impacts on US public lands [61], and US salt marsh habitat restoration [73]. Further tests will identify transferability and opportunities for further improvement.

Applying the recommendations

These recommendations may improve the quality and consistency of results chains developed to address integrated challenges. In addition, our recommendations could be tested, applied and improved in the creation or expansion of generalized results chains. Some efforts exist to build generalized results chains with the intent to standardize understanding and provide broad access to robust syntheses of available knowledge (e.g. Open Standards for Conservation, The International Rescue Committee's Outcomes and Evidence Framework, Duke University GEMS Program). Our recommendations provide a common language that could aid in expanding these generalized results chains to include multiple sector impacts. Access to expanded chains could help researchers and practitioners realize new plausible interventions, highlight the types of impacts that may warrant further exploration, and help identify additional expertise that would be valuable to engage in research or planning efforts.

Application of these recommendations could also aid in metric development for multi-sector efforts. Integration can lead to a proliferation of metrics as lists from multiple disciplines or sectors are combined [e.g. 71,72], rather than strategically selected to reflect causal pathways or strong interactions. Some indices have been designed to address integrated challenges [e.g. 73,74], but choosing relevant indices, or using them effectively in specific contexts remains a challenge. Results chains constructed with harmonized methods can help identify which linkages are both critical and least understood (Figure 2), indicating strong candidate metrics for monitoring and evaluation. For example, beta testing of earlier versions of this guidance by The Nature Conservancy in Kenya helped identify intersecting results chains and supported metric selection for monitoring [75]. The conservation intervention there, herd management for sustainable grazing, requires more herders than traditional grazing, leading to increased employment which is also a local development objective. Similarly, the results chain work showed that improved local forage production for cattle may increase local supplies of milk and meat, possibly leading to improvements in nutrition, an objective of local health programs. The knowledge of these intersections helped stakeholders understand how their interests are connected and led them to choose a reduced set of metrics that still captured the core interests of all engaged sectors, making monitoring efforts more efficient. Finally, the results chain showed a possible unintended consequence, worsening the gender gap in incomes. The intervention improves market access for men (who manage cattle), but not for women (who manage sheep and goats). With this link revealed, the program increased efforts on women's livelihood development programs and added a metric on gender income distribution.

Conclusions

The interconnected nature of global challenges demands a major paradigm shift in strategies, methods, institutions, and norms to match the conceptual shift that is already underway [1•,2•,8•,9,10•,12–14]. We contribute to this shift by reinforcing principles and advancing three methodological recommendations that will aid cross-sector evidence use: (1) create of compatible results chains, (2) consider of all relevant types of evidence to evaluate strength of confidence, and (3) evaluate of the strength of confidence using a unified rubric. These recommendations were acceptable to a broad diversity of disciplinary perspectives, and found to be applicable to a wide range of global challenges. Our process and findings may aid in streamlining the necessary process to align standards and guidance among disciplines regarding evidence use.

Mis-alignment of methods is one barrier among many in this transition. Additional opportunities for advancement include the transformation of institutional incentives and structures to encourage cross-sector efforts [2•]. For example, innovation funds, altered professional incentives or dedicated positions for partnership building can encourage risk taking and exploration beyond traditional sector responsibilities (for example, see University of Washington Population Health Initiative). Expansion of evaluation methods by funders may open doors to further cross-sector exploration and impact (for example, the Global Environment Facility's Integrated Approach Pilots). Mechanisms like the Program-for-Results financing instrument being used by the World Bank and others may create productive opportunities for multi-sector problem solving. Focused, cross-sector funding efforts could also be aided by a common set of priorities highlighting which global challenges most need cross-sector solutions [12]. Alongside these needed opportunities, the principles and recommendations presented here advance a common language and methodology that can underpin research and practice and aid in the harmonization of evidence generation and use across health, development and environment disciplines.

Conflict of interest statement

Nothing declared.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cosust.2019.09.004.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest

1. • Díaz S, Settele J, Brondízio E *et al.*: *Summary for Policymakers Of The Global Assessment Report On Biodiversity And Ecosystem Services Of The Intergovernmental Science-Policy Platform On Biodiversity And Ecosystem Services*. 2019.

This paper synthesizes recent global trends in environmental change and connected human well-being.

2. • Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, Ezeh A, Frumkin H, Gong P, Head P *et al.*: **Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation-Lancet Commission on planetary health**. *The Lancet* 2015, **386**:1973-2028.

This paper summarizes connections between environmental degradation and human death and diseases, termed planetary health. This is the first major analytical paper establishing the linkages between environmental challenges and human health under the framework of planetary health.

3. Naylor RL, Higgins MM: **The rise in global biodiesel production: implications for food security**. *Glob Food Secur* 2018, **16**:75-84.
4. Doak DF, Bakker VJ, Goldstein BE, Hale B: **What is the future of conservation?** *Protecting The Wild*. Washington, DC: Island Press; 2015.
5. Unks RR, King EG, Nelson DR, Wachira NP, German LA: **Constraints, multiple stressors, and stratified adaptation: pastoralist livelihood vulnerability in a semi-arid wildlife conservation context in Central Kenya**. *Glob Environ Change* 2019, **54**:124-134.
6. Grafton RQ, Williams J, Perry CJ, Molle F, Ringler C, Steduto P, Udall B, Wheeler S, Wang D, Garrick D, Allen RG: **The paradox of irrigation efficiency**. *Science* 2018, **361**:748-750.
7. Audibert M: **Endemic diseases and agricultural productivity: challenges and policy response**. *J Afr Econ* 2010, **19**:iii110-iii165.
8. • Yavinsky RW, Lamere C, Patterson KP, Bremner J: **The impact of population, health and environment projects: a synthesis of the evidence**. *Population Council, The Evidence Project, Working Paper*. 2015. Washington, DC.

This paper synthesize the evidence on the added value of integrating population, health and environment interventions compared to the same programs implemented in a traditional sector approach. This is one of the most comprehensive reviews of added value from integration in the literature.

9. Petruney T: *Resource Package for Integrated Development*. Washington, DC: FHI 360; 2016.
10. • United Nations: *Transforming Our World: The 2030 Agenda For Sustainable Development*. . New York 2015.

This paper describes the global development agenda agreed to by the leaders of ~190 nations. It is the formal document establishing the Sustainable Development Goals.

11. Maxwell SL, Fuller RA, Brooks TM, Watson JE: **Biodiversity: the ravages of guns, nets and bulldozers**. *Nature* 2016, **536**:143-145.
12. Ebi KL, Semenza JC, Rocklov J: **Current medical research funding and frameworks are insufficient to address the health risks of global environmental change**. *Environ Health* 2016, **15**:108 http://dx.doi.org/10.1186/s12940-016-0183-3.
13. **New directions in the sociology of aging**. *National Research Council*. Washington, DC: The National Academies Press; 2013 http://dx.doi.org/10.17226/18508.
14. Brandt P: **A review of transdisciplinary research in sustainability science**. *Ecol Econ* 2013, **92**:1-5.
15. Borgatti SP, Mehra A, Brass DJ, Labianca G: **Network analysis in the social sciences**. *Science* 2009, **323**:892-895.
16. Liu J, Mooney H, Hull V, Davis SJ, Gaskell J, Hertel T, Lubchenco J, Seto KC, Gleick P, Kremen C, Li S: **Systems integration for global sustainability**. *Science* 2015, **347**:1258832.

17. Díaz S, Pascual U, Stenseke M, Martín-López B, Watson RT, Molnár Z, Hill R, Chan KM, Baste IA, Brauman KA, Polasky S: **Assessing nature's contributions to people**. *Science* 2018, **359**:270-272.

18. Zinsstag J, Schelling E, Waltner-Toews D, Whittaker M, Tanner M: *One Health: The Theory and Practice of Integrated Health Approaches*. CABI; 2015.

19. Liu J, Hull V, Godfray HC, Tilman D, Gleick P, Hoff H, Pahl-Wostl C, Xu Z, Chung MG, Sun J, Li S: **Nexus approaches to global sustainable development**. *Nat Sustain* 2018, **1**:466.

20. Fargione J, Baumgarten L, Cortez R, Game E, Grimm D, Higgins J, Leberer T, Masuda YJ, Morrison S, Palmer S, Tallis H: *Conservation by Design 2.0 Guidance Document*. Washington DC: The Nature Conservancy; 2016 https://www.conservationgateway.org/ConservationPlanning/cbd/Documents/CbD2.0_Guidance%20Doc_Version%201.pdf.

21. Simons NK, Weisser WW: **Agricultural intensification without biodiversity loss is possible in grassland landscapes**. *Nat Ecol Evol* 2017, **1**:1136.

22. Kumar A, Sah B, Singh AR, Deng Y, He X, Kumar P, Bansal RC: **A review of multi criteria decision making (MCDM) towards sustainable renewable energy development**. *Renew Sustain Energy Rev* 2017, **69**:596-609.

23. Schlüter M, Haider LJ, Lade SJ, Lindkvist E, Martin R, Orach K, Wijermans N, Folke C: **Capturing emergent phenomena in social-ecological systems: an analytical framework**. *Ecol Soc* 2019, **24**:11 http://dx.doi.org/10.5751/ES-11012-240311.

24. Brown RR, Deletic A, Wong TH: **Interdisciplinarity: how to catalyse collaboration**. *Nat News* 2015, **525**:315.

25. Tallis H, Kreis K, Olander L, Ringler C, Ameyaw D, Borsuk M, Fletschner D, Game E, Gilligan DO, Jeuland M *et al.*: *Bridge Collaborative Practitioner's Guide: Principles and Guidance for Cross-sector Action Planning and Evidence Evaluation*. Arlington: The Nature Conservancy; 2017 http://bridgecollaborativeglobal.org/wp-content/uploads/2018/02/Practitioners_Guide_Final_2.pdf.

26. *Using Logic Models to Bring Together Planning, Evaluation, and Action: Logic Model Development Guide*. WK Kellogg Foundation; 2004.

27. Boerma T, Abou-Zahr C, Bos E, Hansen P, Addai E, Low-Beer D: *Monitoring and Evaluation of Health Systems Strengthening*. Geneva: World Health Organization; 2009.

28. *Open Standards for The Practice of Conservation. Version 3.0*. Washington, DC: Conservation Measures Partnership; 2013.

29. *Federal Resource Management and Ecosystem Services Guidebook*. edn 2. Durham: National Ecosystem Services Partnership, Duke University; 2016 https://nespguidebook.com.

30. Hummelbrunner R: **Beyond logframe: critique, variations and alternatives**. *Beyond Logframe; Using Systems Concepts in Evaluation* 2010, **vol 1**.

31. Kitchin R: **Big data, new epistemologies and paradigm shifts**. *Big Data Soc* 2014, **1** 2053951714528481.

32. Newlands NK: *Future Sustainable Ecosystems: Complexity, Risk, and Uncertainty*. Chapman and Hall/CRC; 2016.

33. Beam AL, Kohane IS: **Big data and machine learning in health care**. *JAMA* 2018, **319**:1317-1318.

34. Willcock S, Martínez-López J, Hooftman DA, Bagstad KJ, Balbi S, Marzo A, Prato C, Sciandrello S, Signorello G, Voigt B, Villa F: **Machine learning for ecosystem services**. *Ecosyst Serv* 2018, **33**:165-174.

35. Rolnick D, Donti PL, Kaack LH, Kochanski K, Lacoste A, Sankaran K, Ross AS, Milojevic-Dupont N, Jaques N, Waldman-Brown A, Luccioni A: **Tackling climate change with machine learning**. *arXiv preprint arXiv* 2019. 1906.05433.

36. Gold J: *The What Works Network: Five Years On*. UK, London: What Works; 2018.

37. • Higgins JPT, Green S: *Cochrane Handbook for Systematic Reviews of Interventions*. London: The Cochrane Collaboration; 2017.
This paper establishes the most current guidelines for evaluating strength of evidence in the medical health community. It sets the standard for evidence evaluation in the health community.

38. • Mupepele AC, Walsh JC, Sutherland WJ, Dormann CF: **An evidence assessment tool for ecosystem services and conservation studies**. *Ecol Appl* 2016, **26**:1295-1301.
This paper describes another set of standards for evaluating strength of evidence for environmental applications. This is also not a widely adopted standard, but one used within the environmental community.

39. Khagram S, Thomas CW: **Toward a platinum standard for evidence-based assessment by 2020**. *Public Adm Rev* 2010, **1**:70.

40. Fernandes PM: **Examining fuel treatment longevity through experimental and simulated surface fire behavior: a maritime pine case study**. *Can J For Res* 2009, **39**:2529-2535.

41. Safford HD, Stevens JT, Merriam K, Meyer MD, Latimer AM: **Fuel treatment effectiveness in California yellow pine and mixed conifer forest**. *For Ecol Manage* 2012, **274**:17-28.

42. Alhazzani W, Guyatt G: **An overview of the GRADE approach and a peek at the future**. *Med J Aust* 2018, **209**:291-292.

43. Vandenberg LN, Ågerstrand M, Beronius A, Beausoleil C, Bergman Å, Bero LA, Bornehag C-G, Boyer SC, Cooper GS, Cotgreave I *et al.*: **A proposed framework for the systematic review and integrated assessment (SYRINA) of endocrine disrupting chemicals**. *Environ Health* 2016, **15**:74.

44. Game ET, Tallis H, Olander L, Alexander SM, Busch J, Cartwright N, Kalies EL, Masuda YJ, Mupepele AC *et al.*: **Cross-discipline evidence principles for sustainability policy**. *Nat Sustain* 2018, **1**:452.

45. • Mastrandrea M, Field CB, Stocker TF, Edenhofer O, Ebi KL, Frame DJ, Held H, Kriegler E, Mach KJ, Matschoss PR *et al.*: **Guidance note for authors of the IPCC 5th assessment report on consistent treatment of uncertainties**. *Intergovernmental Panel on Climate Change (IPCC)*. 2010 http://www.ipcc.ch.
This is the standard for use in creating confidence statements for evidence included in the regular global climate assessments, conducted by the world leading IPCC entity. This is one of the most widely used evidence rubrics in the environment community.

46. IPBES – Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: *Guide on the Production and Integration of Assessments from and Across All Scale*. . Kuala Lumpur 2016.

47. Melillo JM, Richmond T, Yohe G: *Climate Change Impacts in the United States: The Third National Climate Assessment*. Washington, DC: U.S. Global Change Research Program; 2014.

48. Ebi KL: **Differentiating theory from evidence in determining confidence in an assessment finding**. *Clim Change* 2011, **108**:693.

49. Alonso-Coello P, Schünemann HJ, Moberg J, Brignardello-Petersen R, Akl EA, Davoli M, Treweek S, Mustafa RA, Rada G, Rosenbaum S, Morelli A: **GRADE Evidence to Decision (EtD) frameworks: a systematic and transparent approach to making well informed healthcare choices**. *BMJ* 2016, **353** i2016.

50. Salafsky N, Boshoven J, Burivalova Z, Dubois NS, Gomez A, Johnson A, Lee A, Margoluis R, Morrison J, Muir M, Pratt SC: **Defining and using evidence in conservation practice**. *Conserv Sci Pract* 2019, **1**:e27.

51. Walters CJ, Holling CS: **Large-scale management experiments and learning by doing**. *Ecology* 1990, **71**:2060-2068 http://dx.doi.org/10.2307/1938620.

52. Ripley M, Jaccard S: *The Science of Adaptive Management*. Switzerland: International Labor Organization; 2016.

53. Smedley BD, Stith AY, Nelson AR (Eds): *Unequal Treatment: Confronting Racial and Ethnic Disparities in Health Care*. Washington, DC: Committee on Understanding and Eliminating Racial and Ethnic Disparities in Health Care, Board on Health Sciences Policy, Institute of Medicine, National Academies Press; 2002.

54. UNEP – Convention on Biological Diversity: *How to Engage Stakeholders and Mainstream Biodiversity*. . Nairobi 2008.

55. ICSU–International Council for Science: *SDG Interactions: From Science To Implementation*. . Paris 2017.

56. Altinbilek D: **The role of dams in development**. *Water Sci Technol* 2002, **45**:169-180.

57. Spiteri A, Nepal SK: **Distributing conservation incentives in the buffer zone of Chitwan National Park, Nepal**. *Environ Conserv* 2008, **35**:76-86.

58. Miguel E, Camerer C, Casey K, Cohen J, Esterling KM, Gerber A, Glennerster R, Green DP, Humphreys Imbens MG *et al.*: **Promoting transparency in social science research**. *Science* 2014, **343**:30-31 http://dx.doi.org/10.1126/science.1245317.

59. United Nations Development Program, PAGE (Partnership on Action for Green Economy): *Integrated Planning and Sustainable Development: Challenges and Opportunities*. . New York 2016.

60. Greenland S, Pearl J, Robins JM: **Causal diagrams for epidemiologic research**. *Epidemiology* 1999, **10**:37-48.

61. Warnell K, Olander L, Mason S: **Ecosystem services conceptual model application: bureau of land management solar energy development**. *National Ecosystem Services Partnership Conceptual Model Series No. 2*. 2018 . Durham, NC *https://nicholasinstitute.duke.edu/conceptual-model-series*.

62. Warnell K: *Oyster Ecosystem Service Logic Model*. . Accessed from Durham: Duke University; 2019 *https://nicholasinstitute.duke.edu/focal-areas/gems/oyster-reef-restoration/oyster-ecosystem-service-logic-model*.

63. Mason S, Olander L, Warnell K: **Ecosystem services conceptual model application: NOAA and NERRS salt marsh habitat restoration**. *National Ecosystem Services Partnership Conceptual Model Series No. 3*. 2018 . Durham, NC *https://nicholasinstitute.duke.edu/conceptual-model-series*.

64. Ikujiro N: **A dynamic theory of organizational knowledge creation**. *Organ Sci* 1994, **5**:14-37.

65. Sandbrook C: *Biodiversity, Ecosystem Services and Poverty Alleviation: What Constitutes Good Evidence?* Cambridge: UNEP-WCMC; 2013.

66. Sutherland WJ, Wordley CF: **A fresh approach to evidence synthesis**. *Nature* 2018, **364**.

67. Climate and Traditional Knowledges Workgroup (CTKW): *Guidelines for Considering Traditional Knowledges in Climate Change Initiatives*. 2014 http://climatetkw.wordpress.com/.

68. Subramanian SM, Pisupati B: *Traditional Knowledge in Policy and Practice: Approaches to Development and Human Well-Being*. Tokyo: United Nations University Press; 2010.

69. Cross R, Doornbos S, Cooney R, Wong P, Mead A, Lindeman K, Kanagavel A, Parvathy S, Tomasini S, Monanari B, Gabrys K, Kehaulani Watson-Sproat T: *Guidance for Integrating Indigenous and Local Knowledge (ILK) in IUCN Red List Assessments*. Gland: IUCN; 2017.

70. Adler CE, Hadorn GH: **The IPCC and treatment of uncertainties: topics and sources of dissensus**. *Wiley Interdiscip Rev: Clim Change* 2014, **5**:663-676.

71. United Nations Sustainable Development Solutions Network: *Indicators and a Monitoring Framework for the Sustainable Development Goals*. . New York 2015.

72. Walters M, Scholes RJ: *The GEO Handbook on Biodiversity Observation Networks*. Springer; 2017.

73. Alkire S, Meinzen-Dick RS, Peterman A, Quisumbing AR, Seymour G, Vaz A: **The women's empowerment in agriculture index**. *IFPRI Discussion Paper 1240*. 2012 . Washington, D.C. *http://ebrary.ifpri.org/cdm/singleitem/collection/p15738coll2/id/127346*.

74. Economist Intelligence Unit: *Global Food Security Index: Measuring Food Security and the Impact of Resource Risks*. . [Accessed 26 June 2019] from 2017 *https://foodsecurityindex.eiu.com/Resources*.

75. Musengezi J: *Social Conservancy Monitoring and Management System (Social CoMMS): 2014 Household Survey Report*. Arlington: The Nature Conservancy; 2015.