Indicators of global sustainable sourcing as a set covering problem: an integrated approach to sustainability

Patrick R. Huber,1,3 Nathaniel P. Springer,2 Allan D. Hollander,1 V. Ryan Haden,2 Sonja Brodt,2 Thomas P. Tomich,2 and James F. Quinn1

1 Information Center for the Environment, University of California, Davis, California 95616 USA
2 Agricultural Sustainability Institute, University of California, Davis, California 95616 USA

Abstract. Sustainability describes a broad set of themes centered on current human uses of the planet’s resources. The multiple uses and users of the term have led to a proliferation of salient issues and associated indicators. We present a new method to systematically link these issues and indicators under two conceptual frameworks of sustainability in order to enable quantitative analyses. We demonstrate this approach with a specific use case focused on the global sourcing of agricultural products. We use the optimization software Marxan in a novel way to develop minimum sets of indicators that provide maximum coverage of sustainability issues. Minimum covering sets were identified and accumulation curves were developed to measure the contribution of each indicator in each set to overall issues coverage. While greater detail in the assessment of each indicator would likely provide more effective sets of indicators, those that were generated provide optimism that this approach can bring better focus to sustainability assessments.

Key words: global sourcing; indicators; Marxan software; minimum covering set; optimization; sustainability.

Citation: Huber, P. R., N. P. Springer, A. D. Hollander, V. R. Haden, S. Brodt, T. P. Tomich, and J. F. Quinn. 2015. Indicators of global sustainable sourcing as a set covering problem: an integrated approach to sustainability. Ecosystem Health and Sustainability 1(2):7. http://dx.doi.org/10.1890/EHS14-0008.1

Introduction

The term sustainability is used to describe a broad set of themes centered on current human uses of the planet’s resources, their future persistence, and the social-ecological systems that provide them (WCED 1987, Tilman et al. 2002). The effective implementation of sustainability actions could benefit from a refinement of the term to better define the goals to which these actions contribute. Numerous global assessments have been conducted with the aim of providing this sort of definitional refinement (e.g., Millennium Development Goals and the planned Sustainable Development Goals; Ash et al. 2010). Approaching sustainability using various conceptual frameworks has led expert groups to focus on differing sets of issues deemed most important for sustainability, though the identified lists of key issues still overlap. For example, viewing sustainability through the lens of human impacts on the planet (e.g., MEA 2010) can lead to a different set of concerns than does the lens of vulnerability of human social and economic structures to changes in planetary systems (Turner et al. 2003).

These global efforts to define and assess sustainability have identified nonidentical combinations of natural and human systems, or issues, that they find most relevant to global sustainability. Lack of congruence points to a missing “unified theory” of sustainability that is agreed upon by researchers, policy makers, and practitioners. To bring the divergent threads of sustainability together, an inclusive theory would need to address the myriad issues that have been identified from various viewpoints. The full suite of sustainability issues uncovered by the global assessments would arguably provide the basis for such a theory.

Sustainability indicators can provide useful metrics to evaluate the condition of the natural and human systems included in sustainability issues (Liverman et al. 1988). They can provide information on the current state of a system, a system’s rate of change, tipping points where a system changes to another state, or the effectiveness of strategies for mitigating impacts or reducing vulnerability (Walters and Holling 1990). The framework that is used to identify important sustainability issues will likely affect the set of indicators that best provides information on global sustainability.
When coupled with the many potential indicators that have been associated with any particular issue, it is challenging to choose a manageable set of measurable indicators that can inform decision-makers on all major sustainability issues with limited redundancy and at a reasonable cost. Experience shows that expert groups often struggle trying to develop comprehensive sets of sustainability indicators. This suggests that an algorithmic approach used to produce candidate sets of indicators that can then be vetted by groups of experts could lead to a more systematic method for selecting sets of complementary indicators. Many optimization algorithms exist (Korte and Vygen 2012), and the use of an appropriate optimization method could provide sustainability science with a systematic approach for reducing the dimensionality of the information needed to assess sustainability. This optimization approach (i.e., identifying the smallest set of entities that can link to the full set of target entities) is known as a “minimum covering set” problem.

While ideally there would be redundancy in the indicators tracked and the associated issues in a given sustainability program, resource and data limitations suggest that a minimum covering approach could serve as at least a starting point in a decision-making process. A minimum set of indicators then would be a core around which a robust assessment strategy could be based.

To investigate this minimum covering set approach to sustainability, we use it to identify the minimum number of indicators required to cover a core set of issues important for the sustainable sourcing of agricultural raw materials. To do this, we used the popular software Marxan. Marxan (Ball et al. 2009) is a conservation planning tool typically focused on designing reserve networks to efficiently address biodiversity goals (e.g., Stewart et al. 2003), but the approach is more broadly applicable to designing conservation-landscape portfolios that need to simultaneously address multiple and dissimilar goals. We took a novel approach and adapted the tool for general, nonspatial use in optimization analysis. Using Marxan enabled the team to apply a widely used tool in the development of an integrated sustainability concept.

**Methods**

To identify the minimum covering sets of indicators for measuring the sustainability of agricultural sourcing of raw materials, we identified two important sustainability frameworks that are crucial for determining relevant sustainability issues and indicators, selected those global sustainability assessments that pertained to the sourcing of agricultural raw materials, culled the identified sustainability issues and indicators from these assessments, standardized issues using a controlled vocabulary, entered them in a relational database, and defined links between these issues and indicators. This produced a global set of indicators that could be used to cover the issues (Fig. 1). The linkages between the issues and indicators are the logical constructs that define the minimum covering set problem, allow for analysis, and set the parameters for the covering set solutions. We then applied an optimization algorithm to these related issue–indicator sets to identify minimum covering sets of indicators to provide coverage for sustainability issues (Fig. 2).

**Data: issues and indicators for two sustainability frameworks**

This minimum covering set approach requires lists of sustainability issues relevant to sustainable sourcing and a database of indicators that can represent those sustainability issues.

**Frameworks**

The term sustainability is a somewhat abstract and ill-defined notion with multiple meanings. In order to operationalize the word for analytical purposes, a more formal definition, or framework is needed. We identified two frameworks to use as lenses through which to view sustainability. The first is an impacts framework, where sustainability refers to minimization of impacts to the planet’s social and natural systems by human actions. The second framework is vulnerability, where sustainability is concerned with the minimization of threats to commodity supply chains due to changes in human and natural systems. We hypothesized that these discrete definitions would lead to nonidentical sets of sustainability issues and associated indicators that would bound the concept of sustainability.

**Issues**

These frameworks pose different, though overlapping, sets of issues in the context of sourcing of agricultural raw materials. To construct these lists of issues, we drew upon three different perspectives: the global perspective as illustrated by sustainability initiatives and assessments; the corporate perspective from the public communications of food companies; and the community perspective from the academic literature on livelihoods (N. P. Springer et al., unpublished manuscript). We then integrated the terminology across the three perspectives to arrive at a list of sustainability issues (e.g., biodiversity and poverty) composed of subsets of component issues (e.g., species diversity and income distribution) to enumerate major elements of the integrated issues (N. P. Springer et al., unpublished manuscript). This approach yielded 44 integrated issues and 388 component issues. These were associated with one or both frameworks for a total of 192 (integrated plus component) issues in the impacts framework and 279 in vulnerability.
Indicators

Our team identified 2,064 sustainability indicators relevant to our list of issues, largely from the same list of global initiatives used to identify the issues (e.g., global mean temperature rise and GDP per capita). Others were gleaned from the academic literature and well-known databases and indices on sustainability (N. P. Springer et al., unpublished manuscript). Some of the initiatives had indicator databases associated with them while others had to be parsed from indicator lists, tables, and document text. We recorded links for each indicator to one or more issues as discussed in the source documents, then standardized the resulting issue–indicator linkage network by cross-walking the multi-source terms to a standard vocabulary based on AGROVOC (Rajbhandari and Keizer 2012) and Library of Congress lists of terms. An example of these linkages is indicator 7 (population using unimproved water source [indicator] linked to issues including water quality and access to clean water).

 ![Diagram showing the relationship between frameworks, issues, linkages, and indicators.](image)

**Fig. 1.** A schematic drawing showing the relationship between the frameworks (impact and vulnerability), issues (integrated and component), linkages, and indicators (2,064 in total) used in the analysis for sustainable global sourcing of agricultural raw materials. In the impacts framework, sustainability refers to minimization of impacts to the planet’s social and natural systems by human actions. In the vulnerability framework, sustainability is concerned with the minimization of threats to commodity supply chains due to changes in human and natural systems. Issues describe sustainability concerns (i.e., biodiversity), indicators are linked to issues (i.e., population using unimproved water source [indicator] linked to issues including water quality and access to clean water).

![Diagram showing the minimum covering set process.](image)

**Fig. 2.** Minimum covering set process, in which one indicator may provide information on multiple issues. In (a), indicator 1 provides useful information about issues 2 and 4, while (b) shows the total set of indicators and related issues. The minimum covering set (indicators 2 and 5) in (c) provides information on all of the issues.
Analysis: Marxan assessment

Classically, Marxan uses two kinds of input types, planning units and species, with the goal of identifying one or more minimum covering sets of potential natural reserves that cover (i.e., in aggregate, include the full set of species), where the goal is to minimize the land cost or area that needs to be set aside. Instead of using spatial areas as planning units, we used the indicators in this manner. It is the set of these entities that is being minimized by the algorithm. Instead of using species distributions or other ecological features in the species category, we used the full set of issues. These are the entities that are to be fully covered by the set of planning units (indicators) selected. As with the species-conservation applications, the algorithms can produce multiple mixes of areas/indicators that are nearly equally effective in covering all of the identified species/issues. These may provide candidate solutions for experts also wishing to apply additional criteria (e.g., indicators for which there is existing fine-scale mapping).

While the algorithm produces a single best minimum covering set of indicators, perhaps more importantly, Marxan produces “irreplaceability” scores for planning units (Carwardine et al. 2007). This aspect of the tool then creates a portfolio of potential planning units, some of which are relatively interchangeable, giving the user flexibility in the application of the results.

For the planning units input file, each indicator was given a cost of 1.0. No planning units were locked in or out of the solution set.

For the species input file, each issue target was set to 1.0. We assumed that any indicator that was selected as part of the solution set associated with an issue provided full coverage of that issue.

We ran Marxan for each of the two conceptual frameworks. Each of these consisted of 100 runs with 50 million iterations for each run. Marxan uses a simulated annealing heuristic that generates multiple suitable results. Each run outputs one suitable set of planning units that meet the inputted conservation goals by scoring and comparing each iteration, or slightly different unique combinations of planning units.

Results

Results included both “best” and “summed” solutions for each analysis. A best solution is the single run out of the full suite of runs (in this case 100) that had the lowest cost, i.e., met the inputted objectives most effectively. The summed solution provides irreplaceability scores (0–100 scale) for each indicator based on the number of times it appears as part of a set identified at the end of a run (Table 1). The indicators selected as the best solution for all of the issues number 23 (range, 22–25) under the impacts framework and 31 (range, 31–35) under vulnerability (Fig. 3). Note that the best solution under the impacts framework is not equal to the minimum number of indicators selected. While this particular set of 22 indicators was the smallest that constituted a low-cost solution, it did not provide coverage of the full suite of issues. Therefore the solution with the best score was not the solution with the overall lowest number of indicators included.

Under both of the frameworks, indicator 246 (global mean temperature rise) was selected in all 100 runs in addition to the best run. The second-highest-scoring indicator in both frameworks was indicator 554 (new biofuels, cellulosic ethanol, biomass-to-liquids technical usage), also in both best runs.

Not all of the indicators receiving high irreplaceability scores were identified in the best solutions (Table 2, Fig. 4). In fact, there were many combinations of indicators selected in the Marxan runs. While 23 indicators comprised the best solution under the impacts framework, 525 indicators were selected in at least one of the 100 runs. For the vulnerability framework, 583 indicators were selected at least once.

Accumulation curves

Species accumulation curves have been used in conservation science to track the contribution of unique features by each unit within a conservation network (e.g., Ugland et al. 2003). These curves plot in decreasing order the contribution to the overall total by each unit within the network.

We developed issue accumulation curves for the indicators in the best solution for each of the frameworks (Fig. 5). The first point on the graph is the indicator providing the greatest issues coverage, the second the greatest coverage of issues not covered by the first indicator, and so on. These curves plot the rapidity with which each set of indicators approaches full coverage of the issues. It also allows for an assessment of the coverage provided by a subset of indicators if the full set of indicators cannot be used (e.g., if there are only enough resources available in a given context to enable the tracking of fewer than the full minimum set of indicators).

In the best Marxan results under both frameworks, indicator 246 (global mean temperature rise) covered the greatest number of issues. This indicator was associated with 91 of 192 impact issues (47.4%) and 104 of 279 vulnerability issues (37.3%). This contribution was far larger than that of any other indicator in either framework. None of the next four highest-contributing indicators were shared between frameworks. To achieve 80% coverage of issues, eight indicators were required under the impacts framework while 11 were required under vulnerability.

Discussion

The development of sustainability as a field of study
Abbott 2000, Kates et al. 2001) has led to a proliferation of conceptual approaches, definitions, and metrics. While this reflects the broad nature of the questions being addressed, the lack of an integrated approach leaves sustainability actors at risk of working in a noncomplementary fashion as goals are being developed and actions undertaken. We believe that our research demonstrates an approach by which an inclusive integration of actors, issues, and conceptual frameworks can be achieved with tractable and salient results as an output.

(While there is no simple test of the “reasonableness” of the minimum covering set results, there were few if any indicators selected by either approach that seemed inconsistent with our expert opinion. Indicators such as global mean temperature rise (e.g., Braganza et al. 2003),

| Indicator                                                                 | ID  | Impacts | Sum | Vulnerability | Sum |
|--------------------------------------------------------------------------|-----|---------|-----|---------------|-----|
| Agricultural subsidies                                                  | 14  | 0       | Y   |               | 2   |
| Civil and political liberties                                            | 25  | 1       | Y   |               | 40  |
| Fertilizer consumption                                                   | 39  | 71      | Y   |               | 23  |
| Percentage of country’s territory in threatened ecoregions               | 61  | Y       | 19  |               | 0   |
| Waste recycling rates                                                    | 85  | Y       | 2   |               | 4   |
| Land tenure                                                              | 95  | Y       | 23  |               | 0   |
| Compliance costs (indirect) to meet standards-specific infrastructure    | 111 | Y       | 1   |               | 0   |
| Access to market information                                            | 123 | Y       | 59  |               | 63  |
| Discrimination (worker)                                                  | 144 | 1       |     |               | 10  |
| Water contamination prevention measures                                  | 169 | 53      | Y   |               | 8   |
| Producer perceptions of community’s care of environment                  | 174 | Y       | 16  |               | 4   |
| Indigenous people’s access and control over traditional lands            | 208 | Y       | 72  |               | 8   |
| Income per capita of enterprise/organization                             | 211 | Y       | 1   |               | 1   |
| Underweight and stunting of children under 5 years of age                | 223 | Y       | 15  |               | 7   |
| Global mean temperature rise                                             | 246 | Y       | 100 |               | 100 |
| Disability-adjusted life years (DALYs)                                   | 310 | 0       | Y   |               | 5   |
| Reports of fish/aquaculture disease                                      | 329 | Y       | 4   |               |     |
| Changes in littoral community                                             | 376 | Y       | 14  |               | 4   |
| Incidents of noncompliance with regulations/voluntary codes              | 456 | 0       | Y   |               | 10  |
| Extreme weather events                                                   | 478 | 0       | Y   |               | 5   |
| Women’s access to education                                              | 503 | 0       | Y   |               | 3   |
| Legal frameworks ensure access and tenure to resources/land              | 537 | 0       | Y   |               | 92  |
| New biofuels, cellulosic ethanol, biomass-to-liquids technical usage     | 554 | Y       | 89  |               | 97  |
| Household membership in any social group? For how long?                  | 840 | 0       | Y   |               | 2   |
| Age of household head                                                    | 844 | 0       | Y   |               | 88  |
| Proportion of population below $1 (PPP) per day                         | 850 | 2       | Y   |               | 10  |
| Duty-free imports from developing and least-developed countries          | 903 | 0       | Y   |               | 13  |
| Road density                                                             | 924 | 3       | Y   |               | 63  |
| Harvest of wood products                                                 | 991 | 42      | Y   |               | 50  |
| Harvest of non-wood forest products                                      | 992 | Y       | 39  |               | 46  |
| Changes in habitat and ecosystem quality                                 | 1054| 40      | Y   |               | 22  |
| Labor force participation rate                                           | 1223| Y       | 36  |               | 0   |
| Cereal yield (kg/ha)                                                     | 1354| 0       | Y   |               | 5   |
| Electric power consumption (kWh per capita)                              | 1407| 0       | Y   |               | 2   |
| Roads, paved (percentage of total roads)                                 | 1436| 0       | Y   |               | 15  |
| Literacy rate, youth male                                               | 1486| 0       | Y   |               | 15  |
| Interest rate spread (lending rate minus deposit rate)                   | 1556| 0       | Y   |               | 30  |
| Out-of-pocket health expenditure                                         | 1652| Y       | 3   |               | 1   |
| GDP per person employed (labor productivity)                             | 1702| 9       | Y   |               | 3   |
| Refugee population by country or territory of origin                     | 1813| 0       | Y   |               | 1   |
| Workplaces in all sectors following basic NHSPS                          | 1845| Y       | 35  |               | 65  |
| Workers covered by services to prevent occupational diseases/injuries    | 1853| 0       | Y   |               | 3   |
| Existence of adequate crop storage facilities                            | 1995| 3       | Y   |               | 13  |
| Diet diversification                                                     | 2000| Y       | 5   |               | 2   |
| Trainings for employees working in areas vulnerable to corruption        | 2058| Y       | 6   |               | 0   |
| Land where pH in the root zone is acidic                                 | 2145| Y       | 1   |               | 0   |
| Incidence of animals affected by illnesses or injuries                   | 2156| Y       | 55  |               | 33  |
| Only legal workers are employed                                          | 2251| 2       | Y   |               | 40  |
| Total revenue (or profit) invested into regional economy                 | 2269| Y       | 22  |               | 1   |
| Workforce adhering to association defending workers’ rights              | 2286| Y       | 11  |               | 2   |
| Animals lost prematurely due to diseases, injuries, accidents             | 2380| Y       | 22  |               | 27  |

Notes: A “Y” under impacts or vulnerability implies that the indicator was part of the best solution. Sum is the number of times out of 100 that the indicator was part of a suitable solution.
development and enforcement of health and safety regulations (e.g., Edberg et al. 2000), access to market information (e.g., Teklehaimanot 2004), and others that were frequently selected, are metrics commonly used to assess some of the identified sustainability issues, and as such were expected to be included in the final sets.

On the other hand, there were some surprises as well. For example, while we expected female literacy rate to be a key indicator for literacy-related issues, youth male literacy rate (1486) was included in the best solution under the vulnerability framework. Gender-related issues were covered by other indicators, rendering several literacy indicators relatively equivalent; we believe that 1486 was stochastically selected from several options for this role in the best solution. Another unexpected example is the high irrereplaceability scores under both frameworks of the indicator new biofuels, cellulosic ethanol, biomass-to-liquids technical usage (554). While this indicator certainly points to important sustainability issues, its nearly unanimous selection was somewhat surprising.

The construction of accumulation curves for these indicator sets provides a valuable tool in the implementation of sustainability actions. Real world sustainability actions typically involve imperfect information and limited resources, so decision support tools that can provide information on non-optimum but implementable solutions are beneficial. The accumulation curves can point to a set of indicators that, while not covering all issues of importance in global sustainability, can provide at least some information on a large majority of those issues. This allows a user to determine what is good enough in the evaluation of sustainability.

The lists generated here together with the accumulation curves developed from them demonstrate a systematic sequence of analytic steps that can benefit experts and decision-makers. While the lists of indicators by themselves should not be taken as definitive indicator sets providing the single blueprint for tracking the full spectrum of sustainability issues, they do provide an example of an efficient solution to a particular sustainability problem as well as sets of alternatives that could serve as the basis for negotiations among diverse stakeholders.

The potential utility of the outputs demonstrates that Marxan is a flexible tool with many potential unexpected and novel applications. While it is typically used in site-specific reserve selection, we have shown that it can successfully be used in other optimization settings, especially those in which it is unclear what an optimal solution might look like. In the case presented here, we identified the general number of indicators that might be required to provide coverage of the major sustainability issues associated with global production of agricultural commodities. A Marxan approach to other questions could provide similar guidance. To our knowledge, this is the first use of Marxan in a context that is neither spatial nor focused on reserve selection. We believe that managers and other decision makers in diverse situations can benefit from use of the tool in assessing the irreplaceability of various types of planning units.

**Table 2.** Indicators identified under both frameworks that had the 10 highest irrereplaceability scores (sum; 0–100) but were not part of the best solution for that framework.

| Indicator | Sum |
|-----------|-----|
| Impacts   |     |
| Fertilizer consumption (39) | 71  |
| Water contamination prevention measures (169) | 53  |
| Harvest of wood products (991) | 42  |
| Changes in habitat and ecosystem quality (1054) | 40  |
| Development and enforcement of health and safety regulations (532) | 34  |
| Turnover/profit coming from short local value chains (2270) | 34  |
| Policies/programs to diversify diets and improve micronutrient intake (515) | 29  |
| Equitable access to and use of natural resources (534) | 23  |
| Animals lost prematurely due to diseases, injuries, accidents (2380) | 22  |
| Farm size (97) | 21  |
| Vulnerability |     |
| Total number disasters per year (298) | 86  |
| Business units analyzed for risks related to corruption (448) | 82  |
| Risk premium on lending (1568) | 67  |
| Workplaces in all sectors following basic NHSPS (1845) | 65  |
| Access to market information (123) | 63  |
| Costs and benefits, certification costs/premiums (1160) | 48  |
| Harvest of non-wood forest products (992) | 46  |
| GDP per capita (1) | 44  |
| Literacy rate, youth female (1485) | 38  |
| Impacts of transporting products used for operations and workers (434) | 37  |

Notes: These indicators are candidates for replacing some of those found in the best solution, thereby providing flexibility in a final indicators set. Indicator IDs are shown in parentheses. NHSPS stands for national health and safety performance standards.
While Marxan was able to be used in the novel way described here, it is not the only optimization approach available to address the minimum covering set problem presented by the complexities of sustainability issues and indicators. For example, integer programming (Balinski and Quandt 1964) could be used to derive minimum covering sets as well. One advantage with the Marxan approach, however, is the relative ease of use of the software and the generally widespread nature of its application by conservation scientists worldwide. However, other optimization algorithms should be assessed for comparison with the results presented here.

The differences in the results between the two conceptual frameworks (impact vs. vulnerability) provide evidence that sustainability concerns and measurements are in part determined by the situational context. The minimum covering set approach produces dissimilar sets of indicators that best cover the relevant issues in efficient ways. A conclusion that can be drawn from this is that there is unlikely a single set of indicators that can be universally thought of as a single best collection of sustainability measurements, even within the narrowed field of global agricultural production. Sustainability, then, is likely to be best described by patterns that emerge from multiple indicator lists generated across diverse contexts.

Our results provide reason for optimism for development of a unified sustainability vision. However some associated next steps could provide additional validity. First, we associated indicators and issues by assessing whether or not an indicator could provide useful information about an issue. A more stringent approach would require an indicator to provide most or all of the pertinent information. Some of the indicators identified in our analyses only shed light on certain aspects of issues they ostensibly cover. More stringent criteria will likely result in larger numbers of indicators in any resulting covering set, leading to an increase in dimensionality in the system and a less tractable set of indicators required for full coverage. However, dimensionality should again be reduced if a rigorous ontology of issue-to-issue relationships is developed that includes system drivers, i.e., issues as drivers of change in other issues. Assessment of colinearity between issues could also be used to reduce dimensionality.

Another potential improvement concerns our assumption of equivalence in value between all indicators. Numerous authors have noted criteria that can be used to assign value to indicators such as measurability, scientific soundness, policy relevance, etc. (e.g., Dale and Beyeler 2001). Quantitative valuation of the indicators in this database would provide added benefit. It could be included in the cost function in Marxan, whereby indicators with a higher assessed value would have a lower cost score and hence a greater likelihood of selection.

One such indicator assessment criterion is whether or
not data to support an indicator currently exist. If there are currently no data that could be used to measure an indicator, it is either not a useful indicator at present or potentially expensive, in terms of time and/or resources needed to create those data. An ideal indicator set for immediate use should be comprised of indicators associated with data.

A goal of this project is to create a customizable minimum covering set tool which could be used by a variety of stakeholders in the global agricultural sourcing community (e.g., food producers, NGOs, government agencies, etc.). This tool would generate context-specific minimum covering indicator sets. Each user could select relevant frameworks, issues, and/or indicators of interest, and contribute their specialized knowledge to the database components and linkages. Analyses could be run to address the particulars of any single use case. This tool, coupled with a fuller, more nuanced set of indicator and issue assessments and linkages, would be valuable in providing the sustainability world with both a flexible and unified approach to sustainability.

Acknowledgments

We would like to thank Mars Incorporated and Kraft Foods for their generous funding of this project. We would also like to thank the Technical Advisory committee and other stakeholders for their valuable feedback and suggestions.

Literature Cited

Abbott, S. B. 2000. Sustainability science and conservation needs. AAAS Annual Meeting and Science Innovation Exposition 166:A15.

Ash, N., et al. 2010. Ecosystems and human well-being. Island Press, Washington, D.C., USA.

Balinski, M. L., and R. E. Quandt. 1964. On an integer program for a delivery problem. Operations Research 12:300–304.

Ball, I. R., H. P. Possingham, and M. Watt. 2009. Marxan and relatives: software for spatial conservation prioritisation. Pages 185–195 in A. Molanen, K. A. Wilson, and H. P. Possingham, editors. Spatial conservation prioritisation: quantitative methods and computational tools. Oxford University Press, Oxford, UK.

Braganza, K., D. J. Karoly, A. C. Hirst, M. E. Mann, P. Stott, R. J. Stouffer, and S. F. B. Tett. 2003. Simple indices of global climate variability and change: part 1—variability and correlation structure. Climate Dynamics 20:491–502.

Carwardine, J., W. A. Rochester, K. S. Richardson, K. J. Williams, R. L. Pressey, and H. P. Possingham. 2007. Conservation planning with irreplaceability: Does the method matter? Biodiversity Conservation 16:245–258.

Dale, V. H., and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1:3–10.

Edberg, S. C., E. W. Rice, R. J. Karlin, and M. J. Allen. 2000. Escherichia coli: the best biological drinking water indicator for public health protection. Journal of Applied Microbiology 88:106S–116S.

Kates, R. W., et al. 2001. Environment and development: sustainability science. Science 292:641–642.

Korte, B. H., and J. Vygen. 2012. Combinatorial optimization theory and algorithms. Fifth edition. Springer-Verlag, New York, New York, USA.

Liverman, D. M., M. E. Hanson, B. J. Brown, and R. W. Meredith. 1988. Global sustainability: toward measurement. Environmental Management 12:133–143.

Millennium Ecosystem Assessment (MEA). 2010. Ecosystems and human well-being: our human planet: summary for decision-makers. Island Press, Washington, D.C., USA.

Rajbhandari, S., and J. Keizer. 2012. The AGROVOC concept scheme—a walkthrough. Journal of Integrative Agriculture 11:694–699.

Stewart, R. R., T. Noyce, and H. P. Possingham. 2003. Opportunity cost of ad hoc reserve design decisions: an example from South Australia. Marine Ecological Progress Series 253:25–38.

Teklehaimanot, Z. 2004. Exploiting the potential of indigenous agroforestry trees: *Parkia biglobosa* and *Vitellaria paradoxa* in sub-Saharan Africa. Agroforestry Systems 61:2:207–220.

Tilman, D., K. G. Cassman, P. A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. Nature 418:671–677.

Turner, B. L., et al. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences USA 100:8074–8079.

Ugland, K. I., J. S. Gray, and K. E. Ellingsen. 2003. The species-accumulation curve and estimation of species richness. Journal of Animal Ecology 72:888–897.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71:2060–2068.

World Commission on Environment and Development (WCED). 1987. Our common future. Oxford University Press, Oxford, UK.

Copyright: © 2015 Huber et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. http://creativecommons.org/licenses/by/3.0/