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Proposal for Increasing Consistency When Incorporating Ecosystem Services into Decision Making

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Introduction

After decades of research and demonstration, use of ecosystem services in decision making is being translated into policy guidance for practitioners.[1] In October 2015, the U.S. Executive Offices of the President—the Office of Management and Budget, the Council on Environmental Quality, and the Office of Science and Technology Policy—released a memo "Incorporating Ecosystem Services into Federal Decision Making" directing federal agencies to develop work plans and implementation guidance by the end of 2016.[2] But many practical questions remain about how ecosystem services can most effectively be used in decision making. The question we explore in this brief is how to achieve consistency in the use of ecosystem services, primarily in terms of which ecosystem services are selected for assessment and how they are quantified.

An initial idea for promoting consistency might be to require all decision makers to consider a common set of ecosystem services, each with a pre-defined metric. Although this strategy might seem logical, it may not provide relevant or useful information for decision makers because even fairly constrained categories of these services—say those for maintaining air and water quality, managing water quantity, and reducing risks from fire, storms, and droughts—when further refined break up into many more services that are defined by who is affected and how they are affected. For example, a water quality management issue results in a change in water quality for downstream stakeholders—which can alter services such as municipal water supplies, irrigation, fishing, swimming, and so on. Each of these services involves different

What Are Ecosystem Services?

"Ecosystem services are the benefits people receive from nature. They encompass nature's contributions to the production of food and timber; life-support processes, such as water purification and coastal protection; and life-fulfilling benefits, such as places to recreate or to be inspired by nature's diversity. There can also be ecosystem disservices, such as mosquito-borne diseases and pollen-induced allergies."

Source: Federal Resource Management and Ecosystem Services Guidebook.

[1] See, for example, Department of Environment, Food & Rural Affairs, *Guidance for Policy and Decision Makers on Using an Ecosystems Approach to Valuation Ecosystem Services* (updated 2014), https://www.gov.uk/guidance/ecosystems-services; United Nations Environment Programme, *Guidance Manual for the Valuation of Regulating Services,* by Pushpam Kumar, Madhu Verma, Michael D. Wood, and Dhaval Negandhi, United Nations Office at Nairobi (Nairobi-Kenya, 2010), http://www.unep.org/pdf/Guidance_Manual_for_the_Regulating_Services.pdf; National Ecosystem Services Partnership, *Federal Resource Management and Ecosystem Services Guidebook,* 2nd ed. (Durham, NC: NESP, Duke University, 2016), https://nespguidebook.com; Patrick ten Brink, ed., The Economics of Ecosystems and Biodiversity (TEEB) in *National and International Policy Making* (London and Washington: Earthscan, 2011); Heidi Wittmer and Haripriya Gundimeda, ed., *The Economics of Ecosystems and Biodiversity (TEEB) in Local and Regional Policy and Management* (London and Washington: Earthscan, 2012).

[2] Memorandum for Executive Departments and Agencies M-16-01 of October 7, 2015, Incorporating Ecosystem Services into Federal Decision Making, Office of Management and Budget, https://www.whitehouse.gov/sites/default/files/omb/memoranda/2016/m-16-01.pdf.

stakeholder populations or beneficiaries. Moreover, each of these services might be more or less relevant in different contexts or regions.

The ecosystem services that should be considered in a particular decision depend on the ecosystem type, the attributes and qualities of that ecosystem, the ways in which surrounding human communities use or appreciate the ecosystem, vulnerabilities and characteristics of those communities, and the preferences and values of human beneficiaries in different areas and policy contexts. They also depend on the temporal and spatial scale of the project, plan, program, or policy under consideration. Consequently, achieving consistency in the selection of ecosystem services to be considered is a complex task, as is achieving consistency in quantification of those services across decision contexts.

Why Is Consistency Needed in Decision Making?

Consistency in ecosystem services measures may be necessary for comparing projects, plans, or programs; tracking progress; simplifying cooperation across agencies and jurisdictions; and streamlining analysis by building on experience.

Consistency can be useful for comparisons of projects, actions, plans, or programs; to determine which activity to fund or how much to fund it (i.e., targeting investment) or to determine how activities compare in achieving their goals (i.e., return on investment). Such comparisons could be used for considering similar projects in different locations (e.g., where conservation reserve dollars should be spent) or deciding which of several very different management alternatives (e.g., investing in farm management versus water treatment facilities to address nutrient loadings) might best achieve objectives and support ecosystem services.

Comparisons of the social value (benefit to society) of projects, actions, plans, or programs using valuation methods do not necessarily require the same ecosystem services to be valued across decision contexts. The relevant requirement for valuation is that the analyses capture all significant changes in social welfare related to ecosystem service changes, as realized across different sites, decision contexts, or both. If different services are valued by affected communities across different contexts, different services should be assessed and valued. Requiring full consistency in the ecosystem services to be valued could detract from valid and reliable estimation and comparison of social value. However, valuation methods are not always applied to inform decisions. When valuation is not applied, consistency in which services are selected and which measures are used for those services increases in importance. Even if the services important in a decision type vary with geography or context, in many cases it is useful to measure a common set of services, or even better, to use one set of consistent metrics for those services common across sites or contexts. It can be useful to track ecosystem service metrics even when valuation is also conducted.

A common set of services and metrics would also help managers track progress for project or program evaluation. Thus trends in outcomes after a policy has been implemented (e.g., number of hospital visits due to wildfire smoke inhalation) or progress toward an implementation goal (e.g., acres with forest understory fuel load cleared) could inform adaptive management planning and future decisions.

Many government actions require cross-jurisdiction (local, state, and federal) and cross-agency (state and federal) cooperation as well as coordination with non-federal partners (local community groups, non-governmental organizations, or businesses). A common, agreed on set of services of interest and a common set of metrics or methods for assessing these services can simplify coordination with partners.

Consistency can also streamline analysis by (1) building a robust set of data and causal models (like ecological production function models) so that practitioners are measuring and estimating a subset of services in the same way, (2) aligning data collection with analysis that links ecological outcomes and social benefits, and (3) systematically including the important services and benefits for specific decision contexts.[3] The result can be more streamlined and cost-effective processes for assessing ecosystem services which also avoids duplication of data collection and analytic effort.

Decision makers may also want a common set of services that can be aggregated across a group of common activities to allow scaling up to assess regional or national impact. One example is aggregation of changes in recreational services like boating, hiking, and camping into a measure of overall change in recreational use across national forests so they can be compared. Although such aggregation is clearly desirable for cross-comparison, it is not the ideal approach because it will

[3] Again, it must be recognized that different services may be valued (or the same services may be valued differently across different contexts). Hence, what is "important" may vary across decision-making contexts.

not necessarily be indicative of aggregate value added or created. Scaling up of value is typically neither simple nor linear and is often misused in ecosystem service assessments.[4] For example, if an angler would be willing to pay $20 to catch one additional trout, per fishing trip, it does not necessarily follow that the same angler would be willing to pay $2,000 to catch 100 additional trout per trip ($20 × 100), due to diminishing marginal utility (each successive unit of a good is frequently worth less to an individual than the previous unit). In general, the limitations and potential errors associated with aggregating up to larger scales from smaller scales should be fully acknowledged and evaluated. A separate assessment of the regional or national scale effect of a suite of policies or actions will usually produce a more meaningful result.

Current Inconsistencies

Inconsistencies in how ecosystem services are currently assessed need to be considered if decision makers desire greater consistency in how ecosystem services are incorporated into decisions.

Inconsistency in services across decision contexts is a fundamental characteristic of ecosystem services because what is important in one geographical, temporal, social, and administrative setting differs from what is important in another setting. As a result, the most relevant set of services for a decision context is always unique. For example, despite a suite of common services produced by coastal salt marsh restoration projects, project A may primarily focus on coastal resilience and carbon sequestration, while project B may focus on habitat for an endangered species in a U.S. Fish and Wildlife refuge. Both projects may use funds dedicated to recovery from Hurricane Sandy. The focus on different services—those most relevant for the specific decision context, location, and affected communities—is good practice for assessing individual project objectives.[5] But it may provide insufficient directly comparable measures of performance if decisions require that projects be compared.[6] Thus effort will be needed to find a set of common measures that are meaningful.

Another type of inconsistency—inconsistency in indicators used to represent change in an ecosystem service—can but does not always result from poor practice. It can result from differences in (1) whether the indicators represent intermediate ecological steps that generate services or more final measures of the production of a good or service (e.g., water storage versus water availability for irrigation); (2) the level of specificity (e.g., fauna of interest, at-risk faunal species, or a specific species); or (3) the specific metric that is used (number of fish caught by recreational anglers or number of trout caught by recreational anglers). Lists of services used for assessments often include a hodgepodge of ecosystem structures (e.g., forest density, barrier island height) or ecosystem functions (e.g., water-holding capacity), which might be what are called intermediate ecosystem services, as well as final goods and services (e.g., people-days of hiking trails used), value of a service (annual net revenue from timber), and perhaps other measures of economic or social impact (e.g., jobs). When ecosystem structures or functions are included in ecosystem services assessments, they often lack sufficient specificity. For example, forest condition in an ecosystem service context might mean amount of carbon in the forest, fuel loads, or amount of habitat for species that need large trees. However, if the reason that forest condition is important (valued) and the stakeholders for whom it is important are not specified, the indicator is not specific enough to provide a measure of a service. These inconsistencies can lead to bias or double-counting.[7] They can also make it unclear whether ecosystem services are being fully incorporated. When assessments stop short of valuation and use non-value-based measures of ecosystem services, efforts to promote consistency in selection and quantification of services may be necessary.

Moving Toward Consistency

Some decisions, for example local community development decisions (e.g., where to place a new park or shopping mall), may require little consistency in selecting what services and measures to use because there is no need for comparison or tracking. In contrast, those decisions supported with federal funding, affected by federal regulations, or on federal lands or waters require some degree of consistency, particularly if decision makers need to make project comparisons, track performance, and assess return on investment.

[4] R.J. Johnston and L.A. Waigner, "Benefit Transfer for Ecosystem Service Valuation: An Introduction to Theory and Methods," in *Benefit Transfer of Environmental and Resource Values: A Guide for Researchers and Practitioners,* edited by R.J. Johnston, J. Rolfe, R.S. Rosenberger, and R. Brouwer (Dordrecht, the Netherlands: Springer, 2015), 237–273.

[5] The focus on measuring only ecosystem services relevant to project objectives may also leave out other important services affected by a decision.

[6] But if valuation methods are used, different services, if important, can be selected, and final aggregated public welfare values can be compared across sites.

[7] Double counting can occur when lists include two measures related to one service or benefit. Water-holding capacity is an intermediate ecosystem function that can lead to a final service like reduced days of flooding per year. Counting both for their flood reduction benefits might create an unfair advantage for projects that improved this service.

Consistency can be embedded in three ways: (1) at the level of the construct or conceptual model connecting ecological changes to social outcomes to determine which services are important in a decision, (2) in the implementation or estimation of that model reflecting understanding of the relationship between ecological changes and outcomes (e.g., whether the production function is linear or not), and (3) in the data or information that is used in the assessment or model. This paper focuses on developing consistency in the conceptual model that will allow decision makers to select a common set of services, but it also recognizes the benefit of using a common set of measures (or indicators). Increasing consistency in the estimations of relationships (production functions) and use of data inputs will progress more readily if federal agencies coordinate their efforts to assemble data and develop modeling infrastructure and share knowledge about the services they are managing.

We propose that selecting a common set of benefit relevant indicators and using a common set of conceptual models, as described below, will increase consistency in the selection of services for assessment in a specified decision context.

Consistency in Use of Indicators and Measures

A common way to achieve consistency in how ecosystem services are assessed is to use a monetary metric, expressed in units of dollars, to capture the value of changes in ecosystem services. When economic valuation is used, different services—those most relevant to the decision—should be selected for each context and the measures used can also vary, while still generating results that can be compared.[8] But it can be difficult to put a dollar value on many important services. Multi-criteria decision analysis—a method that uses non-monetary preference measures—similarly generates metrics in common units (utils). Yet its application is not transferable to other contexts and tends to be less familiar to analysts. Although these valuation methods can allow direct comparison, they can at times reflect inconsistencies in which ecosystem services measures are valued and how they are valued. These inconsistencies can result in significant differences in the values that result for similar services and contexts, raising the question: how can the selection of what is valued and how it is valued be made more consistent? However, in many cases valuation methods will not be used. Other downsides of valuation methods are that they can be difficult and costly to apply; they may face resource, data, or capacity limitations; or they may be uncomfortable or objectionable to some stakeholders and communities.

When valuation methods are not feasible or desirable, and other measures of ecosystem services are being used in decisions, the question becomes how best to generate consistency in the selection and use of "non-value-based" measures. This paper uses the term non-value-based measures to refer to measures that do not convert ecosystem services to a single common metric (such as dollars). These are measures of what is valued and thus are conceptually associated with the values that humans hold for the services but are often heterogeneous indicators of these values.

When to Incorporate Scarcity into Ecosystem Services Measures

If the indicator will be subject to subsequent valuation, direct reflections of scarcity need not be directly "built in" to the indicator itself. It should be accommodated during valuation by accounting for other available sources of supply (i.e., substitutes). In other words, a change in water supply will have less value when water is abundant to begin with. However, if valuation will not occur, BRIs can be developed to reflect scarcity as well. For example, they can measure the change relative to the existing or total supply, thereby providing an indirect and approximate means to infer relative value (assuming all else is constant and satiation has not been reached).

In many cases, modest changes in scarcity may not have a meaningful influence on the consistency of measures across sites. For example, measures of a particular type of timber (harvested for lumber) will be similar, regardless of modest changes in supply and demand. However, in other cases, consistency requires that scarcity be considered. For example, lack of demand for a particular type of recreational fish species, in a particular area, would imply that increases in that species would have no recreational value in that area. In other areas the same species might be highly valued for recreational harvest. Such differences could imply that changes in abundance of that species would not have a similar interpretation in terms of ecosystem service provision across sites, despite the presence of an identical biophysical measure (e.g., changes in abundance of a particular species).

[8] As long as ecosystem service measures are well-defined and allow sufficiently comprehensive estimation of value for each studied policy context and appropriate methods are used, the resulting economic values can remain well-defined and meaningful, regardless of whether identical measures of services are used across studies or contexts. See, e.g., E.T. Schultz, R.J. Johnston, K. Segerson, and E.Y. Besedin, "Integrating Ecology and Economics for Restoration: Using Ecological Indicators in Valuation of Ecosystem Services," *Restoration Ecology* 20(3)(2012): 304–310.

To select a consistent set of ecosystem service (non-value-based) measures that ensure meaningful comparability for assessments (which may or may not include valuation), a level of specificity beyond broad categories of services is needed.[9] For example, decision makers must not only track a change in water supply, but must also consider water supply for specific users (e.g., municipal users), level of access (e.g., capture in reservoir where water is treated and distributed), and, in some cases, scarcity of this water (supply relative to demand). These ecosystem services measures must include consideration of both biophysical metrics and socio-economic context.

This level of specificity, in which a specific service is linked to an identified beneficiary, has been called a benefit-relevant indicator (BRI) or linking indicator.[10] BRIs or linking indicators are the hand-off between ecological and social measures. Good BRIs capture information on changes in the ecosystem and information on how those changes may affect people by considering which services are valued by people, whether there is demand for the services, how much they are used (use values) or enjoyed (non-use value), and whether a given site provides the access necessary for people to benefit from them, among other considerations.[11]

Conceptual Models

Conceptual models are "a simplified visual representation and written description of interactions among natural, social, and economic systems that affect or are affected by identified actions. Such documentation helps analysts and the public clearly understand how ecosystems contribute to the provision of services."*

* Council on Environmental Quality, *Principles and Requirements for Federal Investment in Water Resources*, Executive Office of the President, 2013.

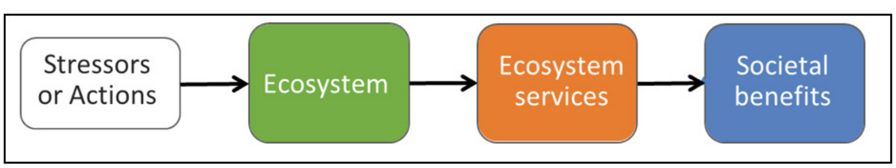
It is essential that BRIs be good indicators of how ecological changes caused by a decision will affect social outcomes; they should not be selected primarily on the basis of data that are readily available or most easily gathered. BRIs are measures of ecosystem service outcomes; they measure what is valued rather than value itself. BRIs are ideal inputs into valuation, and the selection of consistent BRIs (where the same services are relevant and important across decision contexts) can contribute to, but not alone ensure, consistency in valuation and decision making.[12]

Consistency in Selection of Services

How can analysts select a common set of BRIs that are relevant to and meaningful for a set of decisions that need to be compared or tracked over time and that are also meaningful to organizations involved in those decisions? In other words, how can analysts select a consistent set of BRIs to assess ecosystem services for specific decision contexts?

A good way to select ecosystem services measures relevant for the outcomes of interest is to use conceptual models (also known as logical models, means-ends diagrams, box and arrow diagrams, or causal chains). These models map how an action or decision affects ecosystems, which in turn affects ecosystem service production and the benefits received by people (Figure 1). These models account for and can incorporate metrics for non-target or unplanned outcomes, namely co-benefits or unintended consequences, in addition to primary goals or objectives. A conceptual model or set of diagrams with common elements can provide the basis for selecting a relevant and consistent set of BRIs for comparable decision contexts.

Figure 1. Conceptual model for assessing changes in ecosystem services



[9] Ecological features and processes are essential for the provision of ecosystem services but are not the same as services. Until there is some person somewhere who benefits from a given element or process of an ecosystem, that element or process is not a service.

[10] Olander, Lydia, Robert J. Johnston, Heather Tallis, Jimmy Kagan, Lynn Maguire, Steve Polasky, Dean Urban, James Boyd, Lisa Wainger, and Margaret Palmer, "Best Practices for Integrating Ecosystem Services into Federal Decision Making," Durham: National Ecosystem Services Partnership, Duke University, 2015, doi:10.13016/M2CH07; Boyd, James, Paul Ringold, Alan Krupnick, Robert J. Johnston, Matthew A. Weber, and Kim Hall, "Ecosystem Services Indicators: Improving the Linkage between Biophysical and Economic Analyses," *International Review of Environmental and Resources Economics* (2016).

[11] Benefit-relevant indicators (BRIs) are described in more detail in Olander, Lydia, Robert J. Johnston, Heather Tallis, Jimmy Kagan, Lynn Maguire, Steve Polasky, Dean Urban, James Boyd, Lisa Wainger, and Margaret Palmer, "Best Practices for Integrating Ecosystem Services into Federal Decision Making," Durham: National Ecosystem Services Partnership, Duke University, 2015, doi:10.13016/M2CH07.

[12] Boyd, James, Paul Ringold, Alan Krupnick, Robert J. Johnston, Matthew A. Weber, and Kim Hall, "Ecosystem Services Indicators: Improving the Linkage between Biophysical and Economic Analyses," *International Review of Environmental and Resources Economics* (2016).

Development of a Set of Common Causal Chains to Identify Consistent Non-Value-Based Measures

We propose that a set of common conceptual models be used to identify consistent non-value-based measures (BRIs) for tracking and assessing ecosystem services in a particular set of common decision contexts. To illustrate this proposal, we are using national forest plans, which lay out long-term goals and describe the types of projects and programs that will be used to achieve them. These plans are implemented through many individual projects over time, each with specific activities that are consistent with the plans.[13] There are significant similarities in the goals and related actions typical in national forest plans across the United States (Table 1), and these goals and actions can provide the basis for common ecosystem service conceptual models that are meaningful across sites.

Criteria to Improve Conceptual Models

According to ongoing research by Duke University and The Nature Conservancy, conceptual models can be improved by (1) focusing on results and outcomes, rather than execution of activities; (2) capturing target and non-target outcomes, environmentally mediated and direct impacts to people, and non-use values; (3) listing key testable assumptions in each link in the chain; and (4) making level of detail similar across services.

Table 1. Typical goals and actions for national forests

Goal	Actions
Fire risk reduction (frequency, severity)	Thinning, prescribed burns, chemical treatment
Wildlife support	Habitat restoration, road removal, fire management
Timber production	Harvest, thinning, replanting
Drinking water provision	Fire suppression, riparian zone management, thinning to reduce evapotranspiration
Healthy forest system	Invasive species and pest management
Increase recreational opportunities	Improving access (paths, docks), viewsheds, or siting opportunities

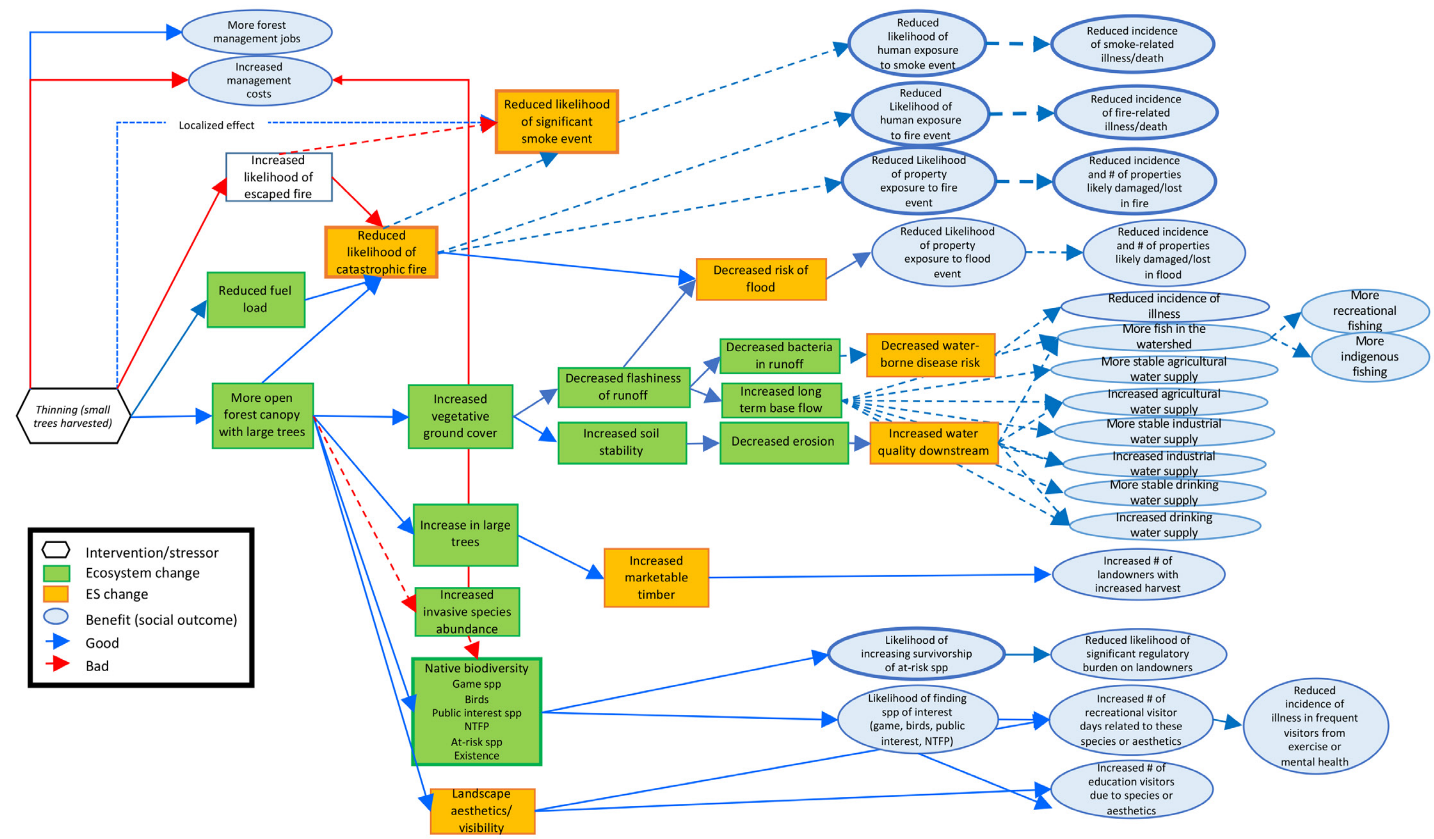
Once this list of common goals and actions is developed, conceptual models (made up of causal chains) can be developed for each distinct action. These models can be generic, reflecting how changes in the ecosystem will most often affect people across a diversity of sites and thus could include a set of services and metrics that can be used at all national forests. Managers of each national forest would start their planning with a relevant set of these generic models (one for each action they propose), along with the common set of services and metrics identified in that model.

Then, they would remove or expand particular parts of these models to tailor the model to the outcomes and measures relevant to their local needs. The use of the generic (common) models would allow national forests to quantify changes in a subset of common services and metrics for comparison across sites even if those services are not of primary importance in all sites. However, the development of consistent metrics should not in any way imply that non-consistent metrics are inferior or less relevant. In some cases, outcomes that are inconsistent across sites or actions may be of the greatest social relevance or value. It is essential that forest managers also consider the services that are unique to their site.

If fire-risk reduction is the goal and a conceptual model for the action of forest thinning is developed, it might yield a relatively robust set of potentially important ecosystem services outcomes that are frequently important across sites and actions (Figure 2). This model includes the primary benefits of fewer or less intense fires such as reduced mortality and property damage and improved species habitat in areas that burn, while also including non-target effects on soils and ground cover that affect aspects of water provision (both quality and quantity). This example also includes some direct social impacts not mediated through the ecosystem—jobs related to forest management and costs of forest management. Though imperfect, this example illustrates the type of conceptual model that could be developed and the level of specificity in outcomes that could lead to consistent measures across decision contexts.

[13] U.S. Department of Agriculture, U.S. Forest Service, *Land Management Planning 101*, by John Rupe and Regis Terney, white paper, U.S. Forest Service (2009), http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5110094.pdf.

Figure 2. Illustrative conceptual model developed for forest thinning to reduce fire risk in western U.S. forests

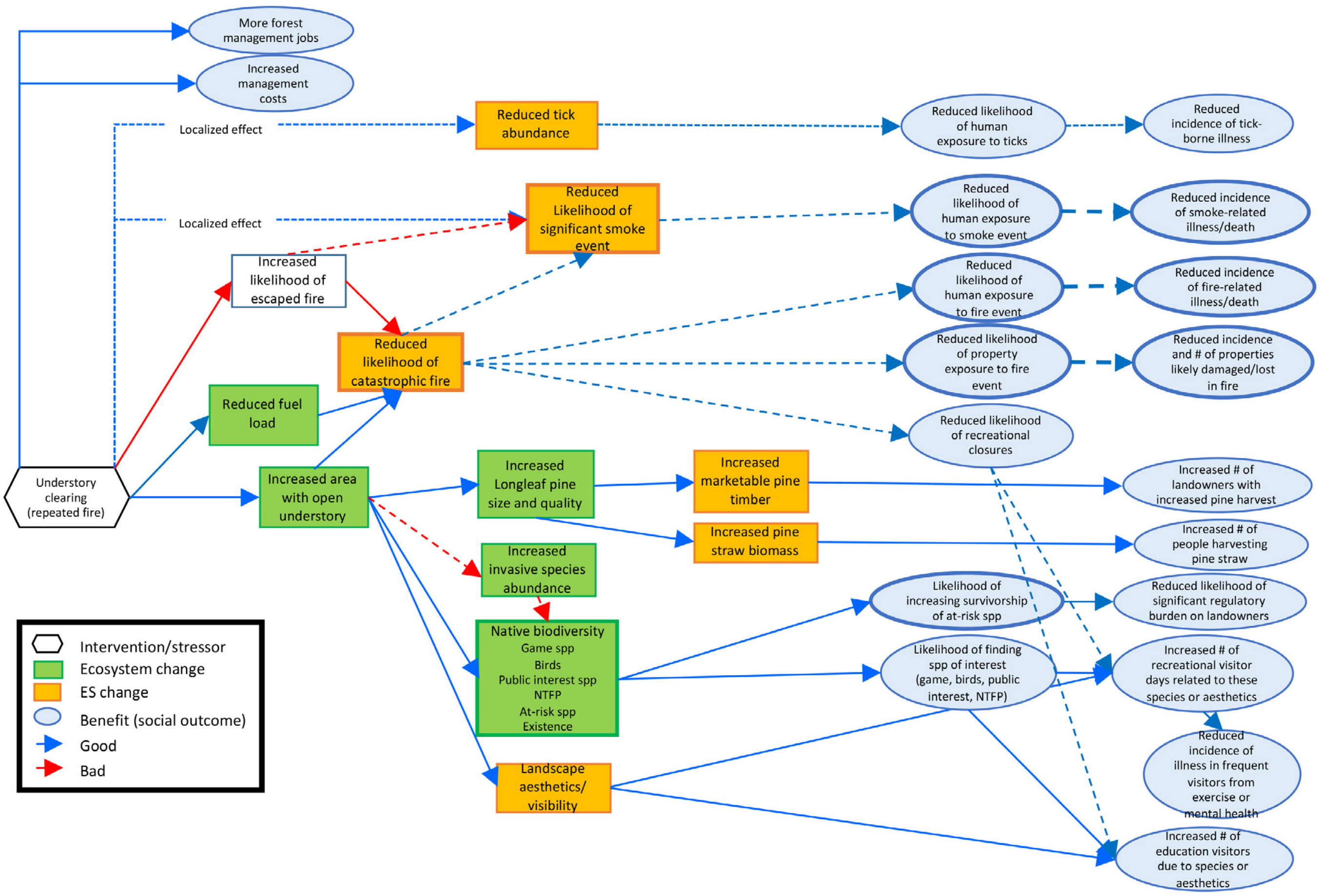


Note: Ovals with dark blue outlines = primary objectives; ovals with light blue outlines = co-benefits or unintended consequences. Large dashed lines = uncertain effects; small dashed lines = local effect. Climate stabilization through carbon sequestration and a few other possible outcomes are not represented because the direction and magnitude of their change are uncertain and possibly not significant.

The conceptual model developed for thinning in western U.S. forests can be adapted slightly (by shifting a few chains) to depict alternative mangement actions like prescribed burns. For example, the alternative diagram would need to add the direct effects of the prescribed fires (e.g., smoke, temporary diminshment of viewsheds) and remove the impacts of mechanical intervention on soils (e.g., compaction and its consequences).

To adapt this model to eastern U.S. forests, the core model depicted here would need to address those forests' primary issues—maintaining resilient habitat and protecting species (Figure 3). Because western forests are predominantly managed by public agencies, and eastern forests are mostly privately owned, the model for eastern forests also requires an extention on the front end (left-hand side) to represent policies or programs that encourage private landowners to thin their forests—incentives, education, or collaboration with a third party. Adding these policies and programs to the model raises the question if and how much they would affect the selection, location, and scale of forest management pracitices, which cascades through any later quantification of the full model. Despite significant differences in eastern and western fire management, the similarities of figures 2 and 3 suggest that a common core model (with a common subset of ecosystem services outcomes) can be developed to cover a suite of related mangement activities across broad geographies—with adjustment to reflect local priorities. They also suggest that decision makers may be able to identify a common suite of services and metrics that could be useful for regional or national comparison and for tracking benefits over time (Table 2).

Figure 3. Illustrative conceptual model developed for understory clearing by prescribed fire for improved health of eastern U.S. longleaf pine forests



Note: Ovals with dark blue outlines = primary objectives; ovals with light blue outlines = co-benefits or unintended consequences. Large dashed lines = uncertain effects; small dashed lines = local effect. Climate stabilization through carbon sequestration and a few other possible outcomes are not represented because the direction and magnitude of their change are uncertain and possibly not significant.

Use of a common causal chain model can aid analysts in selecting the ecosystem services and metrics that are common across geographies and institutions for a given decision context. It can also reduce confusion about the measures or metrics used for those services (e.g., focusing on BRIs rather than ecological structure and function, intermediate ecological changes, or economic outcomes). In the example models (figures 2 and 3), the measures with sufficient specificity to be useful for comparisons would be the social outcomes (things that are valued) in the blue circles as far to the right as possible. These outcomes would be measured using broadly applicable BRIs that will work across geographies and contexts. Selecting only one indicator from each chain should also result in a set of services that is less likely to count the same outcome/benefit twice. The potential for common models of ecosystem service outcomes from different types of management, policy, or infrastructure projects will depend on the degree of similarity in important ecosystem services across ecosystems, geography, and contexts. In some cases most or all important services will be similar.

Where these similarities are found, a subset of common services can be identified and used for comparision of actions, projects, or programs, even if they do not always include the most important services in each context. In other decision contexts, differences across ecosystems or institutions may preclude a common set of services. Models such as those illustrated above can help analysts determine the extent to which consistency is possible.

Table 2. Illustrative set of non-value-based ecosystem services measures (benefit-relevant indicators) from forest-fire-management conceptual models showing where common measures are possible and where they are not

BRIs (assess changes in indicators)	Possible units	Common measure?	
		Western forests	Eastern forests
Incidence of fire-related death in fire-prone areas	Annual deaths from fire relative to population density and scale of fire-prone area		
Incidence of fire-related injury or illness	Annual injuries from fire relative to population density and scale of fire-prone area		
Incidence of properties damaged by fire in fire-prone areas	Annual number of homes lost or significantly damaged by fire relative to home density and scale of fire-prone area		
Smoke-related mortality in airshed of forest fire	Annual deaths from smoke relative to population density and scale of fire-prone area		
Incidence of smoke-related morbidity (respiratory issues) in airshed of fire-prone area	Annual injuries from smoke relative to population density and scale of fire-prone area		
Flood-related mortality in watershed of forest fire	Annual likelihood of number of deaths from flooding relative to population density and scale of fire-prone area in affected watershed		
Flood-related property damage in watershed of forest fire	Annual lkelihood of number of homes lost or significantly damaged from fire-related flooding relative to density of homes and scale of fire-prone area in affected watershed		
Post-fire sedimentation damage to water treatment for municipal users	Number of affected municipal water users in fire-prone watershed each year		
—for agricultural users	Number of affected agricultural water users in fire-prone watershed each year		
—for industrial users	Number of affected industrial water users in fire-prone watershed each year		
Population viability of important wildlife species 1 (a widespread species) affected by change in understory (existence)	Population viability of specific species in fire-managed area (over specified time period)		
Population viability of important wildlife species 2 (locally important)– affected by change in fire frequency (existence)	Population viability of specific species in fire-prone area (over specified time period)		
Population viability of wildlife species 1 (a widespread species)for hunting	Population viability of specific species in fire-prone area (over specified time period)		
Population viability of locally important wildlife species 2 for hunting	Population viability of specific species in fire-prone area (over specified time period)		
Merchantable timber for public sector	Volume of wood harvested annually for USFS in fire-managed areas		
Non-timber non-market forest product collection	Annual number of collectors able to collect NTFPs of interest in fire-managed areas		
Nature visitation	Annual number of recreational visitors per acre in fire-managed area (aggregated measure)*		
Education visitation	Annual number of educational visitors in fire-managed areas		

Note: Dark green = one measure could be used in both management contexts; light green = specific measures may differ (due to different species of importance). * An aggregated measure may need to be disaggregated to capture important outcomes that may diverge with increased specification.

Further Insights on Building Consistent Metrics

Selecting consistent non-monetary metrics (BRIs) that can be compared (and sometimes aggregated) across multiple decision dimensions (e.g., locations and time periods) will require judgments about the degree of similarity in the underlying ecosystem service values. For example, the climate stabilization services derived from a ton of sequestered carbon can safely be treated as constant across geographic areas, but the services and value derived from harvested timber or from wilderness recreation days may vary depending on the types of tree species harvested or recreational activities enjoyed. For example, the economic value of recreation often differs depending on the type and location of recreational activities.[14] Moreover, similar or identical recreational activities may have different value in different areas. For this reason, valuation is beneficial when possible. It allows outcomes to be assessed in terms of the value contributed or the willingness of users to pay for these benefits, thereby capturing differences in value across services and locations.

Rolling together metrics that reflect different and potentially conflicting uses (e.g., hunting versus wildlife viewing) should be avoided. As a general rule, metrics should not be aggregated unless there is clear evidence that doing so would not provide a misleading perspective on the provision and value of ecosystem services. It is prefereable to use monetary or non-monetary values rather that non-value-based measures for ecosystem services when aggregation or rolling up of measures is desired.

As noted above, even when valuation methods result in common units of measure, what services are selected and how they are defined and quantified can vary. Valuing BRIs that are selected using conceptual models (as in Figure 2) can improve consistency in what is valued, increasing specificity in the types of indicators that are used (i.e., ecological indicators, such as openness of understory habitat, as compared to benefit indicators, such as annual number of bird watcher visitors). Although the use of conceptual models can help analysts select consistent measures to be valued, those measures do not have to be the same across sites for valuation to be undertaken. Valuation methods can also be used for comparison of programs, projects, and actions when services differ. Guidance on appropriate and standard methods for valuing different types of services exists.[15] Nevertheless, application of those methods can be inconsistent.[16]

How ecosystem services vary in space and time can also be important, both for service provision and value. How the dynamics depicted in the conceptual models occur over a landscape and over time will affect the size and potential importance of outcomes. The conceptual models provide a basis for conducting quantitative analyses that are spatially explicit. For example, fire models used by the U.S. Forest Service can incorporate data on landscape parameters to estimate the likelihood of fires of different types in different locations given different climate scenarios over time (e.g., FlamMap, www.firelab.org/project/flammap) and thus can be used to fill in the likelihoods for a causal chain in a larger model.

For the conceptual models, the relationships (arrows) linking the system changes (boxes) can be articulated and, in some cases, quantified using ecological production functions that connect management actions to ecosystem services outcomes.[17] Evidence in the form of expert elicitation, published research or models, or research-based models can be matched to each relationship (e.g., how thinning will change likelihood and type of fire) and assessed for its quality (certainty, precision, or repeatability). When ecological production models are spatially explicit, they can be used to test spatially variable management scenarios of activities such as forest thinning and estimate expected outcomes. They can also be compared to other conceptual models with alternative types of forest management, like understory burning or chemical treatment.

Would Using an Ecosystem Services Classification System Be Helpful?

A classification system can provide a relatively detailed matrix of the possible combinations of environmental types and ecosystem uses and benefits to generate a long list of possible ecosystem services outcomes of interest. These systems are by no means a requirement for consistency, but such a matrix or list of uses or beneficiaries can be used as a reference to spur consideration of additional services to help analysts work toward more comprehensive consideration of potential

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[14] See, for example, K. Moeltner and R.S. Rosenberger, "Cross-Context Benefit Transfer: A Bayesian Search for Information Pools," *American Journal of Agricultural Economics* 96(2)(2014), 469–488.

[15] For example, The National Ecosystem Services Partnership, Federal Resource Management and Ecosystem Services Guidebook, 2nd ed., by Lisa Waigner, Robert J Johnston, Kenneth J. Bagstad, Clyde F. Casey, and Tibor Vegh. National Ecosystem Services Partnership, Duke University, Durham (2014), www.nespguidebook.com; Patricia A. Champ, Kevin J. Boyle, and Thomas C. Brown, eds., *A Primer on Nonmarket Valuation: The Economics of Non-Market Goods and Resources* (New York: Springer, 2003); U.S. Environmental Protection Agency, Guidelines for Preparing Economic Analyses, EPA 240-R-10-001 (Washington D.C., 2010, updated 2014), https://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-50.pdf/$file/EE-0568-50.pdf.

[16] James Boyd, Paul Ringold, Alan Krupnick, Robert J. Johnston, Matthew A. Weber, and Kim Hall, "Ecosystem Services Indicators: Improving the Linkage between Biophysical and Economic Analyses," *International Review of Environmental and Resource Economics* 8(3-4)(2016): 359-443. doi:10.1561/101.00000073.

[17] "Ecological production functions characterize relationships between ecosystem condition, management practices, and the delivery of … ecosystem services." A.J. MacPherson, "Ecological Production Functions: A Theoretical and Practical Exploration" (paper presented at United States Society for Ecological Economics Conference, Washington, D.C., May 31–June 03, 2009).

outcomes. They can be used to refine indicators (endpoints) and focus attention on features that are provided by the ecosystem and appreciated by humans. And when analysts conduct valuation, use of classification systems can inform aggregation of services and reduce risk of double counting. However, one-size-fits-all classifications should be used with caution, because one size does not necessarily fit all in the context of ecosystem services.

Initial efforts to list or classify ecosystem services are useful for describing the connections between ecosystems and human well-being.[18] But they are limited as formal classification systems and were not intended to be used as such.[19] They can be difficult to use because of overlapping categories, which can lead to double-counting.

In the United States, the U.S. Environmental Protection Agency (EPA) has developed two related classification systems: the Final Ecosystem Goods and Services Classification System (FEGS-CS) and the National Ecosystem Services Classification System (NESCS).[20] Both systems are focused on identifying and classifying final ecosystem services by linking specific environmental classes with specific categories of human benefits and uses. FEGS-CS approaches the human dimension through a detailed classification of final ecosystem services "beneficiaries," whereas NESCS includes classifications for both human "uses" and human "users" of ecosystem end-products. Recently, a group of practitioners and experts from the National Park Service and the EPA held a workshop to explore how to better communicate the ecosystem services outcomes from reductions in nitrous and sulfurous oxide air pollutants. The group developed causal chain maps using the FEGS-CS system to help articulate the possible ecosystem services endpoints tied to specific beneficiary types. They found the classification system to be a useful tool for organizing the analysis and identifying distinct causal chains.[21]

A number of specific issues need to be considered and addressed when using a classification system. First, are services with non-use values sufficiently represented in these classification schemes, and, if not, how could this be addressed? Can these services simply be added during use and would they fit into the existing classification scheme? Second, could differences in the level of detail and disaggregation provided for different ecosystem services categories create the false impression that those services that are further expanded are more important than the services not expanded? For example, a simple count of the number of water users who care about water supply in a river, say, five (agriculture irrigators, energy generators, municipal water users, industrial water users, navigational users), and the number of recreators who care, say, four (boaters, fisherman, viewers, bird watchers) may be greater than the count of beneficiary groups with existence values for the water resource, say one (households with nonuse values). How do analysts achieve the right resolution and level of detail for all services? And how do analysts ensure that the selected categories and level of resolution are not misinterpreted to mean that each item on the list has equal value. Third, how are important intermediate services like carbon storage and sequestration captured and addressed in systems focused on the final benefits and end users? Moreover, all existing ecosystem services classification systems (including the EPA systems discussed above) have some ambiguities, including the specific point at which "natural" production ends and "human" production begins, and how analysts accommodate the many ways that ecosystems can affect nonuse values. Due to ambiguities such as these, even highly detailed and carefully developed classification scheme cannot alone ensure consistency when applied across different contexts. User caution and judgment will always be required.

The Nature Conservancy (TNC) has taken a different approach to capture all relevant and important services. TNC's practitioners are asked to consider a set of human well-being focal areas gathered from wide-ranging guidance documents, frameworks, and methods. These focal areas include specific aspects of living standards (e.g., income, basic needs), health (nutrition, vector-borne disease), education (training), work and leisure (jobs, personal activities), governance (rules, enforcement), social cohesion (level of cultural exchange, trust), security (safety, income security), and equity (gender

[18] Such initial efforts include G. Daily, ed., *Nature's Services: Societal Dependence on Natural Ecosystems* (Island Press, 1997) and *Millennium Ecosystem Assessment, Ecosystems and Human Well-Being,* by W.V. Reid, H.A. Mooney, A. Cropper, D. Capistrano, S.R. Carpenter, K. Chopra, P. Dasgupta, T. Dietz, A. Kumar Duraiappah, R. Hassan, R. Kasperson, R. Leemans, R.M. May, T. McMichael, P. Pingali, C. Samper, R. Scholes, R.T. Watson, A.H. Zakri, Z. Shidong, N.J. Ash, E. Bennett, P. Kumar, M.J. Lee, C. Raudsepp-Hearne, H. Simons, J. Thonell, and M.B. Zurek, *A Report of the Millenium Ecosystem Assessment* (2005), http://www.millenniumassessment.org/documents/document.356.aspx.pdf.

[19] James Boyd and Spencer Banzhaf, "What Are Ecosystem Services? The Need for Standardized Environmental Accounting Units," *Ecological Economics* 63(2-3)(2007): 616–626.

[20] Landers, D.H., and A.M. Nahlik*, Final Ecosystem Goods and Services Classification System (FEGS)*, EPA/600/R-13/ORD-004914, 2013, http://ecosystemcommons.org/sites/default/files/fegs-cs_final_v_2_8a.pdf; United States Environmental Protection Agency. 2015. *National Ecosystem Services Classification System (NESCS): Framework Design and Policy Application*, U.S. Environmental Protection Agency. EPA 800-R-15-002 https://www.epa.gov/sites/production/files/2015-12/documents/110915_nescs_final_report_-_compliant_1.pdf

[21] Blett, T. F., M. D. Bell, C. M. Clark, D. Bingham, J. Phelan, A. Nahlik, D. Landers, C. Davis, I. Irvine, and A. Heard. 2016. *Air Quality and Ecosystem Services Workshop Report: Santa Monica Mountains National Recreation Area, Thousand Oaks, CA – February 24–26, 2015.* Natural Resource Report NPS/ NRSS/ARD/NRR—2016/1107. National Park Service, Fort Collins, Colorado. . https://irma.nps.gov/App/Reference/Profile/2225739/; personal communication J. Phelan at workshop in New York, May 24, 2016.

income equity).[22] The adequacy of any of these approaches in terms of broad relevance to all beneficiaries depends on the extent to which the consulted practitioners or experts are able to identify outcomes relevant to (and valued by) the general public. Evidence from a variety of research literatures suggests that the values of experts often depart considerably from the values of non-expert beneficiaries.

It is worth exploring the use of classification systems or human well-being focal area lists like those noted above to see if they help identify important services. Tools for identifying (and not overlooking) relevant ecosystem services could be useful particularly if the group of decision makers and experts involved in the causal chain-making exercise are relatively new to the concept of ecosystem services. These classification systems and human well-being lists will work well in combination with clearly articulated and specified causal chain models. Both the conceptual models and the classification systems developed by the EPA are designed to ensure that the user does not (1) miss important ecological and social cascades and interactions, (2) fail to consider the potential for trade-offs or opportunities for co-benefits, and (3) overlook important contextual differences that cause relevant beneficiaries or ecosystem services to differ substantially from those present in predetermined lists or models. At the same time, classification schemes should not be used in the absence of carefully developed conceptual models (and causal chains). Off-the-shelf classification schemes are not intended to be used as a substitute for the development of models and BRIs; rather, they are intended as frameworks for organizing and identifying connections between ecosystems and human well-being—connections that may be helpful for site-specific evaluations.

Next Steps

This policy brief sets forth a proposal for building consistency into ecosystem services applications for common decision contexts. This proposal needs to be tested by practitioners and researchers. Exploration and development of the causal chain-based conceptual models is under way in the United States in a collaboration among the U.S. Geological Survey, other federal agneices, and Duke University's National Ecosystem Services Partnership. Similar exploratory efforts to test the use of the EPA classification system with partner agencies are also under way. In the next few years, these and other similar initiatives will inform best practices on increasing consistency in integrating ecosystem services considerations into decision making, designing conceptual models, and using classification systems.

[22] The Nature Conservancy, Conservation by Design 2.0 Appendix E. (version 1.0, March 2016), https://www.conservationgateway.org/ConservationPlanning/cbd/Documents/CbD2.0_Guidance%20Doc_Version%201.pdf..

National Ecosystem Services Partnership

The National Ecosystem Services Partnership (NESP) engages both public and private individuals and organizations to enhance collaboration within the ecosystem services community and to strengthen coordination of policy and market implementation and research at the national level. The partnership is an initiative of the Nicholas Institute for Environmental Policy Solutions and was developed with support from the U.S. Environmental Protection Agency and with donations of expertise and time from many public and private institutions. The partnership is led by Lydia Olander, director of the Ecosystem Services Program at the Nicholas Institute, and draws on the expertise of federal agency staff, academics, NGO leaders, and ecosystem services management practitioners.

Nicholas Institute for Environmental Policy Solutions

The Nicholas Institute for Environmental Policy Solutions at Duke University is a nonpartisan institute founded in 2005 to help decision makers in government, the private sector, and the nonprofit community address critical environmental challenges. The Nicholas Institute responds to the demand for high-quality and timely data and acts as an "honest broker" in policy debates by convening and fostering open, ongoing dialogue between stakeholders on all sides of the issues and providing policy-relevant analysis based on academic research. The Nicholas Institute's leadership and staff leverage the broad expertise of Duke University as well as public and private partners worldwide. Since its inception, the Nicholas Institute has earned a distinguished reputation for its innovative approach to developing multilateral, nonpartisan, and economically viable solutions to pressing environmental challenges.

Review

The work reported in this policy brief benefited from review from federal agency and academic experts and reflects their valuable feedback. However, it has not undergone a formal review process.

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