U.S. Department of the Interior
Office of Policy Analysis

Report

Complex, interacting issues shape landscape-scale mitigation policy needs

Compensatory mitigation is used to balance competing mission requirements of protecting and developing resources for the Department of the Interior and beyond. While mitigation is driven on an action-by-action basis, the harms to resources and the offsets of those harms occur within complex landscapes. To understand the major issues affecting or affected by landscape-scale mitigation (LSM) policy, we conducted a review of relevant science and policy research. Four main themes emerged: natural processes, socio-ecological factors, economics, and management and policy tools. Ecosystem connectivity and landscape dynamics, timing of mitigation, and capacity for dynamic outcomes are key natural processes affecting LSM policy. Environmental justice and equity, cultural resources, and social norms stood out as key socio-ecological topics for LSM. For economics and LSM, the low elasticity of mitigation credit pricing, the role of environmental and landscape equivalency, the timing of investing mitigation funds, and the effect on other sectors of the economy were relevant. Last, among management and policy topics, key issues included coordination with other restoration and conservation activities, landscape-scale extensions of local mitigation topics (e.g., durability, adaptive management), mitigation translocation, marine LSM, and the landscape context of major categories of mitigation, such as banks. In addition to the policy relevance of each of these topics, the need for coordinating efforts across the landscape, whether through technological or social tools, is clear. Policies addressing these issues will help ensure LSM is as effective as possible in advancing the mission of the Department.

Publication date: 2024-11-01

The Department of the Interior and its bureaus and offices have statutory, regulatory, and policy obligations to protect and manage the Nation's natural and cultural resources. For example, various laws require protecting threatened and endangered species,[1] providing for general conservation,[2] and protecting archaeological resources.[3] At the same time, there are legal requirements and social needs to take or permit actions like energy development,[4] mineral production,[5] or other multiple uses[6] that may harm those resources requiring protection. These diverse requirements can lead to conflicting options for how to carry out our mission. How we resolve such competing interests has shifted over time as science and practice have improved our knowledge and methods for meeting multiple goals.

One key strategy for balancing competing requirements is mitigating the effects of our actions. Given competing needs for actions in a particular place—conserving a resource vs. developing a resource for human use—the preferred order of mitigation is to (1) avoid harms to the protected resource; (2) minimize harms to the protected resource; then (3) allow harm to the protected resource but offset or compensate[a] the effects of the harm. This is the well-known *mitigation hierarchy*[b], typically summarized as to avoid-minimize-compensate, which is foundational in mitigation science and policy.[10,11]

[a] We use "offset" and "compensate" interchangeably here, depending on the norm of the topic at hand.

[b] Note that most contemporary scientific treatments consider a four-stage hierarchy—avoid, minimize, remediate, offset—to recognize that local remediation of impacts to resources will generally be preferable to offsetting the harm at some remote location,[7–9] but that distinction is not reflected the same way in Federal policies such as NEPA regulations.

Table 1. We identified four main domains and over 20 topics in the landscape-scale mitigation literature.

Domain	Topic	Domain	Topic
Natural processes	Landscape ecology	**Economics**	Regulatory predictability
	Connectivity and corridors		Price (in)elasticity
	Metapopulations, etc.		Equivalency Analysis (EA)
	Heterogeneity		Landscape EA
	Timing of mitigation		Timing and investment
	Dynamic outcomes and adaptation		Effects on broader economy
Socio-ecological	Environmental justice	**Mgmt. & Policy**	Action coordination
	Resource "migration" through mitigation		Core mitigation concepts at landscape scale
	Cultural resource impacts		Mitigation translocation
	Sociopolitical dynamics		Jurisdictional fragmentation
			Spatial and mitigation approaches (e.g., ILF, banks)

Considerable attention has been paid to the science and practice of compensatory mitigation at local scales. Less attention has been paid to (a) how individual compensatory mitigation actions affect or are affected by landscape-level dynamics or (b) how large infrastructure projects—especially linear features like roads and transmission lines[12]—affect landscapes and can be mitigated. In many ways, these are cumulative impacts that have been largely underappreciated and unaccounted for in the past, but that are amenable to policymaking to improve outcomes. Further, we know that our actions today, including for mitigation, must account for landscape-level changes driven by climate change[13,14] and other forms of environmental change.[15–17]

Compensatory mitigation can be considered a particular form of the broader domain of ecological restoration. As one practitioner noted, "Restoration is just fixing damage that wasn't mitigated when the damage was done," (R. Madsen, *pers. comm.* to JM). Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" and restoration ecology is the science of the process.[18] Compensatory mitigation can then be considered restoration that is required under law, regulation, or policy.

To better understand the state of the science and practice on the range of topics and issues related to landscape-scale mitigation (LSM), we reviewed key science, policies, and practice to inform policy making. This is intended to complement other knowledge and resources on mitigation that tend to focus on local issues but that may overlap with landscape topics. We structure the results along four major themes: LSM as related to natural processes, the socio-ecological landscape, economic implications, and key management and policy tools (Table 1).

Natural processes

Actions that harm natural resources have effects at multiple scales because those resources are part of larger landscapes. In some cases, classic landscape ecology[19] or ecosystems science address the role of geography in understanding how systems function and interact. Resource managers have learned these general principles in both their formal training and through experience in carrying out management and conservation activities.[20]

The spatially explicit nature of landscapes and patchiness of ecosystems has additional relevance to LSM through key sub-fields of ecology. Individual species are typically distributed in *metapopulations*—discrete populations in patches connected by dispersal and source-sink dynamics[21]—such that the dynamics of one patch may affect the dynamics of others and the system, such as metapopulation persistence. Species are parts of communities structured in *metacommunities*, or groups of interacting species distributed among patches, affected by environmental filtering, competition and predation, ecological drift (i.e., random losses or gains), and

dispersal.[22,23] Metacommunities are embedded in *metaecosystems*, which combine biological processes with ecosystem processes such as the flow of materials and energy through the system.[24,25] Within the scopes of metapopulations, metacommunities, and metaecosystems, the roles of geography, corridors and connectivity, local and multi-scale population dynamics, characteristics of diversity, and capacity for providing services play critical roles in understanding how natural systems function. For LSM, this means policies that span local-level to systems-level issues.

There are several emergent properties of landscapes,[26] that is, characteristics that cannot be defined or predicted from individual components, with relevance to LSM. Three examples are:

- Landscape heterogeneity, a characteristic essential for the maintenance of biodiversity[19,27,28], is a property of the set of areas in a landscape. As such, LSM policies are appropriately scoped for providing direction on the maintenance or dynamics of heterogeneity, rather than policies focused on individual or local actions. Heterogeneity of resources across the landscape also affects whether there are efficiencies to be gained by offsetting multiple resources or processes in one place, which may occur in some cases[29], may not in others[30], or may change with climate change[31].
- Nonlinear dynamics are emergent properties of landscape-scale processes. For example, loss of connectivity among sites is highly nonlinear because of the network structure of a landscape[32]. This matters for LSM because site-specific decisions, like authorizing the destruction or creation of habitats in specific places, will have complex impacts beyond a specific site.
- The core conservation concepts of *r*epresentation, *r*esilience, and *r*edundancy (3Rs)[33] only apply among sites. Ensuring appropriate representation of a species, ecosystem, function, or other resource across a landscape can't be evaluated at a single site. Resilience, whether to climate or other environmental change, is a property of the system. And redundancy may be supported by individual sites but is a characteristic of the whole.

One factor with significant implications for compensatory mitigation is the timing of the harm and the offset.[34] For example, Gutrich and Hitzhusen found the time before ecosystem services were fully available for wetlands in Ohio and Colorado ranged from eight to 50 years, with a median time of 33 years required.[35] Southwell and colleagues considered how to optimally time mitigation given the range of time for recovery, opportunities for pooling investments, and other factors, finding that early versus delayed mitigation depends on the details of the system.[36] The relevance of the timing of the harm and offset can be related to the biology, ecology, or ecosystem processes of the resources. For example, many breeding amphibians require functioning vernal pools in the late winter through spring, a factor essential when planning and carrying out compensatory mitigation and LSM.[37] Further, the timing of mitigation can have an economic dimension (see Economics, below).

Clearly articulating the desired outcomes on natural processes of compensatory mitigation is essential for evaluating success. That process is not necessarily straightforward. Classically, the idea is to offset content and processes to some reference conditions, but such an approach has distinct drawbacks: as Hilderbrand and colleagues discuss, thinking of the goal as a static outcome is not as helpful as aiming for dynamic, adaptive systems.[38] This is particularly important given the need of mitigation (and restoration generally) for adaptation and resilience to climate and other forms of environmental change.[39]

Socio-ecological landscape

Compensatory mitigation has fundamental impacts on humans and our well-being, such as ecosystem services on which people depend (see below). Because resources, people, and our actions are all distributed unequally in space, there is an increased chance of disparate effects. This is especially true given historical and current lines of authority, wealth, and race, among other factors.[40,41] This can be as direct as differences in equity to accessing natural resources and related infrastructure.[42] Past wetlands mitigation has had disparate socioeconomic impacts around Chicago;[43] wetlands mitigation programs

have likely resulted in a "migration" of wetlands ecosystem services from urban areas to rural areas;[44] and could have impacts much more broadly, though the breadth is not yet known.[45]

Critically, it may be challenging to identify environmental injustices arising from compensatory mitigation on a case-by-case basis. The number of people in an affected area might be small, there may be a wide distribution of demographic characteristics, and so-forth. But through the lens of LSM, the potential for harms and benefits can come into sharper focus. The examples referenced above are fundamentally landscape-level evaluations showing cumulative injustice. Relatedly, Accatino and colleagues showed how the spatial distribution of ecosystem functions could be dramatically altered with basic LSM policies, either concentrating functions in small parts of the landscape or distributing them more equitably.[46] We anticipate that a similar pattern would be found for justice issues. In addition to LSM policy to guard against new injustices, LSM policies could work to rectify past injustice, especially when combined with restoration efforts that consider environmental justice issues as part of the decision-making process.[47]

While much of the literature on mitigation is focused on natural resources, cultural resources may also require LSM, in particular avoidance and minimization. For example, archaeological resources occur at specific places but are also part of a larger landscape of cultural resources that requires consideration for their conservation.[48,49] The full suite of sites across a landscape is necessary for building a whole system understanding of past societies and may be essential to cultural continuity today. This holistic view of resources is similarly reflected in Indigenous Knowledge and Indigenous methodologies ways of knowing.[50,51] The Permian Basin Programmatic Agreement from the Bureau of Land Management and partners has been deemed a successful model for a landscape-level approach can work for cultural resources, especially when rapid development pressure targets public lands that have extensive cultural resources.[52] An LSM policy that accommodates both natural and cultural resources can promote a more holistic approach to management and, in turn, support Indigenous culture and knowledges.

Understanding the normative values of the public on a given topic are helpful for drafting policies. We did not find any clear evaluations of broad public views on mitigation or LSM in our review. We did, however, note a pair of academic papers that discuss rising partisanship on mitigation.[53,54] While helpful to understand recent dynamics, these law reviews do not report public attitudes that might inform LSM. Further, it is worth noting there is hesitancy toward mitigation from some conservation scientists and environmental advocates.[55,56] For example, they argue that mitigation "are successful 'symbolic policies,' obscuring biodiversity loss and dissipating impetus for action."[55]

Economics

The interplay of economic processes such as market dynamics, risk, and LSM policies can be direct and complex. On one hand, mitigation can reduce regulatory burdens and improve regulatory predictability by contributing to not just site-specific restoration, but the broader landscape of functions on which people and nature depend.[57] On the other hand, the economics of LSM can be complex. For example, research into mitigation supply and demand suggests that habitat conservation banking credits are price inelastic, indicating that credit pricing policies do not have a strong influence in the conservation banking market.[58] If mitigation credit prices change then demand changes little, and if credit supply changes then price changes little. The reason for the inelasticity appears to be that economic activities—especially those associated with projects such as housing/commercial development, transportation, oil and gas development, and public infrastructure—influence demand for credits while land value and acreage influence the supply. Ultimately, the objective is for the market to help achieve the best outcomes at least cost to all market participants,[59] which LSM policies can support by reflecting economic science.

Economics has played an important role through efforts such as Equivalency Analysis (EA) and similar approaches that are well-known for estimating the value of required compensatory mitigation. Some of these analyses are effectively required under Federal law[60] or regulations and under regular evaluation.[61] New capacities—data, methods—to calculate the monetary

value of natural resources and processes are an area of active development beyond just mitigation and restoration. For example, the international framework for valuing natural capital[62] is essential to the Federal effort to establish natural capital accounts for the US,[63,64] which may improve our ability to account for ecosystem services (i.e., nature's benefits to people and society[65]) in decision making.

In the past decade, additional developments have extended the basic ideas of EA to the landscape, such as through Landscape Equivalency Analysis (LEA). In LEA, the geographic location and scope of impact site and offset site, and their landscape context, are explicitly considered in calculating equivalencies and credits or debits.[66,67] Data limitations, the complexity of the methods, and an historic lack of attention on LSM may have limited the use of LEA in the past. However, technological, data, and computational advances of the past two decades[68–70] may increase LEA feasibility and LSM policy can accommodate its growth.

The timing of LSM overlaps with two key economic issues. First is the role of scale of offsets: in the scope of a landscape it may make ecological and economic sense to wait to carry out an offsetting project while compensation funds are pooled across actions[36]. Second, while there are proposals for complex trading schemes that could offset the challenges of timing issues, the reality is that such approaches are likely to fail in real-world implementation.[56] LSM policies could accommodate both issues by focusing on outcomes and the relevance of simplicity in implementation requirements.

Landscape-scale mitigation can have secondary effects on economic systems. For example, mitigation actions may change recreational opportunities at a local site (e.g., reducing or improving access), then may shape the suite of opportunities for recreation near one-another in the

Box 1. Some management and policy concepts originally developed for site-specific mitigation have clear analogs for landscape-scale mitigation. These include:

- Durability, or the assurance that compensatory actions have an effect lasting at least as long as the duration of the harm from the action being mitigated. If an action harms connectivity on which a resource depends for normal function, then connectivity must be offset.
- Additionality, or ensuring compensatory actions that would not have otherwise been done but for the harm being offset. For example, the mitigating party can only receive offset credits for connectivity, metapopulation source populations, or other relevant processes if those processes are added to the landscape rather than claimed .
- Substitutability, or the concept that a resource or its function may be substituted by offsetting actions. There is only one Grand Canyon, and its landscape cannot be offset or substituted. In contrast, the complex tapestry of habitats in a coastal wetland may be recreated in different places, given the right conditions and treatment.
- Monitoring, or the process of tracking the effects of an action. For LSM, this means monitoring and evaluation not just within sites (e.g., "Is the site in compliance with the terms of the mitigation agreement?") but among sites in the landscape (e.g., "Are the actions among sites producing landscape-level outcomes?"). At the landscape level it is particularly important to avoid monitoring only generalist species that may not be representative of the suite of requirements that need to be offset[35].
- Adaptive management, the process of taking resource management action; monitoring effects of the action; and adjusting subsequent management actions to improve outcomes based on the monitoring[73–75]. There are two main implications of adaptive management for LSM:
    - Landscape-level management programs that include mitigation need landscape-level monitoring that feeds into landscape-level adaptive management decisions.
    - At a programmatic level, adaptive management is analogous to evidence building. Because building evidence to inform policy- and decision-making is required by Federal law[76], LSM policy should include requirements for landscape-level evidence building.

landscape. Compensatory mitigation in a remote location may limit the potential for recreational use because it's not part of a regional landscape ("tourismscape") where people can do several things in a visit.[71] That research also highlighted the importance of establishing a shared community vision for how ecological tourism—and therefore activities like restoration and compensatory mitigation—is part of the fabric of the economic landscape of a community. This underscores the importance of LSM policy as being part of a larger landscape of activities and interests.

Management and policy tools

One of the most fundamental concepts of LSM practice is the need for coordinating actions through management and policy tools. This isn't restricted to coordinating mitigation actions, or actions carried out or permitted just by a single governmental department.[59] Instead, it means coordinating with work on area-based protections,[29,72,73] voluntary restoration activities, actions by States and Tribes, and other efforts that are advancing resource conservation. Authorities for such coordination may include the Fish and Wildlife Coordination Act, the Federal Lands Planning and Management Act, interagency or other multiparty agreements (and their underlying authorities). The full range of possible mechanisms or bodies for coordinating landscape activities and LSM is beyond the scope of this review. Examples range in scale from large segments of the continent, like migratory bird flyways;[c] to regional efforts, like the Southeast Conservation Adaptation Strategy (SECAS);[d] to highly local and detailed efforts, such as the San Diego Mitigation Monitoring Coordination office.[e] Several topics[74] in compensatory mitigation management and policy have developed in the context of local actions and are relevant to LSM coordination (Box 1).

Assisted translocation—the intentional movement of individuals to advance conservation goals—is a tool that practitioners use to advance conservation of populations in the face of local, regional, and global change. "Mitigation translocation" is considered a subset of the translocation topic because it is usually driven by crisis—a need to act immediately to protect individuals from harm of an action—rather than being part of a standing conservation program.[75] Reviews of mitigation translocation found limited evidence of success and broad evidence that key processes of mitigation translocation have not been tracked.[75,76] For landscape-scale mitigation, this suggests policy responses that might include (a) requiring the use of a standard checklist of mitigation translocation issues that need to be addressed for projects and tracking results; and (b) strong priority given to mitigation proposals that include translocations that are part of a conservation translocation plan rather than ad hoc translocations. Further, both translocations and natural movements in the face of climate and other environmental change raise issues of jurisdictional fragmentation.[77]

Most of the literature and policy development for LSM has been focused on terrestrial systems, but impacts to and mitigation in marine and nearshore systems is relevant. Market-based instruments may be used to help mitigate the effects of people's use of marine systems. Some reviews of compensatory mitigation in marine environments found little evidence to support its effectiveness,[55,78] but the landscape-level implications were not investigated. Based on this limited evidence, LSM policy may need a more precautionary approach for marine systems to ensure effectiveness. One general topic of interest demonstrated in a marine environment was the utility of offsets achieved through an action different than the harm. Wilcox and Donlan showed how funds from fishers harming seabirds in bycatch were used to control invasive predators of the seabirds, which was 23 times more cost-effective for conserving the birds than trying to stop fishing activities.[79] An LSM policy could consider when and how to allow offsets other than kind-for-kind to achieve specific objectives.

Last, we close with reference to the three main compensatory mitigation approaches discussed in the literature and policy:[74] in-lieu fee (ILF) mitigation, mitigation banking, and permittee-responsible mitigation. A full discussion of these approaches is beyond the scope of this review, but each has issues relevant to LSM.

[c] https://bit.ly/FWS_flyways
[d] https://secassoutheast.org/
[e] https://bit.ly/SanDiego_MMC

Perhaps most important is spatial aggregation. Mitigation banks tend to be spatially clustered, which means that offsets will be clustered even if the resources or functions were originally spread across a much broader scale,[80] but some researchers have suggested banks have high potential for LSM in principle,[81] The additional flexibility of spatial location for ILF and PRM may alleviate some concern, but the fact that mitigation happens after the impact for both of these—and therefore increases the risk that the offsetting may not be successful—may introduce a tradeoff for decisionmakers to grapple with at landscape scale.

Conclusion

To be most effective, policy and guidance should reflect the current state of knowledge[82] about the needs, effectiveness, and options available for landscape-scale mitigation. In this rapid review, we found over 20 detailed topics in the scientific and policy literature, ranging from knowledge of natural processes to socio-ecological implications to economics to management and policy science. Together, these help to identify the range of issues that decision makers will need to address for LSM policy.

To address several of the issues uncovered in this review, there is likely a need for additional investment—or a coordinated alignment of current investments—to facilitate coordination, whether through technological or social infrastructure. For example, the forthcoming *Conservation and Restoration Atlas*[83] is a promising technological solution that may provide a national-level view of mitigation, restoration, area-based conservation, and other conservation actions to facilitate landscape-level coordination. A complementary option may be to convene workshops to catalog the many landscape-level resource management efforts that are spread across the US and then link them in a central hub or federated resource. Notably, this will mean multi-scale scoping since the focus of such efforts depends on the resources, from small watershed-based scope to regional efforts like SECAS or migratory bird flyways. There are also opportunities for public-private partnerships and for private investment to play a role in expanding mitigation options, reducing mitigation costs, and improving mitigation effectiveness[84]. Any LSM policies should accommodate and support the use of both technology and social approaches. Combined with policies that cover the specific topics discussed above, such an approach would cover most of the key issues that help ensure mitigation across landscapes is as effective as possible.

Methods

We used a structured rapid literature and knowledge review for this work. In brief, we sought to answer the fundamental question, What are the major concepts and themes of landscape-scale mitigation in the literature and in practice that should inform department-level policy? To help guard against spurious results, we restricted our search to seven initial queries focused on seven combinations of "compensatory mitigation," landscape, and terms including "market OR risk," "environmental justice," "metapopulation OR metacommunity OR metaecosystem," "opinion OR values," "policy OR regulation OR law," and "marine OR nearshore." In limited cases when a paper lacked sufficient information to make an informed evaluation of the relevance to LSM, we traced the literature for additional references while being conscious to reduce the risk of data mining. We reviewed all papers at least at the level of abstracts or executive summaries, and more deeply reviewed those that seemed relevant to the policy question noted above. Last, we synthesized our notes to identify dominant themes and sub-topics, as presented above.

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Acknowledgements

We thank members of the Department of the Interior Landscape-level Working Group for many discussions on the issues of mitigation at the landscape scale, which were essential for scoping and carrying out this review.

Peer Review

We thank three peer reviewers who provided very helpful feedback that improved the quality of this Report. The Peer Review Plan and the reviews are available at https://doi.gov/ppa/

Disclaimers

The report content does not necessarily reflect the views and policies of the U.S. Department of the Interior. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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