A Framework for Implementing Biodiversity Offsets: Selecting Sites and Determining Scale

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Biodiversity offsets provide a mechanism for maintaining or enhancing environmental values in situations where development is sought despite detrimental environmental impacts. They seek to ensure that unavoidable negative environmental impacts of development are balanced by environmental gains, with the overall aim of achieving a net neutral or positive outcome. Once the decision has been made to offset, multiple issues arise regarding how to do so in practice. A key concern is site selection. In light of the general aim to locate offsets close to the affected sites to ensure that benefits accrue in the same area, what is the appropriate spatial scale for identifying potential offset sites (e.g., local, ecoregional)? We use the Marxan site-selection algorithm to address conceptual and methodological challenges associated with identifying a set of potential offset sites and determining an appropriate spatial scale for them. To demonstrate this process, we examined the design of offsets for impacts from development on the Jonah natural gas field in Wyoming.

Keywords: biodiversity offsets, mitigation hierarchy, no net loss, Marxan site selection

Between one-third and one-half of Earth's land surface has been altered by human action (Vitousek et al. 1997), resulting in an unprecedented loss of biodiversity. As a result, some 10 to 30 percent of all mammal, bird, and amphibian species are threatened with extinction (Levin and Levin 2004, Kiesecker et al. 2004). Looking forward, such impacts could increase dramatically: the global economy is expected to double by 2030 (World Bank 2007), and unprecedented investments are being made in resource development to support this growth, especially in developing countries (IEA 2007). Given the importance of economic development for improving human well-being, there is greater pressure to find ways to balance the needs of development with those of biodiversity conservation.

Biodiversity offsets are one important tool for maintaining or enhancing environmental values in situations where development is sought despite detrimental environmental impacts (ten Kate et al. 2004, McKenney 2005, Gibbons and Lindenmayer 2007). Offsets are intended to be an option for addressing environmental impacts of development after efforts have been undertaken to minimize impacts on-site through application of the three other steps of the mitigation hierarchy: avoid, minimize, restore (40 C.F.R. 1500.2). They seek to ensure that inevitable negative environmental impacts of development are balanced by environmental gains, with the overall aim of achieving a net neutral or positive outcome (see figure 1).

Offset policies for environmental purposes have gained attention in recent years (e.g., Environmental Defense Fund 1999, Government of New South Wales 2003; see McKenney 2005 for a review). Although the use of offset activity remains relatively limited, offsets are increasingly employed to achieve environmental benefits, including pollution control, mitigation of wetland losses, and protection of endangered species (ten Kate et al. 2004, McKenney 2005). Offset activity is most active for US wetlands, where methods and programs have been under development for the past two decades. Wetland offsets in the United States have increased dramatically, with 6000 hectares (ha) per year in the early 1990s growing to an average of more than 16,000 ha per year since 1995 (Environmental Law Institute 2002). Offset programs have also been established or are developing in other parts of the world, including Australia, Brazil, and the European Union (McKenney 2005, Gibbons and Lindenmayer 2007).

Offsets offer potential benefits for industry, government, and conservation groups alike (ten Kate et al. 2004). Benefits for industry include a higher likelihood that permission will be granted from regulators for new operations, greater

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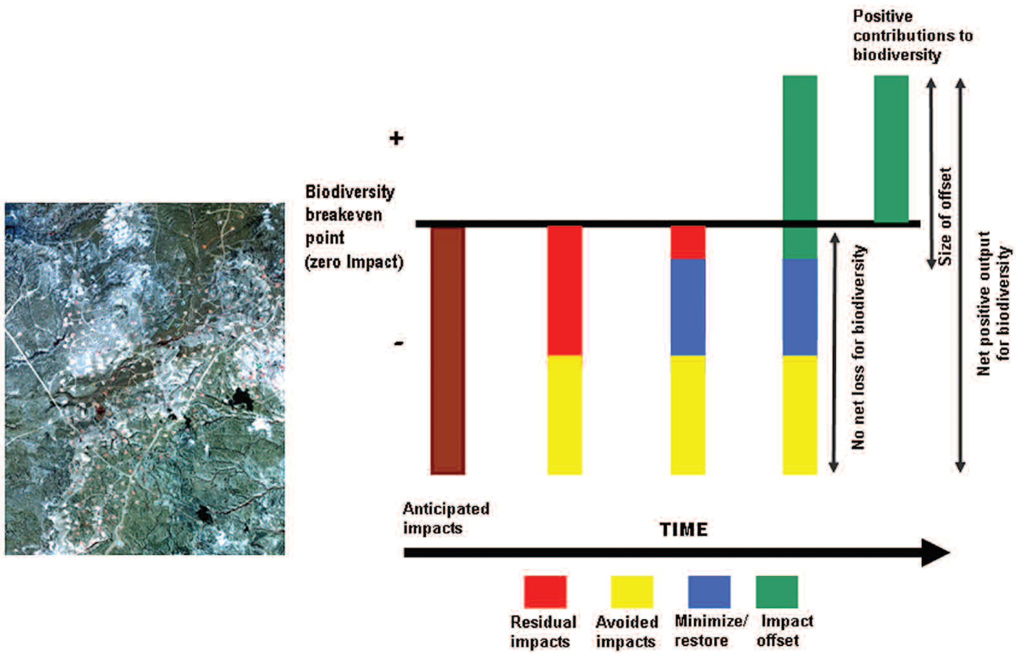

Figure 1. The role of offsets in achieving no net loss (or better) for biodiversity. Impacts to biodiversity are represented here as surface disturbance. Avoided impacts to the project area are in accord with the surface disturbance cap of 5677 hectares (ha), or 46 percent of the project area. Additional surface disturbance will be minimized through the use of drilling mats on 25 percent of the 3100 wells. Wells in the Jonah Field are projected to result in approximately 1.6 ha of surface disturbance per well. Drilling mats reduce approximately 0.81 ha of surface disturbance, resulting in a reduction in approximately 627 ha or about 5 percent reduced surface disturbance. We estimated about 5 percent residual surface disturbance would remain after production activities ceased and restoration was completed in 30 to 50 years. The size of the offset (17,031 hectares) was based on an estimated 3 to 1 ratio of on-site impact to offset (USDOI 2006). The inset is an aerial view of the Jonah Field taken before the infill project that prompted the offset requirement (image courtesy of NASA/GSFC/METI/ERSDAC/JAROS and the US/Japan ASTER Science Team).

societal support for development projects, and the opportunity to more effectively manage environmental risks. Offsets provide governmental regulators with the opportunity to encourage companies to make significant contributions to conservation, particularly when legislation does not require mandatory offsets. Conservation organizations can use biodiversity offsets to move beyond piecemeal mitigation, securing larger-scale, more effective conservation projects. Offsets can also be a mechanism ensuring that regional conservation goals are integrated into governmental and business planning.

Although offsets have great potential as a conservation tool, their establishment requires overcoming a number of conceptual and methodological challenges (Burgin 2008). One of the key questions is how offsets should be located relative to the affected site. When on-site impacts warrant the use of offsets, there is often a tension between choosing sites as close to the impact site as possible (ensuring that benefits accrue to the same area) and choosing sites likely to provide the greatest conservation benefit (with less regard to spatial position). To date, no one has found a way to determine appropriate distances for offsets. Here we propose a framework to address this need. Our proposed framework for offset site selection includes two major components. First, we develop a series of rules (offset goals) for selecting offset sites that meet the conservation needs of potentially affected biological targets (i.e., size, condition, landscape context). Next, we use a site-selection algorithm developed for Marxan (Ball 2000, Ball and Possingham 2000, Possingham et al. 2000) to search for sites at increasing spatial extents. Offset sites can then be chosen from the closest extent at which impact goals are met.

Our objective is to design an approach ensuring that offsets are ecologically equivalent to impact sites and will persist at least as long as on-site impacts, and that they will achieve net neutral or positive outcomes. We propose five steps for this approach: (1) assemble a working group, (2) compile a list of representative biological targets, (3) gather spatial data for biological targets, (4) set impact goals for each biological target, and (5) use the Marxan algorithm at increasing spatial extents to identify potential offset sites. To demonstrate the approach, we present a case study from the Jonah natural gas field located in southwestern Wyoming. British Petroleum, one of the principal operators on the field, expressed the need for a structured framework to guide the disbursement of mitigation funds and invited the Nature Conservancy to design such a plan.

Study area description: Jonah natural gas field

Located in Wyoming's Upper Green River Valley, the 24,407-ha Jonah natural gas field is considered one of the most significant natural gas discoveries in the United States in recent times, with an estimated 7 trillion to 10 trillion cubic feet of natural gas (USDOI 2006). During the last 10 years, the field has become one of the nation's richest gas fields, currently with approximately 500 wells. The Bureau of Land Management (BLM) granted regulatory approval in 2006 to infill the existing 12,343-ha developed portion of the field with an additional 3100 wells (USDOI 2006). As a requirement of the infill project, an off-site mitigation fund of $24.5 million dollars was established (USDOI 2006).

The Jonah Field is located in a high-desert sagebrush ecosystem that provides critical habitat for migratory big game, songbirds, and raptors, within the southern reaches of the Greater Yellowstone Ecosystem. Some of the world's largest herds of large game species (pronghorn antelope, *Antilocarpa americana*) winter here, relying on the valley's snow-free forage to get them through harsh winter weather. Migratory pathways lace the area, connecting the winter range with alpine terrain in five nearby mountain ranges. This area is also a stronghold for the greater sage-grouse (*Centrocercus urophasianus*), an emblematic native game bird now being considered for listing under the Endangered Species Act. Because wildlife in the field had already incurred significant impacts before the infill (TRC Mariah Associates Inc. 2004), off-site mitigation was considered an appropriate tool for the anticipated additional disturbance.

Assembling a working group

A mitigation-design working group was formed to guide development of the process of offset designation and integration of spatial data into the site selection process. All participants had expertise and involvement with the biological systems affected by the Jonah Field development; the group included representatives from state agencies (Wyoming Game and Fish Department, Wyoming Department of Environmental Quality), federal agencies (BLM, US Fish and Wildlife Service), universities, biological consulting firms, and the local agricultural production community. This group helped secure the most current spatial data on species of concern, assessments of the predictive models being developed, and insights into the process being developed. We sought to apply rigorous, objective measures of conservation value whenever possible, recognizing that a quantitative assessment would have to be supplemented by expert opinion.

Compiling a list of representative biological targets

Biological diversity cannot easily be completely and directly measured. Thus, practitioners are forced to select a set of components of biological diversity that can be measured effectively, given existing resources, components that adequately represent the range of biological phenomena in the project area and contribute the most to the overall biological diversity of a project area. Selecting a set of focal targets with sufficient breadth and depth can be done through the coarse-filter/fine-filter approach, as applied, for example, in ecoregional planning by the Nature Conservancy (TNC 2000). "Coarse filter" generally refers to ecosystems; in a more practical sense, it refers to mapped units of vegetation. The basic idea is that conserving a sample of each distinct vegetation type, in sufficient abundance and distribution, is an efficient way to conserve the majority of biological phenomena in the target area. An oft-cited statistic is that coarse-filter conservation will conserve 80 percent of all species in a target area (Haufler et al. 1996). "Fine filter" generally refers to individual species with specific habitat requirements or environmental relationships that are not adequately captured by the coarse filters. Narrow endemic species and extreme habitat specialists, species with restrictive life histories, or those species that have lost significant habitat or are particularly sensitive to human perturbations fall into this category (i.e., IUCN Red List species).

The Nature Conservancy's ecoregional planning uses both coarse- and fine-filter guidelines to identify biological targets. Therefore, for our case study we used the biological target list from the Wyoming Basins Ecoregional Plan (Freilich et al. 2001) crosswalked with information gathered as part of the environmental impact assessment (EIA; USDOI 2006). We selected all ecoregional conservation targets identified within the bounds of the field area as a biological target to be included in the offset design. We selected nine species and one ecological system to represent the biodiversity on the Jonah Field (table 1).

Table 1. Information on targets selected to represent biodiversity on the Jonah natural gas field.

Biological target	Impact goal (hectares)	Data source	Assessment goals met at smaller scale?	Assessment goals met at larger scale?
Burrowing owl	13,690	Deductive model	No	Yes
Cedar-rim thistle	3433	Inductive model	No	Yes
Mountain plover	1390	Deductive model	Yes	Yes
Pronghorn migration routes	7738	Wyoming Game and Fish linear data	Yes	Yes
Pygmy rabbit	7436	Deductive model	Yes	Yes
Sage grouse leks	6	Wyoming Game and Fish point data	Yes	Yes
Sage grouse winter habitat	21,043	Deductive model	Yes	Yes
Sage sparrow	8813	Deductive model	No	Yes
White-tailed prairie dogs	1705	Deductive model	Yes	Yes
Wyoming big sagebrush steppe	22,573	US Forest Service Landfire data	Yes	Yes

Note: Small-scale assessment goals come from analyses for the Pinedale Bureau of Land Management Field Office Boundary; larger-scale assessment goals come from analyses for the Wyoming Landscape Conservation Initiative Boundary.

Spatial data for biological targets

Spatial data were used to quantify impacts associated with development on the Jonah Field and to guide selection of offset sites. We used a combination of point survey data, vegetation cover estimations, and predictive model estimations (table 1). If survey data were sufficient for estimating occurrence patterns, we relied on these data. For example, for pronghorn, we created one-kilometer buffers (Berger et al. 2006) around linear pronghorn migration routes from the Wyoming Game and Fish Department (WGFD 2006). To estimate occurrence patterns of the Wyoming Big Sagebrush Steppe community, we relied on the US Forest Service's Landfire project data of existing vegetation height, type, and percentage cover (USFS 2006).

If survey data were insufficient to estimate occurrence patterns across the study area, we developed predictive models based on species occurrence, observation, and survey data from the Wyoming Natural Diversity Database, Wyoming Wildlife Consultants, Wyoming Game and Fish Department, and the BLM. We initially tried using an inductive modeling approach by developing a CART (classification and regression tree) model (Breiman et al. 1984) with the random forests algorithm through a GIS (geographic information system) tool developed at the University of Georgia called the EDM (element distribution modeling) Tools for ArcGIS (Nibbelink 2006), but our expert biologists were dissatisfied with the models we produced—the models lacked sufficient survey data to generate adequate models. As an alternative, we settled on a simpler approach using deductive models, wherein we identified each species' habitat preferences and created binary models of suitable habitat through a series of GIS overlays based on slope; aspect; topographic roughness; elevation (digital elevation models); stream buffers; and vegetation type, height, and percentage cover. The topographic features (elevation, aspect, slope, roughness) were all derived from the 30-meter National Elevation Dataset assembled by the US Geological Survey (USGS). Vegetation data were obtained from Landfire (USFS 2006), and streams data were based on the National Hydrologic Dataset (USGS 1997). To convert aspect to a continuous linear data set, we calculated the cosine of the aspect multiplied by –100 to produce values ranging from –100 to 100. Topographic roughness was calculated using a 3-by-3 moving-window neighborhood calculation of the standard deviation of the elevation. We validated our habitat models with expert review and survey data. For cedar rim thistle (*Cirsium aridum*), we relied on statewide rare-plant predictive models developed by Fertig and Thurston (2003).

Offset goals for biological targets

Our intention with this analysis was not to reinvent the EIA process, as the literature on this subject is extensive (Sadar et al. 1995, Canter 1996); rather, we intended to provide an approach that could complement existing EIAs. Thus, for this assessment, we used a simple approach to quantify field-level impacts. Spatial data assembled for each of the biological targets were overlaid onto the field boundaries, and estimated acres of habitat within the bounds were included as impacts (table 1). Since it was obvious that impacts associated with development extend beyond areas of surface disturbance, we used the full-field, 24,407-ha boundary, even though the infill project was limited to a 12,343-ha area. These full-field impacts became the input goals for the Marxan algorithm, representing the minimum offset spatial goals.

Selecting potential offset sites with Marxan

When the decision to use offsets is made, there is often a desire to keep them as close as possible to the impact site so benefits accrue to the affected area. The choice of offset location that best balances proximity to the impact site with effectively achieving conservation benefits is often unclear. Here, we used the Marxan (version 1.8.2) site-selection algorithm developed by Ball and Possingham (2000) to illustrate how this tool can be used to determine an appropriate location and spatial extent for offset design. We developed criteria to ensure offsets would serve to mitigate on-site impacts (see below), then we ran analyses at progressively broader spatial extents, with the intention of selecting offsets at the smallest spatial extent at which goals could be met. We chose a nested set of areas in accordance with both biological and political constraints. The first area was limited to the Upper Green River Basin, focusing on the BLM's Pinedale Field Office boundary (figure 2). The second, expanded area included the Wyoming Landscape Conservation Initiative boundary (figure 2) component of the Healthy Lands Initiative of the Department of the Interior.

Marxan, a siting tool for landscape conservation analysis, explicitly incorporates spatial design criteria into the site-selection process. Marxan operates as a stand-alone program and uses an algorithm called "simulated annealing with iterative improvement" as a heuristic method for efficiently selecting regionally representative sets of areas for biodiversity conservation (Possingham et al. 2000). Marxan allows inputs of target occurrences represented as points or polygons in a GIS environment, and makes it possible to state conservation goals in a variety of ways, such as percentage area or numbers of point occurrences. The program also allows the integration of many available spatial data sets on land-use patterns and conservation status, and enables a rapid evaluation of alternative configurations. The ultimate objective is to minimize the cost of the reserve system (i.e., cost = landscape integrity, conservation cost in dollars, size of the reserve, etc.) while still meeting conservation objectives.

For both the fine-scale and broadscale analyses, the working group selected 500-ha hexagons (derived from a uniform grid) as the unit of analysis for running Marxan, because this spatial resolution was sufficient to represent biological targets and also large enough to permit efficient analyses across broad landscape scales. The effectiveness of a contiguous set of hexagonal units for defining natural variability, especially among spatially heterogeneous data sets, is well documented (White et al. 1992). Use of hexagons resulted in 12,159 analysis units (6,079,500 ha) for the larger study area and 1834 analysis units (917,000 ha) for the smaller area. Each hexagon was populated by summing the area of suitable habitat for the targeted community or species.

In addition to the biological information used to select potential offset sites, we incorporated a series of additional rules. First, we guided site selection to areas of high biological integrity (per Copeland et al. 2007). This is equivalent to the "cost" function used by Marxan (Ball and Possingham 2000). Given the difficulty of restoration in this dry sagebrush system (Monsen and Shaw 2000), the team felt it necessary to select areas with high integrity and allow mitigation funding to keep these systems from becoming degraded. Second, we blocked out areas (using status = 3 function; Ball and Possingham 2000) of high oil and gas development potential (based on USGS estimates of undiscovered technically recoverable resources, Energy Information Administration–proved reserve calculations, and a predictive model developed by one of the authors of this article [H. C.]). The team felt that this last rule was critical, given the commitment to maintaining the integrity of the offset for at least as long as impacts are incurred on-site. Because of the high degree of oil and gas activity in this area, we thought it would be prudent to forgo selection of areas with high future development potential for offsets, to prevent the possibility of establishing offset sites that may themselves need to be offset. Moreover, the high cost and regulatory uncertainty associated with working in areas with high resource potential constituted another reason to avoid selecting these areas.

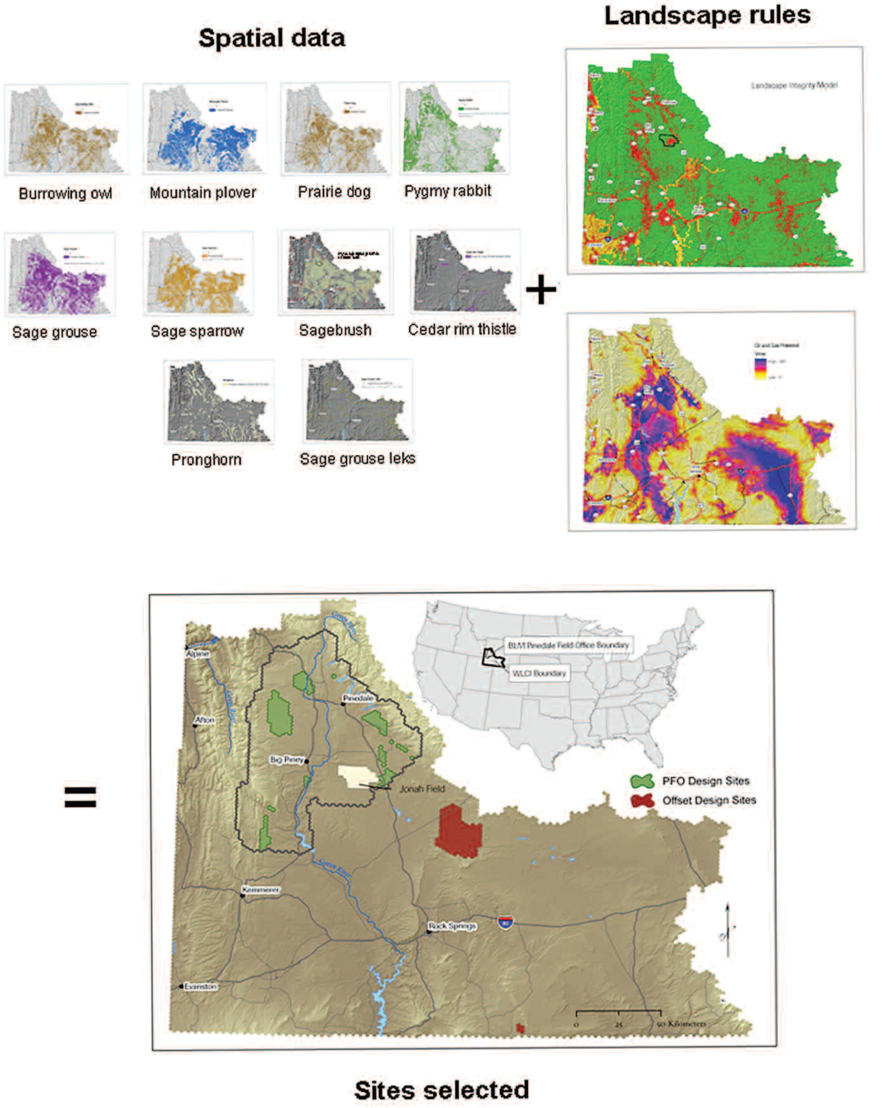

Figure 2. Use of the Marxan algorithm to select suitable offset sites as part of the Jonah natural gas field infill project. Spatial data layers were used both for assessing impacts resulting from development on the field and for selecting suitable offset sites. Landscape rules: "Intactness" (Copeland et al. 2007) and "Oil and Gas Potential" (based on US Geological Survey estimates of undiscovered technically recoverable resources, Energy Information Administration–proved reserve calculations, and a predictive model developed by H. C.) guided the selection of sites to areas of high habitat quality and low oil and gas development potential. Areas in green (smaller spatial extent) and red (larger spatial extent) represent the best fit of the Marxan algorithm based on these specific targets and specified rules. The inset map shows the location of Wyoming within the conterminous United States, as well as the location of the Wyoming Landscape Conservation Initiative and the Pinedale Bureau of Land Management Field Office Boundaries.

Goals achieved

At the smaller spatial extent, we selected 76,517 ha that were consistent with our offset goals. However, for several targets we were unable to meet even the minimum offset goals at the smaller extent (table 1). To achieve no net loss at this smaller spatial extent, given the constraints our team placed on selecting off-site sites (e.g., high intactness, low oil and gas potential), it would be necessary to reduce offset goals by mitigating impacts on-site using a step higher up the mitigation hierarchy. For example, on-site impacts and, in turn, the needs for offsets could be reduced by further avoiding or minimizing the footprint associated with development. Although the selected areas would not be sufficient to achieve no net loss because of the scope of on-site impacts, the selected areas could still be used as offsets when combined with areas from the larger spatial extent. At the larger spatial extent, we selected 62,499 ha, and in contrast to the smaller spatial extent, we found ample opportunity to meet offset goals for all targets (table 1, figure 2). Both the small and larger spatial extents sites selected included a mix of public and private land, and a mix of potential restoration and protection offsets.

Discussion

Biodiversity offsets, the last step in the mitigation hierarchy (avoid, minimize, restore, offset), are conservation actions that seek to counterbalance residual impacts resulting from development with measurable conservation outcomes, with the aim of no net loss for biodiversity. Our study illustrates some general principles in offset design and site selection for mitigating impacts from development on the Jonah natural gas field in southwestern Wyoming. Offsets are intended to provide an additional tool to achieve the no-net-loss goal after efforts have been made to avoid and minimize impacts. To achieve no net loss, offsets—in addition to having a systematic selection process—must ensure that offset actions are genuinely new and additional contributions to conservation, and they will have to quantify ecological quality rather than simply use acreage units. The selection process we have outlined can incorporate these additional requirements.

To trade project impacts for offset benefits, we need to develop an appropriate currency (i.e., area, habitat quality) to ensure that offsets are sufficient. The framework we have developed starts this process by selecting a set of sites that have value for their ability to meet the biologically based offset goals within a landscape context, including consideration of landscape integrity and future potential impacts. As on-the-ground projects are considered, practitioners can establish a finer currency that incorporates the size of the impact and offset, as well as values associated with ecological functions, quality, and integrity. However, most offset programs methods for assessing currency are in their infancy. The exception is wetland offsets, for which methodological developments have been ongoing for more than two decades. Indeed, estimates of the number of available wetland assessment methods range upward of 100 individual tools (Bartoldus 1999). Despite the proliferation of assessment methods, all are subject to criticism, and few are actually used because of the high cost and complexity of application (Kusler 2003). In a study of more than 200 wetland mitigation banks throughout the United States, more than 60 percent of the banks defined credits simply by acreage (Environmental Law Institute 2002).

The framework we have developed will be integrated with the use of an assessment tool, although such a tool is not a key component of our current analysis. For the sagebrush ecosystem, several site assessment tools are available for use (i.e., USFWS 1980, habitat evaluation procedures; USNRCS 1997, ecological site descriptions; Parkes et al. 2003, habitat hectares approach). However, the lessons of wetland mitigation banking show that assessment tools will need to balance time and cost with scientific rigor. By incorporating a valuation process into a site selection framework, we streamline the assessment process. Moreover, if mitigation replacement ratios are adopted, as they are in wetland mitigation banking (see King and Price 2004), then our framework can easily incorporate this by adjusting the goals that are put into the Marxan algorithm.

The majority of offset policies (McKenney 2005) agree that compensatory actions must result in benefits that are additional to any existing values. For our offset design, we guided site selection toward areas with high-quality habitats. These areas may require minimal or no restoration, but they are at risk from future impacts (i.e., residential subdivision, invasive weeds). For example, since the 1970s, rural areas with desirable natural amenities and recreational opportunities throughout the United States have experienced a surge in rural development (Brown et al. 2005), with growth in the mountainous West during the 1990s occurring faster than in any other region of the country (Hansen et al. 2002). Home building in our project area reflected these national trends in the period between 1990 and 2001 (Gude et al. 2007).

We recommend the use of mitigation funds to maintain habitat quality by abating future impacts (i.e., residential development) as well as standard habitat improvements. Although this is different from the emphasis on habitat restoration or creation associated with wetland mitigation (Federal Interagency Mitigation Workgroup 2002), we feel that as long as mitigation action prevents the decline of habitat quality, the averted decline can be measured; and offset planning provides for adaptive management, should conditions or threats change, which can be a practical use of mitigation funds. Given the flexibility of our site-selection framework, offset projects conducted in different ecological or political settings can easily use it to adjust site selection toward areas with more potential for restoration, if that is desired.

Reaching no net loss will come from on-site actions that minimize impacts or restore habitat, combined with off-site actions that provide additional benefits. The appropriate temporal scale should be used when valuing the role of offsets in achieving no net loss. Offsets will need to persist for at least as long as impacts persist on-site, and their value will have to be assessed within a similar temporal framework. For our case study, we use a 30- to 50-year time frame to assess on-site impacts and value on-site restoration and offset value. We recognize, however, that without requiring offset benefits to precede impacts on-site, there may be a temporal lag in achieving no net loss. Offset projects associated with impacts on the Jonah Field will consist of both restoration and protection projects. Valuing restoration projects as a function of habitat improvement is a relatively straightforward process. Valuing protection projects intended to maintain existing quality will involve assessing the background rate of change that necessitates protection (e.g., residential subdivision) and asking what the quality of habitat would be during the time on-site impacts persist if the protection did not exist.

Moving forward, we hope that our study prompts offset practitioners to think strategically about site selection, and to develop practical guidelines for when and how to guide this process. Site selection for offsets will obviously be an exercise in landscape analysis. Quantitative site selection tools (e.g., Arponen et al. 2007) such as Marxan provide a transparent, flexible, and rule-based approach to guide site selection. Where political pressures constrain practitioners to some extent, site-selection algorithms will allow them to determine whether it is possible to meet goals within those constraints. The framework we have developed can be applied if offsets have been selected as an appropriate tool; failure to systematically select suitable sites could reduce the potential benefits for conservation. Moreover, knowing when and how offsets can be applied—and knowing where they cannot—can be difficult to determine; offset use must be complemented by a rigorous process that ensures the mitigation hierarchy has been followed.

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