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# Economic and Ecological Outcomes of Flexible Biodiversity Offset Systems

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**Abstract:** *The commonly expressed goal of biodiversity offsets is to achieve no net loss of specific biological features affected by development. However, strict equivalency requirements may complicate trading of offset credits, increase costs due to restricted offset placement options, and force offset activities to focus on features that may not represent regional conservation priorities. Using the oil sands industry of Alberta, Canada, as a case study, we evaluated the economic and ecological performance of alternative offset systems targeting either ecologically equivalent areas (vegetation types) or regional conservation priorities (caribou and the Dry Mixedwood natural subregion). Exchanging dissimilar biodiversity elements requires assessment via a generalized metric; we used an empirically derived index of biodiversity intactness to link offsets with losses incurred by development. We considered 2 offset activities: land protection, with costs estimated as the net present value of profits of petroleum and timber resources to be paid as compensation to resource tenure holders, and restoration of anthropogenic footprint, with costs estimated from existing restoration projects. We used the spatial optimization tool MARXAN to develop hypothetical offset networks that met either the equivalent-vegetation or conservation-priority targets. Networks that required offsetting equivalent vegetation cost 2–17 times more than priority-focused networks. This finding calls into question the prudence of equivalency-based systems, particularly in relatively undeveloped jurisdictions, where conservation focuses on limiting and directing future losses. Priority-focused offsets may offer benefits to industry and environmental stakeholders by allowing for lower-cost conservation of valued ecological features and may invite discussion on what land-use trade-offs are acceptable when trading biodiversity via offsets.*

**Keywords:** conservation banking, conservation planning, economics, land-use planning, MARXAN, oil sands

Resultados Económicos y Ecológicos de Sistemas de Compensación de Biodiversidad Flexible Habib et al.

**Resumen:** *La meta que comúnmente se expresa sobre la compensación de biodiversidad es la de no tener pérdidas netas de características biológicas específicas afectadas por el desarrollo. Sin embargo los requerimientos estrictos de equivalencia pueden complicar el intercambio de créditos de compensación, incrementar los costos debido a la colocación restringida de opciones de compensación y forzar a las actividades de compensación a enfocarse en características que pueden no representar las prioridades de conservación de la región. Usando a la industria de arenas aceiteras de Alberta, Canadá como un caso de estudio, evaluamos el desempeño económico y ecológico de sistemas de compensación alternativos enfocados ya sea a áreas ecológicamente equivalentes (tipos de vegetación) o prioridades de conservación regionales (caribú y la subregión natural de Dry Mixedwood). Intercambiar elementos de biodiversidad disimilares requiere de estudio mediante una métrica generalizada. Usamos un índice de intangibilidad de biodiversidad derivado empíricamente para enlazar a las compensaciones con pérdidas incurridas por el desarrollo. Consideramos 2 actividades de compensación: protección de suelo, con costos estimados como el actual valor neto de las ganancias de los recursos del petróleo y la madera a pagarse como compensación a los dueños con antigüedad de los recursos; la restauración de la huella antropogénica, con costos estimados a partir de proyectos de restauración existentes. Usamos la herramienta de optimización espacial MARXAN para desarrollar redes*

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*hipotéticas de compensaciones que cumplieran con el equivalente de vegetación o los objetivos de la prioridad de conservación. Las redes que requirieron compensar el equivalente de vegetación costaron entre 2 y 17 veces más que las redes enfocadas en prioridades. Este hallazgo hace dudar de la prudencia de los sistemas basados en equivalencias, donde la conservación se enfoca en limitar y dirigir pérdidas futuras. Las compensaciones enfocadas en prioridades pueden ofrecer beneficios para la industria y para las partes ambientalistas interesadas al permitir una conservación de más bajo costo de características ecológicas valoradas y puede invitar a la discusión de cuales pros y contras del uso de suelo son aceptables cuando se intercambia la biodiversidad por medio de compensaciones.*

**Palabras Clave:** arenas aceiteras, banca de conservación, economía, MARXAN, planificación de la conservación, planificación del uso de suelo

## Introduction

Biodiversity offsets are designed to compensate for residual environmental damage caused by development after avoidance, minimization, and mitigation of environmental impacts have been considered and implemented (ten Kate et al. 2004). The goal of offsets is to compensate for the loss of biodiversity at one location with conservation gains elsewhere. Typical forms of biodiversity offsets include land protection, restoration, or enhancement, and they are typically applied to achieve no net loss of a particular biodiversity feature (Gibbons & Lindenmayer 2007). Offset programs are often designed as markets with tradable credits, where offset providers create credits to sell to developers. Credits may include landowners planting native vegetation to compensate for land clearing (NSW DECC 2007) or providing habitat for the same number of individuals of an endangered species that were disturbed by development (USFWS 2003). Although controversial, protection of existing habitat is considered to contribute to no net loss by preventing future losses that would otherwise occur, although this necessarily results in a decrease in biodiversity relative to a current baseline (BBOP 2012). A handful of offset systems allow substitution of rarer or otherwise more valuable biodiversity features (often termed trading up), but most programs require ecological equivalency between affected and offset biodiversity elements (McKenney & Kiesecker 2010; Quétier & Lavorel 2011).

*Ecological equivalency* is generally defined as an equal value of a biodiversity component or indicator or set of components (e.g., see fig. 2 in Quétier & Lavorel (2011)). Although these requirements are necessary for offset programs targeting specific biodiversity elements, for example, fish habitat (e.g. Fisheries & Oceans Canada 1986), wetlands (USACE et al. 1995), or endangered species (USFWS 2003), it is unclear why equivalency of type should be the presumed goal of a program with a general biodiversity conservation mandate. Instead, substituting dissimilar biodiversity elements via an appropriate currency may enable conservation focused on regional priorities that offers advantages to both industry and environmental stakeholders through cost savings and more valuable conservation benefits, respectively.

The equivalency-of-type requirement creates 3 significant constraints on offset systems. First, it concentrates benefits in ecosystems similar to what has been disturbed, which may not necessarily represent regional ecological priorities such as conservation of rare or endangered species (Underwood 2011) or ecosystems that are underrepresented in the regional conservation network (Margules & Pressey 2000; Kiesecker et al. 2010). Second, adherence to strict equivalency restricts the range of possible offset locations, whereas a flexible system may allow for more efficient use of conservation funds by selecting areas with lower economic costs and greater biodiversity benefits (Naidoo et al. 2006). Finally, heavy restrictions on acceptable offsets can lead to decreased market activity and market failure (Wissel & Watzold 2010). Considering these difficulties, in some jurisdictions it may be worthwhile to consider flexible offsets rather than defaulting to equivalency-based systems. Such a system would still require some market restrictions to direct efforts toward conservation priorities, but restrictions may be balanced against the need for market liquidity (Salzman & Ruhl 2000).

Relaxing the equivalency-of-type requirement creates the need for a generalized or more fungible currency of biodiversity so that offsets of a different feature type will still be of an equivalent magnitude (i.e., quantity and condition) to a given development's effect. This clear link between developments and offsets is also necessary for companies to realize social and reputational benefits (ten Kate et al. 2004). Although straightforward currencies (Parkes et al. 2003) have been criticized as overly simplistic (McCarthy et al. 2004; Walker et al. 2009), balancing scientific detail and ease of measurement is necessary for keeping transaction costs reasonable (Salzman & Ruhl 2000) and gaining widespread adoption by stakeholders (Parkes et al. 2004).

We used the resource-rich boreal forest of Alberta, Canada, as a case study to compare ecological and economic outcomes of offset systems with alternative conservation goals. We used an empirically derived currency of biodiversity intactness (Nielsen et al. 2007) that was based on a standardized provincial monitoring program to quantify biodiversity gains and losses.

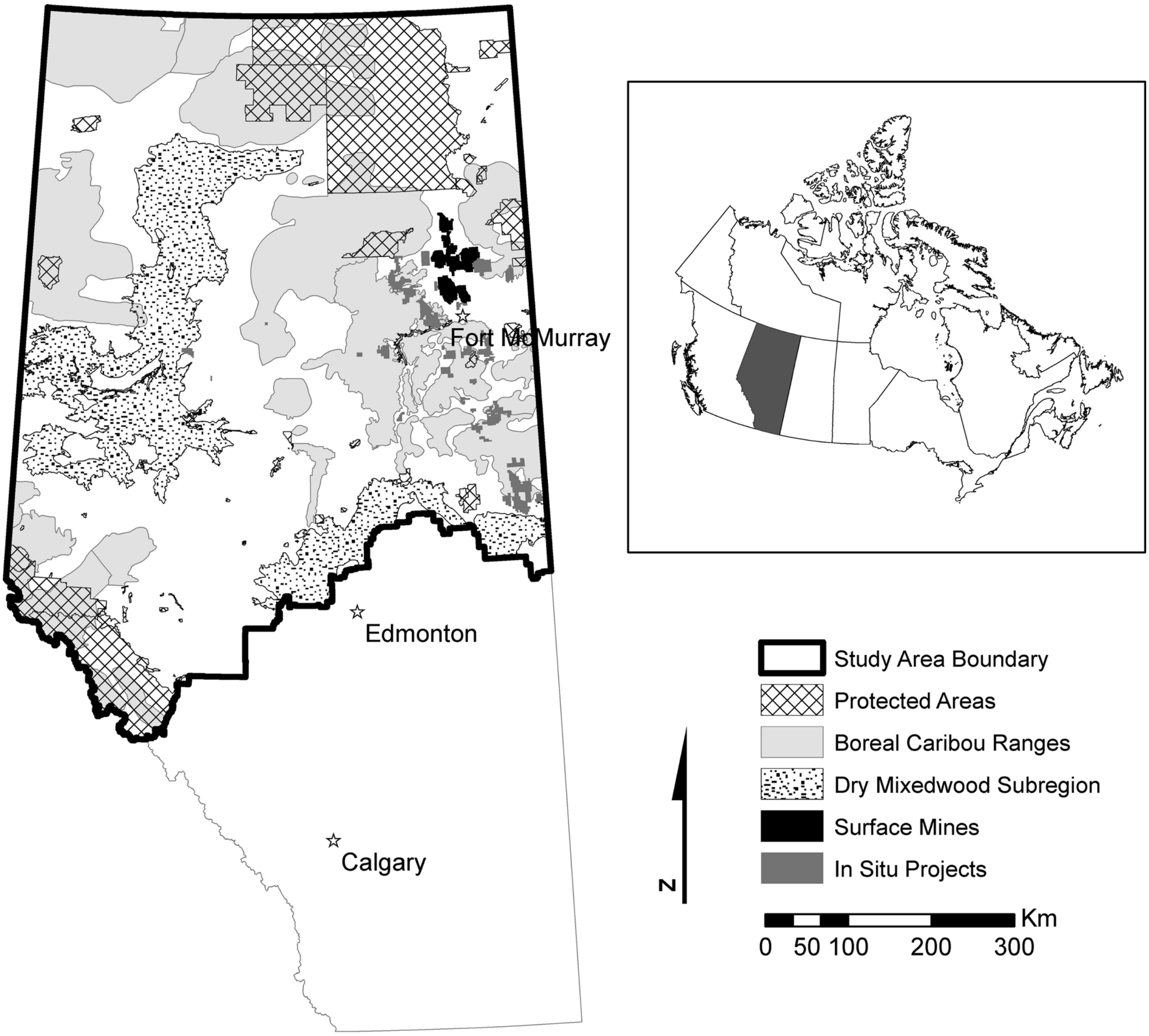


*Figure 1. Study area in Alberta, Canada (inset map), depicting existing protected areas, boreal woodland caribou ranges, Dry Mixedwood natural subregion, and current and future (to 2020) mining and in situ oil sands developments.*

## Methods

### Study Area

The boreal forest of Alberta, Canada, covers approximately the northern half of the province (Fig. 1). Much of this approximately 443,000-km$^2$ region is underlain by bitumen (i.e., oil sands) deposits, and forestry and agriculture are the 2 other principal land uses in the region. Alberta has recently implemented a land-use framework with the goal of long-term planning to balance socioeconomic and environmental objectives across the province; biodiversity offsets have been proposed as a tool to help achieve environmental targets (Government of Alberta 2008). A multistakeholder report recommends a regulated conservation-banking approach as the most appropriate offset framework for Alberta (ABCOG 2009). In this approach, offsets are mandatory for new developments and are purchased by industry from the government or a third party such as a local conservation agency. This approach allows providers to generate offsets in large, contiguous blocks before development occurs. Large, spatially aggregated reserves are more likely to enable long-term species persistence than small, isolated protected areas that may result from creating offsets on a case-by-case basis because large reserves can maintain ecological processes such as interspecific interactions (Rayfield et al. 2009) and natural disturbances (Leroux et al. 2007). Importantly, a proactive approach that uses conservation banking allows for integration with regional plans developed under the land-use framework planning process (ABCOG 2009).

The vast majority (approximately 90%) of boreal Alberta is public land managed by the province in which many rights to natural resources have already been sold to industry, including petroleum leases and timber rights under forest management agreements (FMAs) that cover most of the region. Thus, the provincial government has a central role in implementing offsets in Alberta. For the purposes of this study, we assumed all public land was available for inclusion in an offset system. We excluded private land because a different market system would be required for dealing with private land sales, and the ability to coordinate the location of offsets is unclear with land under the control of a large number of individual owners. Although a fully implemented offset system should allow offsets on private land, integration between public and private offsets was beyond the scope of this study.

### Biodiversity Metrics

We used an index of general "biodiversity intactness" (Nielsen et al. 2007; ABMI 2011) to measure losses and gains in ecological condition across our study area. We based intactness, expressed as a percentage relative to an empirically defined reference system, on data obtained from the Alberta Biodiversity Monitoring Institute (ABMI), a nonprofit, value-neutral research institute that collects standardized monitoring data across Alberta (www.abmi.ca). Because these data are collected in a statistically robust, standardized manner across the entire province, ABMI data are particularly useful for evaluating biodiversity losses and gains at regional scales.

We calculated intactness in a 3-step process (ABMI 2011) at the scale of $1.6 \times 1.6$ km sections of land delineated by the Alberta Township System (ATS). First, we used species abundance data from ABMI field surveys from 2003–2010 to statistically model species-specific relations between anthropogenic footprint and occurrence probability for hundreds of species. In addition to footprint, species models included geographic location, vegetation type, and stand age as covariates to account for the uneven distribution of footprint across regions and land-cover types, although unaccounted-for confounds between footprint and other variables, such as topography, may still exist (ABMI 2011). Second, we applied models for each species to a map of human footprint in each section, including agriculture, residential areas, forestry cutblocks, petroleum developments, and linear features (ABMI 2012). Finally, we averaged predicted absolute difference between current and reference (i.e., defootprinted) conditions for each species by guild (birds, mites, vascular plants, mosses, and lichens) to obtain guild-level intactness values, which we subsequently averaged to obtain overall intactness (ABMI 2011). In this index, the absolute difference accounts for changes from a reference community due to increasing numbers of invasive species or overabundant native species. We used these guilds as a range of indicator groups that were well-represented in the data set.

A region's intactness*area is hereafter referred to as intactness-adjusted area (IAA) and is our chosen currency of biodiversity. Functionally, our metric is a measure of unperturbed area weighted by the value of this land for species common to the boreal forest. Thus, IAA incorporates both the quality and spatial extent of biodiversity. Use of a quality-based metric is essential to account for the enormously variable intensities of different developments. We used the change in IAA ($\Delta$IAA) to measure losses and gains in biodiversity associated with development and offset activities, respectively.

### Biodiversity Losses

For this case study, we developed offsets for biodiversity loss arising from current and future oil sands development. There are 2 broad types of oil sands development: surface mining and in situ development. Surface mining creates a conventional open-pit mine, where native forest and topsoil are completely removed across large areas. In situ development occurs where ore deposits are too deep for mining to be profitable or practical, and bitumen is extracted via wells, usually combined with steam injection to heat and lower the bitumen's viscosity to enable pumping. Well-drilling must be extremely precise, which necessitates creating a high-density grid of narrow (2–8 m) cut lines through the forest (hereafter seismic lines) to conduct detailed sonic testing to create a 3-dimensional map of deposits (Schneider & Dyer 2006). Other footprints in an in situ project area include roads, well pads, pipelines, worker camps, and central processing facilities. Outside central facilities, the majority of forest cover remains present but is highly fragmented by linear features. About 20% of the oil sands area is mineable, and the rest must be extracted with in situ methods (Fig. 2) (Alberta Energy 2012).

We estimated the mean loss of intactness associated with existing oil sands mines (90.6% loss) and thermal in situ projects (23.8% loss) from a map of intactness modeled as a function of human footprint across boreal Alberta (ABMI, unpublished data). We then mapped all current, approved, and proposed oil sands mines (17 mines) and in situ projects (45 projects) until 2020 (ERCB 2011) on the basis of environmental impact assessments and publicly available corporate documents (combined extent of approximately 7400 km$^2$) (Fig. 1). Although biodiversity offsets are not typically imposed retroactively, several companies have already created offsets voluntarily (e.g., Shell Canada) due to heavy public scrutiny of the oil sands industry's environmental impact. Therefore, considering offsets that address the entire industry's footprint is consistent with public expectations. We applied the average expected intactness loss across each project's development area to estimate the total expected $\Delta$IAA

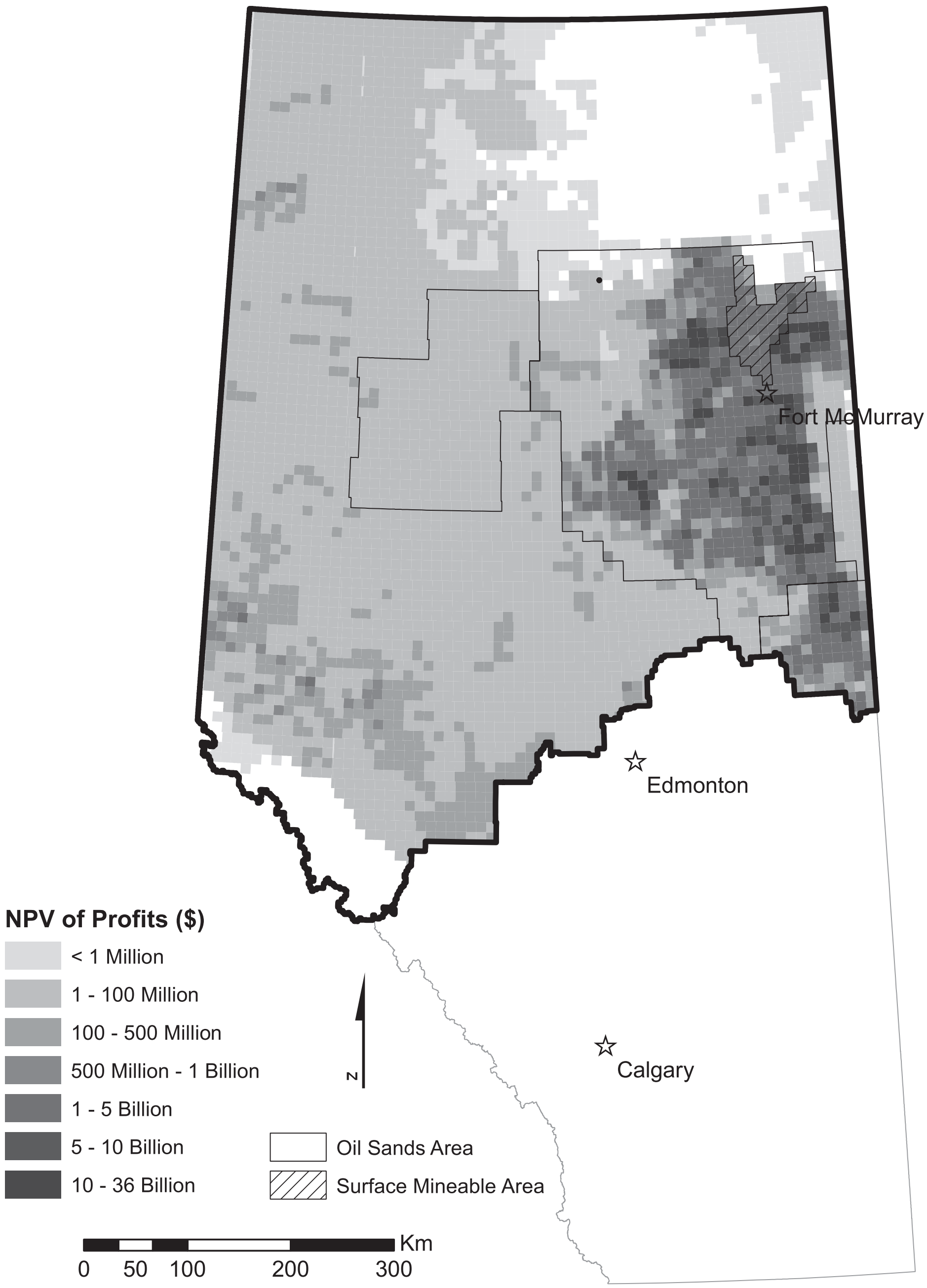


*Figure 2. Estimated net present value of profits ($NPV_P$) of petroleum (conventional oil, natural gas, and oil sands) and timber resources per township (approximately 92 km$^2$) in boreal Alberta, Canada.*

to establish the targets for our offset scenarios. We calculated ΔIAA in 12 vegetation classes and total ΔIAA (Table 1). We obtained vegetation classes from a land-cover layer generated by combining Canadian Forest Service's Earth Observation for Sustainable Development map and Agriculture and Agri-Food Canada's National Land and Water Information Service map (ABMI, unpublished data).

### Offset Activities and Costs

We considered 2 types of offset activities that could provide additional conservation benefits (ten Kate et al. 2004): protection and habitat restoration. Protecting a parcel of land created an IAA credit equal to the expected ΔIAA decrease that would likely occur due to future oil sands development and forestry in the absence of protection. Although allowing the protection of existing intact land to constitute offsets leads to a loss of biodiversity relative to a baseline of today, some degree of biodiversity loss is inevitable in boreal Alberta (Government of Alberta 2012), so the proposed offsets guarantee protection in areas already under lease. Therefore, each parcel of land within the oil sands region (Fig. 2) was assigned a possible IAA credit equal to a thermal in situ bitumen development (23.8% intactness loss*parcel area). The surface mineable area is already nearly completely covered by approved and existing projects, so this region was

**Table 1.** Loss in intactness-adjusted area (ΔIAA) associated with current and future (to 2020) mined and thermal in situ bitumen developments in Alberta, Canada.

| *Vegetation class* | *IAA loss* |
|---|---|
| Coniferous forest, dense | 1112.82 |
| Mixedwood forest, dense | 647.36 |
| Wetland, shrubs | 538.31 |
| Broadleaf forest, dense | 409.86 |
| Wetland, treed | 307.93 |
| Water | 114.59 |
| Herb | 51.03 |
| Wetland, herbs | 44.41 |
| Coniferous forest, open | 29.41 |
| Wetland, unspecified | 27.08 |
| Shrub, tall | 18.30 |
| Mixed-wood forest, open | 0.06 |
| Total | 3301.17 |

unavailable for offsets. For forestry we considered only avoidance of new enduring footprint features (i.e., roads inside and outside cutblocks) because cutblock regeneration is already mandatory and begins immediately following harvest (Schneider et al. 2003), so it could not be considered as an additional gain. Therefore, we estimated IAA credits for foregone forestry from areas adjacent to cutblocks that contained forestry roads (6.7% intactness loss*parcel area).

We estimated the protection cost of a parcel of land as net present value of profits ($NPV_P$) of its petroleum and timber resources (Fig. 2), which would be paid as compensation to buy back tenure rights from the lease holder(s). We generated $NPV_P$ from models developed by Hauer et al. (2010), which incorporate expected costs and resource revenue over time, and the opportunity cost of capital on the basis of a 4% discount rate. In a market-based offset system, $NPV_P$ can be used as an estimate of how much compensation a lease holder would be willing to accept to forego tenure rights. Developers are expected to minimize the cost of offsets and would therefore be motivated to select sites with the lowest $NPV_P$.

Much of boreal Alberta contains legacy footprint from past resource development that is not required to be revegetated (Lee & Boutin 2006), so reclamation of these features is a logical source of offset credits. We considered only reclamation of seismic lines and unimproved roads and trails (forestry roads, winter roads, and all-terrain-vehicle [ATV] trails) because these are among the most abundant human-footprint features in boreal Alberta. Restoration of these features has been demonstrated in Alberta or elsewhere, and restoration costs are reasonably well known (Switalski et al. 2004; Robinson et al. 2010). Revegetation will occur on many seismic lines without human assistance, although the estimated proportion of lines requiring restoration work varies greatly, from 15% to 90% (Lee & Boutin 2006). We assumed that 50% of seismic lines would require active restoration (Schneider et al. 2010). We then calculated the expected intactness of each township after completing restoration work.

We based restoration costs on pilot projects within boreal Alberta. We estimated costs for seismic lines and ATV trails at \$4146/km, winter roads at \$9438/km, other roads at \$8292/km (T. Vinge, personal communication). These estimates included the full cost of restoration, including excavator and support equipment, revegetation, and deposition of coarse woody debris to aid tree establishment. Seismic lines, ATV trails, and most roads require extensive soil decompaction, whereas winter roads, although wider than summer roads, do not require decompaction because vehicles only travel above the snow pack (E. Dzus, personal communication).

We summarized offset potential and costs by townships, the 92-km$^2$ parcels of land comprising 36 ATS sections, which provided a convenient spatial scale for planning because it integrates with existing government administrative processes. Each township's offset potential, ΔIAA, was calculated as

$$\Delta\text{IAA} = A_{\text{twp}} \cdot (\Delta I_p + \Delta I_r), \tag{1}$$

where $A_{\text{twp}}$ is the township's area, and $\Delta I_p$ and $\Delta I_r$ are the predicted gains in intactness (expressed as percent values) from protecting a township and restoring all reclaimable features, respectively. The cost for including a township in an offset system was the sum of its NPV and restoration costs.

### Offset Scenarios

We evaluated offset systems designed under 3 different sets of spatial constraints, each emphasizing different conservation targets that represented recognized conservation priorities for boreal Alberta. Target 1 was general conservation of biodiversity with no spatial constraints; that is, offsets may be located anywhere within the study area. Target 2 was boreal woodland caribou (*Rangifer tarandus caribou*) range (Fig. 1) because caribou are a provincially and nationally threatened species (COSEWIC 2002; ASRD & ACA 2010) subject to considerable public scrutiny, and their decline in Alberta has been linked to land-use change associated with petroleum extraction and forestry (Festa-Bianchet et al. 2011). Target 3 was the Dry Mixedwood (DM) natural subregion of Alberta (Fig. 1), which has undergone considerable land-use change due to agricultural conversion and is under-represented in boreal Alberta's existing protected areas (Schneider et al. 2011); only 1.4% of its area is protected. From the perspective of systematic conservation planning (Margules & Pressey 2000), this would be a high-priority ecosystem for additional protection. It would be difficult to create an entire offset network solely within the relatively small publicly owned portion of the DM region, so we combined this spatial constraint with the caribou range constraint for the third conservation target.

For each of the 3 conservation targets, we evaluated offsets designed under 2 different objectives, for a total of 6 scenarios. For each target, offsets were designed to capture either (A) the equivalent amount of IAA lost due to development from within each vegetation class (Table 1) or (B) the total amount of lost IAA, ignoring vegetation class. For the third target, we required that half the total necessary increase in IAA come from areas in caribou range and half come from the DM region. Scenario 1A most closely represents the traditional view that biodiversity offsets should be equivalent to what was lost. Scenarios 2 and 3 represent a policy where biodiversity offsets are directed toward regional conservation goals that are currently unmet (i.e., trading up) (Kiesecker et al. 2010; Underwood 2011) either with (objective A) or without (objective B) additional vegetation equivalency requirements. Offset studies often use replacement ratios to ensure no net loss of particular biodiversity targets by accounting for different abundances or densities of those targets between offsets and affected sites (Dalang & Hersperger 2010). However, because we were interested in offsetting equal amounts of IAA, rather than identical levels of biodiversity elements such as species, this function of ratios did not apply.

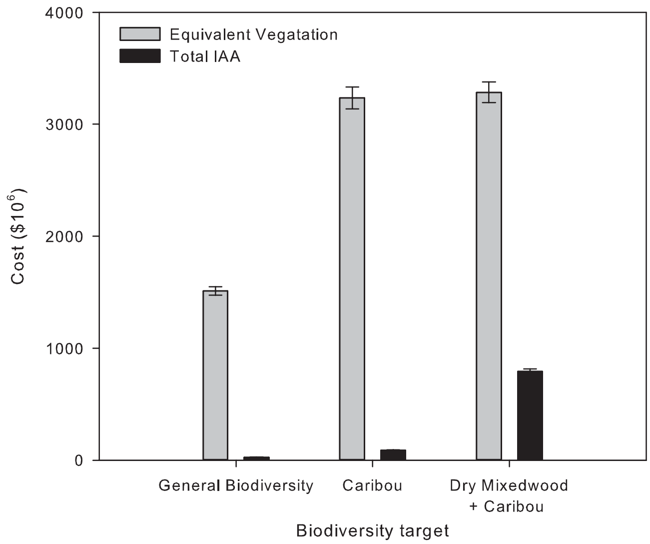


*Figure 3. Cost estimates for 6 prospective offset systems designed to compensate for biodiversity losses, measured in intactness-adjusted area (IAA), expected from current and future (to 2020) oil sands developments in boreal Alberta, Canada. Cost estimates include acquisition and restoration costs. Values represent the means of 100 MARXAN solutions per scenario (lines at top of bars, standard deviation).*

### Offset Creation and Optimization

Following the setting of conservation targets for each offset scenario, we used the program MARXAN (Ball et al. 2009) to create hypothetical offset networks that achieved the targets within the spatial constraints set out by each scenario. MARXAN is a site-selection tool that uses a simulated annealing algorithm to identify efficient solutions to land-use planning problems by considering the spatial distribution of costs and conservation gains associated with potential reserve networks. The study area is divided into a grid of planning units, in this case townships, each of which is assigned a cost (the summed protection and restoration costs) and one or more conservation feature values (the combined potential IAA credits available from protection and restoration). We used the $9.6 \times 9.6$ km ATS township grid to define planning units. Townships with $>50\%$ of their area within existing protected areas were considered already protected and therefore unavailable as offsets. As a result, small protected areas covering only a portion of a township were ignored in the analysis, despite possible practical or logistical reasons to use them as starting points for expanded networks. However, we weighted the acquisition cost of townships containing small parks to adjust for the inaccessible proportion of NPV, so that protecting these planning units was proportionally cheaper. Townships with $>50\%$ privately owned area, consisting largely of agricultural development, were also excluded. The remaining townships (74% of all boreal townships) were included for consideration as offsets. Each township was assigned values for potential IAA gain and cost. We used MARXAN to develop 100 solutions for each offset scenario and compared the cost, size, and distribution of the resulting offset networks.

## Results

The estimated cost of offsets varied dramatically among the 6 scenarios in our case study, from \$25 million to \$3.3 billion (Fig. 3), although these estimates do not represent a full cost analysis and should only be used for reference (see Discussion). Costs increased with the specificity of the conservation features targeted (general biodiversity < caribou < DM + caribou), but the largest increases came from requiring equivalent vegetation to be offset. Costs were up to 2 orders of magnitude greater for each equivalent-vegetation scenario compared with its total-IAA counterpart (Fig. 3). Although the area required for equivalent-vegetation offsets was necessarily larger so as to capture the required amount of each vegetation class (Fig. 4), reserve areas differed by only a factor of 2.5, indicating that the approximately 100-fold differences in cost were driven by the inclusion of a small number of expensive townships. This requirement also resulted in networks containing several small, isolated reserves

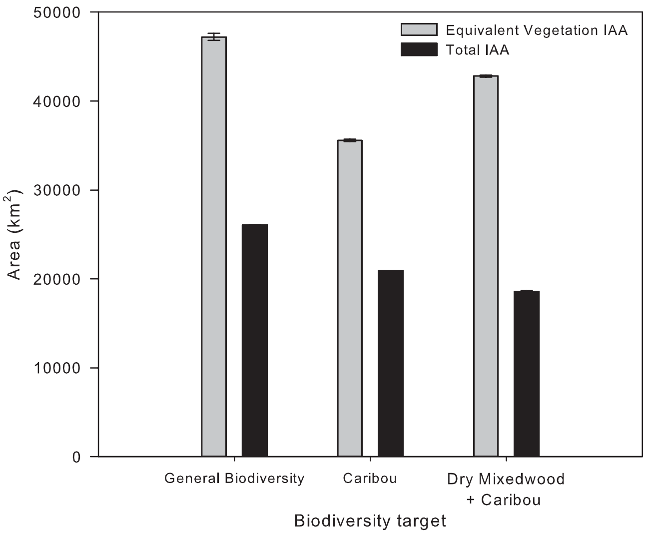


*Figure 4. Area of 6 prospective offset systems designed to compensate for biodiversity losses, measured in intactness-adjusted area (IAA), expected from current and future (to 2020) oil sands developments in boreal Alberta, Canada. Values represent the means of 100 MARXAN solutions per scenario (lines at top of bars, standard deviation).*

(Supporting Information). Solutions generated within each scenario were relatively stable. Depending on the scenario, between 41% and 79% of the planning units included in offset networks were selected in at least 80% of all solutions (Supporting Information). This suggests the majority of townships selected by MARXAN were largely irreplaceable for any efficient solution (Ardron et al. 2010).

## Discussion

In jurisdictions where offsets are being considered with the goal of conserving biodiversity in general, rather than specific at-risk areas or species, the flexible offset approach we evaluated demonstrates the potential cost savings available by departing from the equivalency-of-type paradigm. This is particularly relevant for areas such as Alberta's relatively undeveloped boreal forest, where conservation is necessarily focused on limiting or directing future losses, rather than on re-creating denuded landscapes as in other programs (e.g., USACE et al. 1995), where flexible offsets may be inappropriate. Although the lower costs for systems with less-specific requirements were not surprising, the cost of the traditional equivalent-vegetation scenario (1A) was drastically higher compared with the priority-target scenarios (2B and 3B) (Fig. 3). This result calls into question the prudence of a system focused on equivalency of type. These findings are predicated on the acceptability of a generalized currency such as intactness, such that stakeholders can be satisfied that this metric sufficiently captures ecological value across dissimilar biodiversity elements. Additionally, in all scenarios biodiversity was treated equally across our study region, although other goals, such as maintaining some level of local biodiversity at points throughout the region, may be preferred elsewhere.

The cost savings we found may be unusually large due to the enormously variable resource costs in boreal Alberta (Fig. 2), but opportunities for efficiency gains due to spatially variable conservation costs are likely to exist in most jurisdictions (Naidoo et al. 2006). The higher cost of equivalent-vegetation solutions may be partially attributable to the large planning unit size, which necessitates paying for entire townships to capture any vegetation types that occur as isolated patches. Although the use of smaller planning units may avoid incurring this extra cost, the long-term ecological value of the resulting small, isolated reserves would be questionable (Fahrig 2003), particularly for species such as large vertebrates.

Before any offset system can be implemented, considerable attention must be paid to details that were beyond the scope of our study, particularly how to address time lags and uncertainty in offset benefits. The ecological benefits of some offset activities, such as reforestation, will not be realized for decades or may fail altogether, but requiring offset credits to be secured before development is permitted to proceed and then withholding credits until revegetation is complete would seriously reduce market liquidity (Drechsler & Hartig 2011). Options include allowing development after a certain amount of progress has been made, such as securing land and tenure rights, and a management plan has been approved (McKenney & Kiesecker 2010) or requiring larger offsets to account for the failure probability and time discounting of yet-unrealized offset benefits (Moilanen et al. 2008), which is a principal tenet of habitat-equivalency analysis (NOAA 2006), another environmental compensation system.

One set of costs we did not include in our analyses is the management costs of offsets (Naidoo et al. 2006), which may include administrative and personnel costs of operating new protected areas and location-specific requirements such as predator control for caribou (Schneider et al. 2010) or invasive species management in areas with significant agriculture or road networks (von der Lippe & Kowarik 2007; Cameron & Bayne 2009). Management costs typically rise with economic activity (Balmford et al. 2003), so they would likely be highest in regions that already have high $NPV_P$ values, so we do not believe omitting them significantly altered our findings. Nevertheless, investigating management and other costs is necessary to provide robust estimates of the cost of offsets. Thus, the cost savings in an implemented system may be lower than we report here due to these and other unforeseen costs.

Offset program success also depends on the willingness of developers to comply with requirements and the willingness and ability of regulators to enforce them. Compliance is typically problematic; the amount of compensation achieved frequently falls short of requirements (Fox & Nino-Murcia 2005; Quigley & Harper 2006; Gibbons & Lindenmayer 2007). Although the system described here does not avoid the sociopolitical factors raised by Walker et al. (2009) that may lead to poor compliance, a system that is based on a straightforward, easy-to-measure, fungible currency may help facilitate regulatory oversight.

Offsets have been criticized as symbolic, inadequate measures that are doomed to fail at providing no net loss but provide a veneer of acceptability to environmentally destructive development (Walker et al. 2009). Although we agree with Walker et al. (2009) that no net loss is unlikely to be achievable, if offsets were employed as one of several tools used to bolster a regional conservation plan, success would be measured in the context of their contribution to the overall plan, rather than if they achieved no net loss. For example, in our case study, assessing offsets' contributions to a regional plan could involve estimating expected decreases in extinction risk for caribou herds targeted by offset activities (Supporting Information) via a model incorporating demographic responses to human footprint (Sorensen et al. 2008). Reframing the goal of offset programs as supplementing a regional plan as opposed to negating the effects of development may also earn offsets more support from conservation practitioners who fear offsets will be used as a "license to trash" (ten Kate et al. 2004). Such fears stem directly from the emphasis no-net-loss approaches place on the net difference in biodiversity values (i.e., gains minus losses must be $\geq 0$) without due consideration of what specific features are gained and lost. Biodiversity at 2 different locations is by definition noninterchangeable (Walker et al. 2009), and our approach, which is based on targeting priority features regardless of what features are affected, makes biodiversity trade-offs explicit and invites discussion of what losses may be acceptable to the public.

Ultimately, the conservation features that are targeted—and for what cost—must be determined by the stakeholders involved. Our approach provides estimates of how costs change with alternative offset strategies so that stakeholders may make informed decisions that reflect both the conservation features valued by society and the economic realities that must be considered in any offset program.

## Acknowledgments

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## Supporting Information

Sample MARXAN solutions (Appendix S1) and selection frequency maps (Appendix S2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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