Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION

TECHNICAL ARTICLE

Reclamation and habitat-disturbance effects on landbird abundance and productivity indices in the oil sands region of northeastern Alberta, Canada

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The pace and scale of reclamation in Alberta's oil sands region are increasing, and techniques to measure and validate the ecological function of developing habitats are needed. In Alberta, achievement of equivalent land capability to that present before disturbance is a regulatory requirement of reclamation certification. We compared landbird abundance and productivity indices from mist-netting data collected in 2011–2013 using the Monitoring Avian Productivity and Survivorship (MAPS) protocol with local habitat covariates at 35 monitoring stations in natural, reclaimed, and disturbed habitats. Principal component analysis of habitat covariates explained 83% of the variation in 20 habitat-structure variables. We found significant relationships between habitat covariates and captures of adult birds, young birds, and/or the probability of capturing a young bird (productivity) for 12 landbird species; in some cases, capture responses contrasted with productivity responses to habitat variables. Responses to reclamation age were as expected, given habitat preferences of our target species. Positive responses to reclamation age from obligate forest-dwelling species take more years to become evident than those for species preferring successional-stage habitats, while one species that prefers open, grassland habitats appeared to decline with reclamation age, presumably due to habitat succession. Application of the MAPS protocol as a tool to evaluate and track the performance of reclaimed and disturbed habitats is demonstrated, with landbird abundance and productivity indices in natural habitats being useful indicators of equivalent land capability.

Key words: avian vital rates, boreal forest, equivalent land capability, habitat structure, Monitoring Avian Productivity and Survivorship

Implications for Practice

- Multi-species approaches using capture methods can provide adult population and productivity data to better evaluate wildlife habitat use than presence-absence methods.
- Positive and negative avian abundance responses may be used to track successional habitat development, with increasing abundance responses for forest-dependent species and negative abundance responses for open habitat and grassland-dependent species.
- Divergent productivity and abundance responses of landbirds may suggest the presence of ecological source populations or traps.
- Avian demographic data support the evaluation of reclamation success, inform future reclamation program designs, and identify intervention opportunities if reclaimed habitats appear to be underperforming.

Introduction

Oil sands resource development in the boreal forest of northeastern Alberta, Canada, poses a variety of challenges for conservation, land management, and reclamation. Disturbances caused by industrial development require reclamation to self-sustaining, ecological systems of equivalent land capability, defined as the ability of the land to support land uses similar to those that existed prior to disturbance, although these land uses need not be identical (Province of Alberta 2016). However, specific benchmarks for establishing equivalence have not been defined. Because large areas are becoming available for reclamation, tools that assess wildlife habitat quality in the regulatory context of equivalent land capability are urgently needed.

Author contributions: KF, CG, PP conceived and designed the program; KF, CG conducted and supervised the field data collection; PP supervised data management and quality control; JS analyzed the data; KF, CG, PP, JS wrote and edited the manuscript.

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doi: 10.1111/rec.12478
Supporting information at:
http://onlinelibrary.wiley.com/doi/10.1111/rec.12478/suppinfo

The presence and abundance of landbirds can be used as sensitive indicators of environmental quality and are the focus of many regional and continental-scale monitoring efforts (Gregory & van Strien 2010; Renwick et al. 2012; Gould & Mackey 2015). Monitoring the dynamics and demography of landbirds along a gradient of natural, disturbed, and reclaimed habitats can demonstrate a progression of ecosystem development (Brady & Noske 2010), and ultimately gauge whether or not a reclaimed area has reached equivalent land capability to that before disturbance. However, vital rate data are lacking for most landbird species in the Canadian boreal forest (Thompson 2006; Wells 2011). The capture, marking, and recapture of landbirds can provide a useful tool for measuring habitat quality by providing information on population metrics, including the vital rates (e.g. productivity, recruitment, survival) that drive changes in occupancy and abundance (Saracco et al. 2008; Robinson et al. 2009). Vital rates are directly responsive to environmental stressors and they can more accurately reflect environmental conditions than do occurrence or relative abundance metrics provided by presence-absence approaches (Temple & Wiens 1989; Saracco et al. 2008; Wolfe et al. 2013) currently being used regionally in reclamation monitoring.

In North America, the Monitoring Avian Productivity and Survivorship (MAPS) program has been broadly applied to investigate spatial and temporal variation in landbird vital rates (Saracco et al. 2010, 2012), relationships between vital rates and population change (Saracco et al. 2008), and environmental drivers of vital rates (Nott et al. 2002; LaManna et al. 2012; George et al. 2015). MAPS data have also been used to assess avian diversity and vital rate responses to military activities and habitat change over an 18-year period (Keller et al. 2015) and survival of six species in an urban habitat island (Wolfe et al. 2013).

In 2011–2013 we established a network of 35 MAPS stations in northeastern Alberta, at sites experiencing a range of disturbance related to oil sands extraction activities as well as in natural habitats and habitats that have been reclaimed for various periods of time. Our objective was to provide an initial assessment of how age-specific avian abundance and productivity indices relate to habitat structure, disturbance, and reclamation gradients, and to demonstrate the potential for avian demographic monitoring to assess equivalent land capability following reclamation. In particular, we correlated capture rates of young and adult birds with vegetation metrics and reclamation age (years since completion of vegetation planting) at five MAPS stations where reclaimed habitat covered more than 50% of the station area.

Methods

MAPS Stations

Data were collected at 35 mist-netting stations during the breeding seasons of 2011–2013 in the oil sands region of northeastern Alberta, Canada (Table S1, Supporting Information). Stations were established according to the MAPS protocol; a station comprised an array of mist-nets that captured landbirds nesting within a 100-m perimeter around each net (DeSante et al. 2013). To facilitate comparisons, stations were placed in similar landscapes that included riparian habitats trending to upland and/or lowland habitats. Approximately half of the MAPS stations were placed in entirely or predominantly undisturbed areas, providing reference data on bird abundances and productivity indices in natural, boreal habitats. All other MAPS stations were placed in reclaimed habitats or habitats that included varying degrees of disturbance. Six stations were operated in 2011, 24 stations in 2012, and 34 stations in 2013. Once a station was established, it was operated in all following years, with the exception of a single station (HNGN; Table S1), which was established in 2012 but did not operate in 2013 due to flooding.

Bird Capture

At each station, 8–13, 2.6 × 12 m, 4-panel, 30-mm mesh mist-nets were opened for 6 hours beginning at local sunrise, once in each 10-day period from 10 June to 8 August (MAPS periods 5–10). These six 10-day periods coincided with the nesting and fledging season between spring and fall migrations. Captured birds were identified to species, age, and sex, and a Canadian Wildlife Service-issued numbered aluminum leg band was applied. Age was determined using criteria presented by Pyle (1997) as a young bird that fledged that season (i.e. "hatching year"), or as an adult bird at least 1 year old (i.e. "after-hatching year").

Habitat Structure

Vegetation structure is generally considered a stronger driver of avian habitat use than vegetation species composition or position of the reclaimed or disturbed habitat in the landscape (Brady & Noske 2010; Munro et al. 2011; Gould & Mackey 2015). We characterized habitats at our MAPS stations on the basis of vegetative structure, following the habitat structure assessment protocol of Nott et al. (2003). Station habitat boundaries were delineated using aerial photograph analysis, which were verified during ground-based characterization of horizontal and vertical structure on the basis of plant community composition, vegetation structure, and hydrology. For each habitat type, we recorded data on 17 quantitative or semi-quantitative variables (Table S2), with vertical structure described in terms of area (%) coverage of ground (vegetation <0.5 m), understory (0.5–5 m), midstory (5–15 m), and canopy (>15 m) layers. To derive station-scale habitat metrics, we calculated weighted averages of each of these variables with weights equal to the estimated proportion of each habitat type present at the station. In addition, proportions of natural, disturbed, and/or reclaimed areas at each station were calculated (Table S1) using a geographic information system, confirmed through ground-truthing, resulting in a total of 20 habitat model variables.

Statistical Analyses

To reduce dimensionality of the habitat data and to derive orthogonal covariates for inclusion in linear models of bird captures, we conducted a principal components analysis on the 20 station-scale habitat variables (Table S2). We retained principal component scores for seven axes with eigenvalues (λ) greater than 1 for inclusion as model covariates (Graham 2003; Legendre & Legendre 2012). We interpret principal components in terms of loadings (i.e. correlation) of the original habitat variables with each principal component. We modeled habitat relationships for 12 bird species for which we had an average of at least one young and one adult bird captured per station, per year (>75 captures of each). Species with fewer captures were often characterized by large numbers of stations with zero captures, and attempts to fit models for these species were largely unsuccessful. For the 12 species, we used generalized linear mixed models to examine bird captures as a function of a categorical year effect, habitat principal components, a random station effect, and a mist-netting effort covariate representing the number of net-hours operated at a station during the season (YR_NH).

We examined three response variables: (1) number of young captures, (2) number of adult captures, and (3) the probability of a captured bird being a young bird (i.e. proportion of young in the catch), an index of productivity. For young and adult captures we used Poisson models with log links and for productivity we used binomial models with logit links. We implemented models using the glmer function of the lme4 package (Bates et al. 2013) in the statistical program R (R Core Team 2013). We used the dredge function in the MuMIN package (Barton 2013) to compare all potential combinations of models that included year and effort effects and up to two covariates based on Akaike's Information Criterion corrected for small sample size (AIC_c). We assessed model support using AIC_c model weights, w_i, where $i = 1, \ldots, M$ models and support for individual covariate effects using summed model weights (Burnham & Anderson 2002). Covariate effects were deemed to be statistically significant whenever (1) covariates were included in strongly supported models (lowest AIC_c model or model within two AIC_c points of the best model) and (2) 95% profile confidence intervals for model-averaged regression coefficients did not include zero.

We examined effects of reclamation age on habitat variables and log(+1)-transformed numbers of adult and young birds captured per net hour for the 12 target bird species using data from five stations with more than 50% area in reclaimed habitat (Table S1). Reclamation age varied from 0 years (2012 at SFEN) to 30 years (1983 at GWAY). To explore these relationships, we computed partial correlation coefficients between each of the habitat variables, capture rates, and reclamation age while controlling for the percentage of natural habitat at the station.

Results

Habitat Characterization

Seven principal components (PC1–PC7), when combined, explained 83% of the variation in the 20 habitat structure variables, including proportions of each station in natural, reclaimed, or disturbance states (all PCs with $\lambda > 1$; Table S3). Variance explained by these principal component axes ranged from 24% (PC1) to 5% (PC7; Table S3). A gradient from open to forested habitat was represented by PC1, which was positively related to canopy height and percent of upperstory cover while being negatively related to percent of grass-like plants. PC1, therefore, was positively correlated with the percentage of natural habitat and negatively correlated with the percentage of reclaimed habitat (Table S3; Fig. 1). Aspects of ground cover largely characterized PC2; it was positively related to live ground cover, particularly nonvascular plants, and to percent cover of human-made corridors; and negatively related to forbs, ferns, and dead vegetation (Table S3; Fig. 1). Figure 1 shows the relationship between PC1 and PC2 habitat structure variables, and our MAPS stations. Aspects of the understory largely characterized PC3; it was positively related to nonvegetated ground cover and percent of standing water, and it was negatively related to understory cover, including shrub and herb heights. PC4 was positively related to running water and negatively related to midstory cover, dead-vegetation ground cover, and disturbance percentage. PC5 was positively related to percent cover of human-made structures and disturbance; it was negatively related to live ground vegetative cover, and positively related to woody ground cover. PC6 was negatively related to standing water and understory cover. PC7 was negatively related to cover of human-made corridors and ground cover by forbs and ferns, positively related to woody vegetation.

In the five predominantly reclaimed stations (>50% reclaimed area; BISN, BMLN, CRCL, GWAY, SFEN; Table S1), several of the upper and mid-canopy forest and successional stage habitat variables exhibited positive correlations with reclamation age, whereas some of the ground-level and disturbance variables exhibited negative correlations with reclamation age. Canopy height and midstory vegetation cover both showed strong positive correlations with reclamation age (partial $r > 0.9$, $p < 0.01$). We found slightly weaker positive correlations with shrub layer height, upper canopy cover, and percentage of dead vegetation in the ground cover (partial r approximately 0.6–0.7; Table S4). We found even weaker negative correlations with reclamation age (partial $r < -0.4$) for percentage of woody vegetation, percentage of bare ground cover, and percentage of human-made corridors and structures.

Bird-Habitat Structure Relationships

We found support for habitat-structure effects on adults and young captures or productivity for each of the 12 species (Fig. 2, Tables S5 & S6). Captures of species typical of more open or successional habitats responded negatively to the open-to-forested habitat gradient represented by PC1. This included adult and young captures of Yellow Warbler (YEWA; *Setophaga petechia*), Clay-colored Sparrow (CCSP; *Spizella pallida*), and Lincoln's Sparrow (LISP; *Melospiza lincolnii*). In contrast, captures of both adult and young Canada Warbler (CAWA; *Cardellina canadensis*), a species associated with mature forests, were positively related to PC1. Bird responses to PC2, which was largely defined by a gradient of low-to-high

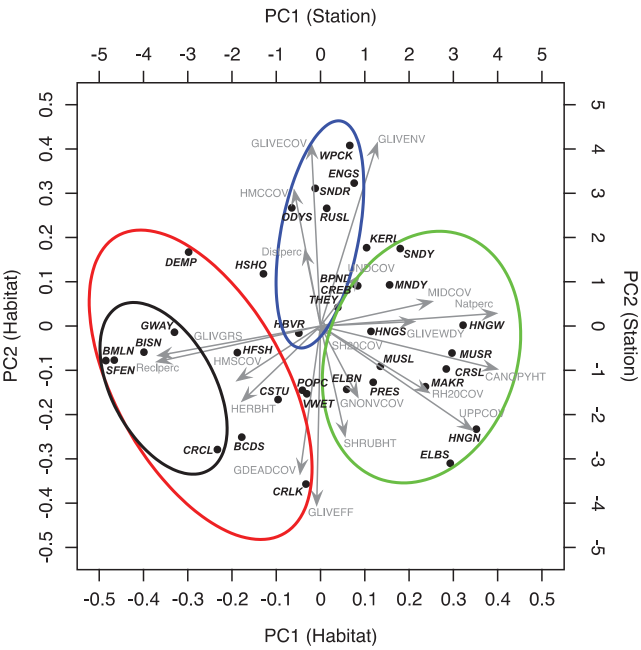

Figure 1. Biplot of station (points and bold italic labels; see Table S1) and habitat variable (gray arrows and labels; see Table S2) scores along the first two principal component (PC) axes. Vectors from the origin to habitat variable scores indicate the direction and correlation of the habitat variable with the PC axes. Colored ovals indicate the groupings of stations composed of primarily natural habitat (green), substantially reclaimed (red), and disturbed areas (blue). The five stations with predominantly reclaimed habitats (>50%) are bounded by the black oval.

nonvascular plant cover and human-made corridors, tended to be negative. Adult captures were negatively related to this axis for four species: Black-capped Chickadee (BCCH; *Poecile atricapillus*), Ovenbird (OVEN; *Seiurus aurocapilla*), Canada Warbler, and White-throated Sparrow (WTSP; *Zonotrichia albicollis*); and positively related to this axis for one species, Tennessee Warbler (TEWA; *Oreothlypis peregrina*). Young captures were negatively correlated to PC2 for Least Flycatcher (LEFL; *Empidonax minimus*) and Black-capped Chickadee and Ovenbird; and productivity of Swainson's Thrush (SWTH; *Catharus ustulatus*) was negatively correlated with this axis. For all seven PCs there were a total of 39 significant relationships among all 12 species: 18 with adults, 12 with young, and 9 with productivity (Fig. 2, Tables S5 & S6).

Among the five stations with predominantly reclaimed habitat, forest-dwelling species showed positive responses to reclamation age, whereas open-habitat species showed negative correlations with reclamation age (Table S7). Positive correlations were found for adult capture rates of species associated with shrub habitats, such as Tennessee Warbler (partial $r = 0.9$, $p = 0.020$) and White-throated Sparrow (partial $r = 0.8$, $p = 0.073$). Weaker positive relationships (partial $r > 0.4$) were found for adult capture rates of Yellow Warbler and Chipping Sparrow (CHSP; *Spizella passerina*), species associated with mid-successional or open-forested habitats, and for young capture rates of Yellow-bellied Sapsucker (YBSA; *Sphyrapicus varius*), Least Flycatcher, and Ovenbird, species associated with more forested habitats. The strongest (albeit nonsignificant) negative correlations with reclamation age were for Clay-colored Sparrow (adults and young), a species characteristic of open and grass-dominated habitats.

Discussion

The diversity of disturbance types and reclamation practices on lands affected by oil sands development provide a major challenge for evaluation of wildlife colonization and use of developing habitats. Nevertheless, our principal components analysis revealed that variables characteristic of later successional habitats correlated positively with natural cover and negatively with developing habitat at reclaimed stations, suggesting that they represented broad habitat gradients that characterize the reclamation process. In addition, we found 39 species-variable responses (across 12 target species) to the seven principal component analyses, indicating that monitoring indices of abundance and vital rates with standardized mist-netting data is a useful tool for measuring avian responses to reclamation efforts and disturbance.

Abundance indices for adult and young birds were largely in accord with known habitat relationships of target species. For example, species associated with open or successional habitats (Least Flycatcher, Yellow Warbler, Clay-colored Sparrow, and Lincoln's Sparrow) were more commonly captured at sites with shorter and more open canopies, greater cover of grass-like plants, more disturbed vegetation, and less-reclaimed areas; while species associated with closed-canopy forests (Canada Warbler) showed opposite responses. Productivity did not appear to respond strongly to the overall open-to-forested habitat gradient represented by PC1; however, we did find productivity relationships with PCs 4 and 5, axes that were associated with disturbance. Forest species, including Least Flycatcher, Ovenbird, and Canada Warbler, tended to have lower productivity at more disturbed sites, while species of more open habitats, including Yellow Warbler and Lincoln's Sparrow, were more tolerant of disturbance.

Although within-species responses of adult and young birds to habitat covariates were largely in similar directions, productivity responses were sometimes opposite in direction. For example, Canada Warbler adults were negatively related to PC2 (associated with relatively open ground cover); while young showed a less negative response, and productivity was positively related to this axis. Although habitat at stations with high PC2 scores might have been favorable for Canada Warbler breeding, relatively few adults may have successfully bred at these stations (e.g. due to saturation of available habitat) or there might have otherwise been some density-dependent reduction in productivity. A similar pattern was found for Chipping Sparrow and PC4. Of the 11 species showing significant adult abundance-habitat relationships, only Lincoln's Sparrow had a significant productivity relationship with the same habitat covariate, but with the sign of the relationship in the opposite direction. Similarly, significant habitat covariate relationships for the productivity

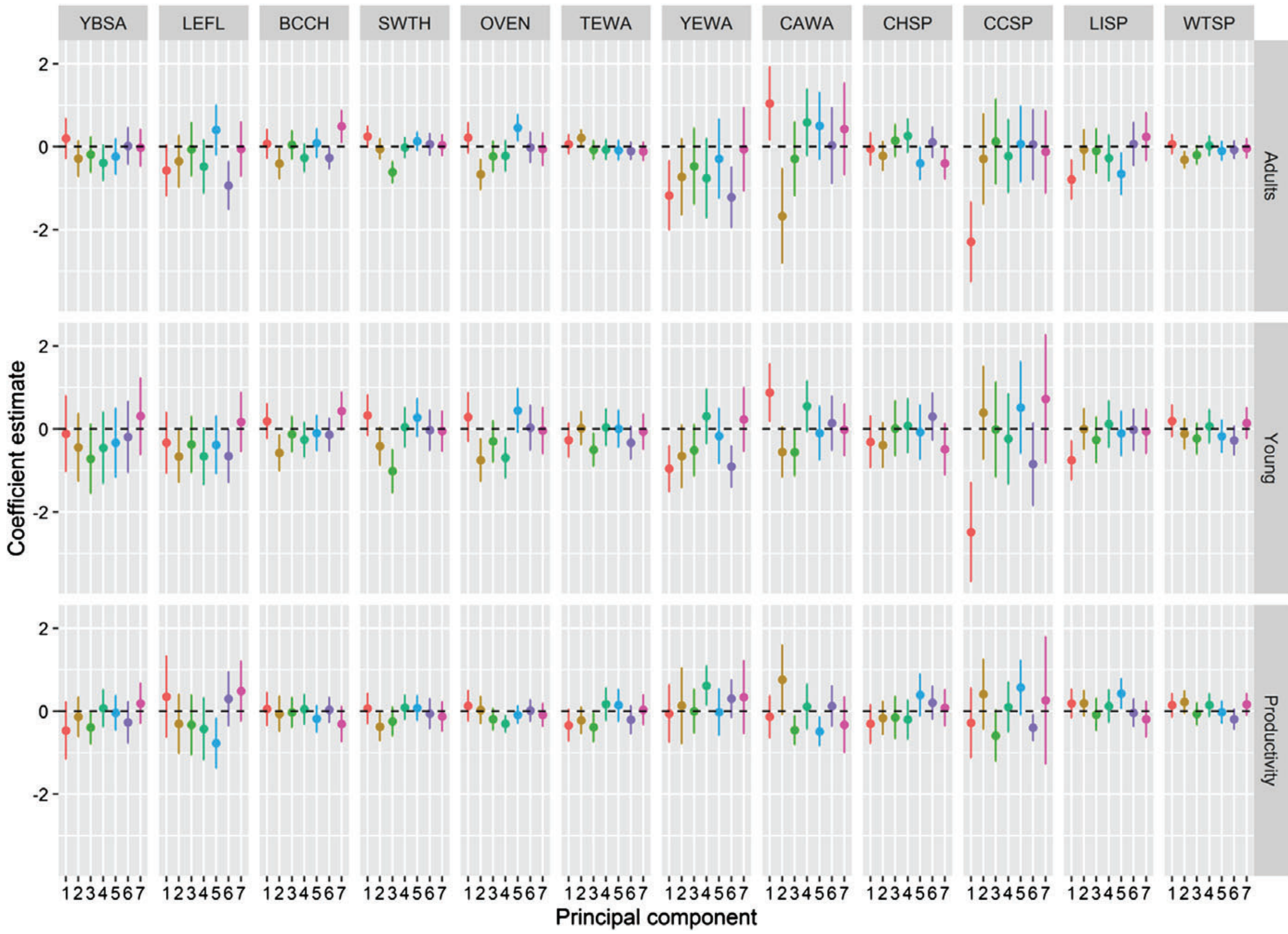

Figure 2. Model-averaged regression coefficients with 95% confidence intervals (on link scale (log for adult and young capture rates, logit for productivity index) for habitat principal components (see Table S3, Fig. 1) based on generalized linear mixed models. The summed Akaike weights for each of these variables are shown in Table S5.

response were found for eight species, and these covariates were either not significant for adult abundance-habitat relationships (seven species) or significant and opposite in sign (again, Lincoln's Sparrow). Inconsistencies in habitat relationships between abundance and productivity highlight the importance of considering multiple demographic variables to identify habitats that may serve as population sources, or sinks that act as ecological traps (Schlaepfer et al. 2002; Keagy et al. 2005).

Several of the upper and mid-canopy forest and successional stage habitat variables exhibited positive correlations with reclamation age (range 0–30 years), whereas some of the ground-level and human-related habitat variables exhibited negative correlations with reclamation age. Gould and Mackey (2015) caution that reclamation age might not be a strong proxy for habitat quality, as age does not explicitly consider habitat structure development and the availability of resources for various bird species. Nevertheless, in our initial examination of the effect of vegetative development using reclamation age, bird responses were largely as expected given habitat preferences of our target species. The lack of significant correlations between some species and reclamation age might be due to the small number of reclaimed habitats available for study, the small patch size of the reclaimed areas in our study relative to the influence of landscape position and surrounding habitats, or limitations imposed by relatively high variability in the datasets.

In conclusion, we found significant relationships between habitat structure and the capture rates of adult and young landbirds and productivity. Consideration of additional demographic parameters, such as adult survivorship, residency, site persistence and movement (Saracco et al. 2010; Ruiz-Gutierrez et al. 2016), and proportion of 1-year-old landbirds will provide a suite of metrics for the assessment of reclaimed habitat quality and development of habitats over time. Demographic monitoring has proven useful in other ecological programs, including wetland and native grassland restoration in agricultural settings (Fletcher et al. 2006) and focal species-based conservation planning (Chase & Geupel 2005), illustrating the importance of identifying the vital rate(s) driving population trends in order to better design and implement management actions. Our results indicate that measurement of avian vital rates against predicted demographic responses and desired outcomes defined in the reclamation planning stage (as suggested by Brady & Noske 2010) should be a primary mechanism for evaluating reclaimed habitat performance in the context of equivalent land capability, and informing future reclamation programs.

Acknowledgments

Funding in support of this project is provided by Syncrude Canada Ltd., Hammerstone Corporation, Canadian Natural Resources Limited, Cenovus Energy, ConocoPhillips Canada, Devon Energy, Husky Oil Operations Ltd., Imperial Oil Ltd., Suncor Energy, and TOTAL E&P Canada, and the Oil Sands Developers Group. Funders were not involved in the design, analyses, or interpretation of the data, or writing of the manuscript. Funders provided logistical support and safety oversight within the boundaries of their operations. The authors are solely responsible for the technical merit of the work presented in this manuscript. G. Coulombe, P. Lai, B. Carnes, R. Dudgrane, R. MacLaughlin, S. Gray, J. Bosman, K. Prince, L. Parker, A. Rosien, J. Johnston, C. Murray, L. Macdonald, and D. Maynard conducted banding operations. E. Rowan, R. Taylor, D. Kaschube, and L. Helton (IBP) provided MAPS protocol-related expertise and support. S. McElroy conducted the habitat structure assessments. K. Michaels conducted the spatial analyses. This is Contribution No. 491 of The Institute for Bird Populations.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Boreal MAPS station descriptions, including percentage areas within the banding station covered by natural habitats, disturbances of the types indicated, reclaimed habitats, and water (flowing or standing).

Table S2. Habitat variables recorded within each of up to five distinct habitat types at a station.

Table S3. Principal component loadings for the first seven principal components (PCs) with eigenvalues greater than 1.

Table S4. Habitat variable partial correlations with reclamation age controlling for % natural habitat area.

Table S5. Model selection results for each species and response (Adults, Young, Productivity) and regression coefficient estimates for principal components (PC1 to PC7) and an effort covariate (YR_NH) representing annual station-specific net-hours.

Table S6. Summed Akaike weights for each species and response variable over all models including each of the explanatory variables, as shown in Figure 2.

Table S7. Adult and young capture rate partial correlations with reclamation age, controlling for % natural habitat area.

Coordinating Editor: Stephen Murphy

Received: 15 May, 2016; First decision: 16 August, 2016; Revised: 29 October, 2016; Accepted: 1 November, 2016