Informing Placer Reclamation Activities With Respect To Enhancing Waterfowl Use

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Conserving Canada's **Wetlands**

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Introduction

Placer gold mining is an important driver of the Yukon's economy, contributing over $46 million toward total GDP including direct, indirect, and induced effects (Vector Research 2018). Placer mining occurs throughout much of the southern half of the Yukon, but is concentrated in the Klondike Plateau near Dawson City (Figure 1). Placer mining involves removing overburden, the top layers of soil and gravel, to access alluvial deposits that contain small nuggets or flakes of gold. The paydirt, the layer of gravel on top of the bedrock that contains the gold, is washed to manually separate the heavier gold particles from the sand and gravel. Sluice boxes are used to capture the gold, while larger gravels are placed in large piles and finer sediments are washed away into settling ponds. Mining operations can result in the formation of open water wetlands due to the flooding of mining cuts and/or the creation of settling ponds. These features persist on the landscape after operations are complete.

Breeding and brood rearing waterfowl often use manmade wetlands (Leschisin et al. 1992; McKinstry and Anderson 2002; Stevens et al. 2003). EDI Environmental Dynamics (2017) showed breeding waterfowl, as well as other birds and mammals, use placer ponds in the Yukon. Concerns about the impacts of placer operations on wildlife and existing methods for successful reclamation of these sites are a current focus of regulators, industry, and First Nations in the Yukon however, regulations and guidelines are lacking. For purposes of this paper, reclamation is considered the manipulation of the physical characteristics of a created wetland to improve its ecological function.

Studies exist that provide guidance for approaches to pond reclamation with the aim of increasing waterfowl values (e.g., McKinstry and Anderson 2002 for bentonite mining), but information about best practices for pond reclamation is lacking for northern environments. To address this information gap, we undertook a project to identify characteristics of ponds remaining after placer mining that correspond with waterfowl use. We collected remotely sensed and field-based data to describe the characteristics of ponds created by placer mining activities in the Indian River watershed, an area with historical and current placer mining (Figure 2). Project results can inform best management practices for placer pond reclamation activities.

Methods

The study area is the Indian River watershed, a 2,227km^2 area located south of Dawson City, Yukon in the Klondike Plateau (Figure 2). The study area is part of Beringia which was unglaciated during the last ice age and is prone to wildfire. White and black spruce dominate mature forests, with pockets of aspen and birch present. Valley bottoms contain fen and swamp complexes underlain by permafrost (Yukon Ecoregions Working Group 2004). Historic mining began in the early parts of the 20th century with the use of dredges on the upper tributaries of the Indian River. Recent operations using modern techniques are more prevalent on the western and eastern portions of the watershed along with a handful of tributaries.

Pond Mapping

High resolution satellite imagery made available from the Geomatics Yukon ArcGIS image server was used to identify shallow open water ponds (see Figure 3 for example). ESRI ArcGIS 10.4 software was used to access this imagery.

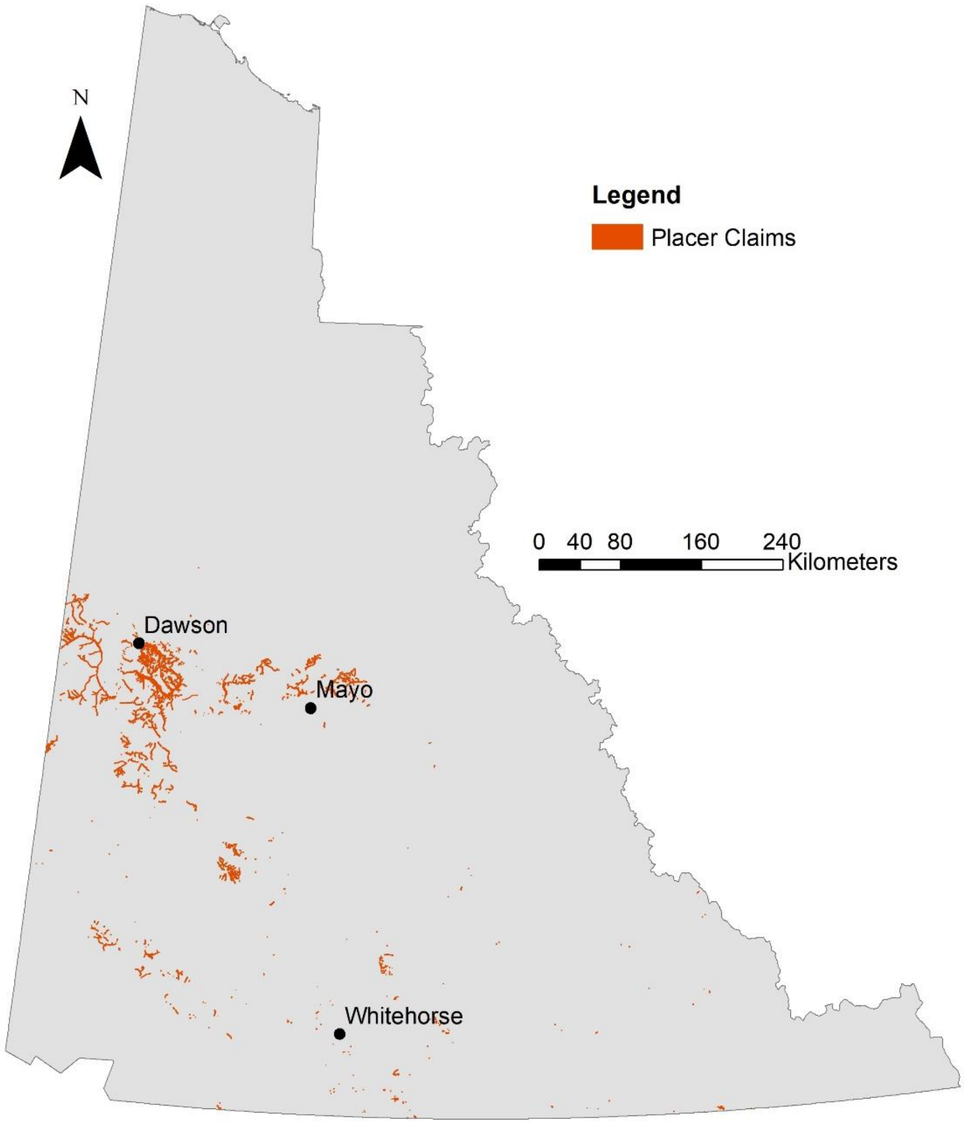

Figure 1: Location of placer mining claims in the Yukon.

After bringing in the high resolution satellite imagery into ArcGIS, we extracted (i.e. clipped) areas of interest (AOI) from the Indian River watershed and portions of the Klondike River valley near Dawson City from the imagery for processing and classification. We determined AOIs by interpreting imagery to identify regions where placer mining activities were active or have taken place. Once an AOI was identified, we created a polygon for that region. Each AOI was also associated with a specific satellite image. Imagery ranged in date and type of sensor used. Refer to Table 1 for satellite imagery extracted and used for classification.

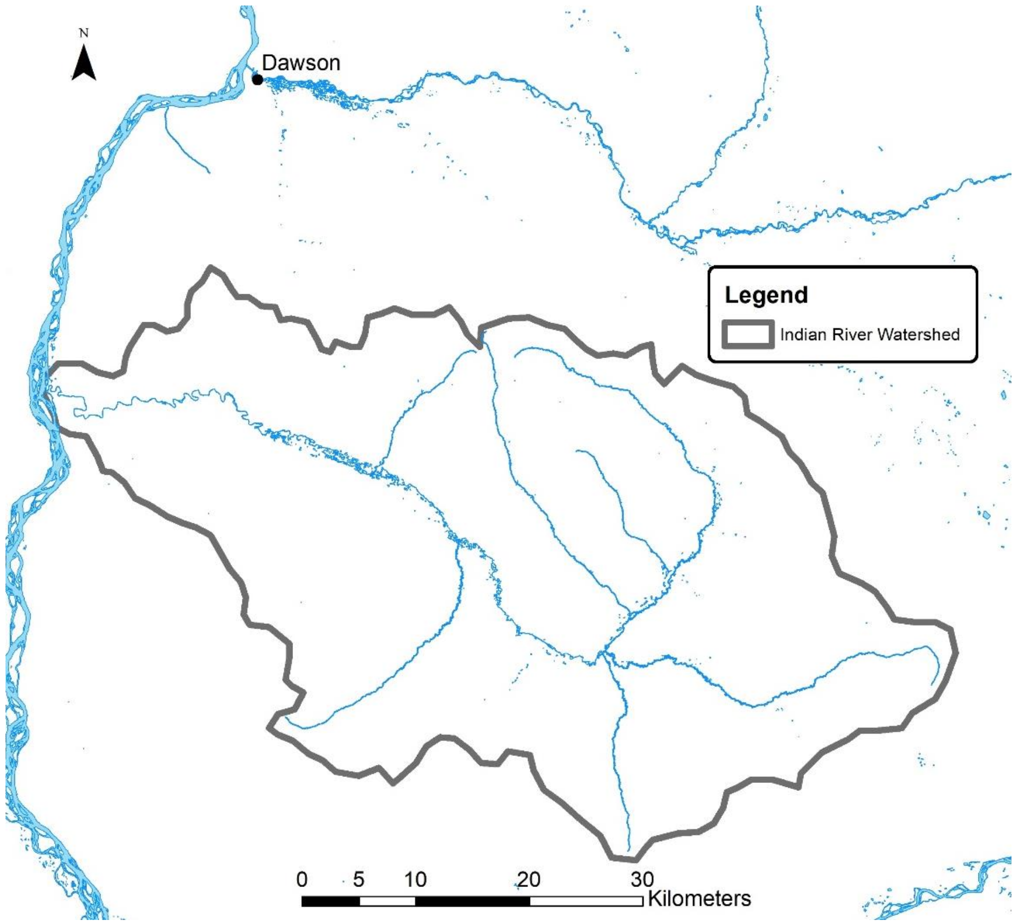

Figure 2: Boundary of the Indian River watershed in west-central Yukon.

Figure 3: Example of high resolution satellite imagery over Dawson, Yukon.

Table 1: Satellite images extracted from the Geomatics Yukon image server.

Sensor	Acquisition Date
GeoEye	03-August-2010
GeoEye	25-July-2009
GeoEye	14-July-2009
GeoEye	06-July-2009
Pleiades	24-July-2015
Pleiades	05-September-2015

We extracted each satellite image corresponding to defined polygon boundaries by using the *Clip* tool in ArcGIS. We created a simple extraction model (Model Builder) in ArcGIS based off this tool (Figure 4). This allowed for the streamlining of image extraction from all AOIs. We extracted imagery using the model, output was in GeoTIFF format.

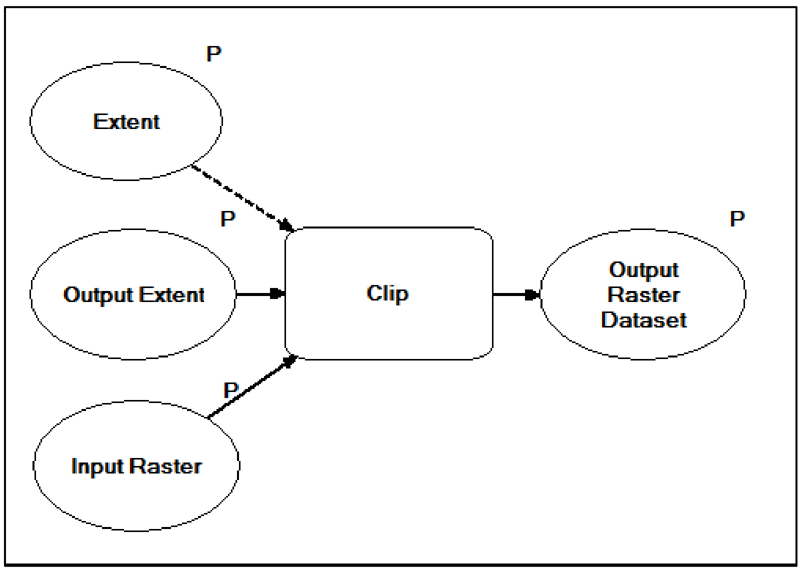

Figure 4: Schematic of the ArcGIS Model Builder workflow.

After obtaining imagery for each AOI, we brought the extracted rasters into eCognition Developer software (9.2) for image classification. The first step in this process segmented the satellite image into image objects. The goal of image segmentation is to create image objects that are as large as possible to reduce processing time and inherent noise, but small enough to discriminate and capture fine features in the landscape. Refer to Figure 5 for an example of image segmentation. We used the Multiresolution Segmentation algorithm with a scale parameter of 50 to determine the size of the objects for object development. We applied a higher weight to the blue band, allowing us to better capture variations in water/non water features.

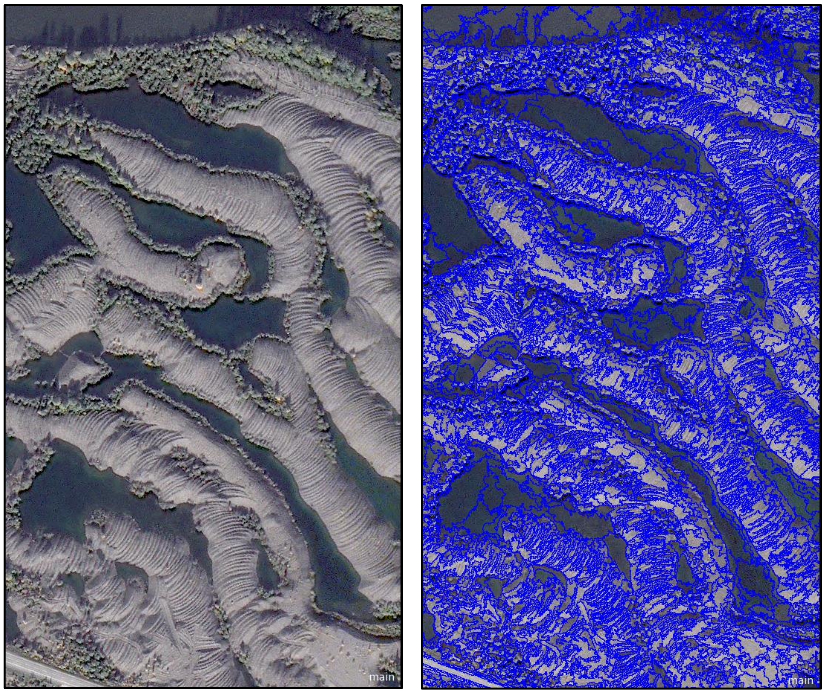

Figure 5: Example of image segmentation. The image on the right shows the image objects that represent relatively homogenous spectral responses.

We classified image objects with a supervised approach using a Support Vector Machine (SVM) classifier. SVMs are a non-parametric statistical learning technique that operate by separating the remotely sensed data into a predefined number of classes (i.e. open water vs. not open water). SVMs were introduced by Vapnik (1979). Samples of Open Water and Not Open Water were chosen within the AOI. These samples were used to train the SVM classifier (Figure 6). Limitations of the classification are mostly related to shadows and clouds present in the imagery. Cloud presence does not allow for any land cover identification. Additionally, haze was present in some imagery, reducing the accuracy of pond boundary identification where present. Tree shadows were also a common limitation. When present near riparian areas these shadows increased the difficulty of river identification.

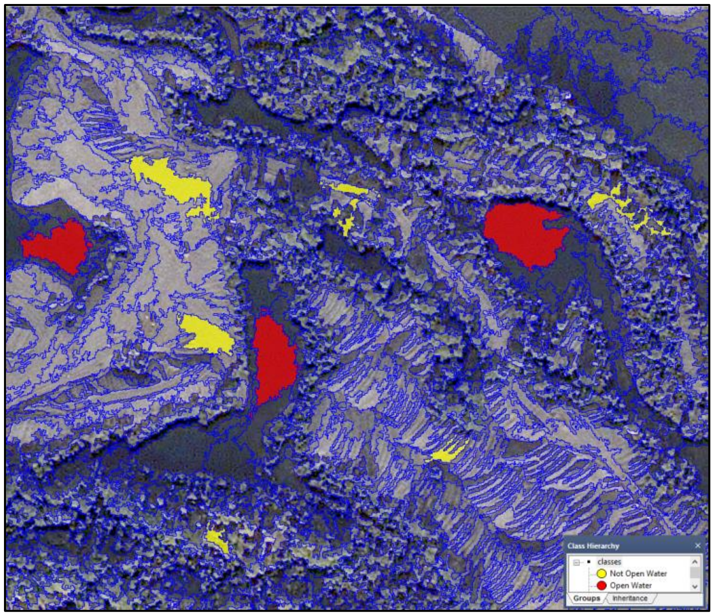

Figure 6: Example of training samples used to identify open water.

After classification, we completed a quality assurance (QA) procedure. Objects classified incorrectly were manually corrected. Open water objects associated with rivers were then differentiated from non-river objects. We then exported the final classification from eCognition as a GeoTIFF Raster. In ArcGIS, we reclassified the raster so that Open Water Ponds were assigned a value of 1 and Rivers were assigned a value of 2. The Not Open Water Class was assigned a value of NoData. We then converted rasters to vector using the *Raster to Polygon* Tool. Lastly, we applied a polygon smoothing technique (based on the Polynomial Approximation with Exponential Kernel smoothing algorithm) using the *Smooth Polygon* Tool. This was done to remove sharp edges associated with raster classifications. Every polygon associated with the final open water classification was classified as a naturally occurring pond (e.g. a shallow open water wetland) or not (e.g. an open water pond resulting from mining). Subsequent GIS analysis was completed on only the open water ponds that were anthropogenically influenced based on image interpretation. Figure 7 summarizes the workflow used to map open water wetlands.

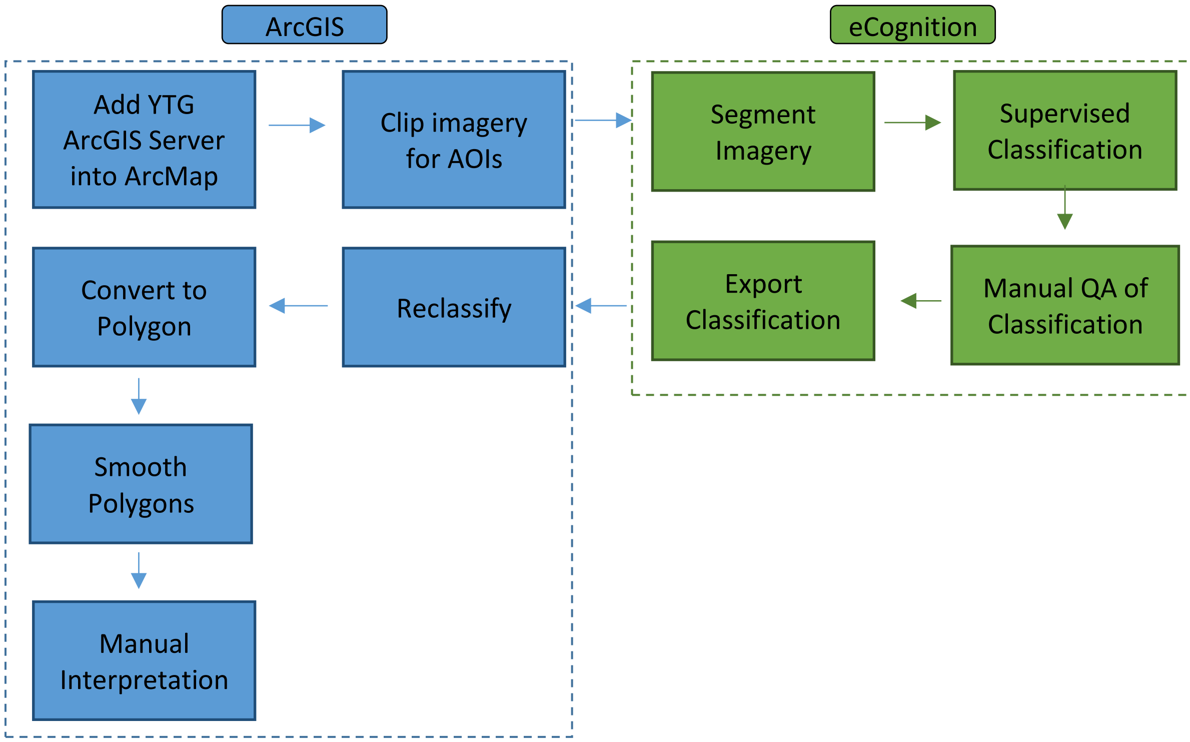

Figure 7: Workflow to map open water ponds created by placer mining activities.

Due to changes on the landscape since the imagery was produced, we remapped some ponds selected for waterfowl surveys using medium resolution (150cm SPOT) imagery available on Geomatics Yukon. These images were taken in September and October 2016. We hand digitized ponds noted during fieldwork as being different from initial mapping work if there was an obvious water body visible in the newer imagery. We set the map scale at 1:1,500 during the digitizing process. We remapped sixteen ponds using this method.

Waterfowl Surveys

We randomly selected 92 ponds that we believed were created by placer mining activity out of 643 identified within the Indian River watershed for waterfowl surveys. We did not use any stratification in selecting ponds. We used a Jet Ranger Helicopter (Bell 206B) for the first three surveys and a MD500 for the second brood survey, due to helicopter availability. Breeding pair surveys occurred on May 25 and June 6 to capture the peak breeding period for waterfowl. Brood surveys occurred on June 27 and July 25 to ensure we spanned as much of the peak brood rearing period as possible. The survey and safety protocol was modified from a Canadian Wildlife Service application outlined in the Black Duck Joint Venture (1996). We flew all surveys at an altitude of approximately 30m above ground level. Ground speeds did not exceed 40 km/h, but were decreased to 20 km/h depending on visibility. We navigated to wetlands using a GPS and ESRI ArcMap 9.1 with integrated Tracking Analysis moving map software. The flight crew included a pilot and a single observer. The observer navigated and recorded observations on the left side of the helicopter (right side when using the MD500). The observer recorded the species, sex, social status, count, and brood age for each observation into hand-held voice recorders. Only 84 ponds were available for survey due to some ponds having been completely removed from the landscape.

Pond Characteristics

We obtained pond characteristics using two methods: GIS analysis and direct measurements at the pond. We used ArcMap to estimate pond size (converted to natural log for modelling purposes), perimeter to area ratio, and percent of open water created by placer mining within a series of buffer distances (90m, 300m, 500m, and 1,000m). We obtained a dataset from the Government of Yukon that mapped natural wetlands in a portion of the Indian River watershed. Where these data were available we determined the amount of each of three natural wetland types (fen, swamp, and natural open water) within the same buffer distances as above. Bog and marsh wetland types were not common enough to be considered for further analysis.

We measured a suite of variables thought to influence waterfowl use at each pond that could be accessed and that had not been significantly altered since imagery was obtained for mapping purposes (n=55). Field crews measured pond depth at a minimum of four locations along a minimum of three transects spaced evenly throughout the pond and averaged the values for each pond. We estimated basin slope at a minimum of four locations along the pond's perimeter by determining the inverse tangent of the angle formed between the water's edge and the horizontal distance to where water depth equaled 40cm (Leschisin et al. 1992). We estimated water clarity at a minimum of four locations within the pond by measuring the percent of water column visible, based on the depth at which a Secchi disk reading was no longer visible (D. Wrubleski, pers. comm). If the Secchi disk was visible at the bottom then our estimate of water clarity was 100%. We additionally recorded categorical variables including stream inflow and/or outflow, beaver dam, beaver lodge, or island. For each pond, we also estimated the percent cover of emergent and submergent vegetation. We described the upland vegetation immediately adjacent to each pond by determining the percent cover of four cover types: grass, shrub, tree, and bare.

Statistical Analysis

Indicated breeding pairs were our measure of pair abundance on surveyed ponds. Indicated breeding pairs for waterfowl include single isolated males, the sum of males in groups of 2-4 individuals, males in a group of two males and a female, and pairs for most species. All other groupings of mixed sex were assumed to be non-breeding or migrant birds. The exceptions were scaup spp. and ring-necked duck, which have a disproportionate number of males (U.S. Fish and Wildlife Service/Canadian Wildlife Service 1987). Indicated breeding pairs for scaup and ring-necked duck were calculated by summing the observed pairs only. For swans, geese, loons and grebes (non-sexually dimorphic species) we assumed a breeding pair to be two birds within close proximity to one another or a single bird on a nest. We used the early pair and brood surveys to estimate pairs/broods of mallard, northern shoveler, and horned grebe while the later surveys were used for American wigeon, green-winged-teal, blue-winged teal, bufflehead, ring-necked duck, and scaup, based on the pair survey with the highest pair abundance. Species were then grouped by foraging guild to increase sample size: dabbling ducks (mallard, American wigeon, green-winged teal, blue-winged teal, and northern shoveler) and diving ducks (Barrow's goldeneye, bufflehead, ring-necked duck, and scaup).

We used Poisson generalized linear models, appropriate for count data, to model duck pairs and broods as a function of the pond characteristics. We screened pond characteristics for inclusion in multivariable models by advancing only those pond characteristics yielding Akaike information criterion (AIC) values less than intercept-only models. Full models were simplified by deleting the least predictive variable, when supported as decreasing AIC. We ran three separate models because not all data were available for all ponds. One model (n = 55) included variables associated with placer mining including pond characteristics and amount of open water due to placer mining within given buffer differences. Natural wetland predictors (percent natural open water, fen, and swamp) were only available on 32 ponds so their effects were considered in a separate model. The 32 ponds used in this model were not a subset of the 55 used in the first model as ponds included in this model did not have to include pond characteristics. Thirdly, from an exploratory perspective, the predictors from the best approximating models were combined and run on a subset of wetlands with both placer and natural wetland data collected (n = 27).

Results

Waterfowl surveys observed 70 indicated breeding pairs and 38 broods (Table 2) across the 84 ponds that were remaining on the landscape. Because pond data and/or natural wetland data was not available for all ponds, the number of pairs and broods used in each model varied (Table 3). The best supported model for each guild and survey period contained a variety of variables with only a handful of consistencies between them (Table 4 for dabbling ducks and Table 5 for diving ducks). The direction of effects are mainly positive with a handful of negative relationships (Table 6). Figures 8-11 show the magnitude and uncertainty associated with the best performing models from Table 3 for each variable for each of guild and survey period. Dabbling duck pairs and broods decreased with increasing amount of naturally occurring open water within 1,000m of the surveyed pond (Figures 8, 10), but increased with increasing amounts of open water created by placer mining although at different distances – 300m for pairs (figure 8) and 90m for broods (Figure 10). Diving duck pairs and broods are correlated with pond size (Figures 9, 11). Dabbling duck and diving duck pairs are positively correlated to the presence of beaver dams and steeper basin slopes (Figures 8, 9). The improved performance provided by combining the best performing models suggests that brood abundance is influenced by surrounding natural wetlands more so than pairs (Table 6).

Table 2: Waterfowl pairs observed on placer mine ponds in the Indian River watershed.

Species	Number of Pairs	Number of Broods
Mallard	18	3
American Wigeon	12	10
Ring-necked Duck	11	2
Bufflehead	7	2
Green-winged Teal	7	13
Canada Goose	5	
Scaup	4	6
Northern Shoveler	2	
Barrow's Goldeneye	2	
Blue-winged Teal	1	
Horned Grebe	1	1
Unknown Diver		1
Total:	**70**	**38**

Table 3: Number of pairs or broods used in each model due to data limitations of field collected data or spatial extent of the natural wetlands dataset.

		Model		
Guild	**Survey**	**Placer Pond**	**Natural Wetlands**	**Combined**
Dabbling Duck	Pair	30	22	19
	Brood	18	12	9
Diving Duck	Pair	20	14	12
	Brood	10	7	6

Table 4: Model selection results from multivariate generalized linear models for dabbling duck pair and brood abundance. The model highlighted in bold was the best performing model as it had the lowest AIC.

Survey	Model	Statistical Model	Minus 2 log Likelihood	Number of Parameters	AIC
Pair	Placer Pond	Full Model: ln(Pond Area) + Water Clarity + % Placer Pond (300m) + Perimeter:Area ratio + Beaver Dam + Inflow/Outflow + Average Depth + Average Slope + Beaver Lodge	76.124	10	96.124
		Remove ln(Pond Area)	76.189	9	94.189
		Remove Water Clarity	76.490	8	92.490
		Remove Perimeter:Area ratio	**77.035**	**7**	**91.035**
		Remove Inflow/Outlfow	79.330	6	91.330
		Remove Average Slope	82.090	5	92.090
		Remove average Depth	85.839	4	93.839
		Remove Beaver Dam	94.572	3	100.572
		Remove % Placer Pond (300m)	110.951	2	114.951
		Remove Beaver Lodge	131.101	1	133.101
	Natural Wetland	Full model: % Natural Open Water (1,000m)+ % Fen (1,000m) + % Swamp (300m)	79.596	4	87.596
		Remove % Fen (1,000m)	**79.719**	**3**	**85.719**
		Remove % Swamp (300m)	83.798	2	87.798
		Remove % Natural Open Water (1,000m)	90.249	1	92.249
Brood	Placer Pond	Full model: ln(Pond Area) + % Placer Pond (90m) + Perimeter:Area Ratio + Water Clarity + Beaver Lodge + Island Present + % Upland Grass + % Upland Shrub	63.671	9	81.671
		Remove Water Clarity	63.674	8	79.674
		Remove Beaver Lodge	63.808	7	77.808
		Remove % Upland Grass	64.627	6	76.627
		Remove ln(Pond Area)	65.861	5	75.861
		Remove Island Present	**67.074**	**4**	**75.074**
		Remove % Upland Shrub	69.733	3	75.733
		Remove % Placer Pond (90m)	72.463	2	76.463
		Remove Perimeter:Area Ratio	84.764	1	86.764
	Natural Wetland	Full model: % Natural Open Water (1,000m) + % Fen (1,000m)	45.301	3	51.301
		Remove % Fen (1,000m)	**46.856**	**2**	**50.856**

		Remove % Natural Open Water (1,000m)	54.707	1	56.707

Table 5: Model selection results from multivariate generalized linear models for diving duck pair and brood abundance. The model highlighted in bold was the best performing model as it had the lowest AIC.

Survey	Model	Statistical Model	Minus 2 log Likelihood	Number of Parameters	AIC
Pair	Placer Pond	Full model: ln(Pond Area) + % Placer Pond (90m) + Perimeter:Area Ratio + Beaver Dam + Island Present + % Upland Grass + Average Depth + Beaver Lodge + Water Clarity + % Emergent Vegetation + Average Slope	48.236	12	72.236
		Remove % Placer Pond (90m)	48.279	11	70.279
		Remove + Perimeter:Area Ratio	48.511	10	68.511
		Remove Island Present	49.059	9	67.059
		Remove % Emergent Vegetation	49.525	8	65.525
		Remove % Upland Grass	50.000	7	64.000
		Remove Average Depth	**51.121**	**6**	**63.121**
		Remove Beaver Lodge	54.509	5	64.509
		Remove Water Clarity	56.681	4	64.681
		Remove Average Slope	58.745	3	64.745
		Remove Beaver Dam	65.304	2	69.304
		Remove ln(Pond Area)	95.949	1	97.949
	Natural Wetland	Full model: % Swamp (1,000m)+ % Fen (300m)	56.820	3	62.820
		Remove % Swamp (1,000m)	**58.796**	**2**	**62.796**
		Remove % Fen (300m)	61.662	1	63.662
Brood	Placer Pond	Full model: ln(Pond Area) + Perimeter:Area Ratio + Beaver Dam + Beaver Lodge + % Upland Grass + Average Depth + Average Slope	39.365	8	55.365
		Remove Perimeter:Area Ratio	39.365	7	53.365
		Remove Average Slope	39.816	6	51.816
		Remove Average Depth	40.343	5	50.343
		Remove % Upland Grass	41.464	4	49.464
		Remove Beaver Lodge	42.615	3	48.615
		Remove Beaver Dam	**43.724**	**2**	**47.724**
		Remove ln(Pond Area)	55.481	1	57.481

Natural Wetland	Full model: % Natural Open Water (500m) + % Swamp (300m)	33.434	3	39.434
	Remove % Swamp (300m)	**34.104**	**2**	**38.104**
	Remove % Natural Open Water (500m)	36.664	1	38.664

Table 6: Direction of effect of variables correlated with pair and brood abundance for dabbling and diving ducks. The combined model takes the variables from the best performing model from the placer pond and natural wetlands models and models abundance. Results for this model are improvement or no improvement over best fitting Placer Pond Model.

Guild	Survey	Placer Pond Model (n = 55)	Natural Wetlands Model (n = 32)	Combined Model (n=27)
Dabbling Duck	Pair	↑ No inflow/outflow	↓ % Natural Open Water (1,000m)	No improvement
		↑ Beaver dam	↓ % Swamp (300m)	
		↑ Beaver lodge		
		↑ Average depth		
		↑ Basin slope		
		↑ % Placer pond (300m)		
	Brood	↑ Upland shrub	↓ % Natural Open Water (1,000m)	Improvement
		↑ % Placer pond (90m)		
		↓ Perimeter:area ratio		
Diving Duck	Pair	↑ Beaver dam	↑ % Fen (300m)	No improvement
		↑ No beaver lodge		
		↑ Basin slope		
		↑ Pond area		
		↓Water clarity		
	Brood	↑ Pond area	↓ % Natural Open Water (500m)	Improvement

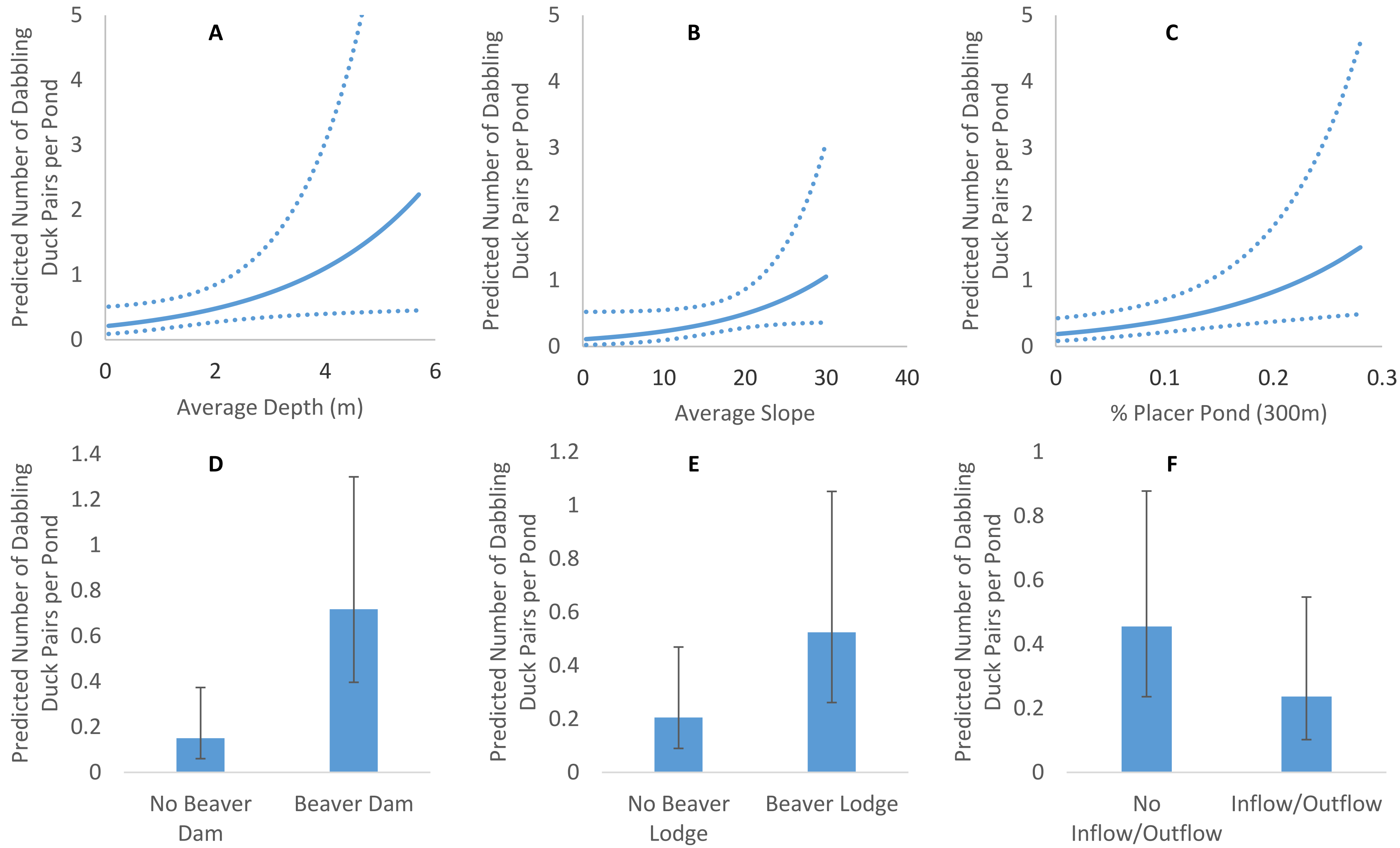

Figure 8: Effects of variables correlated to dabbling duck pair abundance of the best performing model based on lowest AIC value. Error bars are 95% confidence limits. Variables are average depth of pond (A), average basin slope (B), percent placer ponds within 300m (C), presence of beaver dam (D), presence of beaver lodge (E), and presence of inflow or outflow (F).

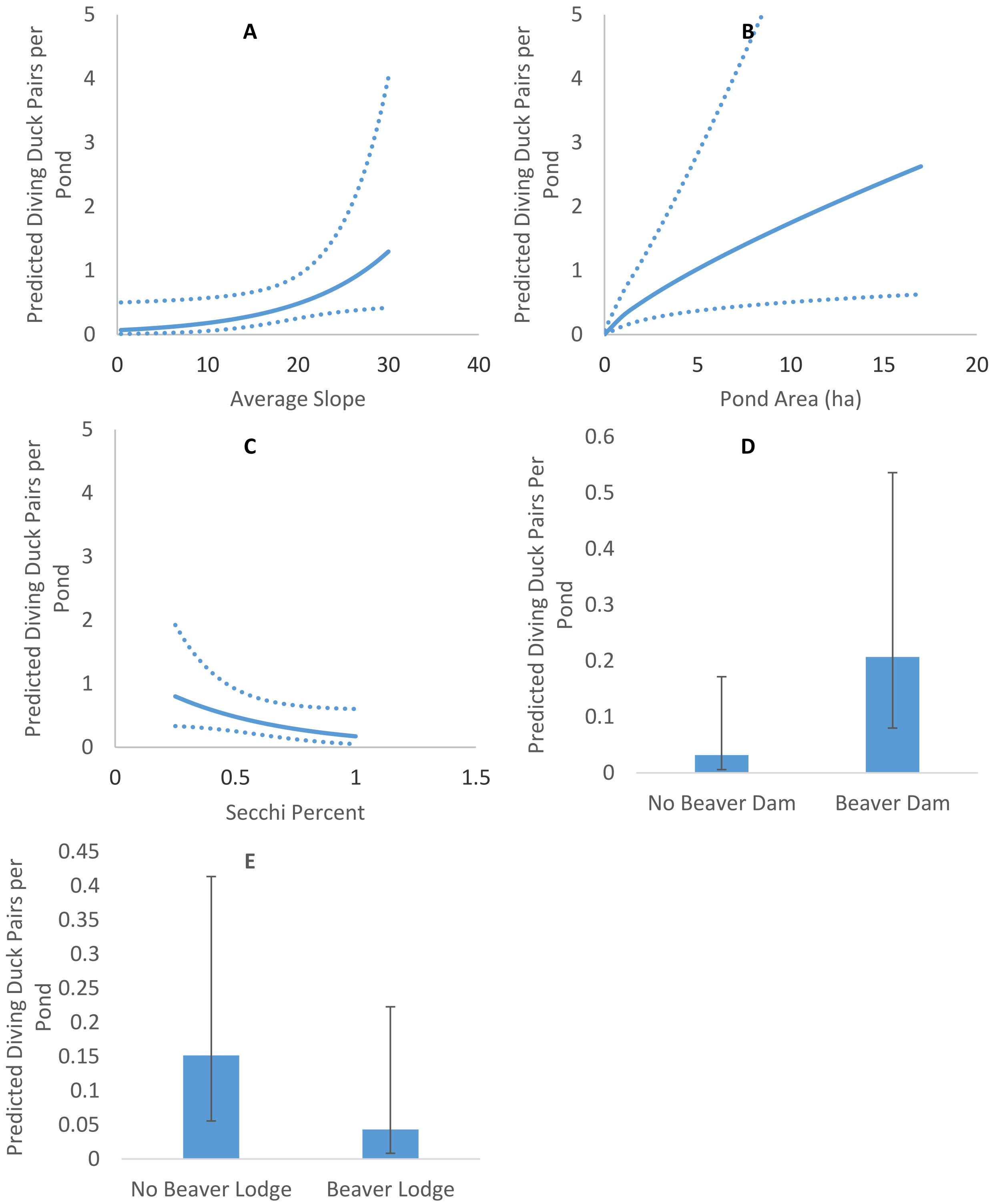

Figure 9: Effects of variables correlated to diving duck pair abundance of the best performing model based on lowest AIC value. Error bars are 95% confidence limits. Variables are average slope (A), pond area (B), water clarity (C), presence of beaver dam (D), and presence of beaver lodge (E).

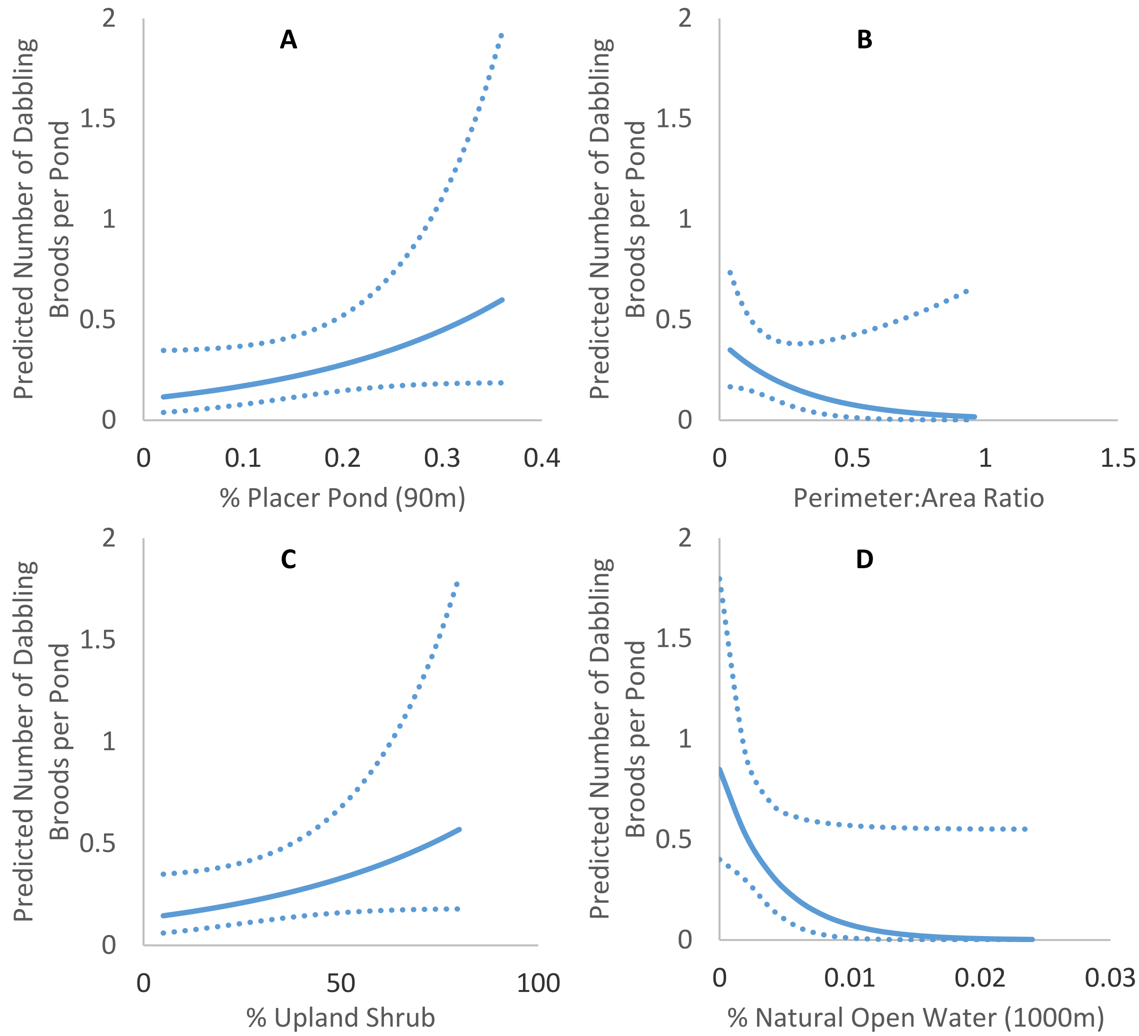

Figure 10: Effects of variables correlated to dabbling duck brood abundance of the best performing model based on lowest AIC value. Error bars are 95% confidence limits. Variables are percent placer pond within 90m (A), perimeter:area ratio (B), percent upland shrub (C), and percent natural open water within 1,000m (D).

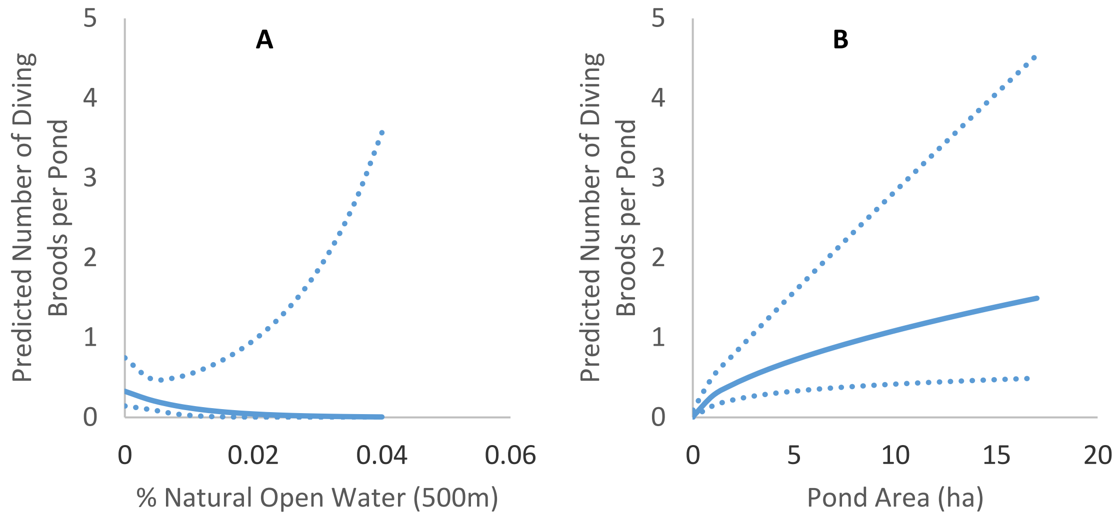

Figure 11: Effects of variables correlated to diving duck brood abundance of the best performing model based on lowest AIC value. Error bars are 95% confidence limits. Variables are percent natural open water within 500m (A) and pond area (B).

Discussion

Firm recommendations on how best to reclaim ponds to increase value to waterfowl cannot be provided based on this study alone for a number of reasons including limited sample size due to the difficulty in obtaining data, high levels of statistical uncertainty, and the correlational nature of the study design. The sample sizes were small due to the limited number of ponds we obtained all data for and low counts and clumped distribution of waterfowl pairs and broods observed. The 70 waterfowl pairs observed during aerial surveys were seen on only 26 ponds. This distribution resulted in zero counts for many ponds that may limit the ability of the model to identify correlations despite using a Poisson generalized linear model to account for count data. Lack of field data collected on all ponds and limited spatial extent of the natural wetlands data further decreased our sample size, resulting in having to use three different models with each having a different sample size. We randomly selected wetlands, therefore the distribution of our surveyed ponds should roughly match what is on the landscape. For example, roughly 66% of all ponds originally sampled were under 0.5ha in size. This lack of larger ponds drove the uncertainty in estimating the effect size (Figure 9 and 11).

We collected field data on only 55 ponds for a couple of reasons. The Indian River watershed is a dynamic landscape due to numerous active placer mines currently in operation. Many ponds have been removed or severely altered due to mining activity or lost for other reasons, such as beaver dam failure, since the date of the imagery used to identify and map ponds (2009-2015). Future work in regions where dynamic landscape change is occurring need to use updated imagery or mapping products or risk similar limitations. Challenges with site access limited our ability to acquire field data for the full number of ponds surveyed for waterfowl. Related to the dynamic landscape, deactivated or washed out roads prevented easy access to study sites. Distance and/ or thick vegetation made foot access with necessary equipment, including canoes and/ or stand-up paddleboards, challenging and in some cases impossible. Up-to-date imagery and closer consideration of accessibility may have minimized this limitation. For natural wetlands, the spatial extent of the data limited the sample size in conjunction with existing field data limitations. Further mapping work is underway to fill this data gap.

Models performed similarly, making it difficult to determine what variables are correlated with waterfowl abundance. In all models, the best performing model differed less than two AIC units from other models. This suggests limited improvement by removing that variable from the model. The model identified correlations however the magnitude of the effect was not large in many cases, such as with diving duck broods and amount of natural open water within 1,000m (Figure 11a). This inability to statistically differentiate the relative importance of the variables and the minimal magnitude of the correlation limits our ability to make robust recommendations regarding how best to improve reclamation activities to improve waterfowl value.

Correlational studies provide information about observed relationships; however, they do not provide information about the mechanisms behind these relationships. This limitation can make it difficult to make recommendations with confidence as it is unclear whether one variable (e.g., pond characteristic) causes another (e.g., waterfowl presence). For correlations found in this study there may not be a corresponding response by waterfowl if future reclamation activities strive to include a given characteristic during pond construction due to that characteristic not necessarily being the cause of the observed waterfowl response. The mechanisms driving the relationships found in this study are unknown and require investigation. Better understanding the mechanisms driving the relationship between waterfowl and pond characteristics will improve recommendations for reclamation.

The results of this study provide an opportunity to inform future reclamation efforts when placer mining activities create a pond. We make the following suggestions (Table 7) with the caveats discussed above. In addition, desired outcomes will need to be determined as part of a reclamation plan as different pond characteristics may provide more benefit for a given foraging guild.

Diving ducks used larger ponds, so building larger ponds might be beneficial for these species. We are unable to suggest a minimum size at this time. Pair numbers of both dabbling and diving ducks increased with basin slope; however, the maximum average slope found in this study was 30°. Consider 30° slopes as a guideline for contouring ponds. Designing ponds without an inflow or outflow and making them deeper may benefit dabbling duck pairs. Absence of inflows and outflows may limit fish populations in ponds and fish presence has been shown to limit waterfowl use (Hanson and Butler 1994). Due to the uncertainty around the relationship of pond depth and its effects on the number of pairs (Figure 8 and 10), depths greater than 2-3m may have unpredictable outcomes.

Considering beaver activity in reclamation plans might affect waterfowl use, as presence of beaver dams was positively correlated with both dabbling and diving duck pairs. Nummi and Holopainen (2014) found that beaver presence increases the abundance of ducks in other parts of the boreal forest and hypothesized that construction of beaver dams release nutrients used by invertebrates that are subsequently used by waterfowl. Beaver lodge presence gave contradictory results which limits our ability to recommend how to deal with their presence. To attract beavers, reclamation plans may consider locating ponds near existing deciduous woody vegetation or planting these species near the pond. Upland shrubby vegetation is attractive to beavers and provides an added benefit of being correlated to higher dabbling duck broods.

Nearby landscape characteristics correlate to waterfowl use and need to be considered in reclamation plans. A surprising result, found using the natural wetland model, is the negative correlation between natural open water and both dabbling and diving duck brood abundance. However, we do not recommend reducing the amount of natural wetlands to improve the use of reclaimed ponds for waterfowl use. What can be considered in reclamation plans is the amount of open water created by placer mining nearby. For dabbling ducks, the surface area of placer ponds within 300 m and 90 m increased the number of dabbling duck pairs and broods, respectively. McKinstry and Anderson (2002) found a relationship between dabbling duck pairs and broods with amount of reclaimed wetlands nearby and suggested this was to allow movement, of broods in particular, between ponds to satisfy all their needs. By coordinating pond reclamation with neighbouring mines or by planning a longer-term reclamation timeline that includes future mining activities, there are opportunities to maximize the landscape scale benefits of pond reclamation for dabbling ducks.

Table 7: List of considerations for improving waterfowl value during reclamation of ponds created by placer mining.

Dabbling Duck Pair	Dabbling Duck Brood	Diving Duck Pair	Diving Duck Brood
Basin slope <30°	Increased surface area of placer ponds within 90m	Larger ponds	Larger ponds
No inflow or outflow	Increase amount of shrub along pond edge	Basin slope <30°	
Depth <3m	Decreased perimeter to area ratio	Encourage beaver dams	
Encourage beaver dams		Decrease water clarity	
Increased surface area of placer ponds within 300m			

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