1. INTRODUCTION

The Mackenzie Delta is one of the most important breeding areas for ducks, geese, and swans in North America (Bellrose 1980). The Delta is also home to two aboriginal groups with settled land claims: the Inuvialuit and the Gwich'in. Waterfowl are an important food source and harvest of renewable resources forms a vital part of the cultures of these people. Maintenance of harvestable populations of wildlife and protection of the environment form a fundamental part of the land claim agreements of both the Inuvialuit and Gwich'in (Committee for Original Peoples Entitlement 1984, Indian and Northern Affairs and Gwich'in Nation 1992).

Planned developments to extract the vast natural gas reserves underlying the Mackenzie Delta (Brackman 2000, Chandler 2004) have the potential to cause long-term degradation of the delta ecosystem (including habitat in the Kendall Island Bird Sanctuary) and reductions in numbers and productivity of migratory birds (Murphy and Anderson 1993, Ritchie and King 2000, Ritchie et al. 2002). Gas and oil development could impact migratory bird populations in several different ways including: (1) habitat loss or alteration; (2) pollution; (3) development-induced changes in predator numbers and movement patterns; (4) disturbance from development, increased transport, and greater access by humans (Murphy and Anderson 1993, Ritchie and King 2000, Ritchie et al. 2002); and (5) increased collisions with tall structures such as communication towers, power-lines, and other oil field structures (Ritchie and King 2000, Erickson et al. 2001, Collins 2002).

Evaluating the cumulative impacts of development on most species of waterfowl or other northern wildlife is difficult because many species are inherently difficult to study and most populations show much natural variability in numbers and reproductive success which detracts from our ability to detect longer term trends. In addition, numbers of migratory birds are potentially influenced by a variety of events and stressors throughout their migratory range that will make even fairly significant industrial impacts on bird populations difficult to detect. Most studies will necessarily conclude that no environmental impacts have occurred. Suitable study species, experimental design, and adequate sample sizes are required to determine impacts of industrial development on waterfowl and other migratory bird populations (Anderson et al. 1999).

At present, there are no detailed programs in place that would allow us to evaluate the long-term impacts of development on the migratory birds of the region. Thus, the goal of this investigation is to evaluate the impacts of gas development on aquatic birds in the Kendall Island Bird Sanctuary and neighboring parts of the Mackenzie Delta using Tundra Swans as a potential "indicator" species. Adult Tundra Swans are large white birds, live in open habitats, and are easily spotted from the air. Because of their visibility, they are one of the most reliable waterfowl species with which to conduct aerial surveys and, once located, complete counts of young are readily obtained. Tundra Swans are widely distributed throughout the Mackenzie Delta (Hines et al. 2005) and their populations and productivity can be monitored in a simple and cost-effective manner (King 1973, Spindler and Hall 1991). Factors affecting reproductive success of Tundra Swans, including weather conditions on the breeding grounds (Lensink 1973, Spindler and Hall 1991) and human disturbance (Scott 1977, Hawkins 1986, Murphy and Anderson 1993), make this species a potentially useful indicator of the cumulative effects of industrial development, climate change, and other stressors impacting the Mackenzie Delta ecosystem.

In 2001-2003, complete aerial counts of swans were carried out during mid-June (nesting) and early August (brood-rearing) in a number of study plots in the Mackenzie Delta Region. Plots were established in 21 treatment or development areas (where gas exploration activities had occurred) and 27 control or reference areas (Figure 1). The main long-term objective of the work is to assess the numbers and reproductive success of Tundra Swans at plots of the two types in the Mackenzie Delta region and, by extension, evaluate the potential effects of proposed development on migratory bird populations. This report describes baseline population parameters for Tundra Swans as they existed in 2001-03, evaluates whether any impacts of development have been so far detected, and presents recommendations for future work.

2. METHODS

2.1 Study area

A 24,185 km^2 area which included much of the important wetland area in and around the Mackenzie Delta was chosen as a study area (Figure 1). The study area is located near the tree line, and both tundra (near the Beaufort Sea) and taiga communities (further inland) are present. The Mackenzie Delta proper covers an area of nearly 15,000 km^2 and is truly a land of lakes. Nowhere else in Canada is there an area of this size with so many lakes, which number in the thousands (Mackay 1963). Delta lakes can be classified into five broad types: abandoned channel lakes; point bar lakes; floodplain lakes; and thermokarst lakes (Mackay 1963). The distribution and types of vegetation present within the Delta are greatly influenced by flooding, sedimentation, and the presence of permafrost. Mackay (1963) recognized six general vegetation regions described as tundra; tundra with scrub willow and ground birch; scrub willow and ground birch; woodland and tundra with much scrub willow and ground birch; open woodland; and continuous woodland.

The Mackenzie Delta is the largest river delta in Canada and one of the most important habitat sites for migratory birds in the North. More than 1% of the national population of at least 20 different species of birds is present in the Delta some time during the spring-fall season each year (Latour et al. 2005) and about one-third of the Eastern Population of Tundra Swans summers in the general region (Hines et al. 2005). Some of the most important habitat for migratory birds occurs at the 623 km^2 Kendall Island Bird Sanctuary in the outer Mackenzie Delta (Alexander et al. 1991, Latour et al. 2005).

Extensive petroleum exploration occurred in the region from the late 1960s through the mid-1980s and led to the discovery of several large gas and oil fields with total volumes of gas estimated to be in the trillions of cubic meters (Morrell 1995, Janicki 2001). Interest in hydrocarbon exploration, in the region and other parts of the North, fell with oil prices in the mid-1980s but increased dramatically in the late 1990s and has remained high since. Evidence of the earlier period of exploration remains visible in the form of seismic lines, permanent camps, pilings that supported drilling platforms and other infrastructure, drilling sumps, capped wells, and discarded materials. More recent exploration is evident from seismic disturbance, permanent camps, drilling platform mounds, capped wells, and some refuse. Detailed descriptions of the Mackenzie Delta can be found in the following reports and numerous references cited therein: physical environment (Mackay 1963, Rampton 1988), flora (Mackay 1963, Corns 1974, Pearce 1986), and fauna (Martell 1984).

2.2 Survey methods and selection of study plots

As a survey method, we chose to carry out total counts of swans in 5 x 5-km sample plots. The size and number of plots surveyed reflected a trade-off among statistical concerns, logistic limitations, and financial realities. Knowledge of the population densities of swans in the region (Hines et al. 2005) and the expected effort required to survey areas of different sizes (R. King, pers. comm.) helped in developing the study design. Two surveys were carried out each year: one count in June to determine numbers of territorial and nesting pairs, and a second count in August to determine the number of broods and total young produced. Counts of adult swans were categorized by their social status: single, paired, nesting, brood-rearing, or flocked (non-breeding).

In 2001, 20 plots (each 25 km^2 in area) were established within the study area at treatment or development sites and an additional 20 randomly placed plots were established at control or reference sites (Figure 1). In 2002, six new randomly located reference plots were added to the sampling program and, in 2003, two additional development plots and one reference plot were added. The latter reference plot was not randomly placed. Instead, it was deliberately established in the Kendall Island Bird Sanctuary where we had two development plots but no reference plots. By chance, most of the randomly selected reference plots had fallen outside the zone of greatest potential industrial development within the Mackenzie Delta. The maximum area sampled in any year (48 plots in 2003 or 1200 km^2) represented 5% of the total study area.

Active gas exploration when the study began in 2001 was primarily high intensity (“3-D”) seismic exploration and the possible locations of new well sites or other new facilities and infrastructure were unknown. Therefore, development plots were selected near exploratory well sites established in the 1970s and 1980s, existing camps, sites of recent 3-D seismic exploration, and gas fields of known importance (Appendix A, B).

2.3 June breeding and August productivity surveys

Aerial counts of swans were carried out in June and August 2001-2003. Timing of the June breeding surveys corresponded to early incubation (11-19 June) and timing of the August productivity surveys corresponded to early to mid brood rearing (3-11 August) when most young were three to four weeks old.

Aerial survey methods were adapted from the United States Fish and Wildlife Service Trumpeter and Tundra Swan survey protocol (U.S. Fish and Wildlife Service 1991) and the standing operating procedures established for breeding ground surveys of waterfowl in North America (U.S. Fish and Wildlife Service and the Canadian Wildlife Service 1987) as modified for helicopter surveys by Hines et al. (2005). A Bell 206 helicopter on floats was used to carry out complete counts of swans along five, 1-km wide north/south transects within each of the 5 x 5 km study plots. With the aid of a laptop computer and "moving map" software, the pilot navigated along the transect line and maintained the helicopter at a ground speed of 80 km/hr or slower and a flight height of 115 m above ground. Two observers, one seated in the left front seat and the other seated in the right rear seat, recorded the number of swans and their locations on 1:60,000 scale satellite images of the study plot. The exact location of each nest was determined using a global positioning system. Each observation was recorded as a single, a pair, a single on a nest, a pair on a nest, or a flock (e.g. ≥ 3 swans judged to be within sight of each other) (U.S. Fish and Wildlife Service 1991). During the breeding season, the two members of a swan pair are not always found together. Therefore, pairs were estimated and referred to as indicated pairs by summing all sightings of one or two swans and then dividing by two (Wilk 1988). This method allows us to compare our results to historical surveys of Tundra Swans in the Mackenzie Delta. Throughout this paper we also refer to "nesting pairs" which equaled the number of nests found.

With the exception of the type of aircraft used, productivity surveys were conducted in a similar way to breeding surveys. In the August surveys, a float-equipped

Cessna 207 fixed-wing aircraft was flown at 135 -155 km/hr and 115 m above ground. The pilot was responsible for observations on the left side of the aircraft and a second observer carried out observations on the right side of the aircraft and assisted in navigation. During the brood-rearing period, swans are invariably located on or near water. Therefore, in plots with few ponds or lakes, actual transects were not followed. Instead, the plot was surveyed in the most efficient manner with observers focusing their attention on the few water bodies present but still covering the entire plot.

2.4 Data analysis

The total number of adult swans, indicated pairs, adults in flocks, nests, broods, and total young were determined for each plot/survey combination. To test for possible violations of the assumptions of parametric tests, the summarized plot data were assessed for normality using Shapiro-Wilk W Test (Sall 2001) (Appendix C), and homogeneity of variances using Levene's test (Tabachnick and Fidell 2001) (Appendix D). A few potential outliers (large counts of flocked swans) were identified (Grubbs 1969); however, we felt that all the counts were an important and valid part of the samples and chose to retain all data in the analyses. Tests were carried out on both untransformed and log transformed data. Where the results of the two tests differed the data that better met the assumptions of the ANOVA were used to interpret the result. Mean estimates and standard errors were calculated using untransformed data, however, median values should also be considered when interpreting results. We used the PROC MIXED procedure in SAS statistical software to conduct a repeated measures ANOVA on the data (Littell et al. 1996). This analysis evaluated potential differences in the count data between plot types and among years, and it took into account the fact that new plots were added to the sampling program in 2002 and 2003, making the experimental design unbalanced.

Of the 9 variables, two plot types, and three years analyzed only 7 of the 54 samples were considered normal without transformation (Appendix C). Logarithmic transformation successfully normalized 29 of the 54 possible samples and the transformed data invariably showed better fit to the data than the untransformed data. We continued using parametric analyses recognizing that ANOVA tends to be robust to minor departures from normality (Sokal and Rohlf 1981: 401,407). We used Levene's test for homogeneity of variances to help determine whether to use untransformed or log transformed data in the repeated measures analysis (Appendix D). We determined that the equality of variance assumption was met in all cases for untransformed data except for August counts of total adult swans, young swans, and adult swans in flocks. After transformation, "August adults in flocks" still did not meet the assumption of equal variances. For Levene's test, we considered P-value=0.025 as moderate inequality and P-value=0.01 as severe inequality of variances (Tabachnick and Fidell 2001). Based on those criteria, the "number of adults in August flocks" was considered to moderately violate the equality of variances assumption of ANOVA.

We obtained three annual indices of the per capita reproductive effort and success of Tundra Swans in reference and development plots: (1) nesting effort - the proportion of indicated pairs nesting; (2) nest success - the proportion nesting pairs successful in producing a brood (Ritchie et al. 2002); and (3) productivity - the proportion of indicated pairs producing a brood. Logit analyses of three-dimensional contingency tables (PROC CATMOD in SAS statistical software, Allison 1999) were used to determine if any of these indices differed by year or treatment type. In the brood success analysis, indicated pairs with broods were designated as successful whereas indicated pairs without broods were designated as unsuccessful. Similarly, the proportion of successful and unsuccessful nests was calculated using the number of broods present in the August surveys and the number of nests present in the June surveys. Standard errors for the proportion of pairs nesting, the proportion of pairs raising a brood, and proportion of nests successful were calculated assuming a binomial distribution (Sokal and Rohlf 1981:77).

3. RESULTS

To simplify the description of the results, we have summarized the repeated measures analysis of variance tests in Table 1. In the text, differences in counts of swans between reference and development plots or among years are stated as being "significant" or "statistically significant" when the associated P-value (shown in Table 1) was 0.05 or less. The actual statistical tests were done using the summarized count data for each plot although, for the sake of convenience, we also refer to significant differences in population densities. Results of tests on both untransformed and transformed data are presented and, with a few exceptions, show high agreement. In the few circumstances where tests on untransformed and transformed results differ, the transformed results should be used.

3.1 June breeding surveys

In June, the average density of Tundra Swans in study plots was 0.93 ± SE 0.14 swans/km^2 (Table 2) and, despite some substantial differences in mean numbers (0.69 ± 0.10 SE for reference plots and 1.22 ± 0.28 SE for development plots), counts of adults in June did not differ significantly between plot types or among years and no interaction effect was observed (Table 1). Differences can be attributed to large counts of flocked non-breeding swans in a few plots. Medians for reference (14 swans, range 1-165) and development plots (15 swans, range 1-306) were similar and help explain the statistical test results.

Mean densities of indicated pairs were remarkably consistent regardless of plot type or year surveyed (Table 3) and showed no evidence of statistically significant variation (Table 1). The average density of indicated pairs over all years and plot types was 0.28 ± SE 0.02 swans/km^2.

Flocked non-breeders averaged 41% of adult swans observed in June (Table 2) and appeared to be much more abundant in development than reference plots (Table 4). Despite the rather large difference in mean estimates between reference and development plots, we detected no statistically significant effect of either plot type or year on numbers of flocked swans present (Table 1).

Nest densities averaged 0.11± SE 0.01 nests/km^2 and the number of nests ranged from 0 to 15 nests per plot (Table 5). Number of nests did not differ significantly between plot types or among years.

3.2 August productivity surveys

In August, the average density of adult swans in study plots was 0.81 ± SE 0.12 swans/km^2 (Table 6). Although average densities appeared to be much higher in development plots (1.15 ± SE 0.25 swans/km^2) than reference plots (0.53 ± SE 0.05 swans/km^2), this difference was not statistically significant (Table 1, Table 6). Again, much of the difference between plot types can be explained by large flocks of swans in a few plots. Median values for reference (12 swans, range 0-58) and development plots (8 swans, range 0-196) help explain these results.

Densities of indicated pairs averaged 0.18 ± SE 0.01 /km^2 overall and were constant between plot types and among years with no interaction effect (Table 1, Table 7).

Flocked non-breeders averaged 57% of the adult swans observed during August surveys including an average of 30% of the adults in reference plots and 71% of the adults in development plots (Table 6, Table 8). The large difference in densities of flocked adult swans in the two plot types (0.2 swans/km^2 in reference plots vs. 0.8 adult swans/km^2 in development plots) was statistically significant for the untransformed data but not for the transformed data. The assumption of equal variances was not met for either untransformed or transformed samples (Appendix D). Due to large counts of swans in only a few plots, the results are inconclusive; however, mean estimates suggest that there might be more flocked non-breeding swans in development plots than reference plots.

Estimates of the number of broods and total young produced were slightly higher in reference than development plots but this difference was not statistically significant. Possible annual variation was observed in the number of broods produced and annual variation in the total number of young produced was significant (Tables 1, 9, 10).

3.3 Per capita reproductive success

We obtained three annual indices of the per capita reproductive effort and success of Tundra Swans in reference and development plots: (1) nesting effort - the proportion of indicated pairs nesting; (2) nest success - the proportion of nesting pairs successful in producing a brood; and (3) productivity - the proportion of indicated pairs producing a brood. Analyses of these indices using multi-dimensional contingency tables indicated that both nest success and productivity were higher in reference than development plots (Table 10, 11). The analysis also suggested that there was significant annual variation in productivity but not in nest success (Table 11). In contrast, we found no statistically significant evidence that nesting effort differed between plot types although this variable did differ significantly among years (Table 11).

3.4 Geographic variation in reproductive success

Inspection of the summarized data suggested some large differences in the number of pairs, nests, and broods from plot to plot. We wanted to find out if such regional variations in reproductive success (specifically low productivity in Mackenzie Delta region where development plots were most highly concentrated) could lead to incorrect conclusions about the impacts of development on swans. In an effort to visualize if or how such variation might influence the results, we plotted relative values (low, medium, high) of three demographic parameters (nesting effort - nesting pair/indicated pair, nest success - broods/nesting pair, and productivity - broods/indicated pair) on maps of the study area (Figures 2, 3, and 4). Values for each demographic parameter were designated as "low" if they were among the lowest 25% of all such values recorded, high if they were in the upper 25%, and medium (all other values). Plots with fewer than 10 indicated pairs of swans over the three-year study period were excluded from the analysis because sample sizes were considered inadequate for calculating average values for the different demographic parameters. The resulting maps suggested possible geographic patterns of reproductive success – productivity and nest success were low to moderate in the Mackenzie Delta proper but higher away from the

Delta. Nesting effort, as indexed by nests per indicated pair, showed no immediately obvious geographic pattern.

4. DISCUSSION

The primary objectives of this report were to present baseline information on the numbers and reproductive success of Tundra Swans in the Mackenzie Delta region, and evaluate if impacts of past and recent natural gas exploration could be detected using swan numbers or productivity as indicators. To address these objectives, we carried out complete counts of Tundra Swans over three years in reference and development plots within the region. As noted previously, swans are potentially useful waterfowl for studying cumulative effects because reliable counts can be carried out throughout the breeding season and swans are known to be sensitive to some forms of disturbance. Given what we now know about the logistics and fiscal realities of carrying out surveys of Tundra Swans in the region, an important question is "Will the samples such as those collected in 2001-03 be adequate to detect actual population changes in population size induced by development or other stressors"?

A possible bias detected in our data was the influence of a few large counts of flocked non-breeding swans on overall estimates of adult numbers. Log transformation of the count data helped overcome this problem by improving distributions, reducing variances, and improving the precision of the estimates. One measure of the suitability of a population estimate for detecting trends is the coefficient-of-variation (CV), calculated as the ratio of the standard error to the mean. CVs for several of the population estimates of swans, particularly the transformed ones (median of 8%, range 3-26%), were as low as those obtained during helicopter transect surveys in the Western Canadian Arctic (Table 12). Using transect surveys repeated over four years, Hines et al. (2005) reported CVs of 0.04 to 0.08 for the two best surveyed species of waterfowl (Tundra Swans and Greater White-fronted Geese *Anser albifrons*). Precision of those surveys was deemed adequate to detect changes in numbers of 20% or less. It is expected that similar degrees of population change should be detectable for Tundra Swans from the plot survey data using the log-transformed counts of adults and indicated pairs in June and August, and nests in June, as CVs for these variables were all < 8%.

Our counts of Tundra Swans indicated no significant differences in average densities of adults, pairs, nests, broods, or young between reference and development plots. In contrast, estimates of per capita reproductive success suggested swans were less successful in development than reference plots. The results of the two analyses seem logically incompatible (similar densities of breeding adults and young produced should reflect similar reproductive success in the two plot types). Increased sampling and further evaluation of the data might be needed to determine if the possible "development effect" is real.

We noted substantial inter-plot differences and potential geographic variation in nesting effort and reproductive success of Tundra Swans. Most development plots occurred in the Mackenzie Delta so we were concerned that the low reproductive success in development plots indicated by some analyses could reflect geographical variation in productivity rather than actual impacts of development per se. A preliminary assessment of the mapped data suggested that low productivity was not just limited to the Mackenzie Delta and lends support to the hypothesis of development-induced impacts. Obviously, there are other factors which might influence these patterns, such as regional variations in weather, habitat, and predator abundance and further investigation is required.

Nest success appeared to be a factor influencing geographic variability in productivity and the potential reference/development differences in reproductive success. Development could influence migratory bird populations through reduced nest success (Truett and Johnson 2000), thus factors influencing nesting success need to be evaluated. We also note that although brood/nesting pair ratios have been used as an indicator of nest success (Ritchie and King 2000), this variable really captures two different demographic processes: nest success (the percent of nests that hatch) and loss of entire broods (which typically occurs within a few days of hatching in other waterfowl species). Both variables have been shown to play a role in the demography of waterfowl populations and ideally need to be separately evaluated.

Despite the statistical inconclusiveness of the results to date, the findings are informative. Particularly, the data suggest that reproductive success of swans within the Mackenzie Delta is lower than in the surrounding area. Whether this reflects the large amount of petroleum exploration and other human activity in the Delta or intrinsic natural differences between the Delta and surrounding areas is not clear. Intensified sampling within the Mackenzie Delta proper and possible stratification of the study area to include more reference plots in the Delta would be valuable.

This study was designed before the exact locations of well sites were well documented. Even if pipeline development goes ahead it is likely that a few of the plots selected as potential development sites in our study will not be developed and could ultimately become reference plots. Similarly, some reference plots may ultimately be developed, although, it is believed that this is less likely to occur over the short term because most reference plots were well outside of lands available for gas exploration.

The approach we have taken in comparisons of data from survey plots has been termed an "Impact-Reference Design" (Anderson et al. 1999:26) and is used in assessments made after potential impacts have already occurred. By adding new plots in development areas to enhance samples sizes, the data collected might also prove to be equally well suited to other study designs as well including the "Before-After/Control-Impact" design (wherein reference and treatment study plots are established prior to development) and the "Impact-Gradient Design" which involves looking at impact indicators (e.g., swan distribution, numbers, or reproductive success) at different distances from the source of impact (Anderson et al. 1999). We believe the study design potentially lends itself well to evaluating impacts by all three approaches.

The results also demonstrate the possible importance of the Mackenzie Delta to flocked non-breeding swans that represent 56% (June) and 71% (August) of total population estimates in development sites. Areas of past or potential development appear to have significantly large numbers of flocked non-breeding swans occurring along point bars of potential transportation channels. Although this study design does not lend itself well to monitoring flocked non-breeding swans, these large gatherings of Tundra Swans may warrant additional monitoring should development activity increase throughout the main channels of the delta.

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