HARLEQUIN DUCK STREAM SURVEYS AND MONITORING IN GLACIER NATIONAL PARK 2008 REPORT

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November 26, 2008

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ABSTRACT

The potential implications of climate warming on wildlife populations have posed a suite of new challenges for natural resource managers. Results of climate change are evident in Glacier National Park, Montana, in which >2/3 of its 150 glaciers have disappeared since 1850, possibility resulting in ecosystem scale impacts. One species of concern in the Glacier ecosystem is the harlequin duck (*Histrionicus histrionicus*) because of uncertainty about population viability and habitat degradation. Harlequins migrate from coastal waters to Glacier for breeding and are dependent on turbulent, food-rich streams for nesting. Data collection on harlequins in Glacier has consisted primarily of annual pair and brood surveys along Upper McDonald Creek. A need has existed for surveying other drainages and little data exists on stream and habitat attributes at harlequin locations, which is information needed to better understand harlequin resource requirements. The goal of this study was to begin to address these data needs for the park. To accomplish this I (1) designed a sampling scheme for selecting streams to survey for harlequins, and (2) surveyed streams and collected stream and habitat attribute data at harlequin and random locations from May through September 2008. A total of 120 streams in 19 drainages were surveyed, totaling 306.2 km of effort. Seventy-three harlequin groups were observed on four different streams with a total of 69 on the lower portion of Upper McDonald Creek. I used a habitat use/availability analytic framework combined with information-theoretic model selection techniques to examine the influence of stream and habitat attributes on the probability of harlequin landscape use. Stream width and depth were both positively correlated with the probability of harlequin use in the top approximating models, suggesting the potential for increased resource availability in larger streams is an important factor in habitat selection. Both deciduous and mixed coniferous/deciduous understory cover types were positive effects on harlequin use, which may be attributed to the protection that vegetative cover provides from predators. The harlequin population estimate was 76 ducks (95% confidence interval: 23, 128), which should be considered to be a conservative estimate. Although the effect of climate warming to date on the breeding harlequin population in Glacier is not fully known, results from this study document the importance of stream attributes and riparian habitats for harlequins. Continued monitoring is required to determine the role of drainages other than Upper McDonald Creek in supporting harlequins and whether these streams contain sufficient resources for ducks throughout the entire breeding season.

INTRODUCTION

The impacts and potential implications of climate warming on wildlife populations have posed a suite of new challenges for natural resource managers and biologists (Root and Schneider 2006). In addition to the difficulty of managing wildlife given complex sources of uncertainty, which includes climate stochasticity (Nichols et al. 1995), climate change has resulted in added concern about the long-term viability of many populations within current ranges (Parmesan 2006). While polar and mountaintop range-restricted species may be most at risk from global warming (Parmesan 2006), other species may also be vulnerable owing to habitat specialization and small populations. Gradual changes in factors affecting resources, such as plant species composition, growing season length, snowpack accumulation, and precipitation trends, may render high quality habitats less desirable because of resource limitations. Alterations in biotic and abiotic factors from climate change may also facilitate the colonization of competitor or predator species into the ranges of sensitive species. Therefore, understanding the resource requirements for at-risk species is essential for planning conservation strategies given climate change scenarios. This challenge of understanding the potential effects of global warming on wildlife is especially imperative in National Parks, whose mission includes protecting and preserving species (Burns et al. 2003).

Results of climate change are particularly evident on the landscape of Glacier National Park, Montana, in which over two-thirds of its 150 glaciers have disappeared since 1850, potentially resulting in ecosystem scale impacts (Hall and Fagre 2003). Despite reductions in the abundance of some species, the Glacier ecosystem has retained the majority of its native species, making it a strategic location for wildlife conservation because of the potential for Glacier to be a source to contribute to populations beyond park boundaries. One species of concern in the Glacier ecosystem is the harlequin duck (*Histrionicus histrionicus*) because of uncertainty about population viability and habitat degradation. Harlequins migrate inland from coastal waters for breeding and are dependent on turbulent, food-rich streams for nesting (Ehrlich et al. 1988). Adequate loafing sites (e.g., rocks, logs, gravel bars) along streams may be important habitat components, as well as backwater streams for brood rearing (Kuchel 1977, Heath 2001). Harlequins arrive in the Glacier ecosystem beginning in April with breeding pairs traveling together (Smith et al. 2000). Adult males migrate back to wintering grounds by late June, shortly after females begin incubation. The brood-rearing period lasts until mid-September, when females and young migrate back to coastal wintering grounds (Regehr et al. 2001).

Harlequins have a life history in which relatively high adult survival and long reproductive life spans are counterbalanced with generally low and variable annual productivity and recruitment. Delayed breeders with most birds not breeding until at least ages two or three, harlequins develop long-term pair bonds with pair formation occurring on wintering grounds (Robertson et al. 1998, Smith et al. 2000, Rodway 2007). Females can raise only one brood per year (one to seven young per brood) because males depart breeding areas shortly after incubation begins, making nest success imperative for population viability. The low, irregular levels of reproductive success, combined with relatively advanced age at first reproduction, make harlequins sensitive to environmental stochasticity (Esler et al. 2002). Given their life history characteristics, unique habitat requirements, and ecological niche as a river specialist, harlequins may be adversely affected by climate change because of resource requirements. The harlequin has been designated a Montana "Species of Concern" and a "Sensitive Species" by the U.S. Forest Service and Bureau of Land Management (Hendricks 1999; Montana Fish, Wildlife and Parks 2008). Additionally, the U.S. Fish and Wildlife Service classified harlequins to be of moderately high conservation importance throughout the Rocky Mountains in Montana (North American Waterfowl Management Plan Committee 2004).

Data collection on harlequins in Glacier during the past 20 years has consisted primarily of annual pair and brood surveys along Upper McDonald Creek between Lake McDonald and Logan Creek from late spring through summer (Hendricks et al. 2004, Secrest and Elwood 2006). These surveys have documented variability in both within and among year counts of adults and juveniles (Secrest and Elwood 2006). Observations of harlequins in drainages other than Upper McDonald Creek have been incidental and, therefore, a need has existed for surveying other drainages. Further, little data on stream and habitat attributes at harlequin locations in the park exist, which is information needed to better understand harlequin resource requirements and how climate change may affect the breeding population within Glacier. The goal of this study was to begin to address these two data needs for the park. Objectives of this work were to: (1) design a sampling scheme for selecting streams to survey for harlequin presence; (2) survey these streams and collect stream and habitat attribute data during summer 2008; (3) evaluate the effectiveness of the sampling design; (4) provide a sampling protocol to the park for use in future years; (5) conduct habitat use/availability analyses to begin to understand factors influencing harlequin distribution, and (6) estimate the population size of harlequins in Glacier for 2008. This work provides initial steps towards understanding resource requirements of harlequins within Glacier while presenting a framework for future population monitoring.

STUDY AREA

Glacier National Park (Figure 1) encompasses a variety of biomes, ranging from grasslands to temperate forests to alpine tundra, which are situated amidst rugged mountains along the Continental Divide. Because the elevation within the park ranges between 950 m and 3,190 m and includes both west and east sides of the Continental Divide, the Glacier ecosystem harbors a diverse array of plant and animal species. Harlequin duck distribution encompasses the entire park on both sides of the Continental Divide, but is primarily restricted to stream drainages below subalpine elevations. The majority of Glacier is undeveloped with the exception of visitor centers and lodging located in the Many Glacier area and along the 80 km Going-to-the-Sun Road, which traverses the park from west-to-east and crosses the Continental Divide. West of the divide, Going-to-the-Sun Road parallels Lake McDonald and McDonald Creek, while east of the divide part of the road borders Saint Mary Lake.

Winters in Glacier are severe and characterized by deep snowpack that, during the spring and summer melt period, feeds streams passing through glacially sculpted valleys. Between 1977 and 2007 at the Many Glacier SNOTEL site (latitude 48˚47'; longitude –113˚40'; elevation 1508 m, Natural Resources Conservation Service 2008), maximum daily snowpack snow water equivalent (SWE) ranged between 11.3 cm and 68.7 cm (mean = 39.2 cm; standard error (SE) = 2.2). During winter 2008 the maximum daily snowpack SWE was 42.3 cm.

For spring and summer at the Many Glacier SNOTEL site during 1987-2007 the mean average maximum daily temperature for May was 14.0˚C (SE = 0.5), June was 18.0˚C (SE = 0.4), July was 23.1˚C (SE = 0.6), August was 22.8˚C (SE = 0.5), and September was 17.4˚C (SE = 0.6). During 2008 the average maximum daily temperature was 12.8˚C for May, 17.8˚C for June, 23.6˚C for July, 22.4˚C for August, and 16.9˚C for September. Historic precipitation trends for spring and summer at the Many Glacier SNOTEL site between 1979-2007 were as follows. The average total monthly precipitation for May was 9.4 cm (SE = 0.6), June was 11.2

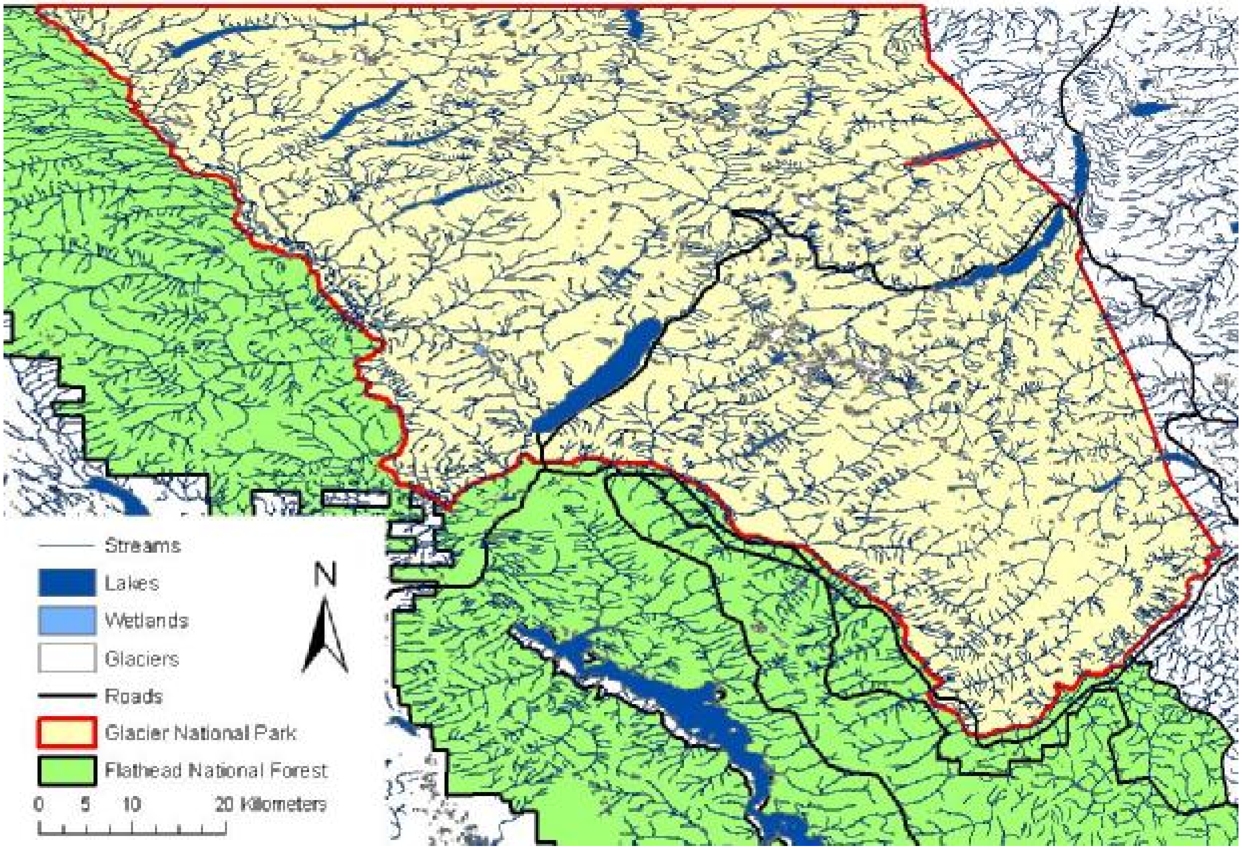

Figure 1. Streams, lakes, wetlands, and glaciers in Glacier National Park and the surrounding portions of the Flathead National Forest located in northwest Montana.

cm (SE = 1.0), July was 5.2 cm (SE = 0.8), August was 4.6 cm (SE = 0.7), and September was 7.9 cm (SE = 0.9). During 2008 the total monthly precipitation for spring and summer months was: 14.6 cm for May, 11.0 cm for June, 2.6 cm for July, 8.7 cm for August, and 4.9 cm for September.

METHODOLOGY

Stream Survey Sampling Design

I developed a sampling design to select streams to survey for harlequin presence based on a multistage, stratified random sampling scheme (Thompson 2002). To develop a "sampling universe" from which to select streams, I began with the GIS stream layer for Glacier National Park (Figure 1) from The National Hydrography Dataset (U.S. Geological Survey 2000). Because harlequins are likely to predominantly use second order or higher streams, I removed small tributary streams from the GIS layer with stream level categories (U.S. Geological Survey 2000) of 8, 9, and 10, and level 6 and 7 streams classified as first order (Cole 1994). Also, because harlequins are most likely to use streams with riparian vegetation and cover (Heath et al. 2006), I removed streams of level 6 and 7 located in alpine and barren, rock talus habitats. This provided a sampling universe consisting of M = 807 streams throughout Glacier (Figure 2).

I then categorized streams into one of 48 drainages (N), where a drainage consisted of at least one stream and possibly one or more tributary streams. Each drainage was placed into one of six strata (h) based on the total number of streams (M_i) within drainage i, with M_i ranging between one and 54 (mean = 16; SE = 2). Stratum 1 consisted of drainages with $1 \leq M_i \leq 3$; stratum 2 with $4 \leq M_i \leq 6$; stratum 3 with $7 \leq M_i \leq 11$; stratum 4 with $12 \leq M_i \leq 20$; stratum 5 with $21 \leq M_i \leq 32$, and stratum 6 with $M_i > 32$. The number of drainages within each stratum (N_h) were: $N_1 = 7$, $N_2 = 7$, $N_3 = 11$, $N_4 = 10$, $N_5 = 7$, and $N_6 = 6$ (Table 1). For the two-stage sampling design I chose the drainage to be the primary unit and streams within the drainage to be secondary units (Thompson 2002). The practical advantage of two-stage sampling is that it is logistically easier and more cost effective to observe many secondary units that are clustered

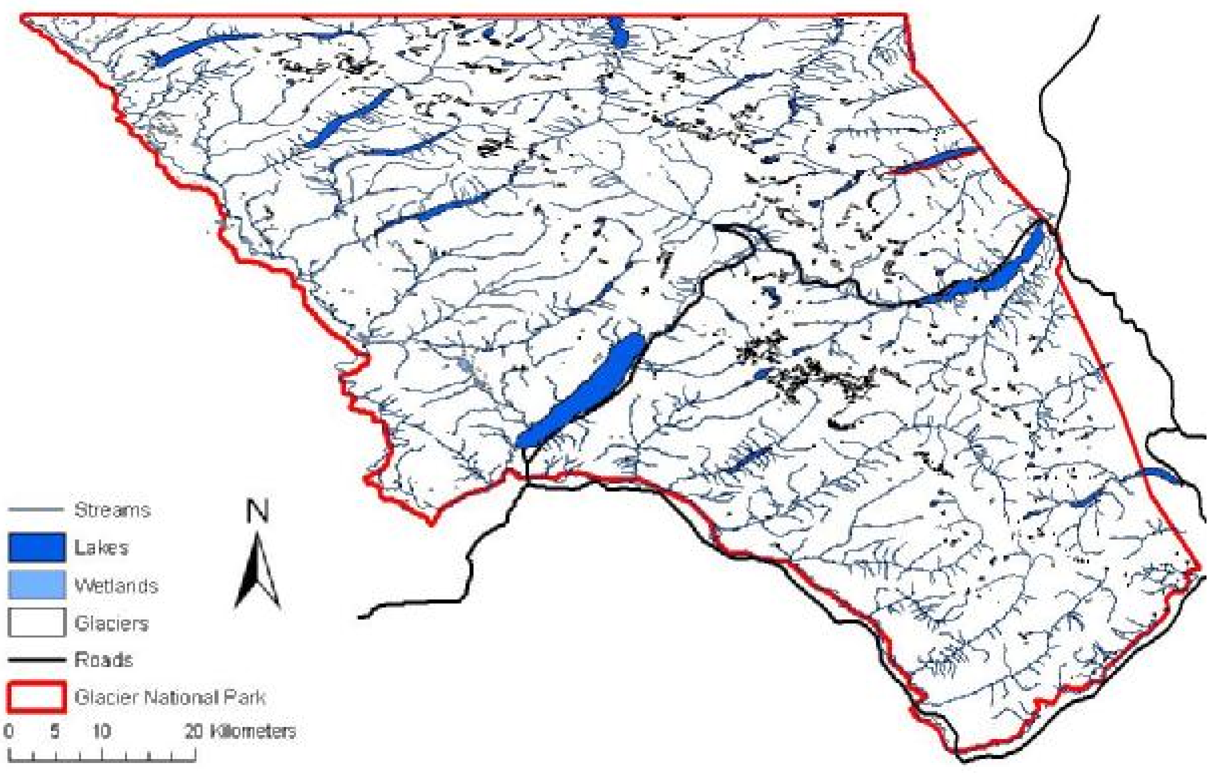

Figure 2. The "sampling universe" of 807 streams throughout Glacier National Park. Lakes, wetlands, and glaciers are also depicted.

Table 1. The drainages in each of the six strata. Strata were defined based on the total number of streams (M_i) within the drainage as described in the text.

Strata	Drainages
1 $1 \leq M_i \leq 3$	Kishenehn Creek, Lake Creek, Mud Creek, Shields Creek, Spruce Creek, Starvation Creek, Virginia Creek
2 $4 \leq M_i \leq 6$	Akokala Creek, Midvale Creek, Mud Lake, North Fork Belly River, Olson Creek, Summit Creek, Valentine Creek
3 $7 \leq M_i \leq 11$	Anaconda Creek, Bear Creek, Boulder Creek, Boundary Creek, Dutch Creek, Lee Creek, Mokowanis River, Otatso Creek Railroad Creek, Reynolds Creek, Rubideau Creek
4 $12 \leq M_i \leq 20$	Camas Creek, Divide Creek, Ford Creek, Kennedy Creek Lincoln Creek, Muir Creek, North Fork Cut Bank Creek, Ole Creek, Swiftcurrent Creek, Two Medicine Creek
5 $21 \leq M_i \leq 32$	Coal Creek, Harrison Creek, Kintla Creek, Logging Creek, Park Creek, Quartz Creek, Red Eagle Creek
6 $M_i > 32$	Belly River, Bowman Creek, McDonald Creek, Nyack Creek, Saint Mary River, Waterton River

rather than the same number of streams randomly spread throughout the entire park. Based on an estimate of the time required for a four-person crew to survey streams between May-September and the trade-off in sample size and variability for a population estimate, I assumed that surveys could be conducted in approximately 40% of all drainages. Therefore, I chose a random sample of drainages (n) without replacement consisting of approximately 40% of drainages within each stratum such that, in total among all strata, n = 20. I then selected a random sample of tributary streams (m_i) without replacement within each drainage such that $m_i = 0.5M_i$ for all drainages except those where M_i = 1, 2, or 3, in which case all streams in the drainage were included in the sample. Overall, m_i ranged between two and 26 (mean = 8.7; SE = 1.6) with the total sample size among all drainages of m = 173 (Figure 3).

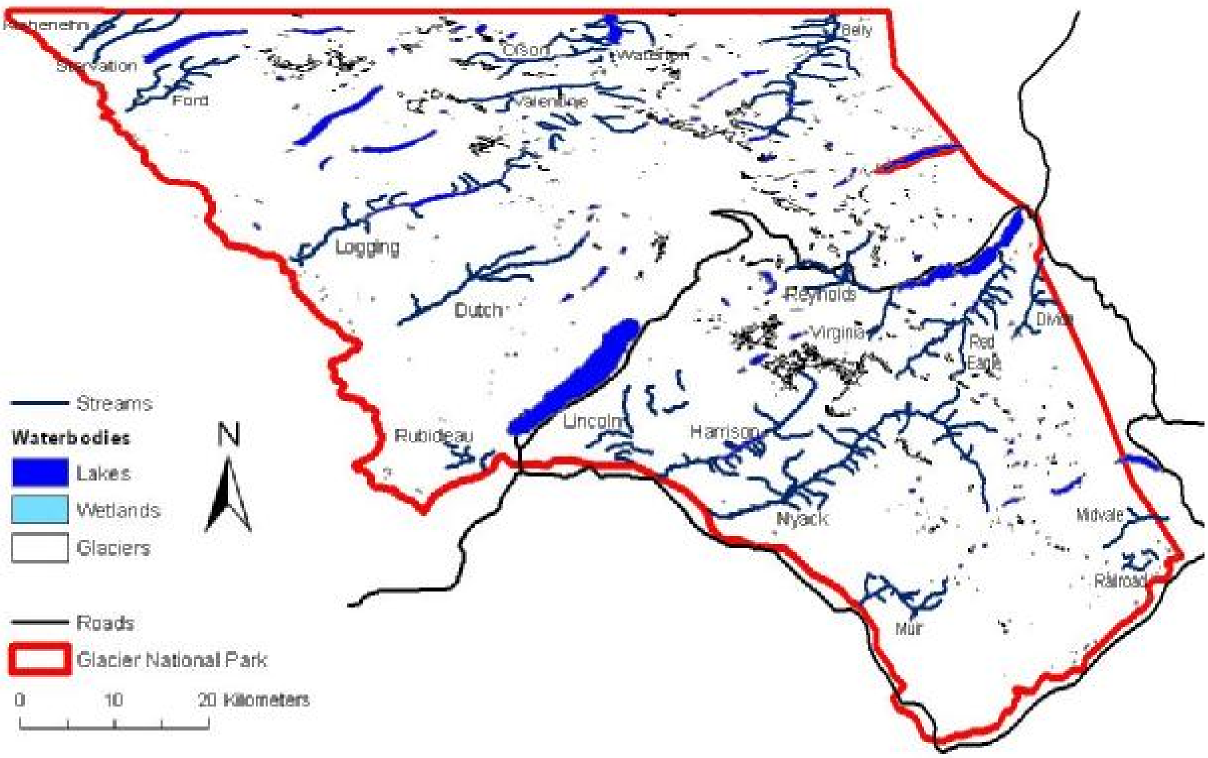

Figure 3. The 20 drainages and 173 streams that were selected for conducting harlequin duck surveys from May through September 2008 in Glacier National Park.

Data Collection

For each selected stream within a drainage, crew members conducted surveys for harlequins by walking along the stream bank or, when possible, through the stream channel. Observers mapped the location of harlequin individuals or groups, and recorded the age and sex composition of the ducks. Observers recorded stream and habitat attributes at each used location and at randomly chosen points along each survey stream. The number of random points per stream was based on the entire length of the stream such that there was one random location for every 800 m of stream. Observers recorded wetted and bankfull stream widths using a rangefinder, where the wetted width is the width of the stream that actually contains water and the bankfull width is the width of the stream if it was full of water. Wetted and bankfull stream depths were recorded at the edge of the stream or stream bank, respectively, with a meter stick at a distance of arm's length into the stream channel. Obtaining stream depths farther into the channel was not possible for safety reasons because surveys were conducted during high runoff periods in spring. Observers recorded the stream habitat class (pool, glide, riffle, rapids, cascade, falls, dry) according to U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program guidelines (Kauffmann et al. 1999). The categorization of stream class was made from examination of 5 m upstream and 5 m downstream from the sampling point location.

Observers classified the riparian habitat and areal cover for the canopy (>5 m high), understory (0.5 to 5 m high), and ground (<0.5 m high) layers on the stream bank for a 10 m x 5 m area around the sampling point, with the 10 m segmented evenly between 5 m upstream and 5 m downstream from the location. Classifications for the canopy layer were coniferous, deciduous, mixed coniferous/deciduous, and no canopy. The understory layer included the classifications for the canopy layer along with shrubs. The ground layer classifications were grasses, shrubs, forbs, ferns, or no layer. Areal cover for each layer, which is considered to be the amount of shadow cast when the sun is directly overhead, was classified as absent (0%), sparse (1-10%), moderate (11-40%), heavy (41-75%), or very heavy (>75%). Observers recorded the presence or absence of a gravel island/bar within 5 m upstream and 5 m downstream from the sampling point location. Finally, observers recorded the number of large woody debris (LWD) pieces and number of boulders within 50 m upstream of the sampling point. The amount of boulders and LWD pieces were divided into the following categories: (1) none, zero boulders or LWD pieces; (2) low, 1-149 boulders or pieces; (3) medium, 150-299 boulders or pieces, and (4) high, ≥300 boulders or pieces.

Statistical Analyses

Habitat Use/Availability Model Development. I used a binary response variable for modeling the probability of harlequin landscape use. Each of the "used" harlequin locations was assigned a 1 while each of the random, "available" locations was assigned a 0. I then used habitat and stream attribute data collected at harlequin and random locations during surveys to develop covariates. For stream attributes I used the wetted stream width and depth at each location for covariates WIDTH and DEPTH, respectively. Based on the stream classification I defined a categorical covariate, CLASS, with the classifications: (1) CASCADE; (2) FALLS; (3) GLIDE; (4) POOL; (5) RAPID, and (6) RIFFLE. I defined a categorical covariate, BAR, with a 1 denoting presence of a gravel bar and 0 an absence. For habitat attributes I developed two categorical covariates based on the canopy habitat type (CANOPY) and understory habitat type (UNDERSTORY). The CANOPY covariate was classified as (1) CONIFEROUS; (2)

DECIDUOUS; (3) MIXED, or (4) NONE, while UNDERSTORY was categorized as (1) CONIFEROUS; (2) DECIDUOUS; (3) MIXED; (4) NONE, or (5) SHRUB. I defined a covariate, LWD, as the category of the number of large woody debris pieces (NONE, LOW, MEDIUM, HIGH). Finally, I defined COVER as the average percent areal cover for the canopy, understory, and ground layers combined. To calculate an average based on cover categories I designated the percent cover for each cover classification to be the maximum percent cover possible for that category (i.e., absent, 0%; sparse, 9%; moderate, 40%; heavy, 75%; very heavy, 100%). I then assigned the appropriate percentage to the cover category observed and calculated the average of the three layers to determine COVER.

I developed and compared *a priori* hypotheses, expressed as multiple logistic regression use/availability models (Hosmer and Lemeshow 2000, Manly et al. 2002), to estimate the relative contributions of stream and habitat attributes in affecting the probability of harlequin use. While forming the model list, I calculated variance inflation factors (VIFs; Neter et al. 1996) to quantify multicollinearity among model predictors and removed models containing covariates having a VIF>5 from the *a priori* list. Hypotheses were expressed as 64 candidate models consisting of biologically plausible additive effects of covariates (Appendix A). I formulated a hypothesis for each covariate regarding the direction of its effect on the probability of harlequin use. First, I predicted that the probability of use would be positively correlated with both stream width and depth because larger streams would be more likely to contain more food resources. Second, I hypothesized that use would be higher in stream areas classified as riffles or rapids because the fast moving, turbulent nature of these areas would provide increased food abundance owing to higher dissolved oxygen levels in the water (Cole 1994). Conversely, I expected that use would be lower in stream areas classified as pools or glides because of the lack of turbulence in the water, and for cascades and falls because water conditions would be rough for foraging. Third, I hypothesized that use would be positively correlated with the presence of a gravel bar because of the added loafing habitat these areas would provide. Fourth, I anticipated that use would be greater in areas with coniferous, deciduous, and mixed canopies, and lower in areas with no canopy, because of the added protection from predators that trees would provide. Likewise, I predicted that use would be greater in areas with coniferous, deciduous, mixed, and shrub understories, and lower in areas without any understory layer. Fifth, I hypothesized that use would be positively correlated with the average cover for all forest layers because of the added concealment from predators and protection from weather that increased cover provides. Finally, I predicted that use would be positively correlated with the amount of large woody debris pieces around the location because greater amounts of woody debris in the stream channel would provide more areas for loafing and protection from predators.

I used logistic regression techniques in R version 2.6.0 (R Development Core Team 2007) to fit models and estimate covariate coefficients. I calculated a corrected Akaike's Information Criterion (AIC_c) value for each model and then ranked and selected the best approximating models using ΔAIC_c values (Burnham and Anderson 2002). Finally, I calculated Akaike weights (w_i) to obtain a measure of model selection uncertainty (Burnham and Anderson 2002).

Exploratory Modeling. I used the top six best approximating models from the ***a priori*** modeling effort to examine whether inclusion of different stream and habitat attribute covariates improved the model (i.e., decreased the AIC_c value). I developed the following exploratory covariates. I defined $COVER_{canopy}$, $COVER_{understory}$, and $COVER_{ground}$ to be the category in which the canopy, understory, and ground cover layers, respectively, were classified: (1) ABSENT; (2) SPARSE; (3) MODERATE; (4) HEAVY, and (5) VERY HEAVY. I also defined a covariate, BOULDER, to be the category of number of boulders (NONE, LOW, MEDIUM, HIGH). I replaced the ***a priori*** COVER covariate in each model with $COVER_{canopy}$ and calculated the AIC_c values for the six models. I also replaced COVER with $COVER_{understory}$ and $COVER_{ground}$, and calculated AIC_c values for the six models for each substitution. I then replaced COVER with additive combinations of $COVER_{understory}$ + $COVER_{ground}$ and $COVER_{understory}$ + $COVER_{ground}$ + BOULDER, and calculated AIC_c values for the six models for each substitution.

Stream Width and Depth Analyses of Variance. I developed analysis of variance (ANOVA) models to examine the effects of stream and survey date, as a blocking factor (Neter et al. 1996), on both stream width and depth. Each stream that was surveyed was assigned a unique identification number, denoted STREAMID. Survey date was assigned to one of nine two-week intervals, defined as DATE, between May 20 through September 18 corresponding to the date on which stream width and depth measurements were made. I considered three competing models for each response variable: (1) STREAMID; (2) DATE, and (3) STREAMID + DATE. I used ANOVA and regression techniques in R version 2.6.0 (R Development Core

Team 2007) to fit models and estimate factor coefficients and mean squares. I calculated adjusted R^2 and AIC_c values for each model and then ranked and selected the best approximating models using ΔAIC_c values (Burnham and Anderson 2002).

Estimation of Population Size. The population size of harlequins within Glacier was estimated from stream survey data using multistage sampling equations provided in Thompson (2002). An unbiased estimator of the total number of ducks in the i^{th} drainage is

$$\hat{y}_i = \frac{M_i}{m_i} \sum_{j=1}^{m_i} y_{ij} , \qquad (1)$$

where y_{ij} is the number of ducks in the j^{th} stream within the i^{th} drainage (Thompson 2002). The unbiased estimator of the population total is then given by

$$\hat{t} = \frac{N}{n} \sum_{i=1}^{n} \hat{y}_i , \qquad (2)$$

with an estimated variance of

$$\hat{\text{var}}(\hat{t}) = N(N-n)\frac{s_u^2}{n} + \frac{N}{n}\sum_{i=1}^{n} M_i(M_i - m_i)\frac{s_i^2}{m_i} , \qquad (3)$$

where s_u^2 is the sample variance between primary unit totals and s_i^2 is the sample variance within primary units (Thompson 2002).

RESULTS

Streams Surveyed and Harlequin Duck Locations

A total of 120 streams within 19 drainages were surveyed from May through September 2008 (Figure 4). Of the 120 streams, 101 were examined and deemed to have inadequate habitat for harlequins (e.g., low stream flow; dry channel). The total distance of streams surveyed for the 19 streams with sufficient habitat was 306.2 km. Of the 19 drainages surveyed, 14 were from the original sample: Belly River, Divide Creek, Harrison Creek, Kishenehn Creek, Lincoln Creek, Logging Creek, Midvale Creek, Nyack Creek, Railroad Creek, Red Eagle Creek, Reynolds Creek, Rubideau Creek, Virginia Creek, and Waterton River. The six drainages not surveyed from the original sample were Dutch Creek, Ford Creek, Muir Creek, Starvation Creek, Olson Creek, and Valentine Creek. In place of some of the drainages from the original sample, five drainages—Boundary Creek, McDonald Creek, Otatso Creek, St. Mary River, and Two Medicine Creek—were added to the sample during the season to examine additional streams

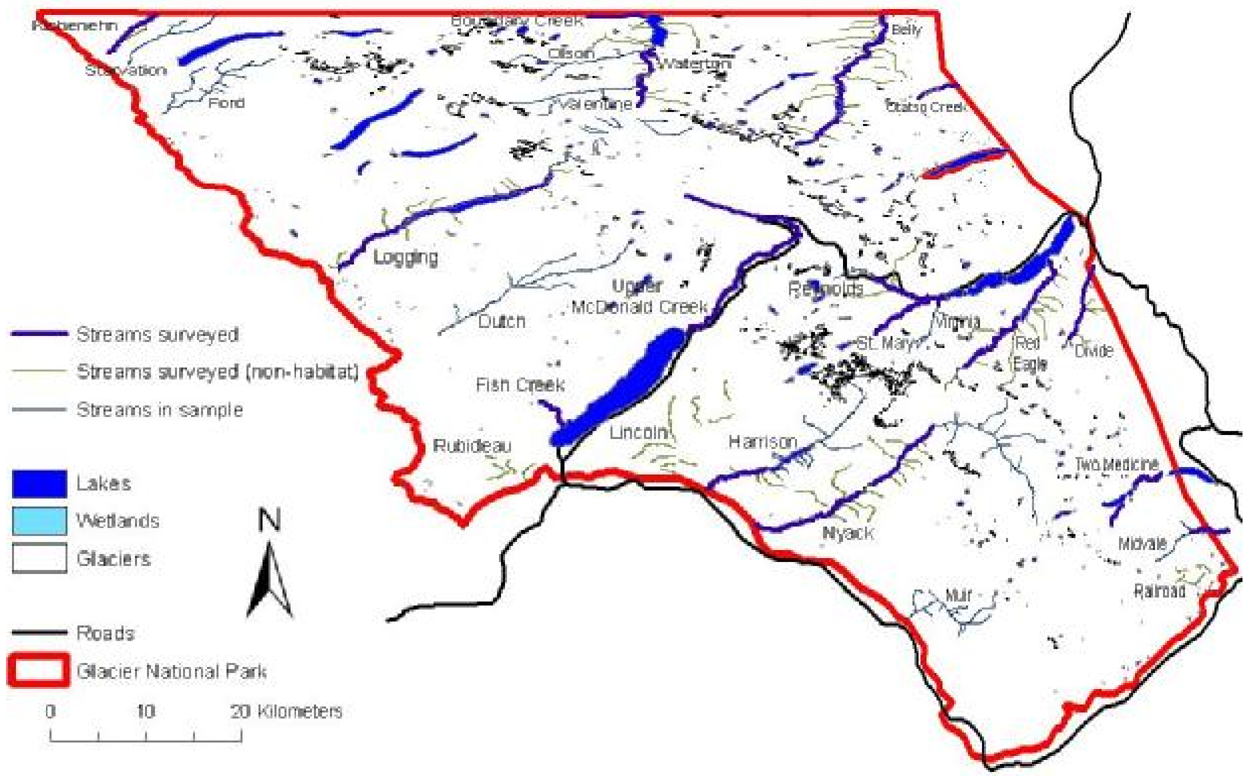

Figure 4. The distribution of the streams and stream segments that were surveyed from May through September 2008 in Glacier National Park. Streams surveyed are depicted in dark blue (bold), streams without adequate harlequin habitat are in green, and streams from the original sample that were not surveyed in blue.

previously documented to have harlequin presence. Each drainage and stream was surveyed once during the field season with the exception of the lower portion of Upper McDonald Creek, which was surveyed eight times in conjunction with National Park Service monitoring efforts. Of the 306.2 km of streams surveyed, 126.4 km was along the lower portion of Upper McDonald Creek.

Seventy-three harlequin duck groups were observed on four different streams (Figure 5), with 69 observations occurring on the lower portion of Upper McDonald Creek during the eight surveys (Figures 6*a* and 6*b*). The other streams on which harlequins were observed were: Boundary Creek (Figure 7), Fish Creek (Figure 8), Otatso Creek (Figure 9), and the upper (north) portion of Upper McDonald Creek (Figure 10). Each survey on Upper McDonald Creek resulted in variable counts of harlequins, including juveniles during the brood-rearing period (Table 2). Fifty-five of the 73 groups were recorded during the pairing period (May-June), while the remaining 18 were observed during the brood-rearing period (late July-September). Group size during the pairing period ranged between one and three harlequins (mean = 1.6; SE = 0.1), with 15 and 12 groups consisting of unpaired males and females, respectively. Of the 55 groups observed during the pairing period, one was located on Fish Creek (Figure 8) while the rest were on Upper McDonald Creek (Figure 6*a*). During the brood-rearing period, group size varied from one to seven ducks (mean = 3.7; SE = 0.4) with two groups consisting of an unpaired female and one group of a paired male and female without juveniles. Of the 18 groups, 12 contained one or more juveniles with one adult female. Within these 12 groups the number of juveniles per group ranged from two to six ducks (mean = 3.4; SE = 0.4). Fifteen of the 18 groups observed during the brood-rearing period were located on the lower portion of Upper McDonald Creek (Figure 6*b*), while one was on the upper portion of Upper McDonald Creek (Figure 10). The other two groups, each consisting of one adult female with two juveniles, were located on Boundary Creek (Figure 7) and Otatso Creek (Figure 9).

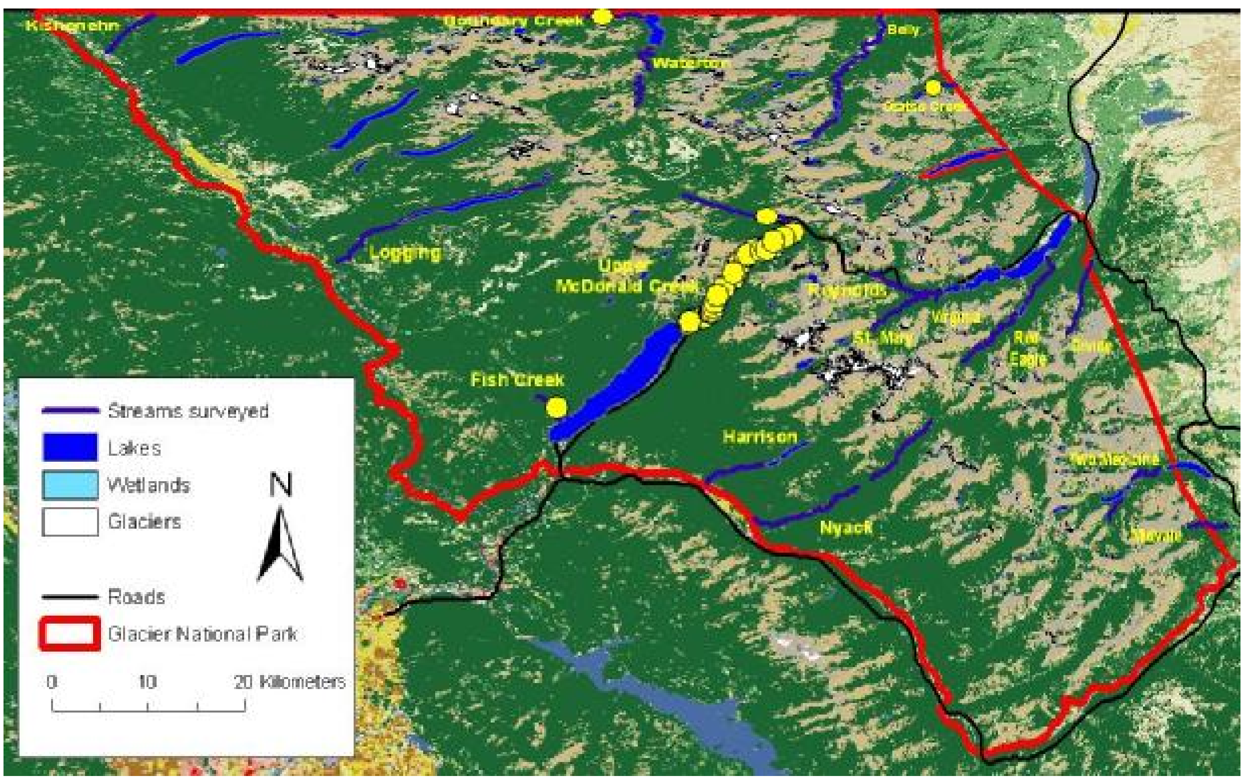

Figure 5. The distribution of the 73 harlequin duck groups that were observed during surveys conducted from May through September 2008 in Glacier National Park. Each group is represented by a yellow circle. Land cover is depicted with the major cover types coded as follows: forest (green), grassland/meadow (light brown), lakes/water (blue), snow/ice (white), talus/rock (gray), wetlands (light blue).

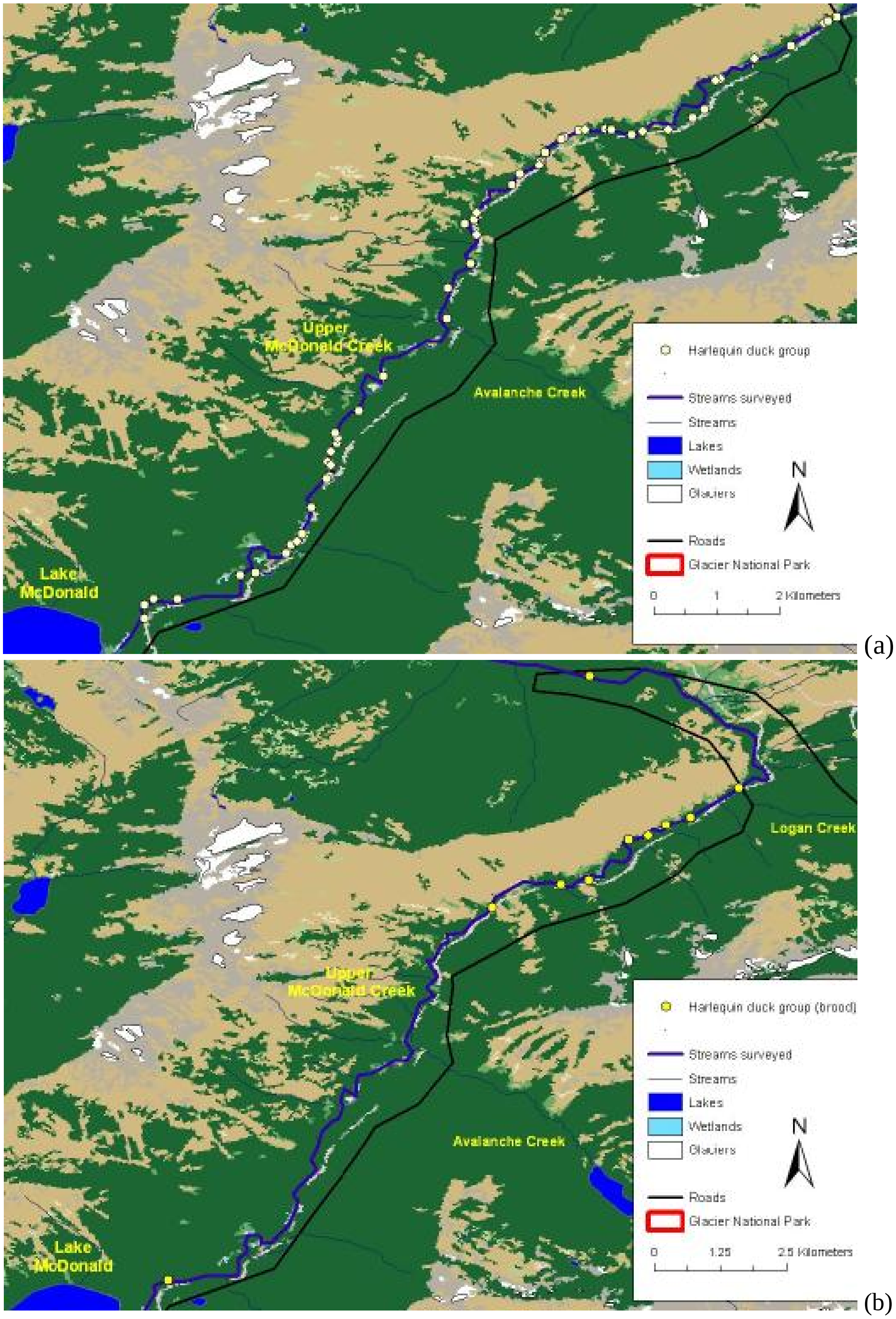

Figure 6. The distribution of harlequin duck groups consisting of (*a*) adult male/female pairs and individuals, and (*b*) adult females with a brood along Upper McDonald Creek. Land cover is depicted with the major cover types coded as follows: forest (green), grassland/meadow (light brown), lakes/water (blue), snow/ice (white), talus/rock (gray), wetlands (light blue).

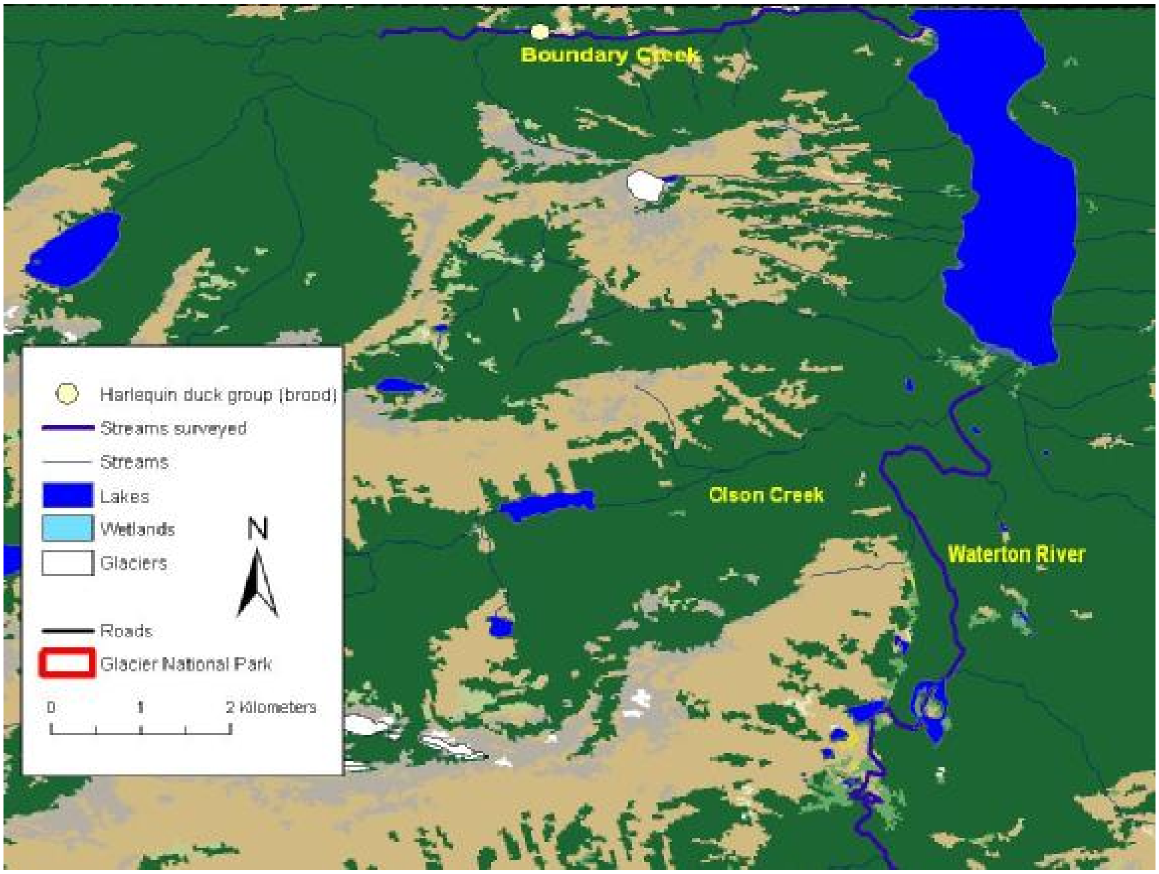

Figure 7. The location of the harlequin duck group (one female with two juveniles) observed on Boundary Creek. Land cover is depicted with the major cover types coded as follows: forest (green), grassland/meadow (light brown), lakes/water (blue), snow/ice (white), talus/rock (gray), wetlands (light blue).

Complete stream and habitat attribute data were collected at 59 of the harlequin locations and at 202 randomly selected locations along the streams that were surveyed. Stream wetted width at harlequin locations and random locations ranged between 3 m and 133 m (mean = 33.7; SE = 2.4) and 4 m and 283 m (mean = 18.6; SE = 1.4), respectively. Stream wetted depth at harlequin locations and random locations ranged from 5.4 cm to 256.4 cm (mean = 50.0; SE = 6.5) and 5.1 cm to 120.5 cm (mean = 29.0; SE = 1.2), respectively. Forty-nine percent of harlequin locations occurred in stream areas with a gravel island or bar, while 41% and 37% of harlequins observed were located in rapid and riffle stream classes, respectively. The majority of harlequin locations were in areas of the low category of large woody debris (71% of locations) and low boulder counts (56%). Harlequins were most frequently observed in coniferous (54%) and mixed (34%) canopy habitat types, a mixed understory habitat type (59%), and shrub (54%)

and shrub/grass (31%) ground habitat types. Locations were most frequent in heavy (44%) and moderate (29%) canopy cover, heavy understory cover (59%), and very heavy (34%), heavy (27%), and moderate (27%) ground cover.

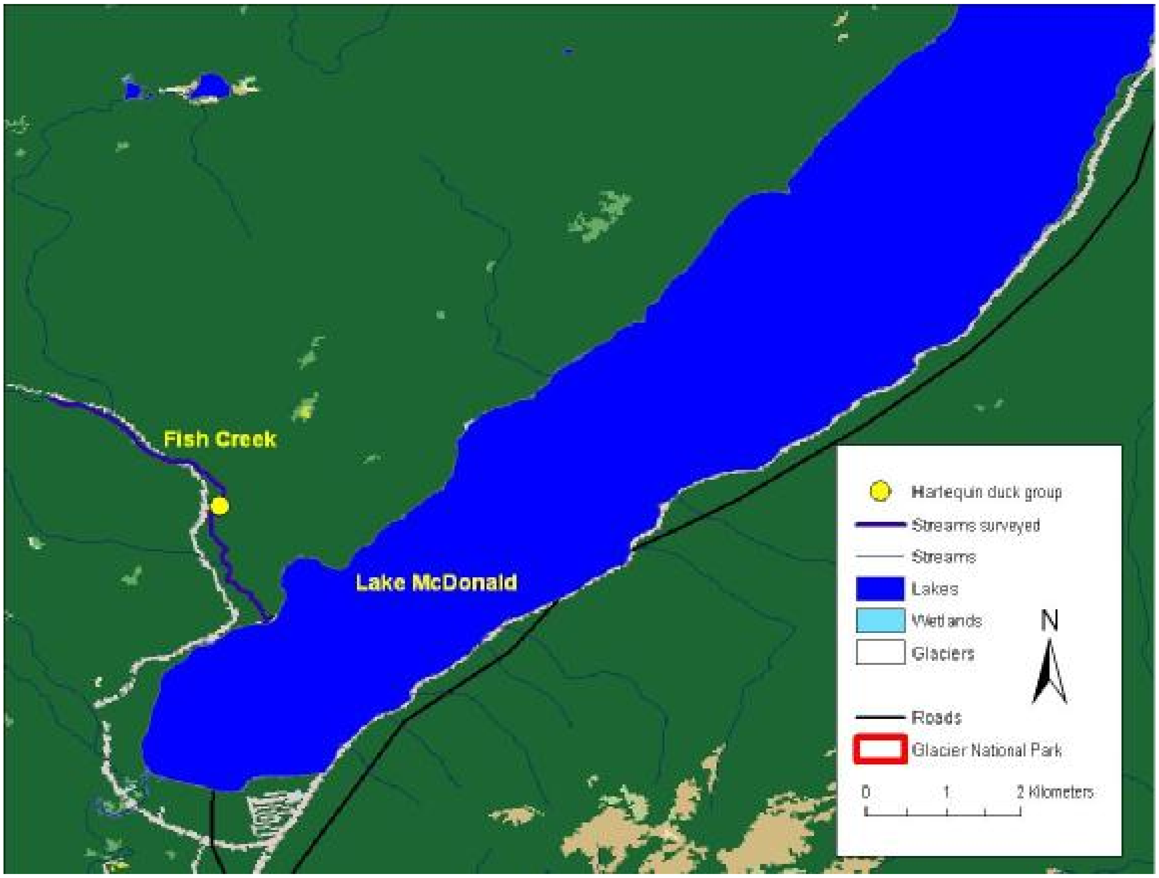

Figure 8. The location of the harlequin duck group (one female and one male) observed on Fish Creek. Land cover is depicted with the major cover types coded as follows: forest (green), grassland/meadow (light brown), lakes/water (blue), snow/ice (white), talus/rock (gray), wetlands (light blue).

Table 2. Harlequin duck age and sex composition, and total counts from surveys conducted on Upper McDonald Creek between May 21 and August 22, 2008.

Survey Date	Number of Adult Males	Number of Adult Females	Number of Juveniles	Total
May 21	8	7	0	15
May 28	12	10	0	22
June 4	12	5	0	17
June 13	17	13	0	30
July 24	1	3	3	7
August 1	0	7	12	19
August 8	0	11	15	26
August 22	0	1	3	4

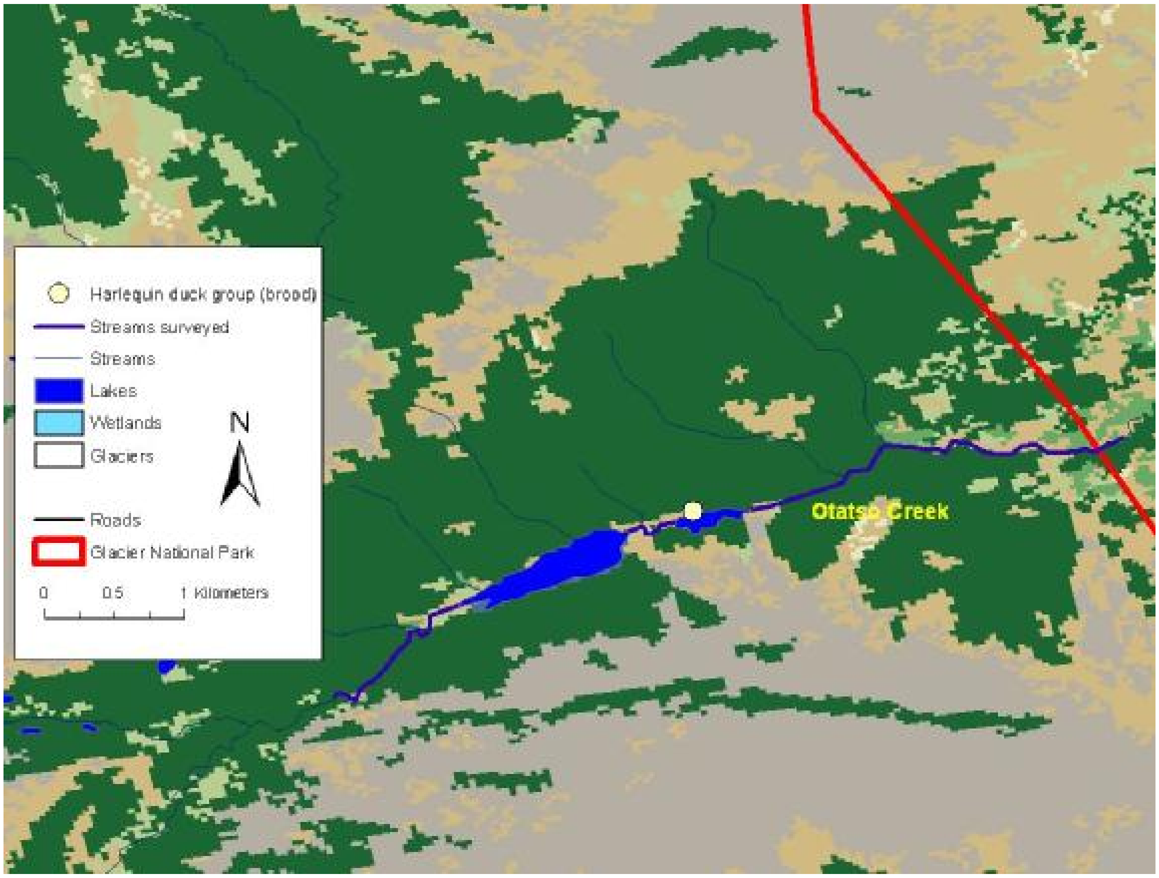

Figure 9. The location of the harlequin duck group (one female with two juveniles) observed on Otatso Creek. Land cover is depicted with the major cover types coded as follows: forest (green), grassland/meadow (light brown), lakes/water (blue), snow/ice (white), talus/rock (gray), wetlands (light blue).

Modeling Harlequin Duck Landscape Use

There were three top approximating models with $\Delta AIC_c < 2$ for the *a priori* modeling analysis (Table 3; Appendix A). The highest supported model had $w_i = 0.281$ and a relative likelihood of 1.1 compared to the second best model that had $\Delta AIC_c = 0.18$, suggesting two comparable highly supported model structures supported by the data (Table 3). The third best model had $\Delta AIC_c = 1.79$ and $w_i = 0.115$ (Table 3). All three top models contained significant WIDTH, DEPTH, and UNDERSTORY covariates that had confidence intervals not spanning zero (Table 4). As hypothesized, the WIDTH and DEPTH covariates were positively correlated with use, as were DECIDUOUS and MIXED understory covariate categories (Table 4). All other covariates contained in the top approximating models had confidence intervals that overlapped zero.

For the exploratory modeling analyses, substitution of $COVER_{canopy}$ for COVER resulted in a lowest model AIC_c of 212.99, which was no improvement over the lowest AIC_c value from the ***a priori*** modeling of 209.33. Substitution of $COVER_{understory}$ for COVER resulted in a lowest AIC_c of 207.55, which was an improvement from the ***a priori*** modeling. Substitution of $COVER_{ground}$ for COVER resulted in a lowest AIC_c of 204.46, which was an improvement over the ***a priori*** results. Substitution of $COVER_{understory}$ + $COVER_{ground}$ for COVER resulted in a lowest AIC_c of 202.83 (Table 5), which was the greatest decrease in AIC_c compared to ***a priori*** modeling for the exploratory modeling. Substitution of $COVER_{understory}$ + $COVER_{ground}$ + BOULDER for COVER resulted in a lowest AIC_c of 209.52, which was no improvement.

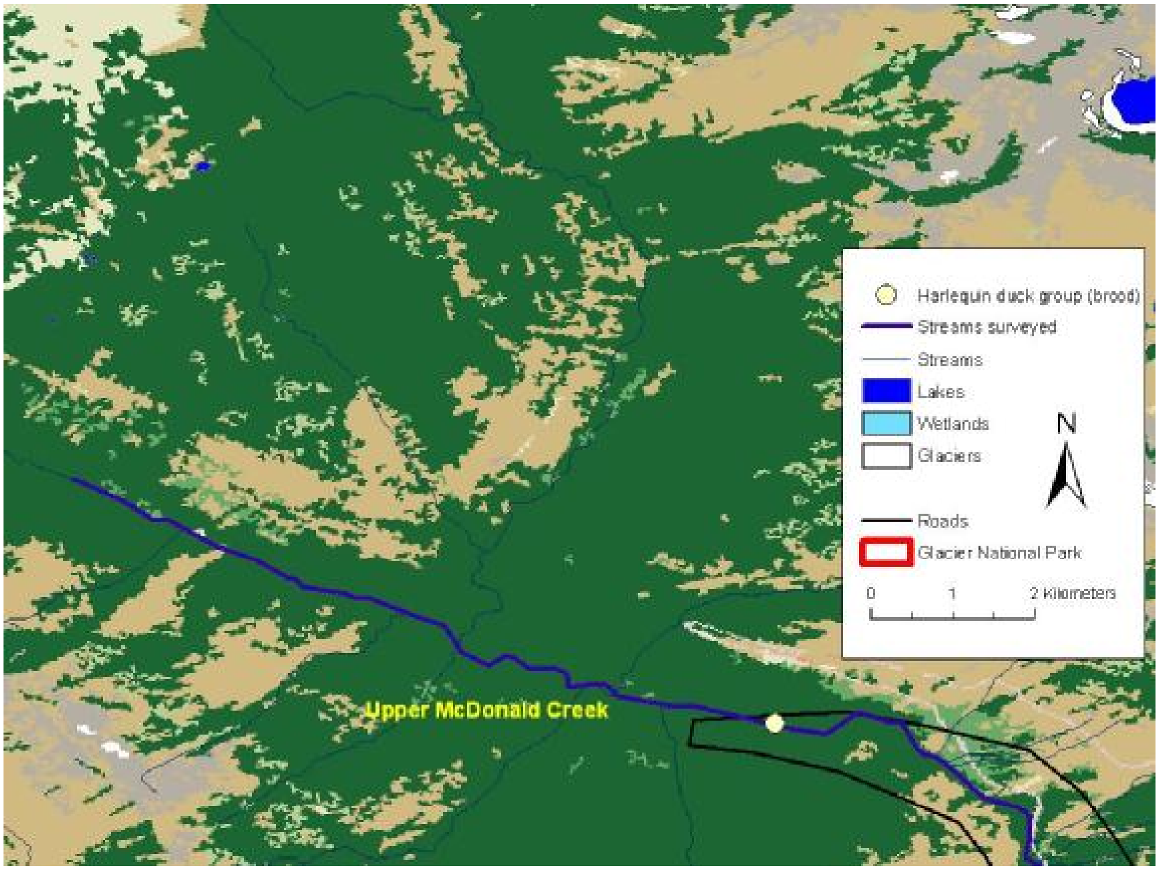

Figure 10. The location of the harlequin duck group (one female with four juveniles) observed on the upper (north) portion of Upper McDonald Creek beyond Logan Creek. Land cover is depicted with the major cover types coded as follows: forest (green), grassland/meadow (light brown), lakes/water (blue), snow/ice (white), talus/rock (gray), wetlands (light blue).

The exploratory models with $COVER_{understory}$ + $COVER_{ground}$ substituted for COVER had three models with $\Delta AIC_c < 2$ (Table 5). The second and third best approximating exploratory models differed from the top model by ΔAIC_c values of 0.97 and 1.94, respectively (Table 5). The DEPTH covariate was a significant, positive effect in all three top exploratory models, while WIDTH had confidence intervals not spanning zero in two of the three models (Table 6). The MIXED UNDERSTORY covariate was positively correlated with use, but only had confidence intervals that did not span zero in the third best model (Table 6). While substituting $COVER_{understory}$ + $COVER_{ground}$ for COVER lowered AIC_c values, neither $COVER_{understory}$ nor $COVER_{ground}$ were significant effects in the top models (Table 6).

Table 3. Model selection results for *a priori* hypothesized models examining the effects of stream and habitat attribute covariates on the probability of harlequin duck landscape use in Glacier National Park. The six best approximating models are presented along with the number of parameters (*K*), the ΔAIC_c value, and the Akaike weight (w_i).

Model	**Structure**	***K***	**ΔAIC_c**	**w_i**
28‡	$\beta_0 + \beta_1$(WIDTH) + β_2(DEPTH) + β_3(CLASS) + β_4(UNDERSTORY) + β_5(COVER)	13	0.000	0.2813
44	$\beta_0 + \beta_1$(WIDTH) + β_2(DEPTH) + β_3(CLASS) + β_4(UNDERSTORY) + β_5(COVER) + β_6(LWD)	16	0.181	0.2569
32	$\beta_0 + \beta_1$(WIDTH) + β_2(DEPTH) + β_3(CLASS) + β_4(UNDERSTORY) + β_5(COVER) + β_6(BAR)	14	1.789	0.1150
48	$\beta_0 + \beta_1$(WIDTH) + β_2(DEPTH) + β_3(CLASS) + β_4(UNDERSTORY) + β_5(COVER) + β_6(LWD) + β_7(BAR)	17	2.433	0.0833
52	$\beta_0 + \beta_1$(WIDTH) + β_2(DEPTH) + β_3(CLASS) + β_4(CANOPY) + β_5(UNDERSTORY) + β_6(COVER)	16	3.007	0.0625
60	$\beta_0 + \beta_1$(WIDTH) + β_2(DEPTH) + β_3(CLASS) + β_4(CANOPY) + β_5(UNDERSTORY) + β_6(COVER) + β_7(LWD)	19	3.392	0.0516

‡ AIC_c value for model 28 is 209.329.

Table 4. Covariate coefficient values with lower (LCI) and upper confidence intervals (UCI) for the three best approximating models with $\Delta AIC_c < 2$ for the model analyses examining the effects of stream and habitat attributes on the probability of harlequin duck landscape use in Glacier National Park. Bold notation denotes significant coefficients at $\alpha = 0.05$. Covariates are described in the text; N/A denotes that the covariate was not included in the model.

Covariate	**Model 28** β_i (LCI, UCI)	**Model 44** β_i (LCI, UCI)	**Model 32** β_i (LCI, UCI)
Intercept ‡	**-4.696 (-7.038, -2.354)**	**-5.541 (-8.211, -2.871)**	**-4.666 (-7.002, -2.330)**
WIDTH	**0.044 (0.013, 0.074)**	**0.038 (0.007, 0.069)**	**0.045 (0.013, 0.076)**
DEPTH	**0.072 (0.026, 0.118)**	**0.067 (0.019, 0.115)**	**0.070 (0.024, 0.117)**
CLASS = FALLS	-0.007 (-2.924, 2.909)	-0.114 (-3.070, 2.841)	-0.040 (-2.953, 2.873)
CLASS = GLIDE	-1.439 (-3.613, 0.735)	-1.473 (-3.686, 0.741)	-1.392 (-2.953, 2.873)
CLASS = POOL	1.457 (-0.944, 3.858)	1.610 (-0.919, 4.140)	1.452 (-0.950, 3.855)
CLASS = RAPID	0.925 (-0.930, 2.779)	0.915 (-0.984, 2.815)	0.957 (-0.889, 2.803)
CLASS = RIFFLE	0.236 (-1.644, 2.116)	0.165 (-1.768, 2.098)	0.303 (-1.577, 2.182)
UNDERSTORY = DECIDUOUS	**1.288 (0.129, 2.447)**	**1.333 (0.142, 2.524)**	**1.301 (0.143, 2.460)**
UNDERSTORY = MIXED	**1.482 (0.592, 2.372)**	**1.421 (0.497, 2.344)**	**1.527 (0.626, 2.427)**
UNDERSTORY = NONE	-15.3 (-2481, 2450)	-15.1 (-2490, 2460)	-15.2 (-2471, 2441)
UNDERSTORY = SHRUB	21.1 (-8981, 9023)	20.7 (-8990, 9031)	21.0 (-8972, 9014)
COVER	0.005 (-0.016, 0.026)	0.010 (-0.012, 0.033)	0.006 (-0.016, 0.027)
BAR = YES	N/A	N/A	-0.264 (-1.041, 0.513)
LWD = LOW	N/A	1.009 (-0.228, 2.245)	N/A
LWD = MEDIUM	N/A	0.504 (-0.861, 1.869)	N/A
LWD = NONE	N/A	19.7 (-7048, 7087)	N/A

‡ The intercept term for model 28 includes CLASS = CASCADE and UNDERSTORY = CONIFEROUS; the intercept for model 44 includes CLASS = CASCADE, UNDERSTORY = CONIFEROUS, and LWD = HIGH; the intercept for model 32 includes CLASS = CASCADE, UNDERSTORY = CONIFEROUS, and BAR = NO.

Table 5. Model selection results for the exploratory models examining the effects of stream and habitat attribute covariates, with the substitution of $COVER_{understory}$ + $COVER_{ground}$ for COVER from ***a priori*** models, on the probability of harlequin duck landscape use in Glacier National Park. The six best approximating exploratory models are presented along with the number of parameters (*K*) and ΔAIC_c value.

Model	**Structure**	***K***	**ΔAIC_c**
28e‡	$\beta_0 + \beta_1(WIDTH) + \beta_2(DEPTH) + \beta_3(CLASS) + \beta_4(UNDERSTORY) + \beta_5(COVER_{understory}) + \beta_6(COVER_{ground})$	20	0.000
44e	$\beta_0 + \beta_1(WIDTH) + \beta_2(DEPTH) + \beta_3(CLASS) + \beta_4(UNDERSTORY) + \beta_5(COVER_{understory}) + \beta_6(COVER_{ground}) + \beta_7(LWD)$	23	0.972
32e	$\beta_0 + \beta_1(WIDTH) + \beta_2(DEPTH) + \beta_3(CLASS) + \beta_4(UNDERSTORY) + \beta_5(COVER_{understory}) + \beta_6(COVER_{ground}) + \beta_7(BAR)$	21	1.943
48e	$\beta_0 + \beta_1(WIDTH) + \beta_2(DEPTH) + \beta_3(CLASS) + \beta_4(UNDERSTORY) + \beta_5(COVER_{understory}) + \beta_6(COVER_{ground}) + \beta_7(LWD) + \beta_8(BAR)$	24	3.374
52e	$\beta_0 + \beta_1(WIDTH) + \beta_2(DEPTH) + \beta_3(CLASS) + \beta_4(CANOPY) + \beta_5(UNDERSTORY) + \beta_6(COVER_{understory}) + \beta_7(COVER_{ground})$	23	5.145
60e	$\beta_0 + \beta_1(WIDTH) + \beta_2(DEPTH) + \beta_3(CLASS) + \beta_4(CANOPY) + \beta_5(UNDERSTORY) + \beta_6(COVER_{understory}) + \beta_7(COVER_{ground}) + \beta_8(LWD)$	26	5.827

‡ AIC_c value for model 28e is 202.831.

Stream Width and Depth Analyses of Variance

There were a total of 261 width and depth measurements made on 19 streams. For the ANOVA analyses I removed two measurements from the Otatso Creek drainage that were made on a wide, shallow pond. I also removed 29 measurements from Red Eagle Creek because it was the only stream surveyed during the fifth two-week date interval and a coefficient estimate for DATE = 5 was undefined for the STREAMID + DATE model.

The best approximating model for the width response variable was STREAMID + DATE, which was very highly supported (ΔAIC_c = 0.00, AIC_c = 1642.19, w_i = 1.000, adjusted R^2 = 0.51, K = 25). The second best model was STREAMID (ΔAIC_c = 73.65, w_i << 0.001, adjusted R^2 = 0.30, K = 18) and the third best model was DATE (ΔAIC_c = 84.24, w_i << 0.001, adjusted R^2 = 0.23, K = 8). The top model contained significant STREAMID (P << 0.001, mean square = 622.8, degrees of freedom (*df*) = 17) and DATE (P << 0.001, mean square =

Table 6. Covariate coefficient values with lower (LCI) and upper confidence intervals (UCI) for the three best exploratory models with $\Delta AIC_c < 2$ for the exploratory model analysis examining the effects of stream and habitat attributes, with the substitution of $COVER_{understory}$ + $COVER_{ground}$ for COVER in the *a priori* models, on the probability of harlequin duck landscape use in Glacier National Park. Bold notation denotes significant coefficients at $\alpha = 0.05$. Covariates are described in the text; N/A denotes that the covariate was not included in the model.

	Model 28e	**Model 44e**	**Model 32e**
Covariate	β_i (LCI, UCI)	β_i (LCI, UCI)	β_i (LCI, UCI)
Intercept ‡	-19.7 (-4532, 4493)	-20.3 (-4525, 4485)	-19.73 (-4511, 4471)
WIDTH	**0.0302 (0.0004, 0.0600)**	0.025 (-0.004, 0.054)	**0.031 (0.001, 0.061)**
DEPTH	**0.085 (0.032, 0.137)**	**0.080 (0.026, 0.134)**	**0.083 (0.031, 0.136)**
CLASS = FALLS	0.502 (-2.746, 3.750)	0.252 (-3.148, 3.652)	0.458 (-2.794, 3.710)
CLASS = GLIDE	-0.212 (-2.712, 2.289)	-0.331 (-2.958, 2.295)	-0.144 (-2.626, 2.338)
CLASS = POOL	1.983 (-0.613, 4.579)	2.142 (-0.698, 4.983)	1.982 (-0.607, 4.571)
CLASS = RAPID	1.922 (-0.286, 4.130)	1.884 (-0.488, 4.256)	1.946 (-0.241, 4.134)
CLASS = RIFFLE	1.408 (-0.810, 3.626)	1.320 (-1.084, 3.725)	1.472 (-0.734, 3.678)
UNDERSTORY = DECIDUOUS	1.289 (-0.007, 2.584)	1.238 (-0.069, 2.546)	1.289 (-0.010, 2.588)
UNDERSTORY = MIXED	0.990 (-0.004, 1.984)	0.849 (-0.198, 1.896)	**1.040 (0.034, 2.047)**
UNDERSTORY = NONE	-0.3 (-5117, 5116)	-0.503 (-5110, 5109)	-0.250 (-5087, 5087)
UNDERSTORY = SHRUB	20.1 (-8314, 8354)	19.4 (-8517, 8556)	20.0 (-8299, 8339)
$COVER_{understory}$ = SPARSE	13.8 (-4498, 4526)	13.8 (-4491, 4519)	13.9 (-4477, 4505)
$COVER_{understory}$ = MODERATE	14.3 (-4498, 4526)	14.2 (-4491, 4519)	14.3 (-4477, 4505)
$COVER_{understory}$ = HEAVY	15.6 (-4497, 4528)	15.5 (-4489, 4520)	15.7 (-4475, 4506)
$COVER_{understory}$ = VERY HEAVY	15.9 (-4497, 4528)	15.9 (-4489, 4521)	16.0 (-4475, 4507)
$COVER_{ground}$ = SPARSE	0.804 (-1.973, 3.581)	0.172 (-3.223, 3.567)	0.816 (-2.001, 3.633)
$COVER_{ground}$ = MODERATE	0.823 (-1.018, 2.664)	1.086 (-0.806, 2.978)	0.846 (-1.007, 2.699)
$COVER_{ground}$ = HEAVY	-0.457 (-2.185, 1.271)	-0.253 (-2.034, 1.528)	-0.414 (-2.158, 1.330)
$COVER_{ground}$ = VERY HEAVY	-1.276 (-3.117, 0.566)	-1.095 (-2.974, 0.784)	-1.245 (-3.095, 0.606)
BAR = YES	N/A	N/A	-0.278 (-1.119, 0.562)
LWD = LOW	N/A	1.125 (-0.186, 2.435)	N/A
LWD = MEDIUM	N/A	0.480 (-0.976, 1.937)	N/A
LWD = NONE	N/A	19.4 (-7348, 7387)	N/A

‡ The intercept term for model 28e includes CLASS = CASCADE, UNDERSTORY = CONIFEROUS, $COVER_{understory}$ = ABSENT, and $COVER_{ground}$ = ABSENT; the intercept for model 44e includes CLASS = CASCADE, UNDERSTORY = CONIFEROUS, LWD = HIGH, $COVER_{understory}$ = ABSENT, and $COVER_{ground}$ = ABSENT; the intercept for model 32e includes CLASS = CASCADE, UNDERSTORY = CONIFEROUS, BAR = NO, $COVER_{understory}$ = ABSENT, and $COVER_{ground}$ = ABSENT.

911.2, *df* =7) factors, and had an error mean square (MSE) of 64.3 with *df* = 205. Relative to Upper McDonald Creek during the first two-week interval of May 20-June 1, 11 of the other 17 streams surveyed had significantly smaller stream widths (Table 7). In addition, compared to the May 20-June 1 interval, streams during the four date periods after July 14-27 had significantly smaller widths (Table 7).

The best approximating model for the depth response variable was DATE, which was highly supported ($\Delta AIC_c = 0.00$, $AIC_c = 1759.46$, $w_i = 0.999$, adjusted $R^2 = 0.17$, $K = 8$). The second best model was STREAMID + DATE ($\Delta AIC_c = 21.66$, $w_i < 0.001$, adjusted $R^2 = 0.17$, $K = 25$) and the third best model was STREAMID ($\Delta AIC_c = 49.27$, $w_i << 0.001$, adjusted $R^2 = 0.02$, $K = 18$). The top model contained a significant DATE factor ($P << 0.001$, mean square = 898.9, *df* = 7) and had an MSE = 117.5 with *df* = 222. Relative to the May 20-June 1 interval, streams during the June 2-15 period had significantly greater depths while those during August 25-September 7 and September 8-19 had significantly shallower depths (Table 7).

Population Estimates

The estimated population size of harlequins, including juveniles, in Glacier for summer 2008 was 217 ducks based on Equations 1 and 2. The estimated size of the breeding (adult) population of harlequins for 2008 was 159 ducks. Because the majority of tributary streams in drainages provided inadequate harlequin habitat and no ducks were observed on a few tributary streams, estimation of a meaningful term for the s_i^2 component of variance in Equation 3 was not possible. The lack of suitable stream levels and habitat provided by most tributary streams makes inclusion of them in a sampling design unnecessary. Therefore, I modified the sampling design to consist solely of a stratified sampling scheme and removed the majority of tributary streams within drainages from the sampling universe. I present the modified sampling design and corresponding equations for estimating the population size in Appendix B.

Using Equations B1 and B2 in Appendix B for the modified sampling design, the estimated population size of harlequins, including juveniles, in Glacier for summer 2008 was 76 ducks with a 95% confidence interval of 23 to 128 ducks. I used the maximum number of adult males, adult females, and juveniles observed in any one of the eight surveys on Upper McDonald Creek to determine a count of 45 ducks for that stream (Table 2). With the addition of the male/female pair on Fish Creek and the female with four juveniles on the upper portion

Table 7. Factor level coefficients and lower (LCI) and upper confidence intervals (UCI) for the top approximating analysis of variance models examining the effects of stream and date on stream widths and depths. Bold notation denotes significant coefficients at $\alpha = 0.05$; N/A denotes that the factor was not included in the model.

Model	**WIDTH = STREAMID + DATE**	**DEPTH = DATE**
Factor	β_i (LCI, UCI)	β_i (LCI, UCI)
Intercept ‡ (STREAMID = Upper McDonald Creek + DATE = May 20-June 1)	**33.645 (29.556, 37.733)**	**15.128 (11.373, 18.883)**
DATE = June 2-June 15	3.896 (-1.018, 8.810)	**7.918 (2.959, 12.878)**
DATE = June 16-June 29	-0.975 (-8.368, 6.419)	-3.946 (-11.371, 3.479)
DATE = June 30-July 13	-6.346 (-14.816, 2.124)	0.292 (-5.379, 5.963)
DATE = July 14-July 27 §	N/A	N/A
DATE = July 28-August 10	**-11.072 (-16.846, -5.298)**	-4.291 (-9.329, 0.748)
DATE = August 11-August 24	**-10.437 (-19.615, -1.259)**	-5.428 (-13.124, 2.268)
DATE = August 25-September 7	**-12.992 (-18.683, -7.301)**	**-7.160 (-12.514, -1.807)**
DATE 9 = September 8-September 19	**-19.359 (-26.570, -12.148)**	**-6.102 (-11.199, -1.005)**
STREAMID = Belly River	**-6.924 (-12.059, -1.788)**	N/A
STREAMID = Boundary Creek	**-8.253 (-16.319, -0.187)**	N/A
STREAMID = Divide Creek	**-17.499 (-26.550, -8.447)**	N/A
STREAMID = Harrison Creek	**-24.684 (-31.251, -18.116)**	N/A
STREAMID = Kishenehn Creek	**-10.621 (-17.321, -3.922)**	N/A
STREAMID = Logging Creek	**-17.647 (-23.591, -11.702)**	N/A
STREAMID = Fish Creek	**-30.645 (-46.883, -14.406)**	N/A
STREAMID = Midvale Creek	**-21.845 (-29.976, -13.713)**	N/A
STREAMID = Midvale Creek tributary	**-27.645 (-43.883, -11.406)**	N/A
STREAMID = Nyack Creek	3.747 (-2.830, 10.323)	N/A
STREAMID = Otatso Creek	-12.208 (-26.028, 1.613)	N/A
STREAMID = Reynolds Creek	**-14.584 (-24.203, -4.965)**	N/A
STREAMID = St. Mary River	0.483 (-5.133, 6.100)	N/A
STREAMID = Two Medicine Creek	-1.903 (-10.701, 6.895)	N/A
STREAMID = Paradise Creek	**-15.239 (-25.246, -5.232)**	N/A
STREAMID = Virginia Creek	-13.653 (-29.859, 2.553)	N/A
STREAMID = Waterton River	1.048 (-5.869, 7.966)	N/A

‡ The intercept for the DATE model is DATE = May 20-June 1.

§ No coefficient was estimated for the July 14-27 period because only one stream was surveyed during these dates.

of Upper McDonald Creek, the total count for the drainage was 52 ducks assuming no harlequin was counted twice. The surveys on Boundary Creek and Otatso Creek each resulted in one female with two juveniles. Therefore, the total duck count used to determine the estimate with juveniles was 58 harlequins. The estimated size of the breeding population of harlequins for 2008 was 44 ducks with a 95% confidence interval of 11 to 77 ducks. The total count used for the adult population estimate was 35 harlequins.

DISCUSSION

Stream size was one of the predominant factors influencing harlequin duck landscape use in Glacier National Park during 2008. Both stream width and depth were positively correlated with the probability of harlequin use in the top approximating models, suggesting that the potential for increased resource availability in larger streams is an important factor in habitat selection by harlequins. In eastern North America, Rodway (1998*a*) found harlequins to be food limited during the breeding season, and Robert and Cloutier (2001) documented a strong dependence of harlequins on insects. While wider streams are more likely to contain greater invertebrate abundance owing to increased surface area of stream substrate, deeper, turbulent streams may be more productive because of higher amounts of dissolved organic carbon (DOC) (Kiffney et al. 1997). Increased stream turbulence and/or higher levels of DOC result in decreased transmission of ultraviolet (UV) radiation (Morris et al. 1995, Williamson et al. 1996), which has implications on the abundance of benthic invertebrates. Increased transmission of UV radiation results in decreased algal biomass and invertebrate assemblages, with the effects more pronounced in shallow streams (Kiffney et al. 1997). Streams within Glacier and the Rocky Mountains have higher DOC levels during the springtime snowmelt when organic matter is prominent in runoff (Kiffney et al. 1997). Thus, stream conditions during late spring and early summer may present unique foraging opportunities to harlequins that become more limited as stream levels fall throughout summer. Bond et al. (2007) documented the importance of food resources in breeding ground streams for females because of egg formation that occurs in late spring. If the trend in climate warming continues and snowpack accumulation decreases, then the duration of springtime snowmelt and runoff will decrease and stream levels within Glacier will decrease more rapidly during summer. Further, decreased depths and water flow rates may contribute to increases in water temperature, which may subsequently affect invertebrate species composition and abundance (Fagre et al. 1997). The lack of harlequin observations on streams other than Upper McDonald Creek may already partially be a result of effects from climate warming.

Two types of understory vegetation cover were positively correlated with harlequin landscape use in the top approximating models. Both deciduous and mixed coniferous and deciduous understory cover types were positive effects on harlequin use, which may be attributed to the protection that understory vegetative cover provides from predators. While the NONE and SHRUB categories of understory cover were not statistically significant in the top models, this likely owes to the lack of harlequin observations that occurred in areas with these cover types. Presence of cover has been documented to affect harlequin habitat use along breeding streams in Labrador. Heath and Montevecci (2008) found that in drainages with a high risk of predation from raptors, harlequins used areas of streams with overhanging vegetation that afforded concealment of adult ducks, nest sites, and juveniles. Also, Rodway (1998*b*) discovered vegetation along shorelines was an important factor affecting use of streams by harlequins. In addition to the concealment value that understory cover provides, it may offer ducks, especially females with juveniles, protection from wind, sun, and rain. While the average amount of cover covariate for the canopy, understory, and ground layers had confidence intervals that spanned zero in the top models, it was included in all three of the most highly supported models. Further, in exploratory modeling efforts, inclusion of the amounts of understory and ground cover improved the top models. Collection of additional data at harlequin locations would likely lend support to the importance of the amount of cover, in addition to the presence of cover, in affecting harlequin stream use.

The Upper McDonald Creek drainage may contain unique ecological conditions for harlequins compared to other drainages within Glacier. Observers on the June 13 survey along Upper McDonald Creek counted 30 adult harlequins within 20 groups, which were both high numbers for 2008, in the 15.8 km of stream surveyed. The maximum number of adults observed on Upper McDonald Creek in 2008 was slightly above average as the maximum number of adults observed per year on surveys of Upper McDonald Creek from 1991-2006 ranged between 12 and 41 ducks (mean = 24.8; SE = 2.2) (Secrest and Elwood 2006). The 2008 count equates to an average of 1.3 groups/km and 1.9 ducks/km. Although all other drainages were surveyed only once during the field season, the maximum number of groups observed within any of these drainages was one, at densities of 0.2 groups/km and 0.6 ducks/km. Results from the ANOVA examining stream and date factors on stream width may lend further insight. The average stream width on Upper McDonald Creek was significantly larger than 11 other streams surveyed. Seven other streams had average widths not statistically different from Upper McDonald Creek, although Otatso Creek and Virginia Creek were much narrower on average despite confidence intervals that slightly spanned zero (Table 7). The potential for increased food availability on the wider portions of Upper McDonald Creek may provide resources that are sufficient enough to support high densities of harlequins compared to the majority of other streams within Glacier. Another unique aspect of Upper McDonald Creek is that it mostly parallels a portion of Going-to-the-Sun Road. While this has potential implications in terms of human disturbance on foraging behavior and nest success, continued use of the stream by harlequins and females with broods suggests some habituation and/or preference for this stream segment for other reasons. One possibility may be a lower risk of predation from raptors and other species because of the increased presence of humans and vehicles, which may result in avoidance behavior of some predator species (e.g., Bautista et al. 2004).

The variability in harlequin counts along Upper McDonald Creek during 2008 and previous years (Secrest and Elwood 2006) may be the result of several factors, all of which warrant additional research and that are limitations of this study. The extent of harlequin movements among drainages and the distances of these movements are unknown. It is possible that harlequins present on Upper McDonald Creek during one survey move to a neighboring drainage by the time the next survey is conducted. Interdrainage movements may also be a factor as to why so few harlequins were observed throughout the park in 2008. The timing of surveys may have been such that ducks had moved out of the drainage being surveyed and into adjacent drainages. To begin to address questions about harlequin movements among drainages a telemetry study will be needed. A second unknown factor that may influence variability in counts is detectability of harlequins. There are three periods throughout the breeding season during which adult female harlequins may be more or less likely to be sighted on a survey. It is likely that harlequins are most detectable throughout the pairing period, during which they undergo courtship displays and many groups consist of a male and female pair. During the incubation period, when males leave females to tend to the eggs and nest, detectability is likely to be at its lowest because successful nests should be mostly concealed by vegetation. Finally, during brood rearing, detectability is likely to be higher than during incubation, but lower than during pairing because of increased use of concealed and backwater regions of streams for protection of young. Because streams were surveyed during the incubation period in 2008, it is possible that lower detectability resulted in some ducks being missed on surveys. Likewise, because early season stream surveys had to be conducted along the stream bank rather than by walking in the channel, harlequins may have been missed in areas with dense vegetation. A double sampling scheme (Thompson 2002) and use of telemetry with individual ducks could begin to address detectability questions for harlequins. A third unknown is the timing of the incubation period and whether it varies with elevation. If ducks at higher elevations begin establishing nests and incubating later than those in lower elevation drainages, then it may be possible to continue pair surveys later into June on higher elevation streams. Surveys along Upper McDonald Creek have generally not been conducted between late June and mid-July because of the likelihood that females will be nesting. The timing of incubation could be studied in conjunction with detectability. A final unknown is how much variability is introduced into counts from climate stochasticity. A spring characterized by above average precipitation and flooding, such as in 2008, may result in increased nest failure or the inability of harlequins to establish nests, or increased movement among drainages as ducks attempt to find the best quality resources. Only through continued data collection through a variety of conditions can climate effects be evaluated.

The population estimate of 44 adults and 76 total harlequins in Glacier for 2008 should be considered to be a low and conservative estimate. In addition to limitations of the study discussed above that may have led to undercounting and/or missing groups, the original sampling design developed prior to the 2008 surveys used a two-stage sampling approach and considered individual streams to be a sampling unit. This type of design seems to not be necessary because of the lack of quality harlequin habitat that most tributary streams had throughout the entire breeding season. Therefore, I developed a modified sampling design that is provided in Appendix B that can be employed in future years. In Appendix B I provide details of both a completely stratified random sampling approach and one that considers selection of “priority” drainages with previous harlequin sightings along with a stratified random sample. Budget and time constraints will determine whether drainages should be surveyed more than once. Ideally, given the variability in counts from surveys along Upper McDonald Creek, drainages could be surveyed at least once during the pairing period and then again during brood rearing. However, a two survey per drainage approach would not have been feasible during 2008 when flooding and snow prohibited access to many drainages in May and June. Improved road access and hiking conditions from July through September provided opportunities for more efficient surveying during the brood rearing period. In Appendix C I provide estimates of the amount of time required to complete stream surveys based on the 2008 results.

Although the effect of climate warming to date on the breeding harlequin population in Glacier is not fully known, results from this study document the importance of stream attributes and riparian habitats for harlequins. Continued monitoring is required to determine the role of drainages other than Upper McDonald Creek in supporting harlequins and whether these streams contain sufficient resources for ducks throughout the entire breeding season. Additional data is also needed to determine whether the lack of harlequins on these streams is a one-year event or a trend that foreshadows potential problems for harlequins within Glacier. If the lack of harlequins outside of the McDonald Creek drainage was a random occurrence, then it may owe to particularly wet spring weather that resulted in prolonged flooding along streams and delayed snowmelt. The later date of snowmelt and persistence of snow into summer at higher elevations during 2008 may have precluded harlequins establishing nests in certain drainages. Because of the high density of harlequins on Upper McDonald Creek, it is also possible that a source-sink population structure exists between the McDonald Creek drainage and surrounding streams in Glacier and the Flathead National Forest. Heath et al. (2006) documented source-sink population dynamics for harlequins in which a drainage with a stable, high-density subpopulation of harlequins was the source of emigrants for surrounding sink subpopulations that had highly variable numbers of ducks. The drainage containing the source subpopulation was characterized by low predation risk, while drainages with sink subpopulations had higher risk (Heath et al. 2006). Although much additional data must be collected in Glacier on harlequin abundance, demographics, and movements before a source-sink population hypothesis could be tested, understanding implications of such metapopulation dynamics is essential because climate warming effects may exacerbate stream and habitat conditions in drainages containing sink subpopulations. With increasingly poor quality stream and habitat attributes these sink drainages would be more likely to experience subpopulation “extinctions” in the future, leaving the breeding population within the Glacier ecosystem potentially isolated to only a few higher quality streams.

ACKNOWLEDGEMENTS

The National Park Service and Glacier National Park Fund provided funding for this study. I would like to thank Glacier National Park Wildlife Biologist Steve Gniadek for facilitating obtaining funding for this study, and providing training and logistical support during the field season. Thanks to Glacier National Park biologists, rangers, and staff for logistical support with the backcountry surveys and study. Thanks to David Andersen of the University of Minnesota for support with this work through the university. Finally, thanks to Matthew Chappell, Christian Hagenlocher, Nathan Muhn, and Ashley Van Vossen for their hard work and efforts gathering data.

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APPENDICES

APPENDIX A

Tables of the candidate models and model selection results for the a priori analysis examining the effects of stream and habitat attributes on the probability of harlequin landscape use.

Table A1. The 64 *a priori* candidate models evaluated using multiple logistic regression techniques for examining stream and habitat attribute covariates on the probability of harlequin duck landscape use in Glacier National Park. The covariates are described in the main text.

Model	Model Structure
1	WIDTH + DEPTH
2	WIDTH + CLASS
3	DEPTH + CLASS
4	WIDTH + DEPTH + CLASS
5	WIDTH + DEPTH + BAR
6	WIDTH + CLASS + BAR
7	DEPTH + CLASS + BAR
8	WIDTH + DEPTH + CLASS + BAR
9	WIDTH + DEPTH + LWD + COVER
10	WIDTH + CLASS + LWD + COVER
11	DEPTH + CLASS + LWD + COVER
12	WIDTH + DEPTH + CLASS + LWD + COVER
13	WIDTH + DEPTH + BAR + LWD + COVER
14	WIDTH + CLASS + BAR + LWD + COVER
15	DEPTH + CLASS + BAR + LWD + COVER
16	WIDTH + DEPTH + CLASS + BAR + LWD + COVER
17	WIDTH + DEPTH + CANOPY + COVER
18	WIDTH + CLASS + CANOPY + COVER
19	DEPTH + CLASS + CANOPY + COVER
20	WIDTH + DEPTH + CLASS + CANOPY + COVER
21	WIDTH + DEPTH + BAR + CANOPY + COVER
22	WIDTH + CLASS + BAR + CANOPY + COVER
23	DEPTH + CLASS + BAR + CANOPY + COVER
24	WIDTH + DEPTH + CLASS + BAR + CANOPY + COVER
25	WIDTH + DEPTH + UNDERSTORY + COVER
26	WIDTH + CLASS + UNDERSTORY + COVER
27	DEPTH + CLASS + UNDERSTORY + COVER
28	WIDTH + DEPTH + CLASS + UNDERSTORY + COVER
29	WIDTH + DEPTH + BAR + UNDERSTORY + COVER
30	WIDTH + CLASS + BAR + UNDERSTORY + COVER
31	DEPTH + CLASS + BAR + UNDERSTORY + COVER

Table A1 continued

32	WIDTH + DEPTH + CLASS + BAR + UNDERSTORY + COVER
33	WIDTH + DEPTH + LWD + CANOPY + COVER
34	WIDTH + CLASS + LWD + CANOPY + COVER
35	DEPTH + CLASS + LWD + CANOPY + COVER
36	WIDTH + DEPTH + CLASS + LWD + CANOPY + COVER
37	WIDTH + DEPTH + BAR + LWD + CANOPY + COVER
38	WIDTH + CLASS + BAR + LWD + CANOPY + COVER
39	DEPTH + CLASS + BAR + LWD + CANOPY + COVER
40	WIDTH + DEPTH + CLASS + BAR + LWD + CANOPY + COVER
41	WIDTH + DEPTH + LWD + UNDERSTORY + COVER
42	WIDTH + CLASS + LWD + UNDERSTORY + COVER
43	DEPTH + CLASS + LWD + UNDERSTORY + COVER
44	WIDTH + DEPTH + CLASS + LWD + UNDERSTORY + COVER
45	WIDTH + DEPTH + BAR + LWD + UNDERSTORY + COVER
46	WIDTH + CLASS + BAR + LWD + UNDERSTORY + COVER
47	DEPTH + CLASS + BAR + LWD + UNDERSTORY + COVER
48	WIDTH + DEPTH + CLASS + BAR + LWD + UNDERSTORY + COVER
49	WIDTH + DEPTH + CANOPY + UNDERSTORY + COVER
50	WIDTH + CLASS + CANOPY + UNDERSTORY + COVER
51	DEPTH + CLASS + CANOPY + UNDERSTORY + COVER
52	WIDTH + DEPTH + CLASS + CANOPY + UNDERSTORY + COVER
53	WIDTH + DEPTH + BAR + CANOPY + UNDERSTORY + COVER
54	WIDTH + CLASS + BAR + CANOPY + UNDERSTORY + COVER
55	DEPTH + CLASS + BAR + CANOPY + UNDERSTORY + COVER
56	WIDTH + DEPTH + CLASS + BAR + CANOPY + UNDERSTORY + COVER
57	WIDTH + DEPTH + LWD + CANOPY + UNDERSTORY + COVER
58	WIDTH + CLASS + LWD + CANOPY + UNDERSTORY + COVER
59	DEPTH + CLASS + LWD + CANOPY + UNDERSTORY + COVER
60	WIDTH + DEPTH + CLASS + LWD + CANOPY + UNDERSTORY + COVER
61	WIDTH + DEPTH + BAR + LWD + CANOPY + UNDERSTORY + COVER
62	WIDTH + CLASS + BAR + LWD + CANOPY + UNDERSTORY + COVER
63	DEPTH + CLASS + BAR + LWD + CANOPY + UNDERSTORY + COVER
64	WIDTH + DEPTH + CLASS + BAR + LWD + CANOPY + UNDERSTORY + COVER

Table A2. Model selection results from the *a priori* modeling analysis that evaluated stream and habitat attribute covariates on the probability of harlequin duck landscape use in Glacier National Park. The number of parameters (*K*), AIC_c value, ΔAIC_c value, and the Akaike weight (w_i).are provided for each model. The complete model list is provided in Table A1. The covariates are described in the main text.

Model	**K**	**AIC_c**	**ΔAIC_c**	**w_i**
28	13	209.329	0.000	0.2813
44	16	209.510	0.181	0.2569
32	14	211.118	1.789	0.1150
48	17	211.762	2.433	0.0833
52	16	212.336	3.007	0.0625
60	19	212.721	3.392	0.0516
56	17	214.349	5.020	0.0229
25	8	214.534	5.205	0.0208
41	11	214.685	5.356	0.0193
64	20	215.060	5.731	0.0160
43	15	215.621	6.292	0.0121
29	9	215.817	6.489	0.0110
42	15	216.571	7.243	0.0075
45	12	216.637	7.308	0.0073
49	11	217.346	8.017	0.0051
47	16	217.891	8.563	0.0039
57	14	218.074	8.745	0.0035
46	16	218.605	9.276	0.0027
59	18	218.895	9.566	0.0024
53	12	218.986	9.657	0.0022
27	12	218.987	9.658	0.0022
58	18	219.433	10.105	0.0018
61	15	220.203	10.875	0.0012
26	12	220.289	10.960	0.0012
12	12	220.628	11.299	0.0010
31	13	220.953	11.625	0.0008
30	13	221.123	11.794	0.0008
63	19	221.205	11.876	0.0007
62	19	221.659	12.330	0.0006
51	15	222.348	13.019	0.0004
50	15	222.813	13.484	0.0003
16	13	222.841	13.513	0.0003
36	15	222.923	13.595	0.0003
54	16	224.099	14.770	0.0002
4	8	224.426	15.097	0.0001
55	16	224.502	15.173	0.0001
40	16	225.180	15.851	0.0001
20	12	225.712	16.383	0.0001
8	9	226.267	16.938	0.0001

Table A2 continued

11	11	227.458	18.129	0.0000
10	11	227.493	18.164	0.0000
24	13	227.752	18.423	0.0000
34	14	228.529	19.200	0.0000
35	14	228.729	19.400	0.0000
14	12	229.612	20.283	0.0000
15	12	229.615	20.286	0.0000
38	15	230.767	21.438	0.0000
39	15	230.863	21.534	0.0000
33	10	233.654	24.325	0.0000
9	7	234.821	25.492	0.0000
19	11	235.433	26.104	0.0000
2	7	235.552	26.223	0.0000
18	11	235.612	26.283	0.0000
37	11	235.775	26.446	0.0000
17	7	235.814	26.486	0.0000
6	8	236.612	27.283	0.0000
13	8	236.716	27.387	0.0000
22	12	237.062	27.733	0.0000
21	8	237.368	28.039	0.0000
3	7	237.400	28.071	0.0000
23	12	237.595	28.266	0.0000
1	3	239.438	30.109	0.0000
7	8	239.471	30.142	0.0000
5	4	240.615	31.286	0.0000

APPENDIX B

Modification of the Stream Survey Sampling Design

I modified the original two-stage sampling scheme to consist solely of a stratified random sampling design (Thompson 2002). Because the majority of tributary streams within drainages were found to have insufficient harlequin habitat during the 2008 surveys, I began by modifying the sampling universe of 807 streams depicted in Figure 2 of the main text. I removed tributary streams that were classified as intermittent and those that were unnamed in the GIS stream layer for Glacier National Park from The National Hydrography Dataset (U.S. Geological Survey 2000). While intermittent and smaller, unnamed streams may have adequate water flow during May and June, the highest likelihood for observing harlequins during the entire summer will be on the largest perennial streams within a drainage. After removing the tributary streams, I had a modified sampling universe of 111 streams within 48 drainages (Figure B1).

As with the original sampling design, streams were categorized into one of 48 drainages (N), where a drainage consisted of at least one stream and possibly one or more tributary streams. Each drainage was placed into one of six strata (h) based on the total number of streams (M_i) within drainage i. Because the purpose of stratification was to categorize drainages by their size, which may be related to overall resource availability for harlequins, the drainages were placed in the same strata as in the original sampling design (Table B1) based on the sampling universe of 807 streams. Stratum 1 consisted of drainages with $1 \leq M_i \leq 3$; stratum 2 with $4 \leq M_i \leq 6$; stratum 3 with $7 \leq M_i \leq 11$; stratum 4 with $12 \leq M_i \leq 20$; stratum 5 with $21 \leq M_i \leq 32$, and stratum 6 with $M_i > 32$. The number of drainages within each stratum (N_h) were: $N_1 = 7$, $N_2 = 7$, $N_3 = 11$, $N_4 = 10$, $N_5 = 7$, and $N_6 = 6$ (Table B1).

To use this sampling design in future years, the following steps should be followed to choose a sample of streams for surveying. Based on an estimate of the number of drainages that can be surveyed, a sample of drainages (n) is chosen. The selection of the sample of drainages from each stratum should occur with a probability that is proportional to the stratum size, N_h (Thompson 2002). For example, if it is estimated that 25% of all drainages (12 drainages) can be surveyed, then $n_1 = 2$, $n_2 = 2$, $n_3 = 3$, $n_4 = 2$, $n_5 = 2$, and $n_6 = 1$. The sample of drainages is randomly chosen without replacement for each stratum from the list of drainages in Table B1. Then, all streams within the selected drainage that are in the sampling universe of 111 streams (Figure B1) are surveyed. The main difference between the modified and original sampling

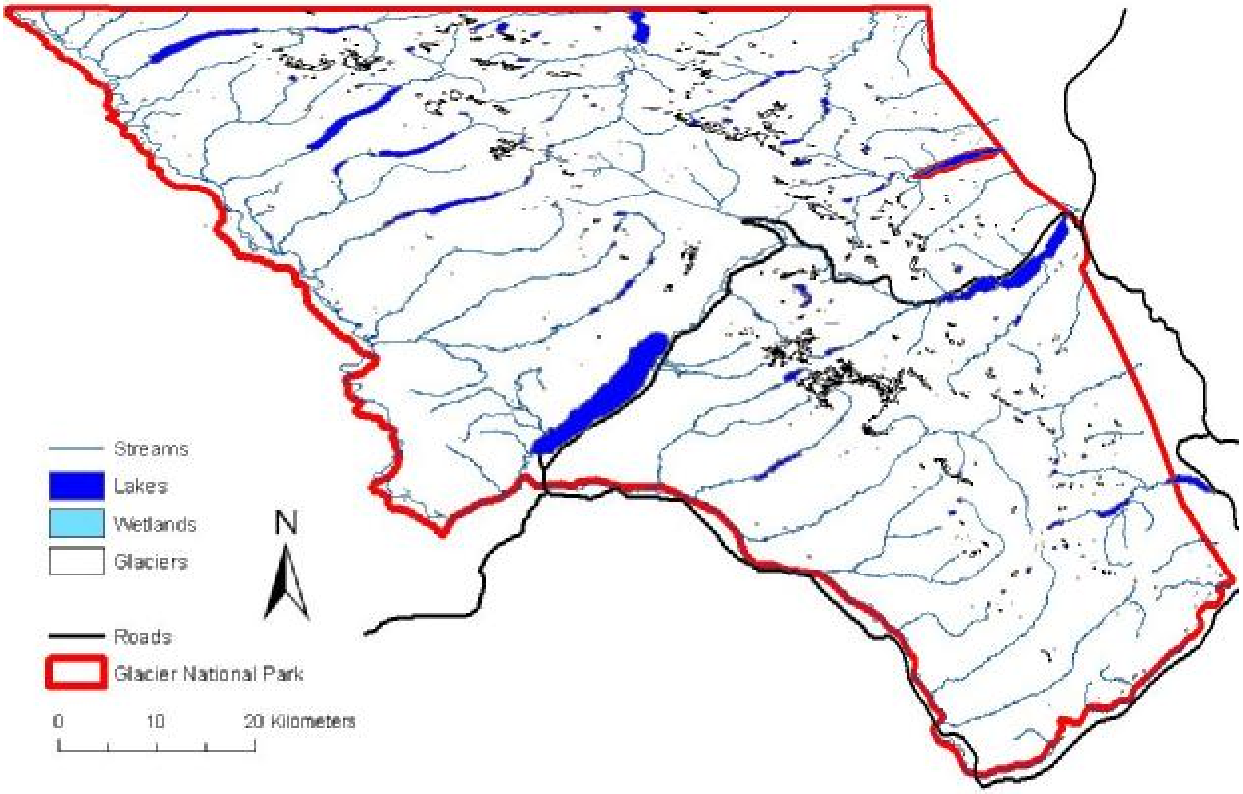

Figure B1. The modified "sampling universe" of 111 streams throughout Glacier National Park to be used in conjunction with the stratified random sampling design.

designs is that the modified design uses random selection without replacement only of drainages, and does not consider streams as an individual sampling unit. A complete list of streams within the modified sampling universe is provided in Table B2.

Estimation of Population Size with the Modified Sampling Design

The population size of harlequins within Glacier is to be estimated based on results from the stream surveys using stratified sampling equations provided in Thompson (2002). The unbiased estimator for the total number of ducks for the h^{th} stratum is given by

$$\hat{t}_h = \frac{N_h}{n_h} \sum_{i=1}^{n_h} y_{hi} , \qquad \text{(B1)}$$

where y_{hi} is the number of ducks in the i^{th} drainage, N_h is the total number of drainages in the h^{th} stratum, and n_h is the number of drainages in the h^{th} stratum randomly selected without replacement for surveying. The unbiased estimator for the population total is

$$\hat{t} = \sum_{h=1}^{6} \hat{t}_h \,, \tag{B2}$$

with an estimated variance of

$$\hat{\text{var}}(\hat{t}) = \sum_{h=1}^{6} N_h (N_h - n_h) \frac{s_h^2}{n_h} \,, \tag{B3}$$

where

$$s_h^2 = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2 \tag{B4}$$

is the sample variance from stratum h and

$$\bar{y}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} y_{hi} \tag{B5}$$

is the sample mean for stratum h (Thompson 2002).

Table B1. The drainages in each of the six strata. Strata were defined based on the total number of streams (M_i) within the drainage as described in the main text.

Strata	**Drainages**
1 $1 \le M_i \le 3$	Kishenehn Creek, Lake Creek, Mud Creek, Shields Creek, Spruce Creek, Starvation Creek, Virginia Creek
2 $4 \le M_i \le 6$	Akokala Creek, Midvale Creek, Mud Lake, North Fork Belly River, Olson Creek, Summit Creek, Valentine Creek
3 $7 \le M_i \le 11$	Anaconda Creek, Bear Creek, Boulder Creek, Boundary Creek, Dutch Creek, Lee Creek, Mokowanis River, Otatso Creek Railroad Creek, Reynolds Creek, Rubideau Creek
4 $12 \le M_i \le 20$	Camas Creek, Divide Creek, Ford Creek, Kennedy Creek Lincoln Creek, Muir Creek, North Fork Cut Bank Creek, Ole Creek, Swiftcurrent Creek, Two Medicine Creek
5 $21 \le M_i \le 32$	Coal Creek, Harrison Creek, Kintla Creek, Logging Creek, Park Creek, Quartz Creek, Red Eagle Creek
6 $M_i > 32$	Belly River, Bowman Creek, McDonald Creek, Nyack Creek, Saint Mary River, Waterton River

Stream Survey Sampling Design with "Priority" Streams

If it is desired to place a priority on drainages and streams that have had harlequin ducks observed on them during previous years, then a slight modification of the sampling design provided above is needed. Drainages that have had the highest number of previous harlequin sightings between 1988-2008 include: Boundary Creek, McDonald Creek, Olson Creek, Otatso Creek, Reynolds Creek, St. Mary River, Two Medicine Creek, and Waterton River (S. Gniadek, *personal communication*). The Red Eagle Creek drainage could also be included in this list, but the drainage burned a few years ago and the lack of canopy and understory cover may be insufficient for harlequin duck use and, therefore, it likely should not be considered a priority for surveying. Of the eight drainages with the highest number of sightings, one is in stratum 2, three are in stratum 3, one is in stratum 4, and three are in stratum 6 (Table B1). Selection of these eight drainages for surveying before any random sample is chosen would then leave a sampling universe of 76 streams within 40 drainages. The number of drainages within each stratum then becomes: $N_1 = 7$, $N_2 = 6$, $N_3 = 8$, $N_4 = 9$, $N_5 = 7$, and $N_6 = 3$.

From an estimate of the number of additional drainages that can be surveyed, a random sample of drainages is chosen. As before, the selection of the sample of drainages from each stratum should occur with a probability that is proportional to the new stratum size after removal of the eight drainages (Thompson 2002). The sample of drainages is randomly chosen without replacement for each stratum from the list of drainages in Table B1. Then, all streams within the selected drainage that are in the new sampling universe of 76 streams are surveyed.

Based on stream survey results from surveying the random sample of drainages, population estimates for each stratum and the entire population can be calculated with Equations B1 and B2. The total number of ducks from surveys conducted in the eight "priority" drainages should then be added to these estimates to obtain the estimate of the population size total. The variance of the estimate for the population within the sampling universe of 76 streams can be calculated using equations B3 through B5.

Table B2. The streams and their corresponding drainages in the modified sampling universe of 111 streams for Glacier National Park. The drainage number and stratum are provided for each drainage.

Stream	Drainage	Drainage Number	Drainage Stratum
Akokala Creek	Akokala	1	2
Parke Creek	Akokala	1	2
Long Bow Creek	Akokala	1	2
Anaconda Creek	Anaconda	2	3
Bear Creek	Bear	3	3
Autumn Creek	Bear	3	3
Belly River	Belly	4	6
Redgap Creek	Belly	4	6
Boulder Creek	Boulder	5	3
Boundary Creek	Boundary	6	3
Bowman Creek	Bowman	7	6
Numa Creek	Bowman	7	6
Jefferson Creek	Bowman	7	6
Pocket Creek	Bowman	7	6
Camas Creek	Camas	8	4
McGee Creek	Camas	8	4
Coal Creek	Coal	9	5
Elk Creek	Coal	9	5
Peril Creek	Coal	9	5
Pinchot Creek	Coal	9	5
Divide Creek	Divide	10	4
Dutch Creek	Dutch	11	3
Ford Creek	Ford	12	4
Harrison Creek	Harrison	13	5
Kennedy Creek	Kennedy	14	4
Kintla Creek	Kintla	15	5
Agassiz Creek	Kintla	15	5
Red Medicine Bow Creek	Kintla	15	5
North Fork Kintla Creek	Kintla	15	5
Kishenehn Creek	Kishenehn	16	1
Lake Creek	Lake	17	1
Lee Creek	Lee	18	3
Jule Creek	Lee	18	3
Lincoln Creek	Lincoln	19	4
Walton Creek	Lincoln	19	4
Logging Creek	Logging	20	5
Upper McDonald Creek	McDonald	21	6
Lower McDonald Creek	McDonald	21	6
Jackson Creek	McDonald	21	6
Fern Creek	McDonald	21	6

Table B2 continued

Howe Creek	McDonald	21	6
Alder Creek	McDonald	21	6
Apgar Creek	McDonald	21	6
Fish Creek	McDonald	21	6
Continental Creek	McDonald	21	6
Sprague Creek	McDonald	21	6
Flattop Creek	McDonald	21	6
Snyder Creek	McDonald	21	6
Longfellow Creek	McDonald	21	6
Avalanche Creek	McDonald	21	6
Logan Creek	McDonald	21	6
Mineral Creek	McDonald	21	6
Midvale Creek	Midvale	22	2
Mokowanis River	Mokowanis	23	3
Kaina Creek	Mokowanis	23	3
Whitecrow Creek	Mokowanis	23	3
Mud Creek	Mud	24	1
Mud Lake	Mud Lake	25	2
Mud Lake tributary	Mud Lake	25	2
Muir Creek	Muir	26	4
North Fork Belly River	North Fork Belly	27	2
North Fork Cut Bank Creek	North Fork Cut Bank	28	4
Atlantic Creek	North Fork Cut Bank	28	4
Nyack Creek	Nyack	29	6
Thompson Creek	Nyack	29	6
Pacific Creek	Nyack	29	6
Stimson Creek	Nyack	29	6
Ole Creek	Ole	30	4
Debris Creek	Ole	30	4
Olson Creek	Olson	31	2
Thunderbird Creek	Olson	31	2
Otatso Creek	Otatso	32	3
Park Creek	Park	33	5
Quartz Creek	Quartz	34	5
Cummings Creek	Quartz	34	5
Rainbow Creek	Quartz	34	5
Railroad Creek	Railroad	35	3
Red Eagle Creek	Red Eagle	36	5
Medicine Owl Creek	Red Eagle	36	5
Reynolds Creek	Reynolds	37	3
Rubideau Creek	Rubideau	38	3
Saint Mary River	Saint Mary	39	6

Table B2 continued

Wild Creek	Saint Mary	39	6
Baring Creek	Saint Mary	39	6
Rose Creek	Saint Mary	39	6
Two Dog Creek	Saint Mary	39	6
Shields Creek	Shields	40	1
Spruce Creek	Spruce	41	1
Spruce Creek tributary	Spruce	41	1
Starvation Creek	Starvation	42	1
Summit	Summit	43	2
Swiftcurrent Creek	Swiftcurrent	44	4
Iceberg Creek	Swiftcurrent	44	4
Canyon Creek	Swiftcurrent	44	4
Cataract Creek	Swiftcurrent	44	4
Apikuni Creek	Swiftcurrent	44	4
Ptarmigan Creek	Swiftcurrent	44	4
Allen Creek	Swiftcurrent	44	4
Windy Creek	Swiftcurrent	44	4
Two Medicine Creek	Two Medicine	45	4
Dry Fork	Two Medicine	45	4
Appistoki Creek	Two Medicine	45	4
Aster Creek	Two Medicine	45	4
Paradise Creek	Two Medicine	45	4
Valentine Creek	Valentine	46	2
South Fork Valentine Creek	Valentine	46	2
Virginia Creek	Virginia	47	1
Waterton River	Waterton	48	6
Camp Creek	Waterton	48	6
Kootenai Creek	Waterton	48	6
Cleveland Creek	Waterton	48	6

APPENDIX C

Time Estimates of Stream Surveys

A total of 120 streams within 19 drainages were surveyed from May 12 through September 18 during the 2008 field season. Of the 120 streams, 101 were examined and deemed to have inadequate habitat for harlequins and, therefore, required little to no effort. These surveys were accomplished with a field crew of a total of four people that worked variable dates throughout the field season. Crew members worked in groups of at least two people. Two people were present for all surveys between May 12 and September 18. One person was present between May 27 and July 31, while the other was available between June 12 and August 12. These efforts amount to a total of 55.4 weeks of work and based on an eight hour per day, 40 hour work week, these efforts total 2,217 hours for the entire season.

Survey efforts for the eight surveys in the lower portion of the Upper McDonald Creek drainage totaled approximately 32 hours per survey (four people with eight hours of effort per person). The average amount of time spent surveying each of the remaining 18 drainages was, therefore, 109 hours per drainage. This accounts for the effort to drive and/or hike to the start point of each survey from West Glacier. The most notable effort to access drainages involved the Waterton River drainage as well as drainages on the east side of the park, including the Belly River, Otatso Creek, and Two Medicine Creek. Because of flooding and a later date of snowmelt than in recent years, the crew was unable to accomplish many surveys in May and early June. A later date of opening for the higher elevation portions of Going-to-the-Sun road also added substantial travel time to access east side drainages. Therefore, the estimate of 109 hours per drainage is conservative.