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agricultural intensification that may affect aerial insect abundance including changing crop types and amounts (Paquette et al. 2013; Stanton et al. 2018) and insecticide use (Nocera et al. 2012; Hallmann et al. 2014). In areas with highly intensive agriculture practices, such as areas with crop fields, insect abundance is lower than in native vegetation (Attwood et al. 2008). Agricultural

METHODS

Study Area

Field work was conducted in the lower mainland of British Columbia, Canada (49°10′ 8.15″N, 123°5′58.60″W) in 2015 and 2016. There were 11 study sites representing 3 habitat types: agriculture with crop (hereafter "crop," n = 4); agriculture with livestock, including both cows and horses (hereafter "pasture," n = 4); and non-agriculture (hereafter "non-agriculture"; a park, a marina, and a municipal works yard, n = 3). All sites were surrounded to a radius of 300 m with their assigned habitat type.

Nest Monitoring

We checked Barn Swallow nests twice a week from May 4 to August 6 in 2015 (n = 258) and May 2 to August 10 in 2016 (n = 230). Barn Swallows nested on or in barns, old sheds, or other buildings. We recorded the date on which the first egg of a clutch was laid (lay date), clutch size, hatch date, brood size (best estimate closest to fledging), and if a nest fledged (1 = at least one nestling fledged, 0 = no nestlings fledged). We determined the hatch date (day 0) of nestlings using an ageing guide by Morales Fernae et al. (2012). We assumed the average fledge date was day 21 (hatch day 0) based on data from Campbell et al. (1997; mean: 20.5 days, range: 19–24) and known average fledging age for our study sites, which was also 21 days (range: 18–23) over 2 yr (n = 14). Nests were considered to have fledged young if the nest was empty, and nestlings were day 18 or older with no signs of predation (i.e. broken nest, blood, dead nestlings). We assumed that nests edged on the day following the last day they were observed in the nest. Nest siblings were assumed to have fledged on the same day (Turner 2006).

Radio Telemetry

We used radio telemetry to track the habitat use and survival of Barn Swallow fledglings (defined as birds up to 21 days after leaving the nest) in 2015 and 2016. We affixed radio transmitters to 35 nestlings in 2015 (LOTEK Picopip Ag379 VHF radio transmitters, battery life of ~29 days and range of ~1 km) and 48 nestlings in 2016 (LOTEK digitally coded nano-tag NTQB-2 radio transmitters, battery life of ~33 days, ~5.0 s burst interval rate and range of ~1 km). In 2015 we selected 12 nestlings from pasture sites, 12 from crop sites, and 11 from non-agriculture sites. In 2016, because of logistics (non-agricultural sites were distant from other sites), radio transmitters were only put on nestlings from crop (n = 23) and pasture (n = 25) sites. One or two nestlings per nest were randomly selected and fitted with radio-transmitters 15 days post-hatching (range day: 14–17) (Grüebler and Naef-Daenzer 2008). We used leg-loop harnesses to attach radio transmitters (0.35–0.42 g; Rappole and Tipton 1991) with a non-permanent harness (Kesler 2011). Harnesses were fitted based on an allometric function from Naef-Daenzer (2007) for European Barn Swallows and adjusted accordingly once radio transmitters were fitted to nestlings. Radio transmitters plus harnesses weighed less than 0.6 g, which is <5% of average nestling body weight (Fair et al. 2010). Measurements were taken by two observers in 2015, and one of those same observers in 2016. We measured tarsus to the nearest 0.05 mm, wing chord and tail length to the nearest 0.5 mm, and mass to the nearest 0.5 g of each nestling equipped with a radio tag.

Fledglings were tracked for ~1 mo after fledging using hand-held receivers, 3-element folding YAGI antennae (2015, 2016), and automated MOTUS radio towers (2016). We attempted to locate each individual fledgling a minimum of 1–2 times per week (mean: 5 locations per bird). We conducted scanning surveys in 2015, searching for fledglings initially at nest sites (n = 10) and then we used data from eBird sightings (https://ebird.org) and personal observations to track fledglings. In 2016 we conducted standardized surveys once a week for each site (n = 8) in [(ing)5>>> BD19 (o0037)3 of 4[(ing) and pementing sts onceve(ing)5n-1

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directional Yagi antennae (5 or 9 elements) connected to a LOTEK SRX 800 automated receiver or a SensorGnome receiver (sensorgnome.org). ree towers had a range of ~1–2 km with the fourth having a greater range of 5–10 km. Towers were erected before nestlings were equipped with radio transmitters and were used to locate tagged birds after leaving their natal site and to increase hand-held tracking e ciency, as well as to con rm fates (dead or alive) of individuals during analysis.

Post- edging Habitat Use

To analyze post-fledging habitat use, we calculated the percent available and percent use of each habitat class per individual location point. Available habitat was calculated by creating a buffer around each individual bird location point and calculating the proportion of each habitat class within that buffer using ArcGIS (ESRI, Redlands, California, USA). Increased fledgling movement away from the nest was addressed by splitting habitat use into 2 different time periods, days 1–6 and day 7, based on information from this study and from European Barn Swallows (Naef-Daenzer and Grüebler 2014) showing that fledglings start to move farther from nest sites after 6 days, and following similar methods as Dunn et al. (2017). Buffers for each time period were calculated separately as the average distance between location points for each individual. We calculated a 0.33 km buffer for the first period (days 1–6) and a 3.56 km buffer for the second period (day 7). We calculated used habitat as the percentage of observed bird locations by habitat across all locations per individual. We calculated available habitat as the average percentage of each habitat type in each location buffer across all locations per individual. To determine habitat types, a digital map was created for each location based on several different landcover datasets; a crop cover dataset (Fraser Lowland Agricultural Crop Cover Surveys [Public]; Ducks Unlimited Canada et al. 2017), the Sensitive Ecosystems Inventory dataset (Sensitive Ecosystem

2014

correlation test, to examine the effect of overall distance (total location points for each fledgling) from the nest and number of days since birds fledged, between years and within each year (2015, 2016) separately.

Post-fledging habitat use. To test our prediction that fledglings use pasture habitat more than it is available, we compared used to available habitat with a parametric compositional analysis using the ADEHABITAT package and [illegible] function (Calenge 2006). We separated the post-fledging habitat use period into days 1–6 and days ≥7 to account for increased fledgling movement over time away from the nest. Used and available habitat types were calculated as the proportions of used and available total area, with totals summing to 1. Any zero values in the matrices were replaced with 0.0001 value, and we repeated the analysis with additional values (i.e. 0.00001) to determine if there was an effect of this value, as this arbitrary number can influence results (Dunn et al. 2017). Compositional analysis assumes independence of data points; however, our data violate this assumption where we have 2 individuals tagged from the same nest (Aebischer et al. 1993). Therefore, we removed data location points where nest siblings were found together, although there were few cases where this occurred (n = 10 of total n = 289). We did not use a 2-level spatial analysis approach recommended by Aebischer et al. (1993) because habitat selection at the home range or site level was by adult Barn Swallows, not the fledglings studied, and individuals were too mobile to quantify a home range (Dittmar et al. 2014).

Post-fledging survival. To determine if natal habitat, or fledgling quality or behavior variables, had an effect on post-fledging survival we ran Cox proportional hazard models to day 21 using radio-tracking data. We selected day 21 based on European Barn Swallow fledgling data from Naef-Daenzer and Grüebler (2014) where fledglings generally do not emigrate from their natal site prior to day 21 and our own data that showed the majority of fledglings moved farther from the natal site after day 21. We recorded the date of the last confirmed sighting where a fledgling was alive. Initially, we considered the event of interest to be mortality; however, we only confirmed deaths for 6 of 81 fledglings (13.5%), where a bird was considered dead if either remains of the bird or feathers were found with a radio transmitter, the location of the transmitter did not change for 3 days or more, or a transmitter was found damaged with feathers. Kershner et al. (2004) suggested fledglings were dead if their tag location did not change for 3 days or more. Furthermore, there was a year bias (5 events occurred in 2015, 1 event in 2016), so we had insufficient data for a robust analysis of year or habitat using these data. Therefore, we classified fledglings where the signal was lost before day 21, the harness and transmitter were found intact, or where fledglings were only tracked in the nest and never located out of the nest as mortality events (n =

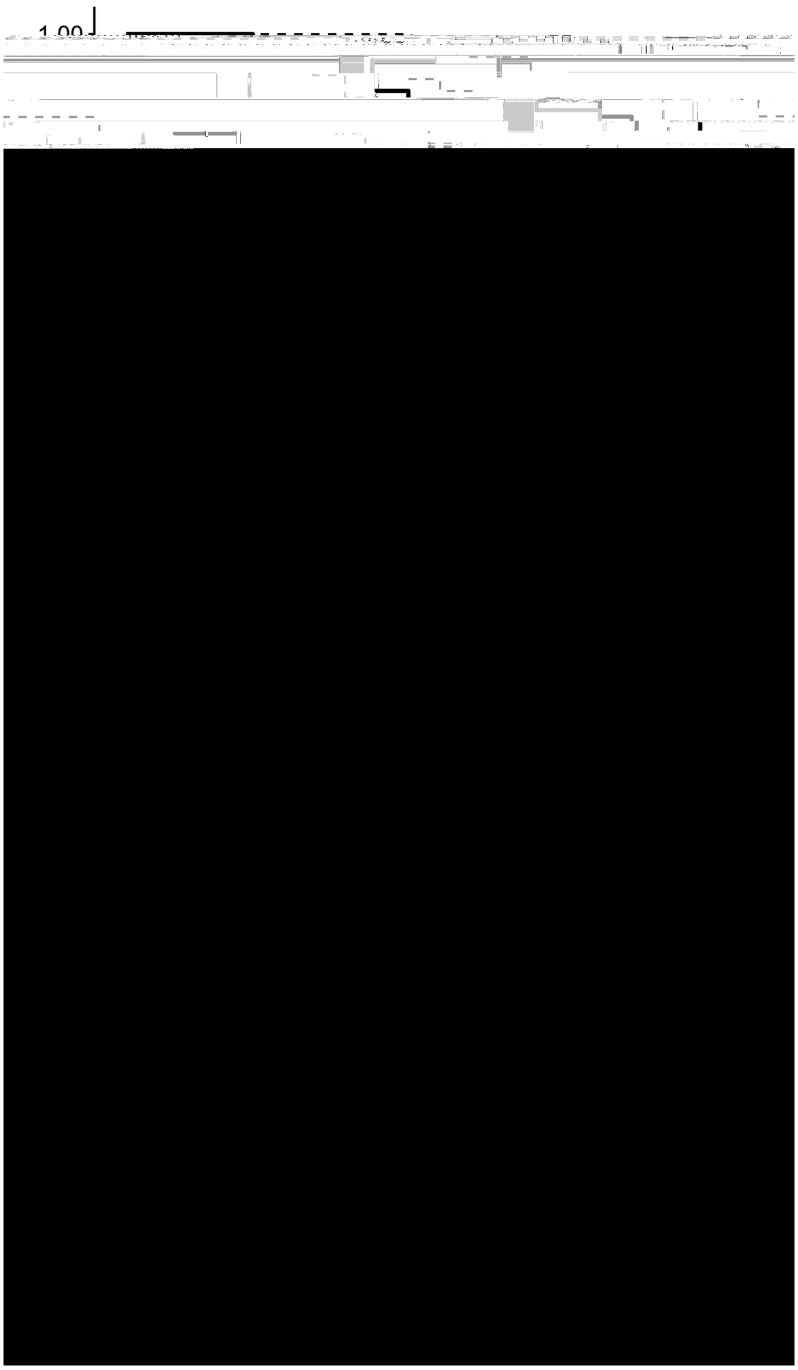

FIGURE 4.Kaplan-Meier curve of survival over time (solid lines) showing cumulative survival probability of Barn Swallow fledglings with 95% upper and lower confidence intervals (dashed lines) (A) hatched in crop (n) hatched in crn) (t)6 (ched in cr)765625 c5 -1.11t.ple o-ag

date is likely explained by non-agriculture sites having an overall slightly later breeding season (approximately a week later) observed over a 4-yr period, likely due to higher altitudes of non-agriculture sites (C. K. Boynton, personal observation).While there was no significant difference in maximum distance traveled, perhaps due to small sample size, it was striking that non-agriculture fledglings only traveled maximum distances of 5 km away from the nest site, compared to both crop and pasture fledglings, which traveled up to 19 km from their nest sites. This could be in part due to sampling efforts in 2015 compared to 2016 (non-agriculture fledglings only tracked in 2015) or the difficulty of tracking around the non-agriculture sites due to terrain. We found no other indication besides smaller tarsi that fledglings hatched in non-agriculture habitats were low quality as there was no difference between mass, wing chord, or brood size across natal habitats.

Our results are consistent with other studies of passerines during the post- edging period, which show that as edglings get older they steadily increase the distance from their nests (e.g., White-throated Robins, Cohen and Lindell 2004; Dickcissels [[illegible]], Berkeley et al. 2007; Eastern Bluebirds, Jackson et al. 2011; Grasshopper Sparrows [A[illegible]], Streby and Andersen 2013 [illegible]

Barn Swallows from Evans et al. (2003, 2007), Grüebler et al. (2010), and Or owski and Karg (2013), had any effect on post-fledging survival, indicating this type of habitat is less important for Barn Swallows in our study area during the post-fledging stage. In Europe, aerial insect abundances are higher over pasture (Evans et al. 2007) and in the presence of livestock (Grüebler et al. 2010, Or owski and Karg 2013), and adult Barn Swallows forage predominantly where there is a higher abundance of aerial insects (Evans et al. 2003). However, similar patterns have not been shown for post-fledging Barn Swallows and our data suggest fledglings do not follow this same pattern, especially as the total number of insects at pasture sites has been shown to be higher than crop sites (W. Boynton et al., personal communication). We would expect that if pasture habitat is vital to fledgling Barn Swallows, those hatched in pasture habitat would stay close to the natal site for the duration of the post-fledging period before migrating. Conversely, fledglings hatched in non-pasture habitats should have higher maximum distances if they moved preferentially to forage in pasture habitats. However, fledglings hatched in pasture habitat exceeded distances from the nest of 15 km, similar to those hatched in crop habitat, survival rates, further research is needed on this period, and for other aerial insectivore species, which may be experiencing similarly low post- edging survival, potentially causing population declines.

Overall, we found only minor e ects of natal habitat on both edgling quality and behavior. Also, contrary to our predictions, we found that Barn Swallow edglings use crop habitat more than pasture. erefore, if crop elds undergo a decline or transformation through agricultural intensi cation and crop conversion, Barn Swallow edgling survival could be negatively a ected. is could have several implications for conservation of this species, currently listed as reatened under the Species at Risk Act in Canada (Government of Canada 2017). If low juvenile survival in the post- edge stage is driving population declines in this species, protection of post- edge habitat could be critical. As crop habitat appears important for edgling Barn Swallows after they leave the nest, conversion of this habitat type, creating a more homogeneous landscape could have further negative implications for an already declining species.

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Author contributions: C.K.B. conducted the literature review, performed the fieldwork, collected and analyze data and drafted the manuscript. N.M. formulated the idea, co-supervised the project and edited the manuscript. T.W. co-supervised the project and edited the manuscript.

Data depository: Analyses reported in this article can be reproduced using the data provided by Boynton et al. (2020).

Conflict of interest statement: We confirm there are no financial interests, connections, or other situations that might raise the question of bias in the work reported or any of the conclusions reached in this manuscript for any of the authors.

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