Bald Eagle Movements Relative to the Naval Support Activity Cutler in Cutler, Maine

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Naval Facilities Engineering Command, Public Works Department Maine, Natural Resource Program
(Cooperative Agreement No. N62470-17-2-8002)

Executed through the Cooperative Ecosystem Studies Units (CESU) National Network:
Avian and Bat Surveys at Northern Maine Naval Installations &
Follow-On Bald Eagle Telemetry and Use Surveys at Naval Support Activity Cutler, Cutler, Maine

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FRONT COVER PHOTO: Bald Eagle from the Sprague Neck nesting territory after release. Photo credit: Chris DeSorbo, BRI.
INSET PHOTO: https://www.pexels.com

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1.0 EXECUTIVE SUMMARY

The Naval Support Activity Cutler[1] (Installation hereafter), located in Cutler, Maine is a globally significant communication facility owned and operated by the U.S. Navy. The Installation is comprised by sixteen 244 – 305 m (800 – 1,000 ft.) communications towers and extensive anchoring cables and guy wires that represent potential collision risks to birds. We instrumented GPS/GSM transmitters to six adult Bald Eagles associated with nesting territories ≤15 km from the Installation to characterize their horizontal (home range) and vertical (altitude) space use patterns relative to the Installation. Bald Eagle home ranges, represented by 50%, 75% and 95% Utilization Distributions (UDs), ranged widely among individuals at the 95% contour level (11.1 – 395.1 km^2; mean ± SD: 143 ± 146 km^2). UDs were highly centered around nest sites, particularly at the 50% contour level (i.e., "core use areas"), which ranged from 0.3 – 3.05 km^2 (mean ± SD: 1.6 ± 1.2 km^2). Most individuals showed notable fidelity to their nest sites throughout much of the year; however, multiple eagles visited distant areas 60 km to the west and 80 km to the east along the Maine/New Brunswick coastline, and areas to the north up to 150 km away in Maine and New Brunswick. Individuals in our study used much larger areas during the non-breeding/winter period (1 Nov – 14 Mar) than the breeding/post-breeding/winter period (15 Mar – 31 Oct); the average 95% contour (year 1) was over ten times larger in the non-breeding period (482 km^2) than the breeding period (38.5 km^2).

Our limited sample of resident Bald Eagles ≤15 km from the Installation supported the assumption that territory proximity to the Installation strongly influences the probability that individuals will use the Installation hazard areas. The UDs of four pairs associated with nesting territories ranging 0.99 – 3.83 km from the Installation intersected the hazard area boundary, whereas the UDs of two pairs 5.72 km and 11.22 km from the Installation did not. Intersections of Bald Eagle UDs with the Installation hazard areas were predominantly at the 95% contour level, ranging from 0.02% - 100% overlap. No Bald Eagle core use areas overlapped with the Installation hazard areas. Bald Eagles generally had a higher probability of using the hazard areas during the non-breeding/winter season than the breeding/post-breeding period. The proportion of the combined hazard area coinciding with a Bald Eagle UD during the non-breeding period (mean: 60%) was nearly three times greater than the mean for the breeding/post-breeding period (23%) at the 95% contour level, and 16 times greater at the 75% level. We also characterized the altitude of transmitter-instrumented Bald Eagles within the hazard areas. The mean daily altitude for individuals was greater in the primary hazard area (mean ± SD: 62.2 ± 74.2 m) than in the secondary hazard area (37.7 ± 39.4 m) ($p < 0.0001$, $x^2_1 = 21.1$, $n = 422$; pooled dataset). The vast majority of mean daily altitude estimates were in the lower quarter of both

[1] formerly the Naval Computer Telecommunications and Area Master Station Atlantic Detachment, Cutler

tower heights; the median daily altitude estimate in the primary hazard area (38.9 m) was 16% the height of the 244 m towers and 13% of the height of the 305 m towers.

The two methods we used to assess the "encounter risk" of resident Bald Eagles ≤15 km of the Installation (UD sampling / proximity vs. inter-nest distance) were in relative agreement, collectively suggesting that individuals from 7-8 different nesting territories (39 – 44% of the 18 within the study area) located <5.5 km from the Installation had a high risk of entering the hazard areas. We make recommendations for further actions and study on the basis of the findings of the present study.

2.0 INTRODUCTION

The Naval Support Activity Cutler[2] (Installation hereafter), located in Cutler, Maine is a globally significant communication facility owned and operated by the U.S. Navy. The facility contains two antenna arrays (the north array and the south array), each consisting of a tuning tower (helix house) and 13 supporting grounded towers ranging from 244 – 305 m (800 – 1000 ft.) in height. Each array has an additional elevated horizontal sky mast that holds transmission equipment components (i.e., diamond panels and insulators) and connects the helix houses to the supporting towers. All towers are anchored by an extensive network of guy wires.

The various structures comprising the Installation represent potential flight hazards to birds. The Installation lies within eastern Washington County, an area that represents a population stronghold for Bald Eagles (*Haliaeetus leucocephalus*) in Maine and the broader New England Region (MDIFW 2019). At the time of the last statewide survey in 2018, the Maine Department of Inland Fisheries and Wildlife (MDIFW) documented 734 Bald Eagle nesting pairs statewide, 157 (21%) of which were in Washington County[3]. Several Bald Eagle pairs nest on shorelines and coastal islands within the general vicinity of the Installation. One nest is located within the property boundary of the Installation.

At least five[4] Bald Eagles have been killed or seriously injured at the Installation since the 1980s (Tetra Tech 2018*a*). While specific causes of most of the mortalities were not determinable, these cases are of concern to the U.S. Navy and wildlife agencies, particularly given regulatory protections for Bald Eagles through the Bald and Golden Eagle Protection Act, and guidelines aimed at protecting eagles outlined in the National Bald Eagle Management Guidelines (USFWS 2007), the Land-based Wind Energy Guidelines (USFWS 2012), and the Eagle Conservation Plan Guidance (USFWS 2013).

Past efforts to assess risks the Installation poses to Bald Eagles were conducted using Bald Eagle Use Surveys following protocols outlined by the USFWS Land-Based Wind Energy Guidance and the Eagle Conservation Plan Guidance (Tetra Tech 2018*b*). During 12 monthly surveys, that study tallied 68 Bald Eagle observations, 18 of which were in flight or perching within the Installation hazard area. The majority of Bald Eagle observations occurred during the spring, and the fewest were observed during the winter. While past observational surveys notably improved

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[2] formerly the Naval Computer Telecommunications and Area Master Station Atlantic Detachment, Cutler

[3] Bald Eagle population growth in Washington County has slowed dramatically from the prior statewide survey in 2013; from 23.6% (26 new nesting pairs) to 5.4% in 2018 (well below the rate of statewide pop. growth).

[4] Tally includes an injured Bald Eagle in 2013 that required euthanasia.

understanding of Bald Eagle behavior and collision risks within the Installation hazards, quantitative information on Bald Eagle space use (i.e., home range), seasonal residency patterns and migration habits remained lacking. Such information would significantly improve understanding of Bald Eagle use patterns and potential risks the installation might pose to Bald Eagles.

Over the last several decades, wildlife researchers have increasingly used animal tracking technologies to collect high-resolution, highly accurate and individualized information on animal movements. Tracking data is increasingly being used to inform wildlife risk assessments, management plans and conservation priorities (DeSorbo et al. 2015, 2020, Mojica et al. 2016, Miller et al. 2019). Further developments in the animal movement models have also markedly improved in recent years, thus improving the accuracy of management actions.

In this study, we investigated movement patterns of resident Bald Eagles in the vicinity of the Installation using GPS-GSM transmitter technology to gain insights on the potential risks this facility might pose to the local population. The objectives of this study were to: (1) characterize full-year and seasonal space use patterns of Bald Eagles in the study area, (2) characterize the space use patterns of resident Bald Eagles relative to the hazard areas of the Installation, (3) characterize the altitude of Bald Eagles within the Installation hazard areas, and (4) assess the encounter risk for resident Bald Eagles ≤ 15 km of with the Installation.

This study was completed as part of the Installations Integrated Natural Resource Management Plan in cooperation and coordination with Sikes Act partners (US Fish and Wildlife Service - Maine Field Office and Maine Department of Inland Fisheries and Wildlife). The project was executed through The Cooperative Ecosystem Studies Units (CESU) National Network (Avian and Bat Surveys at Northern Maine Naval Installations, Follow-On Bald Eagle Telemetry and Use Surveys at Naval Support Activity Cutler, Cutler, Maine).

3.0 METHODS

3.1 Navy Base Reference Terminology

In this report, we refer to the U.S. Navy property boundary associated with the Installation as the Cutler property boundary (12.21 km^2) (**Map 1**). The 3.1 km^2 area beneath all towers, guy wires, and the sky mast is referred to as the primary hazard area. This area contains the majority of the structures that pose potential collision risks for birds. Surrounding the primary hazard area is a 200 m buffer (2.7 km^2) of open space habitat referred to as the secondary hazard area. The secondary hazard area contains guy wires and rigging at reducing altitudes; however, this area contains no towers and fewer structures than primary hazard area. The primary hazard area and the secondary hazard area are collectively referred to as the combined hazard area (5.8 km^2) throughout this report.

3.2 Field Surveys and Sample Selection

To locate potential options for transmitter sample targets, we surveyed known Bald Eagle nesting territories ≤15 km of the Installation by boat based upon nest site information established during 2013 and 2018 statewide aerial surveys conducted by MDIFW (MDIFW 2019). Surveys were conducted on 17 May 2017, and continued throughout capture efforts on 1 – 4 June 2017 and 4 – 7 June 2019. We attempted to distribute capture sites around the Installation as much as possible.

We collected information on Bald Eagle reproductive status during field surveys (i.e., no. adults present, nesting activity, no. young observed) to provide further context for movement patterns of individuals instrumented with transmitters. Not all nest sites were visible by boat. When young were detected, we estimated the approximate age of young using nestling feather development patterns described in Bortolotti (1984*a*).

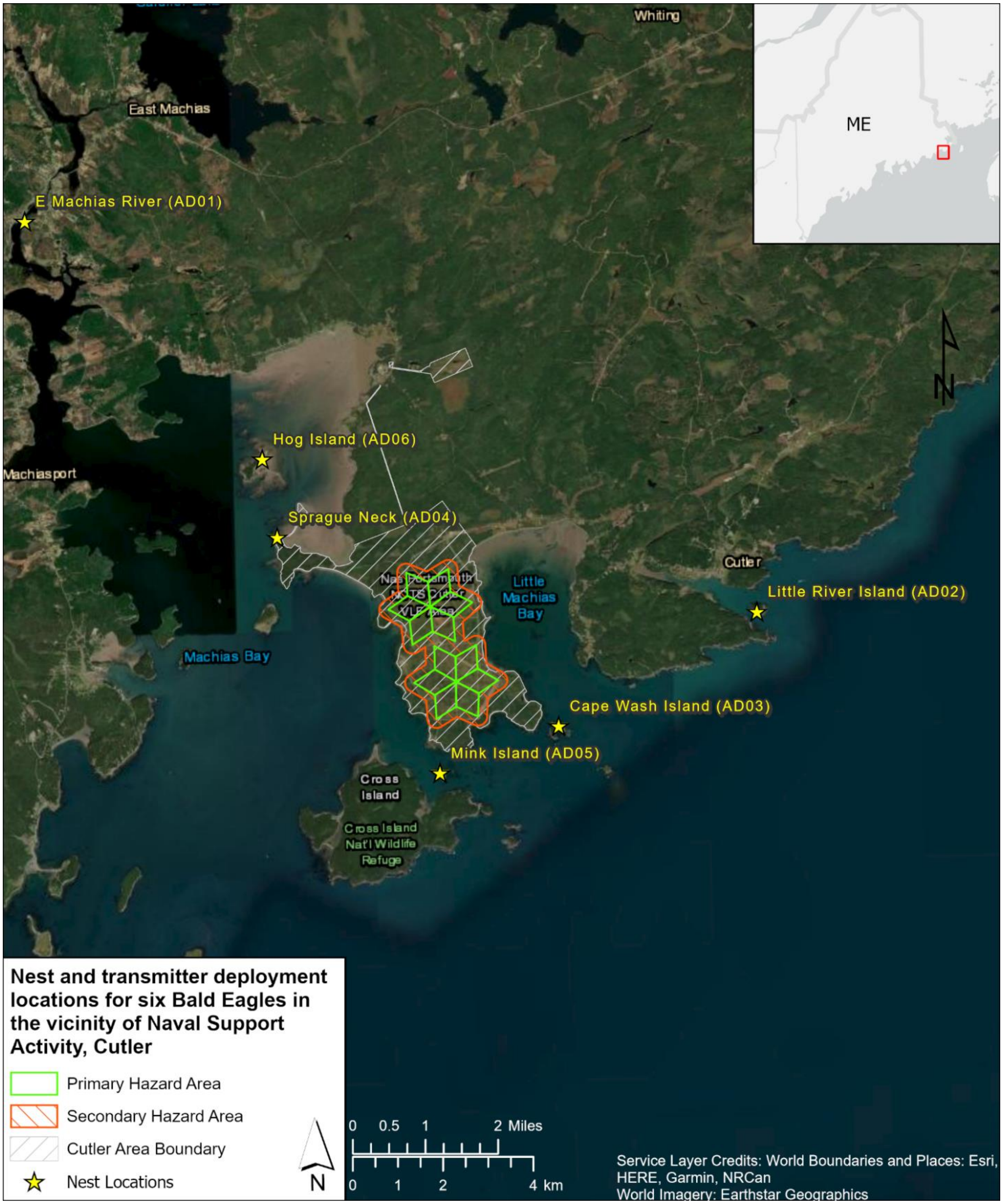
3.3 Bald Eagle Capture, Transmitter Instrumentation and Programming

Bald Eagles were captured using a floating fish snare (Jackman et al. 1993). Once captured, individuals were fitted with hoods, weighed, measured for a variety of morphometrics (Bortolotti 1984*b*) and banded with uniquely coded leg bands (USGS bird bands and alpha-numeric red color bands; Acraft Sign & Nameplate Co. Ltd., Edmonton, AB, CAN). Blood and feather tissues were also collected from individuals to be used towards ongoing contaminant (i.e., Pb, Hg) investigations.

Table 1. Capture location, date, gender, banding information and breeding status of six adult Bald Eagles instrumented with transmitters in the vicinity of the Installation.

Animal ID	Location	Nest ID[a]	Gender[b]	Captured	USGS band no. (RL)	Color Band code (Red)	Breeding	Nest Obsevation
AD01	East Machias River	693A	M	6/1/17	0709-03735	H / D	yes	2 chicks, 6 wks on 6/1
AD02	Little River Island	211D	F	6/2/17	0709-03737	C / Z	yes	1 chick, 7 wks on 6/2
AD03	Cape Wash Island	224C	M	6/3/17	0629-52385	6 / E	probable	nest not visible; 2 ads
AD04	Sprague Neck	678B	M	6/4/17	0709-03749	D / C	yes	1 chick, 4 wks on 6/4
AD05	Mink Island	121C	M	6/5/19	0709-05953	D / U	probable	nest not visible; 2 ads
AD06	Hog Island	232C	M	6/6/19	0709-04538	H / E	yes	1 chick, 5-6 wks on 6/5

[a] Nesting territory assigned by MDIFW.
[b] Gender determined based on bill depth and hallux morphometrics as described in Bortolotti (1984*b*).



Map 1. Primary and secondary hazard areas within the Installation, and deployment sites associated with six Bald Eagle nesting territories.

We captured a total of six adult Bald Eagles (4 in 2017 and 2 in 2019) and instrumented them with GPS/GSM transmitters (Cellular Tracking Technologies, Rio Grande, NJ; 2017 units: CTT-1000-CDMA series, 3rd Generation; 2019 units: CTT-1000-BT3). Transmitters deployed in 2019 had greater programming capabilities than those deployed in 2017. Transmitters were instrumented to individuals using a backpack-style harness made of Teflon ribbon (Bally Ribbon Mills, Bally, PA) (Steenhof et al. 2006). Transmitters were typically programmed to record one GPS fix approximately every 15-20 minutes, from sunrise to sunset (sunrise and sunset zenith angles: 102 degrees, corresponding to Nautical Twilight). Duty cycles were modified remotely on occasion in response to changing seasons and changes in transmitter charging. Both horizontal and vertical (meters above mean sea level) location estimates were typically obtained during each GPS fix. The horizontal location accuracy of GPS locations has been reported by the transmitter manufacturer as approximately ± 5 m (2dRMS 95%), while the vertical accuracy is considered to be ± 7.5 m (2dRMS 95%) (Waltermire et al. 2016). Each GPS fix is associated with an index rating of the quality of the geometry for each GPS fix for both horizontal (HDOP) and vertical (VDOP) GPS estimates that can be multiplied by GPS accuracy to estimate location error (Miller et al. 2019). Transmitters also recorded ambient temperature, an activity index, the number of satellites used to acquire GPS fixes, and other sensor data.

3.4 Generating Space Use Models

We analyzed horizontal GPS location data to characterize Bald Eagle space use generally, and relative to the Installation. The day in which transmitters were deployed was excluded from analyses. To remove implausible or erroneous GPS location estimates, we applied a max speed filter that excluded locations with instantaneous speeds >100 kph (62 mph). We generated Utilization Distributions (UDs) for individual Bald Eagles using dynamic Brownian Bridge Movement Models (dBBMM; Kranstauber et al. 2012). A UD is a space use probability with respect to time, therefore showing the probability of where an animal might be found at any randomly chosen time (Powell and Mitchell 2012). Due in part to their ability to account for temporal autocorrelation, Brownian Bridge Movement Models have several advantages over prior spatial modelling approaches such as Kernel Density Estimates (Kie et al. 2010, Walter et al. 2011, Fischer et al. 2013). The dBBMM improved upon the original BBMM in several aspects, particularly in accommodating dynamic sampling schedules (Kranstauber et al. 2012). Since large error ellipses generated by imprecise location estimates and large temporal data gaps can be problematic in generating UD surfaces, we removed all location estimates fixed by <3 satellites and then generated individual UD surfaces for datasets containing temporal data gaps of ≤3 days within years (based on 1 June). Individual UD surfaces within each bird-year were then averaged into an annual composite weighted by the number of days of the total represented within a year. For individuals that acquired multi-year datasets, we averaged annual composite surfaces into an overall multi-year composite. Models were created using the 'move' package (version 3.0.1) in R (version 3.6.2) (R Core Team 2020).

3.5 Characterizing Space Use

To characterize Bald Eagle space use, we report 50% (i.e., core use, or core foraging areas; Ford and Krumme 1979), 75% and 95% UD areas for individuals instrumented with transmitters. UD areas are reported within individual years (delineated based on 1 June) and additionally during two different time periods roughly delineated by both breeding chronology and season:

1. Breeding/post-breeding: March 15 – Oct 31 – encompasses the majority of the breeding cycle and the subsequent post-fledging period, which spans much of the spring/summer and autumn.
2. Non-breeding: Nov. 1 – March 14 – encompasses the non-breeding season, the majority of which occurs during the winter months and early spring.

3.6 Territory / Nest Site Fidelity (as Indicated by Distance from Nest)

Since the extent of fidelity to nesting territories has management implications in Bald Eagles, we quantified the fidelity of transmitter-instrumented Bald Eagles relative to nest sites. We measured the Euclidian distance between individual GPS location estimates and nest sites associated with instrumented individuals using ArcMap 10.8.1 (ESRI 2020). To accommodate differences in the number of GPS fixes acquired within a day, we averaged distance to nest data by day for each individual, and then summarized basic statistics for daily measures within individuals by year (mean, median, SD, min, max).

3.7 Characterizing UD Overlap with the Installation

To evaluate the potential exposure of Bald Eagles to hazards associated with the Installation, we evaluated spatial overlap between both individual and composite Bald Eagle UDs and the primary, secondary, and combined hazard areas of the Installation. Installation boundaries were defined by a GIS coverage provided by the U.S. Navy (I. Trefry, U.S. Navy, unpubl. data).

3.8 Bald Eagle Altitude in Hazard Areas

To gain insights on the perching or flight altitude of Bald Eagles within the Combined Hazard Area, we summarized GPS altitude estimates for all location estimates falling within the Combined Hazard Area. We removed all locations with a VDOP or HDOP value >10 (Miller et al. 2019), and five notable altitude outliers (1,212 – 5,371 m) identified using an outlier box plot. To accommodate differences in the number of fixes acquired daily by different individuals, we averaged altitude estimates within each day for all individuals prior to analysis. Using this mean daily altitude dataset for individual and pooled individuals, we compared the mean daily altitude of Bald Eagles within the primary hazard area vs. the secondary hazard area using a Wilcoxon test in JMP 9.0 (SAS 2010). To characterize Bald Eagle use of the hazard areas and to evaluate potential risks for collision, we compared pooled daily altitude means to the altitude of both the shorter (244 m; 800 ft.) and taller (305 m; 1000 ft.) communication towers.

3.9 Assessing Encounter Risk for Resident Bald Eagles within 15 km of the Installation

In order to assess the probability that resident adult Bald Eagles ≤15 km of the Installation might encounter structural hazards associated with it, we used two approaches for evaluating risk.

3.9.1 Approach 1: UD Sampling and Proximity

To assess encounter risk using Approach 1, we used UD polygons of the individuals tracked using telemetry to evaluate the encounter risk of sampled nest sites relative to the Installation. Next, we developed risk categories for sampled nests, and then applied those risk categories to unsampled nests on the basis of their proximity to the Installation. Space use criteria used to assess risk of sampled individuals is presented in Table 2.

Assessment for sampled individuals/nesting territories

Table 2. Criteria used to assess the risk that adult Bald Eagles sampled in the present study would enter the hazard areas associated with the Installation based on space use characteristics derived from telemetry. Year 1 and overall composite UDs at all contour levels within either time period (breeding/post-breeding and non-breeding) and overall were considered in assessments.

Encounter Risk Category	Space Use Criteria
Low	No portion of the Primary, Secondary, or Combined Hazard area coincided with the UD of an individual (no overlap), AND the nearest UD polygon was >3 km from the outer secondary hazard area boundary.
Moderate	No portion of the primary, secondary or combined hazard area coincided with the UD of an individual (no overlap), BUT a UD polygon lies within 3 km of the Secondary Hazard area boundary; AND/OR travel between UD polygons within 20 km of the Installation would require travel through the Primary, Secondary or Combined Hazard areas.
High	A portion of the Primary, Secondary or Combined Hazard area coincided with the UD of an individual (overlap exists).

Assessment for unsampled nesting territories ≤15 km from the Installation

Using the encounter risk categories for sampled individuals derived from their space use characteristics (**Table 2**), we applied risk categories to unsampled nest sites on the basis of their distance to the Installation. Distance ranges used to derive encounter risk categories for unsampled nests are presented in Table 3.

Table 3. Criteria used to determine encounter risk for unsampled Bald Eagle nests within 15 km of the Installation.

Sampled Nests			Unsampled Nests
Risk based upon UD overlap	Nest to Installation Distance Range for Sampled Nests		Nest to Installation Distance Range (to categorize unsampled nests).
Low	11.22 km (n = 1)	→	>11 km
Moderate	5.72 km (n = 1)	→	5.6 – 11.0 km
High	0 – 3.82 km (n = 4)	→	0 – 5.5 km

3.9.2 Approach 2: Inter-nest Distance

We also evaluated the risk that Bald Eagles would enter the hazard areas using methods recommended in the Eagle Conservation Plan Guidance for Land-based Wind Energy (USFWS 2013). This method entails calculating the mean inter-nest distance of all nesting territories within a prescribed radius of a wind energy project and then applying a buffer of half this mean value to all nests to evaluate potential territory overlap with the project area. We calculated the mean inter-nest distance for 18 nests ≤15 km (9.3 mi) of the Installation (10,164 m), and then applied a buffer of half this distance (half inter-nest distance: 5,082 m radius) to the most recently used nest site within each territory. Nests in which the estimated territory area buffer intersected the Installation hazard areas were categorized as having a high encounter risk.

4.0 RESULTS AND DISCUSSION

Data Summary

After filtering, GPS transmitters instrumented to the six adult Bald Eagles in our study fixed a total of 271,425 horizontal location estimates. Collectively, these locations were fixed over a total of 2,618 days. Transmitters deployed in 2017 fixed between 1 – 71 locations a day (mean ± SD: 36.7 ± 25.0 locations) while those deployed in 2019 fixed between 1 – 3,140 locations a day (mean ± SD: 302.2 ± 441.7 locations)[5].

[5] Differences in the number of locations fixed per day were due to transmitter capabilities, programming, solar charging and other factors (see methods).

4.1 General Space Use Patterns of the Study Population

4.1.1 UD Area (Year-round)

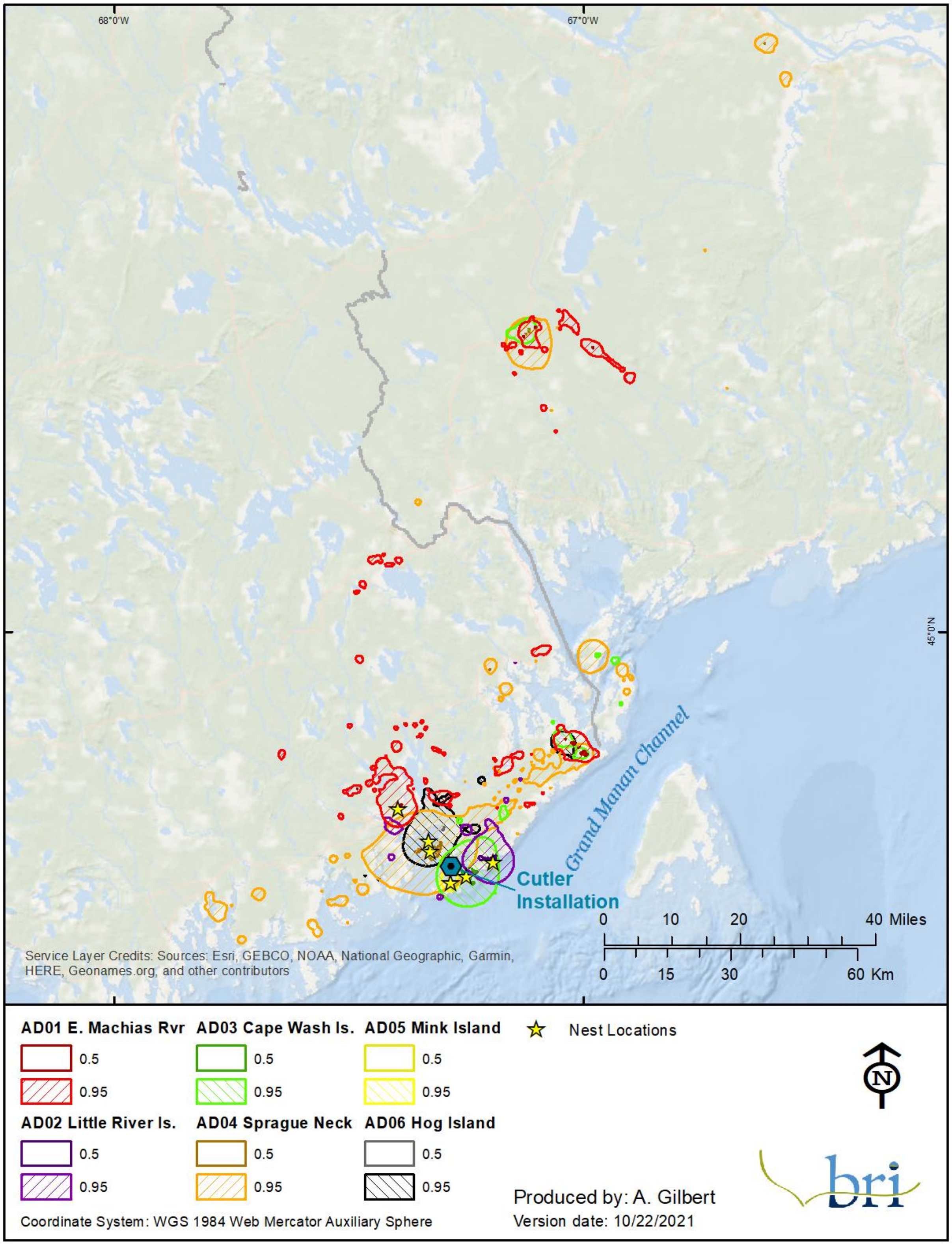
All Bald Eagle UDs estimated from GPS telemetry were highly centered upon nest sites. Several individuals showed varying degrees of habitat use elsewhere – predominantly in eastern Maine and New Brunswick, Canada (**Map 2**). Year-round UD areas (95% contour) for individuals during their first year (year 1) ranged widely among individuals from 11.1 – 395.1 km^2 (mean ± SD: 143 ± 146 km^2) (**Table 4**). Home range areas at the 95% contour level in our sample generally span the range reported in literature for adult Bald Eagles in western North America and Louisiana (Kocina and Aagaard 2021). Core use areas (50% contour) during year 1 ranged from 0.3 – 3.05 km^2 (mean ± SD: 1.6 ± 1.2 km^2).

Table 4. Areas (in km^2) of Bald Eagle utilization distributions for six adult Bald Eagles in the vicinity of the Naval Support Activity, Cutler.

			Total UD area in km^2		
Animal ID	Location (name)	Year	50%	75%	95%
AD01	East Machias River	1	0.78	3.54	23.9
		*2**	*3.31*	*20.47*	*374.4*
		*3**	*0.09*	*0.26*	*1.07*
		all	**1.62**	**10.50**	**152.4**
AD02	Little River Island	1	2.36	8.09	69.5
AD03	Cape Wash Island	1	2.59	10.45	223.4
		2	0.55	4.63	40.8
		all	**1.60**	**7.90**	**125.5**
AD04	Sprague Neck	1	3.05	12.9	395.1
AD05	Mink Island	1	0.4	2.1	11.1
AD06	Hog Island	1	0.3	5.7	135.3
		2	0.9	4.0	18.2
		all	**0.4**	**5.4**	**99.6**
	Year 1 Avg:		**1.6**	**7.1**	**143.0**
	Year 1 SD:		**1.2**	**4.1**	**146.3**

* GPS data indicated that AD01 showed little fidelity to its nesting area towards the end of year 1 and throughout years 2 and 3. Thus, years 2 and 3 (*italics*) were excluded from some analyses.

Of the three transmitter-instrumented individuals that provided data for >1 year, it was evident that one of them (AD01 East Machias River) no longer exhibited fidelity to its original nesting territory toward the end of year 1 and throughout year 2 and year 3. Since space use data for this individual is less comparable to that from the other individuals (AD02 – AD06) that remained associated with their nesting territories throughout their respective tracking periods, we excluded year 2 and year 3 for AD01 from most data summaries and comparisons.



Map 2. Full extent utilization distributions of six transmitter-instrumented Bald Eagles in the vicinity of the Installation.

While home range patterns have been reported for post-fledging and subadult Bald Eagles in Maine (McCollough 1986, DeSorbo et al. 2015, 2020) and elsewhere (Kocina and Aagaard 2021), few studies[6] have characterized the home range of adult Bald Eagles. In a recent literature review by Kocina and Aagaard (2021), only eight studies reported home range data for adult Bald Eagles, and all but one in Louisiana were conducted in Western North America.

4.1.2 Space Use by Breeding Stage / Season

Analyses of Bald Eagle space use patterns within designated breeding cycle/seasonal time periods suggested individuals have different space use characteristics during the two periods (Table 5). UD areas were larger in the non-breeding period than in the breeding/post-breeding period in 6 out of 7 resident[7] eagle-years at the 95% contour level (Table 5). The mean UD areas across all individuals in year 1 of the breeding/post-breeding period (mean ± SD: 38.5 ± 30.0 km^2; range: 22.9 – 92.0 km^2) was substantially smaller than the mean for the non-breeding period (mean ± SD: 482 ± 749 km^2; 14.1 – 1,968.4 km^2); however, sample sizes preclude powerful statistical comparisons. The mean year 1 95% UD area of individuals during the non-breeding period was notably influenced by an outlier (AD04; 1,968.4 km^2); however the (year 1) mean for all individuals remained more than four times (184.6 km^2) greater than the mean for the breeding/post-breeding period after AD04 was excluded. The pattern of larger space use in the non-breeding period vs. the breeding/post-breeding period was generally also mirrored at the 50% and 75% contour levels except for AD05 (Mink Island) and AD06 (Hog Island), both of which had relatively small 50% and 75% UD areas during breeding/post-breeding period (Table 5).

[6] B. Massey, UMASS, also instrumented adult Bald Eagles for a forthcoming dissertation.
[7] Excluding years 2 & 3 for AD01_East Machias River.

Table 5. Annual Space Use (as indicated by Utilization Distribution area) of Bald Eagles during the Breeding/post period (15 Mar. – Oct 31) and the Non-breeding period (1 Nov. – 14 Mar.).

			Total UD area in km^2					
			Breeding/Post			Non-breeding		
Animal ID	**Location (name)**	**Year**	**50%**	**75%**	**95%**	**50%**	**75%**	**95%**
AD01	**East Machias River**	**1**	**0.59**	**3.2**	**26.0**	**1.1**	**3.6**	**16.6**
		*2**	*3.9*	*25.2*	*435.2*	*1.0*	*4.6*	*32.2*
		*3**	*0.1*	*0.3*	*1.1*	-	-	-
AD02	**Little River Island**	**1**	**1.5**	**4.8**	**22.9**	**3.8**	**11.9**	**96.9**
AD03	**Cape Wash Island**	**1**	**1.4**	**6.8**	**92.0**	**5.4**	**22.0**	**418.5**
		2	0.2	1.4	10.4	3.6	13.7	103.1
AD04	**Sprague Neck**	**1**	**2.2**	**7.2**	**54.6**	**14.2**	**103.9**	**1,968.4**
AD05	**Mink Island**	**1**	**0.8**	**2.7**	**10.1**	**0.1**	**0.6**	**14.1**
AD06	**Hog Island**	**1**	**0.8**	**5.4**	**25.1**	**0.1**	**16.8**	**376.8**
		2	0.9	4.0	18.2	-	-	-
	Year 1 Mean:		**1.2**	**5.0**	**38.5**	**4.1**	**26.5**	**481.9**

* GPS data indicated that AD01 showed little fidelity to its nesting area towards the end of year 1 and throughout years 2 and 3. Thus, years 2 and 3 (*italics*) were excluded from some analyses.
Conversions: 1 km^2 =100 ha = 247 acres.

The suggestion from our data that Bald Eagles use larger areas during the non-breeding period as compared to the breeding period analyzed is further supported by the fact that this difference was evident despite a smaller number of days in the non-breeding period (133 days) than in the breeding/post-breeding period (152 from 1 June; 230 days for full period). In several individuals, larger areas during the non-breeding period reflected visits to distant habitats in eastern Maine and New Brunswick, Canada. These excursions may be necessitated by lower availability of fish and seabirds and other prey in breeding areas during the winter months.

4.1.3 Space Use of Non-residents

UD area comparisons of AD01 (East Machias River) during years 2 and 3 may provide perspectives on non-resident, and possibly non-breeding adult Bald Eagles in eastern Maine (Table 5). In this case, the pattern was reversed; a notably smaller area was used during the non-breeding period than in the breeding/post-breeding period.

4.1.4 Insights on Territory Fidelity (via Distance from Nest measurements)

Distance measurements between the GPS location estimates for Bald Eagles and their respective nest sites demonstrated a relatively high degree of fidelity to territories and nest sites. The median daily distance individuals travelled from their nest sites within transmit years was <2 km in 80% of all 'eagle-years' tallied (Table 6). If we again exclude year 2 and year 3 for AD01, no daily distance median exceeded 1.6 km from the nest for any individual within a year.

Table 6. Descriptive statistics for mean and median daily distances GPS transmitter-instrumented Bald Eagles travelled from their nests within a 'transmit year' (deployment - 1 June). The greater mean daily distance of AD04 reflects a short-term winter movement to New Brunswick, Canada.

Animal			Daily Distance					
ID	**Location (name)**	**Year**	**No. days**	**Mean**	**Median**	**SD**	**Min**	**Max**
AD01	East Machias River	1	365	4.2	0.6	14.6	0.0	83.4
AD01	*East Machias River*	*2**	*311*	*38.9*	*31.9*	*24.1*	*3.7*	*86.8*
AD01	*East Machias River*	*3**	*155*	*32.7*	*32.8*	*0.5*	*30.4*	*34.8*
AD02	Little River Island	1	320	1.9	1.1	3.7	0.1	34.5
AD03	Cape Wash Island	1	363	4.5	0.9	14.7	0.1	92.2
AD03	Cape Wash Island	2	248	1.4	0.7	3.7	0.0	28.9
AD04	Sprague Island	1	200	11.7	1.3	28.2	0.2	146.5
AD05	Mink Island	1	221	1.2	1.0	1.3	0.0	15.2
AD06	Hog Island	1	361	2.1	0.7	4.4	0.0	29.0
AD06	Hog Island	2	82	1.6	1.6	0.8	0.2	3.7
	Year 1:	**1**	**-**	**4.2**	**1.0**	**10.2**	**0**	**146.5**

* GPS data indicated that AD01 showed little fidelity to its nesting area towards the end of year 1 and throughout years 2 and 3. Thus, years 2 and 3 (*italics*) were excluded from some analyses.

Distance to nest means were noticeably influenced by outliers. Year 1 means ranged from 1.2 – 11.7 km across individuals, and only one individual had a Year 1 mean daily distance >4.5 km (AD04) Sprague Neck; mean: 11.7 km; Table 6). Variability in distances individuals travelled from their nests within transmit years was relatively low for several resident eagles (see standard deviations; Table 6). Of the eight eagle-years we considered to be residents (i.e., excluding AD01 year 2 and 3), five of them (62.5%) had SDs < 5 km. The maximum distance any individual was recorded from its nest site within a year ranged from 30 - 150 km (mean ± SD: 64 ± 37 km). The most distant locale visited by any individual studied was a landfill near the St. John River in Fredericton, New Brunswick, Canada, visited in the early fall (AD04 Sprague Neck) (Map 2). Information quantifying the extent to which resident Bald Eagles remain on territory throughout the year has numerous management implications for the Installation and a variety of other facilities that pose potential injury risks to individuals.

4.2 Bald Eagle Use Patterns Relative to the Installation

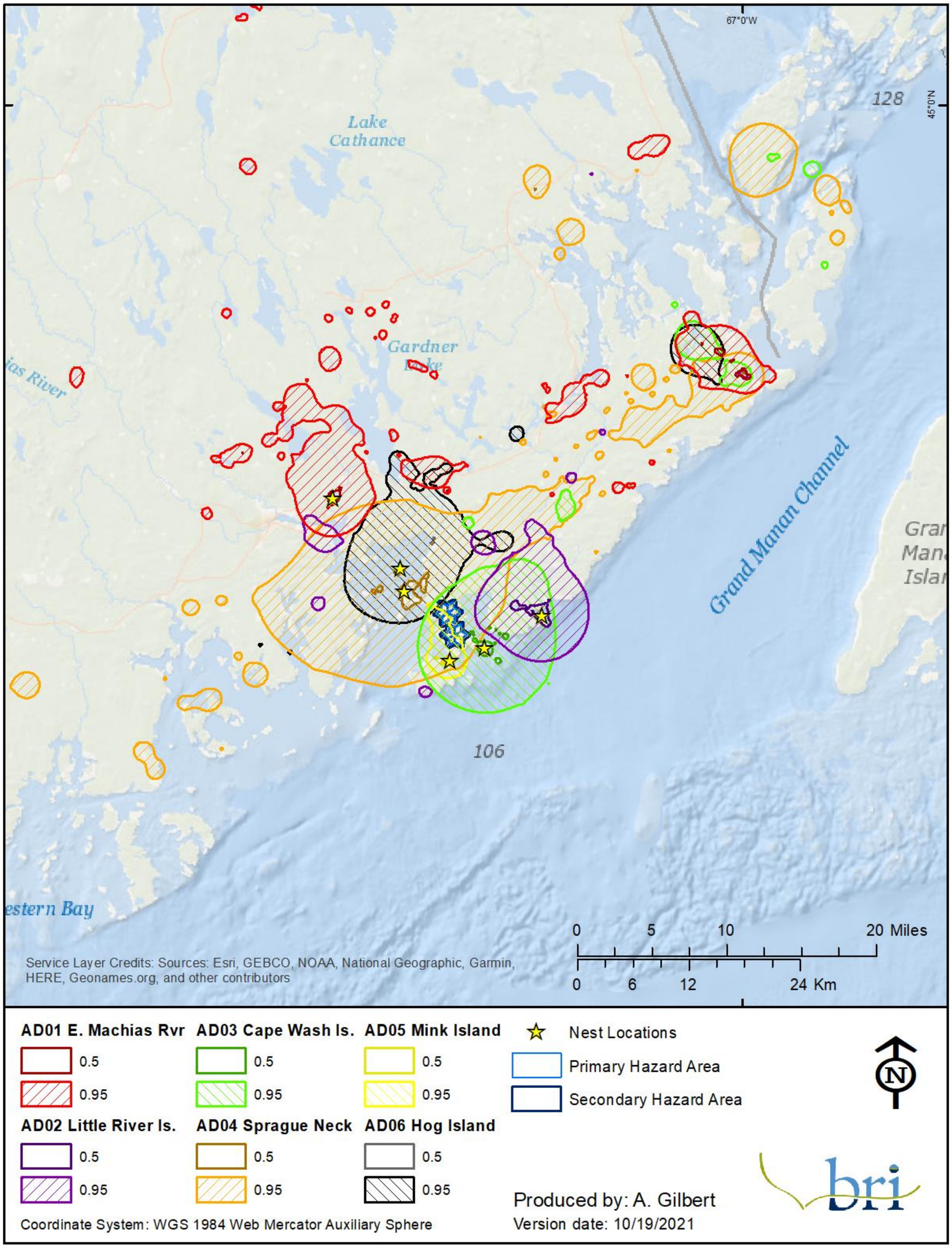
4.2.1 Proximity

Telemetry data supports the assumption that the probability that a resident Bald Eagle might enter the Installation is in part a function of the proximity of its nest/nesting territory to the Installation. Of the six Bald Eagle nesting territories/individuals represented in our sampling effort, four (67%) had 95% composite contour UDs that intersected at least the secondary hazard area, while UDs from two individuals (23%) did not (**Map 3**, **Table 7**). Nest sites of the two individuals with UDs that did not intersect the hazard area were located 5.72 km (AD02 Little River Isl.) and 11.22 km (AD01 East Machias River) from the secondary hazard area boundary, while the nest sites of individuals with use areas that did intersect the hazard area ranged between 0.99 – 3.83 km from the secondary hazard area boundary.

4.2.2 Space Use Overlap with the Installation

The extent of UD overlap with the hazard areas varied widely within the subset of individuals we studied. The proportion of hazard area overlap was generally similar between the primary and secondary hazard areas. Table 7 shows the proportion of the different hazard areas that coincided with a composite eagle UD at different contour levels.

In our sample of year-round composite UDs, no individuals exhibited a UD overlap with the hazard areas at the 50% UD level. This finding likely reflects the relatively small size of core use areas overall in our sample (i.e., Year 1 mean: 1.6 km^2; **Table 4**). Only two of the six individuals studied had UDs that coincided with either the Primary or Secondary hazard areas at the 75% contour level (AD03 and AD05); however the extent of hazard area overlap in these cases was relatively small (range: Primary: 0.16% - 3.5% overlap; Secondary hazard area: 1.3% - 5% overlap; **Table 7**). Four of the six individuals studied (66%) had UDs that coincided with the hazard areas at the 95% contour level. Of those four individuals, the extent of hazard area overlap varied widely. AD06 exhibited low levels of hazard area overlap (0.02 – 1.4%), AD05 exhibited a moderate degree of overlap (42 – 43%), while two individuals (AD03 and AD04) exhibited complete hazard area overlap (100%) (**Table 7**).



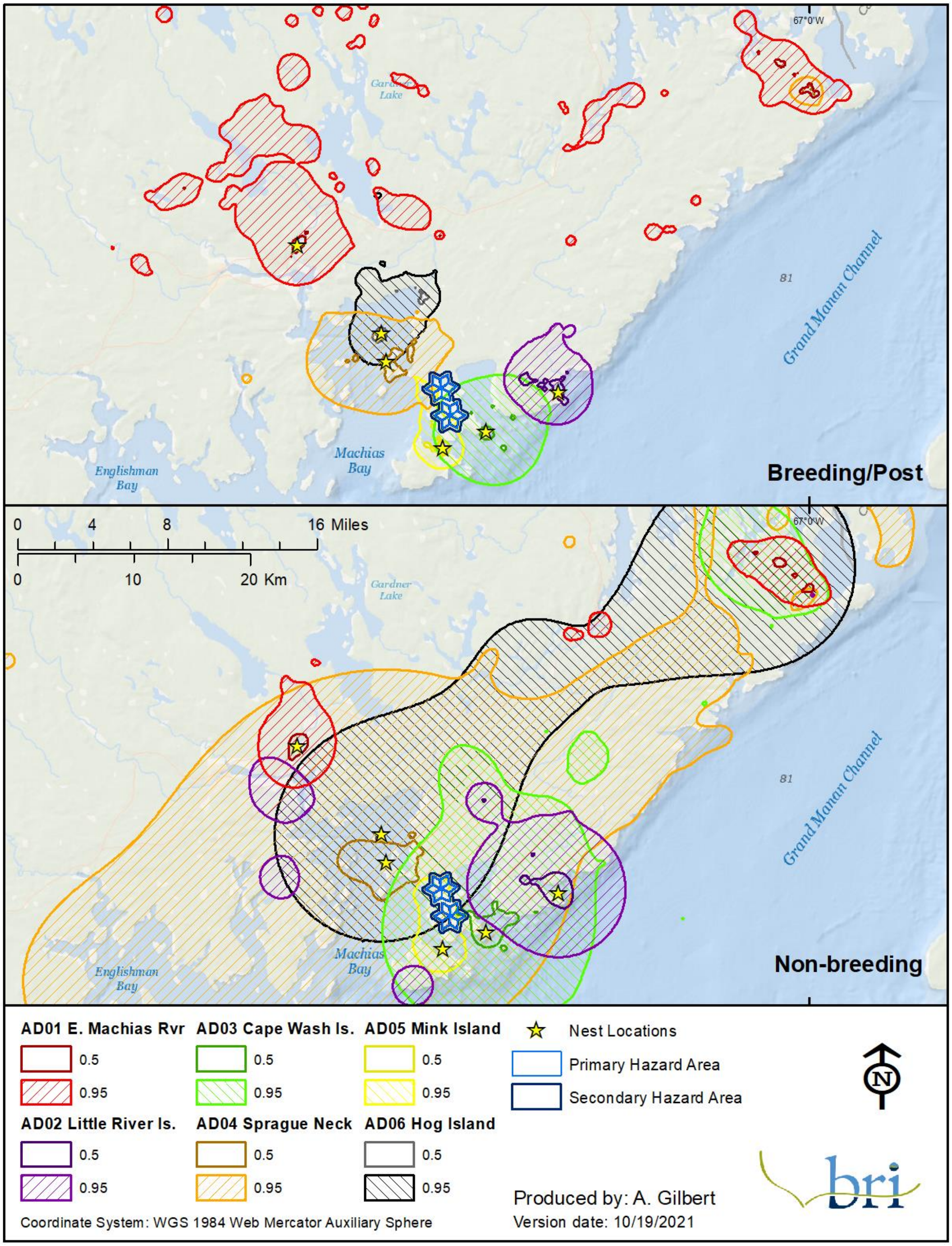
Map 3. Composite utilization distributions of six adult Bald Eagles within the general vicinity of the Installation. Map scale is not full extent.

Table 7. Proportion of the primary and secondary hazard areas of the Installation coinciding with composite Utilization Distributions (50%, 75% and 95% contours) of six Bald Eagles instrumented with GPS transmitters. Dashes signify 0% overlap. A value of 100% w within a contour column (e.g., AD03; 95%) indicates that 100% of the hazard area overlaps with the 95% UD contour for that individual, while a value of 5% for an individual at the 75% UD level indicates only 5% of the hazard area coincided the UD for that individual at this intermediate contour level. UD overlap at the 50% contour level represents the highest encounter risk to individuals.

		Percentage of Area Coinciding with UD					
		Primary Hazard Area			Secondary Hazard Area		
Animal ID	Location (name)	50%	75%	95%	50%	75%	95%
AD01	East Machias River	-	-	-	-	-	-
AD02	Little River Island	-	-	-	-	-	-
AD03	Cape Wash Island	-	3.5%	100%	-	5%	100%
AD04	Sprague Neck	-	-	100%	-	-	100%
AD05	Mink Island	-	0.16%	42%	-	1.3%	43%
AD06	Hog Island	-	-	0.02%	-	-	1.4%

4.2.3 Influences of Breeding Stage/Seasonal Time Periods on Bald Eagle Space Use at the Installation

Our limited sample of transmitter-instrumented Bald Eagles suggests that breeding stage and/or season influence the probability that some individuals might use areas associated with the Installation (**Map 4**). Since hazard area overlap proportions were similar between the primary and secondary hazard areas within periods for the majority of individuals, we focus further comparisons on the combined hazard area. Preliminary comparisons in our dataset suggest the probability of hazard area use by adult eagles may be greater during the non-breeding period than the breeding/post-breeding period due to an apparent expansion of area use in the non-breeding period (**Map 4**, **Figure 1**).



Map 4. All-years composite utilization distributions of six transmitter-instrumented adult Bald Eagles within the vicinity of the Installation during two different breeding cycle/seasonal periods.

At the 95% contour level, the UDs of four individuals intersected the combined hazard area during either or both time periods; three during the breeding/post-breeding period (range: 7 – 99.2%), and four during the non-breeding period (range: 76.2 – 100%) (**Figure 1**). At the 75% contour level, the UDs of three of the six individuals intersected the combined hazard area during at least one time period (**Figure 1**). Of these four intersections, two occurred during the breeding/post-breeding period (range 1.6 – 3.1%) and two occurred during the non-breeding period (30.4 – 47.5%). At the 50% contour level (not shown), the UDs of two of the six transmitter-instrumented individuals intersected either the primary or secondary hazard areas at low levels of overlap (0.11 – 4.3%).

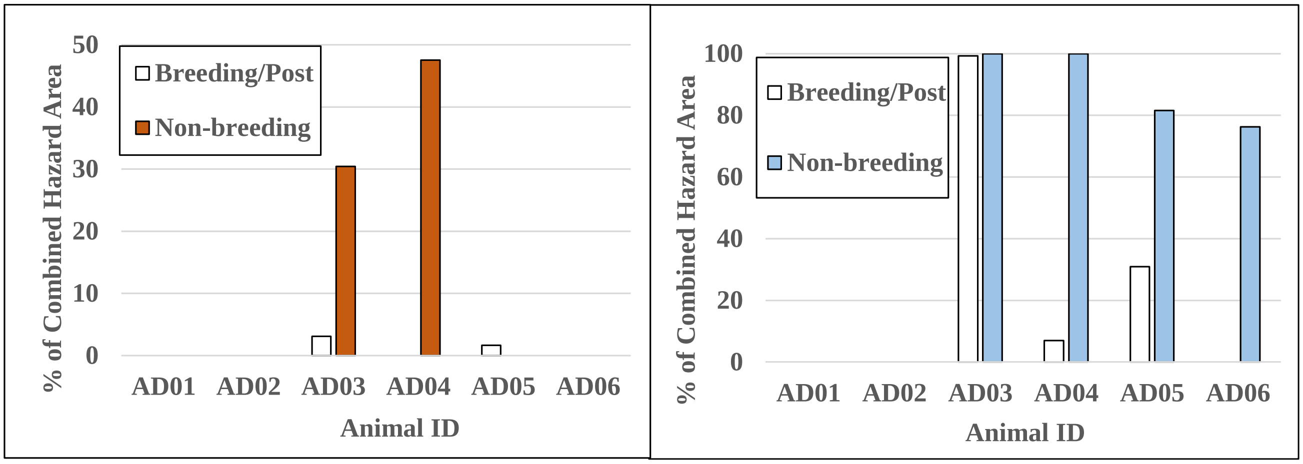


Figure 1. Percentage of the combined hazard area overlapping with utilization distributions (year 1) of six adult Bald Eagles at 75% (left) and 95% (right) contour levels during two different time periods (Breeding/post: 15 Mar – 31 Oct; Non-breeding: 1 Nov – 14 Mar).

Sample sizes preclude powerful statistical comparisons of mean hazard area overlap areas between seasons; however, our data suggests that the probability of hazard area use is greater during the non-breeding period than the breeding/post-breeding period. When averaging across all six individuals, the mean hazard area overlap with the combined hazard area during the non-breeding period (60%) was nearly three times greater than the mean for the breeding/post-breeding period (23%) at the 95% contour level and 16 times greater at the 75% level. **(Figure 2)**.

Further study employing larger sample sizes would be required to verify the suggestion from this study that the probability of hazard area use may be greater during the non-breeding period than the breeding/post-breeding period. Other studies in juvenile Bald Eagles have also reported substantial home range expansions in the winter months as compared to the summer months (DeSorbo et al. 2015, 2020). Increased use of habitats within the open spaces of the Installation is plausible given Maine Bald Eagles commonly scavenge carrion during the winter months.

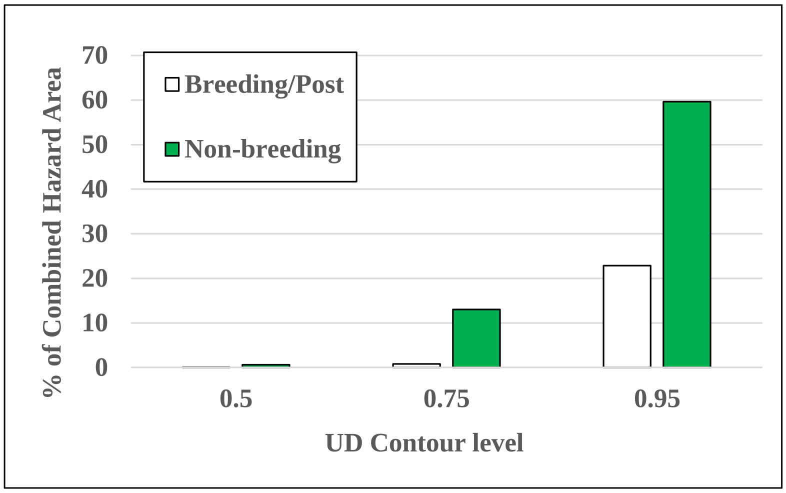


Figure 2. Mean proportions of the combined hazard area that coincided with 50%, 75% and 95% UDs of six resident adult Bald Eagles during two time periods.

4.2.4 Bald Eagle Altitude in the Installation

GPS telemetry provided specific and accurate data on Bald Eagle altitude within the primary and secondary hazard areas. Three individuals fixed altitude estimates in the hazard areas (AD03 Cape Wash, AD04 Sprague Neck and AD05 Mink Island). Due to differences in use of the hazard areas among individuals and differences in duty cycle capabilities among transmitters (see methods), the altitude dataset was predominantly comprised of locations fixed by AD05 Mink Island. Differences in the number of daily transmissions among individuals were standardized by averaging daily altitude estimates in analyses.

Primary vs. Secondary Hazard Area Comparison

Comparisons of daily altitude estimates between primary and secondary hazard areas indicate Bald Eagles perch or fly at higher altitudes in the primary hazard area than the secondary hazard area (**Figure 3**). Mean daily altitude estimate sample sizes were limited within some individuals, thus statistical comparisons between primary and secondary hazard areas were only feasible for the pooled dataset and for AD05 individually. Within the pooled dataset, the mean daily altitude estimate in the primary hazard area (mean ± SD: 62.2 ± 74.2 m) was nearly twice that found in the secondary hazard area (37.7 ± 39.4 m) ($p < 0.0001$, $x^2_1 = 21.1$, $n = 422$). These differences remained significant for solely AD05 (Primary: mean ± SD: 59.0 ± 62.3 m; Secondary: 39.4 ± 45.4 m) ($p < 0.0001$, $x^2_1 = 15.29$, $n = 251$). Indications of higher Bald Eagle perch or flight altitudes in the primary hazard area were expected given the much broader range of perch height options in this area (i.e., 0 – 305 m); whereas perching options are far more limited and notably lower within the secondary hazard area.

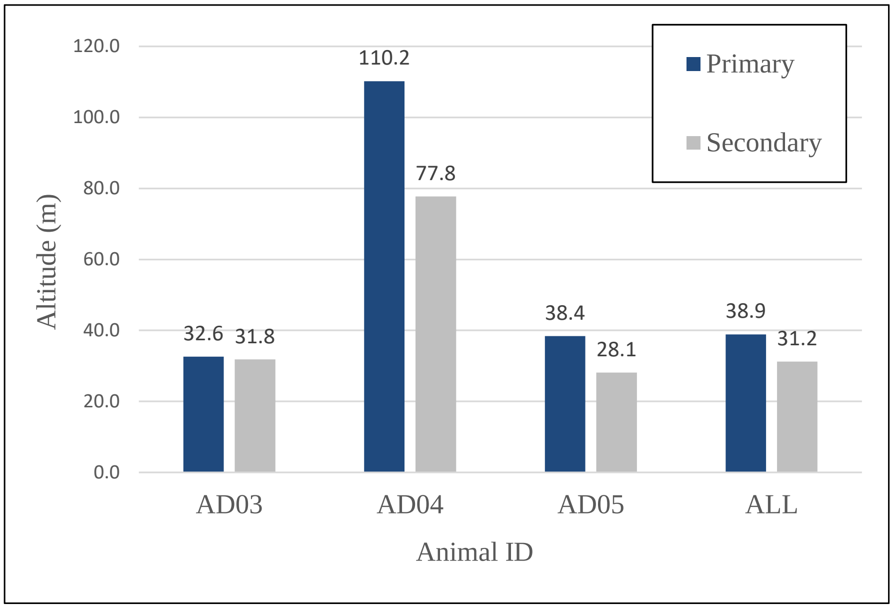


Figure 3. Medians of mean daily altitude estimates for three transmitter-instrumented Bald Eagles within the primary and secondary hazard areas of the Installation.

Altitude versus Tower Height

The majority of both individual (i.e., raw data estimates) and daily-summarized altitude estimates were well below the maximum height of both the shorter (244 m) and taller (305 m) towers within the Primary Hazard Area (**Figure 4**). Fifty percent of the pooled mean daily altitude estimate data was between 26 m (25% quantile) and 62 m (75% quantile) in the primary hazard area; and 90% of the data was below 150 m. The overall median daily altitude estimate in the primary hazard area (38.9 m) was 16% the height of the 244 m towers and 13% of the height of the 305 m towers.

Findings that flight altitudes rarely exceed the tower heights are unsurprising overall given the large height of the towers and the corresponding height of the trees abutting the secondary hazard area that attract individuals for perching (DeSorbo et al. 2018). GPS altitude data is consistent with limited field observations of eagles perching on the towers themselves and in trees abutting the secondary hazard area (DeSorbo et al. 2018, Tetra Tech 2018*b*). Since the horizontal sky mast and associated cabling in the upper tier of the tower array pose a significant collision hazard to birds, indications from tracking data that Bald Eagles are predominantly attracted to lower altitudes within the hazard areas may significantly lower their collision risk.

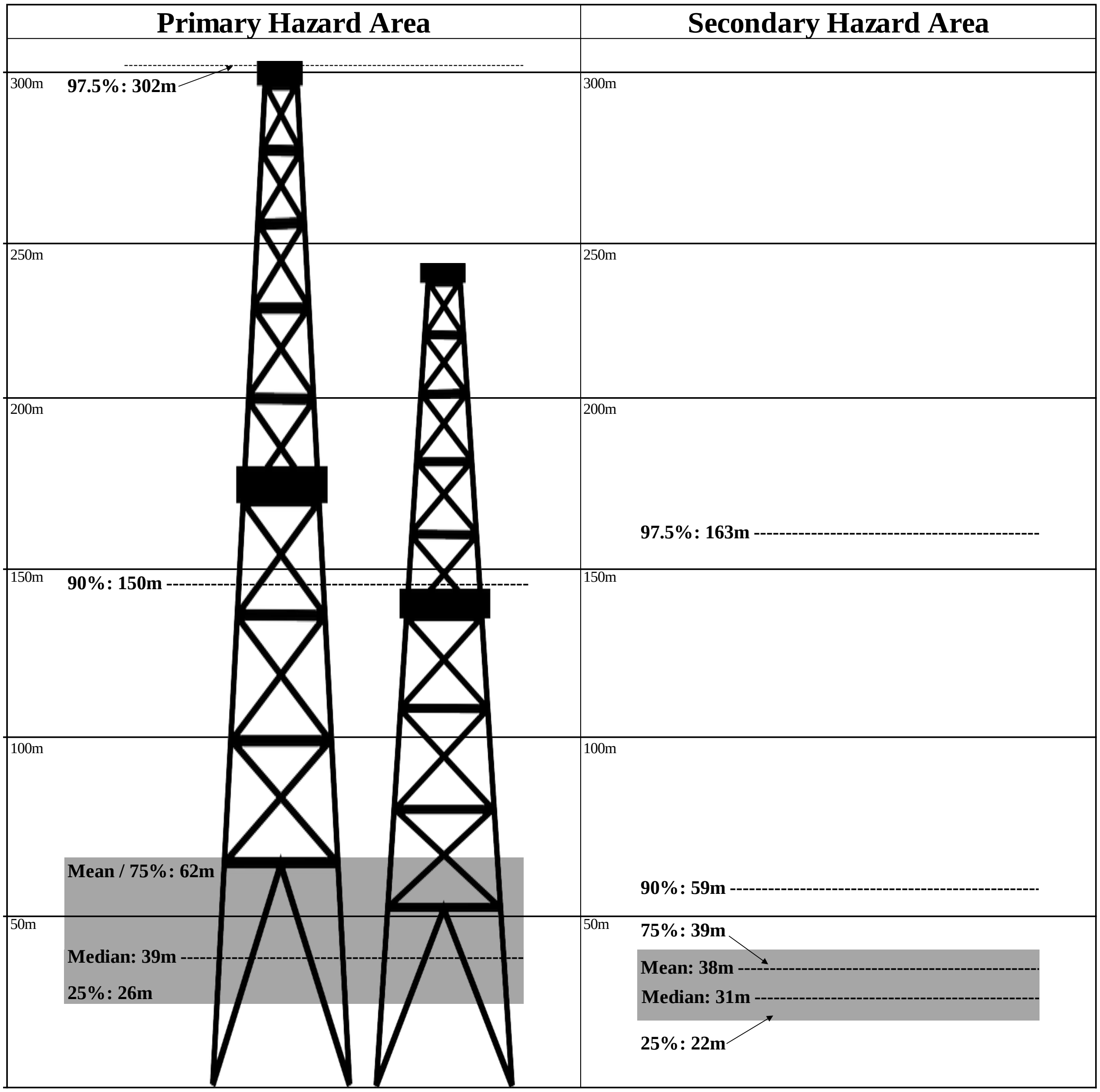


Figure 4. Mean, median and quantiles (25%, 75%, 90% and 97.5%) for pooled mean daily altitude estimates for six transmitter-instrumented Bald Eagles in the primary and secondary hazard areas of the Installation, relative to the heights of 244 m and 305 m communication towers located within the primary hazard area. Gray boxes show 25 – 75% quantiles. Supporting cables pass through airspace throughout the secondary hazard area where they area also anchored.

4.2.5 Encounter Risk Assessment for Bald Eagle Nesting Territories ≤15 km of the Installation

Approach 1: UD Sampling and Proximity

Assessment for sampled individuals/nesting territories

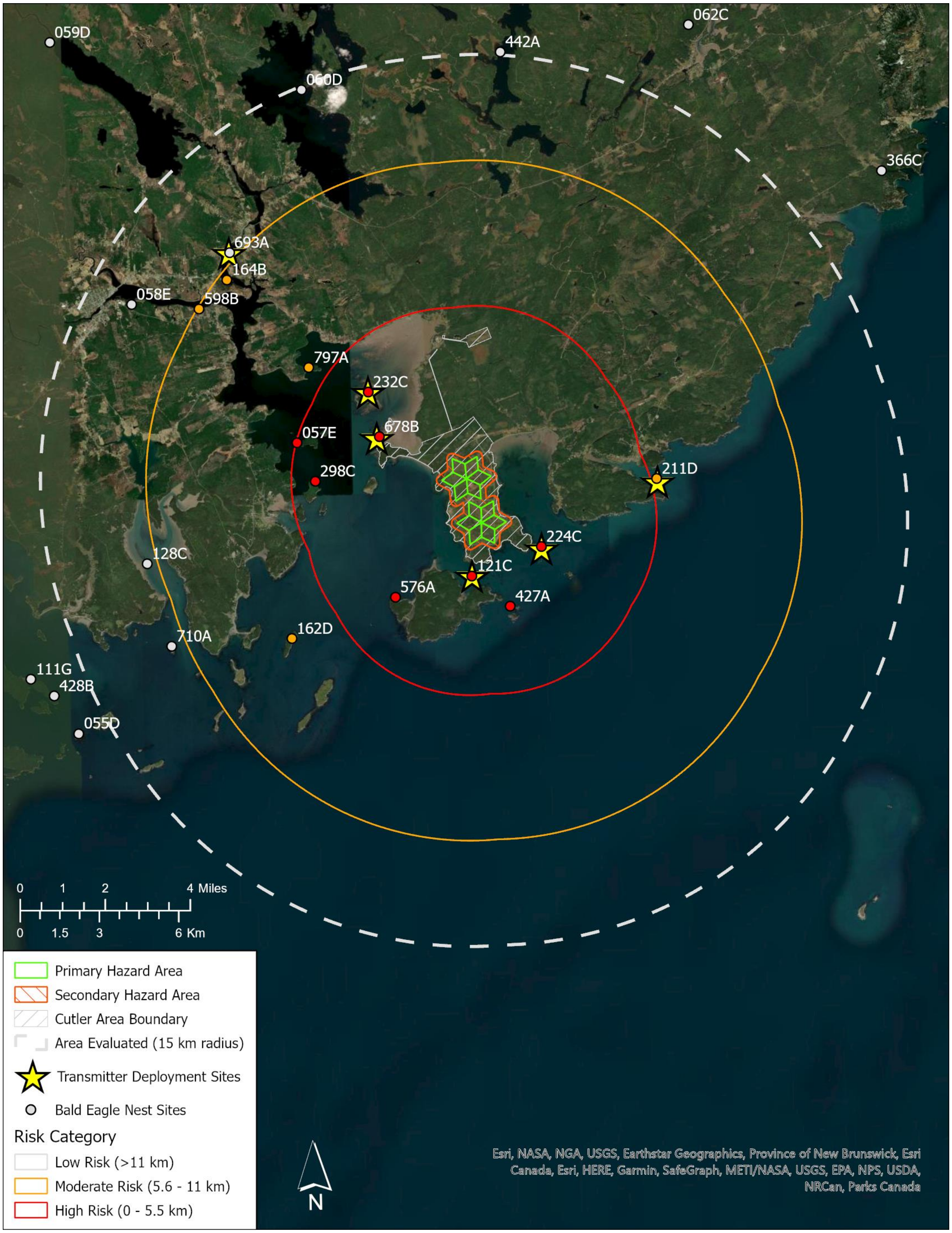
While our sample size of transmitter-instrumented Bald Eagles was limited, Bald Eagle space use data suggested our sample sites spanned the full range of encounter risks associated with the Installation. In general, individuals associated with nest sites closer to the Installation had higher probabilities of using the hazard areas than those from more distant nest sites. Based on our risk criteria for sampled nests (Table 2), we determined that one sampled nesting territory was low risk (17%), one was moderate risk (17%), and four (66%) were high risk (Map 5).

Assessment for all nesting pairs ≤15 km from the Installation

To expand our encounter risk assessment beyond sampled nests within our study area, we assessed the encounter risk of all 18 nesting territories located within 15 km of the Installation (6 sampled, 12 unsampled). Using our distance-based risk criteria (Table 3), we determined that under half (44%) of these nesting territories had a high encounter risk, while the remainder of nesting territories were distributed evenly between low and moderate encounter risk categories (Table 8, Map 5).

Table 8. Estimated encounter risk for individuals from 18 resident adult Bald Eagle nesting territories (nests) within 15 km of the Installation of encountering hazards associated with the Installation based upon transmitter-instrumented space use data and distance-based risk criteria (see methods).

Risk Category	Range	Nests	Percent
Low	>11 km	5	28%
Moderate	5.6 - 11.0	5	28%
High	0 - 5.5 km	8	44%
	Total:	**18**	**100%**



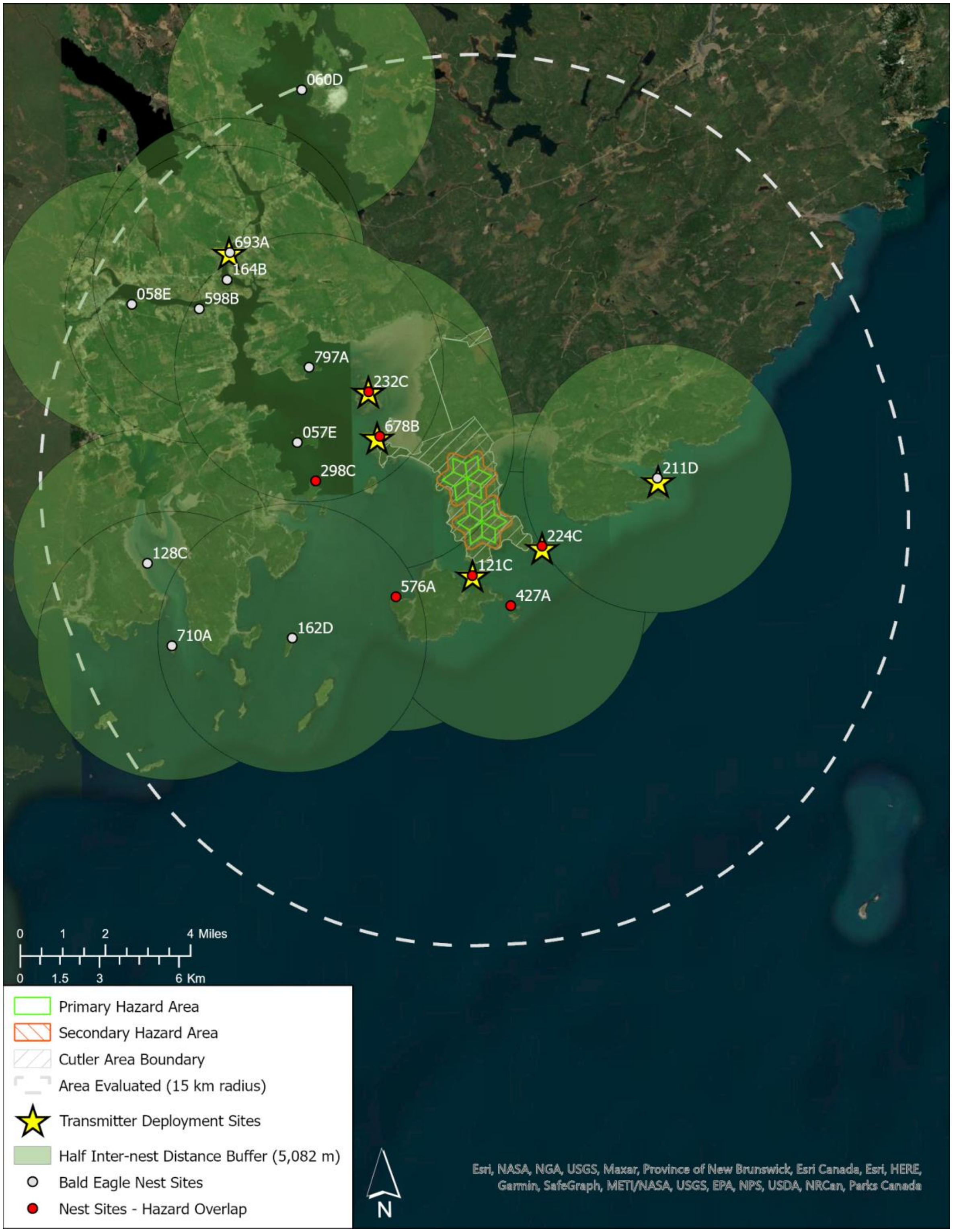
Map 5. Encounter risk assessment for resident Bald Eagles (associated with nesting territories within 15 km of the Installation) derived from transmitter-instrumented Bald Eagle use patterns and distance-based risk criteria (see methods) relative to the Installation.

Approach 2: Inter-nest Distance

The mean inter-nest distance for nesting territories ≤15 km of the Installation was 10,164 m. Therefore, the buffer (applied as a radius) to all nests within our study area was 5,082 m, resulting in an estimated (circular) territory area of 81 km^2. The buffers for seven of the 18 nests in our study area (39%) intersected the Installation hazard areas (**Map 6**). Estimations of the encounter risk using half of the mean inter-nest distance were therefore in relative agreement with those determined using Approach 1 (UD Sampling and proximity), which identified eight nesting territories to be at a high risk of territorial overlap with the hazard areas.

Risk Estimation Approach Comparisons and Considerations

It should be noted that because nest density changes geographically, shifts in the area used for inter-nest distance calculations strongly affect territory area estimates. Previous studies evaluated the inter-nest distance Bald Eagle nests within 5 mi (8 km) of the Installation (>10 nests; Tetra Tech 2018). That study calculated a mean inter-nest distance of 2,044 m. After application of a 1,022 m radius (3.2 km^2) buffer to all nesting territories to approximate territory size, that study concluded that three nesting territories (Sprague Neck, Mink Island, Cape Wash) intersected the Installation boundary, but not the hazard areas. Therefore, the expansion of the area over which the mean inter-nest distance was evaluated from 8 km to 15 km resulted in a five-fold increase in the inter-nest distance (and associated buffer), a roughly 25x increase in the territory area estimation, and an increase in the number of territories identified as being at risk of using the hazard areas from 0 to 7 nests. Evaluations of encounter risk estimation approaches in this study suggest that territory sizes ≥81 km^2 (or a territory buffer radius ≥5,082 m) are necessary to accurately estimate the risk that adult resident Bald Eagles might encounter hazards within the Installation. Since Bald Eagle territory sizes will vary regionally depending on a variety of factors (food availability, migratory habits, nesting density), the present study demonstrates that measuring space use for a sample of individuals is a viable means of assessing the encounter risk of Bald Eagles in our study area and validating the inter-nest distance value used in risk assessments. It is to be noted however, that notable increases in food availability (particularly carrion) or scavenging rates at the Installation will likely attract Bald Eagles from potentially great distances and as such would likely negate the risk assessment outlined in this study.



Map 6. Encounter risk assessment for resident Bald Eagles (associated with nesting territories within 15 km of the Installation) identified using overlap of territory buffers (based upon half inter-nest distance radius of 5,082 m) with the hazard areas.

4.3 Study Limitations

Findings in this study were derived from a small sample size of individuals. All six individuals captured and tracked using GPS telemetry were resident adults associated with nesting territories <12 km from the Installation. Of the six individuals studied, five were males. These factors may limit applications of our findings to non-resident eagles (i.e., non-breeders, floaters, migrants, overwintering eagles), or eagles in different age classes (i.e., subadults or fledglings), which visit eastern Maine from origin populations in Florida or Canada. Notable differences in local weather patterns and food availability among regions may also limit comparability among study populations.

4.4 Summary and Conclusions

This study provides first-time quantitative characterizations of space use (i.e., home range) by resident adult Bald Eagles in eastern Maine. Data on habitat use and migration patterns in these individuals provide insights on movement patterns of other coastal-dwelling eagles in eastern Maine. Our analyses supported the general assumption that the proximity of nesting territories to the Installation is a key factor influencing the probability that resident eagles will enter the hazard areas, with the likelihood of use being greater in the non-breeding period (1 Nov – Mar 14) than the breeding/post-breeding period (15 Mar – 31 Oct). When Bald Eagles enter the hazard areas, GPS estimates indicate they predominantly use lower altitudes relative to the height of the towers. Tracking data also demonstrated a high degree of fidelity to nest sites and nesting territories. The two methods we used to assess the encounter risk of resident Bald Eagles ≤15 km of the Installation (UD overlap / proximity vs. mean inter-nest distance) were in relative agreement, collectively suggesting that individuals from 7-8 different nesting territories (39 – 44% of the 18 within the study area) located <5.5 km from the Installation were at increased risk of entering the hazard areas. The characterizations of both vertical and horizontal space use established in this study provide high resolution information that can guide management decisions related to the Installation. Given the lack of home range, habitat use and migratory connectivity information for adult Bald Eagles in Northeastern North America, information elucidated in this study may help inform Bald Eagle conservation and management decisions elsewhere.

4.5 Recommendations for Management Actions and Further Study

Eastern Maine is a population stronghold for Bald Eagles in Maine and New England. While population growth appears to have slowed in eastern Maine compared to previous measures (MDIFW 2019), coastal islands and shorelines in the vicinity of the Installation are likely to continue hosting high densities of Bald Eagles well into the future, and a portion of those eagles will be at risk of entering the Installation hazard areas. Findings of the present study should be considered collectively with previous work on the Installation including the Bird and Bat Conservation Strategy (Tetra Tech 2018*b*) and the Eagle Protection Plan (EPP) (Tetra Tech 2018*a*) to inform future management actions aimed at Bald Eagle risk reduction. Several management actions aimed at avoiding and minimizing risks noted in the EPP include prompt removal of animal carcasses from the hazard areas, evaluation of the pros/cons of Osprey nest removal, consideration of installing visual markers on guy wires, evaluating habitat modifications to lower prey availability to Bald Eagles on the Installation, evaluating the Bald Eagle prey base on the Installation (i.e., waterfowl use of ponds) and assessing how mowing operations impact eagle foraging (Tetra Tech 2018*a*).

We additionally recommend:

- Regular (i.e., every 3-5-years) re-assessment of rapidly developing technological innovations that would: (a) improve the efficiency of detecting live, injured or dead animals (including eagles) in the hazard areas (i.e., remote technologies), and (b) deter Bald Eagles, white-tailed deer and other animals from entering and perching within the hazard areas (i.e., visual, aural tactile deterrents), particularly during inclement weather and periods of low Bald Eagle prey availability.
- Given animal carcasses attract scavengers, efforts should be made to inspect and repair fences designed to exclude large mammals from the hazard areas, particularly during the winter when use by both eagles and ungulates appear to be highest.
- Consider avoiding management actions that would significantly increase carcass persistence rates. Current carcass persistence rates at the Installation are low (≤18.4 hrs; I. Trefry, pers. comm.) due to high levels of activity from skunks, raccoons and other mammals (Tetra Tech 2017).
- Further evaluations of additional habitat management actions, such as mowing and removal of shrubbery and saplings outside the secondary hazard area may improve the probability of detecting bird carcasses.
- We recommend initiation of a database to record the specific perch locations of Bald Eagles on trees, platforms and towers by Navy personnel or contractors that could be used to inform future management actions aimed at deterring perching activities. Perch locations noted in Tetra Tech Inc (2018) and the dataset for this study could be easily incorporated into this database.
- Given that proximity of nest sites to the Installation is likely a key predictor of risk and the population is still growing, we recommend regular Bald Eagle surveys at approximately 5-year intervals to determine the location and occupancy of nesting territories within 15-20 km of the Installation and

periodic re-evaluation of risk evaluations using the mean inter-nest distance approach. If desired, a follow-up survey in June-early July to count surviving young would enable assessments of Bald Eagle productivity (chicks fledged per occupied nest) for the local population.

- To address outstanding data gaps, we recommend additional studies to better understand the use of the Installation by Bald Eagle fledgling and visiting winter migrants using telemetry or other methods.

4.6 Acknowledgements

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