The Impact of Highly Pathogenic Avian Influenza (HPAI) on Cape Breton Island's Bald Eagle (*Haliaeetus leucocephalus*) Population

By

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Abstract

In 2022 Nova Scotia was subjected to a widespread outbreak of highly pathogenic avian influenza (HPAI) virus. The eastern region of the province experienced extreme numbers of infected Northern Gannets washing up along the coastlines of Cape Breton Island. The outbreak occurred during the Bald Eagle breeding season, late May into early June, in Cape Breton. HPAI is spread through ingestion or contact with bodily tissues and fluids, posing a risk for species that scavenge on carcasses. Bald Eagles are carrion feeders and favour easily accessible and ample food sources. Bald Eagles foraged on diseased carcasses of Northern Gannets during the spring and summer of 2022, raising concern for the impact HPAI would have on the Island's eagle population. This study aimed to (1) determine if nesting activity was lower across the Bald Eagle population of Cape Breton Island in the breeding season following a significant HPAI outbreak and (2) determine if Bald Eagle nests with a foraging range that overlapped with marine coastline had lower rates of active nests when compared to nests where foraging ranges did not overlap. Overall there was a lower number of active Bald Eagle nests across Cape Breton Island in 2023 when compared to 2022. There was no significant correlation between foraging range overlapping with Northern Gannet carcass availability and nest status. This research has the potential to inform management decisions surrounding Bald Eagles in Nova Scotia and provides a baseline evaluation of the regional Bald Eagle population response following a major disease outbreak.

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1. Introduction

1.1 Bald Eagle Significance, Behaviour, and History

Bald Eagles (*Haliaeetus leucocephalus*) are a culturally and environmentally significant species (Buehler, 2022; United States Fish and Wildlife Service [USFWS], 2021). The Bald Eagle holds different significances for different Indigenous peoples (Sanipass, 2020), in Mi'kmaq culture, Kitpu (Bald Eagle) is a symbol of love and represents a relationship with the Creator (Sanipass, 2020). During prayer ceremonies, the feather of the Bald Eagle is used as a way of delivering messages to the Creator (Sanipass, 2020; Welker, 2022). In the United States, the Bald Eagle was selected as the Nation's emblem in 1782 and is used as a symbol of freedom and democracy. More recently, thanks to conservation efforts, the species is a well-known example of the success of environmental stewardship efforts (Buehler, 2022).

Bald Eagles are found across North America, throughout Canada, Alaska, the continental US to the northern Mexico (USFWS, 2021; Buehler, 2022). Bald Eagles belong to the genus *Haliaeetus*, sea eagles, which also includes the Steller's Sea-Eagle (*Haliaeetus pelagicus*), Pallas' Fish-Eagle (*Haliaeetus leucoryphus*) and White-tailed Eagle (*Haliaeetus albicilla*) (Buehler, 2022). Bald Eagles are the only *Haliaeetus* found in North America, aside from a vagrant Steller's Sea-Eagle recently reported in the Canadian Atlantic Provinces and northeastern United States (Buehler, 2022; Lundy, 2023).

Bald Eagles display sexual dimorphism and vary in size depending on their latitude, with females averaging 25% larger body mass than males across their range (Buehler, 2022). Their wingspan averages between 1.8 and 2.4 metres, with larger birds being found in the northern latitudes (Buehler, 2022).

Like all raptors, Bald Eagles possess strong taloned feet, keen eyesight, and a hooked beak, characteristics common among birds of prey (Buehler, 2022). Although equipped for hunting, Bald Eagles are opportunistic feeders with their diet dependent on the food sources available to them within their territory (Buehler, 2022; Cash, 1981; Ogden, 1983). Studies on their diet have indicated that when easy food sources are available, Bald Eagles are quick to switch to that new source (Ogden, 1983; Todd et al., 1982). Although they are opportunistic feeders, Bald Eagles do show a preference for fish (Buehler, 2022; Ogden, 1983).

However, they also consume carcasses of birds, and mammals, and will scavenge carrion when abundant and readily available as a food source (Cash 1981; Todd et al., 1982). Bald Eagles can be kleptoparasites, meaning they will actively steal food from individuals both outside and within their species (Elliser et al., 2022). Their diverse foraging habits allow them to take advantage of a wide variety of food sources, but also exposes them to risks associated with these behaviours such as vehicular collisions, disease and poisoning (Mathieu et al., 2021). Lead poisoning contracted from gut piles or waterfowl that have been shot using lead bullets, as well as lead tackle used in fishing, is a rising concern for Bald Eagles (Mathieu et al., 2021). In Nova Scotia, the Department of Natural Resources and Renewables (DNRR) receives several reports of raptors that suffer from lead poisoning each year (DNRR pers. comm.). Their position in the food web as an apex predator also presents the problem of bioaccumulation (USFWS, 2021). Their vulnerability to bioaccumulation of environmental contaminants makes eagles a frequent focal species in contaminant assessment studies (Golden & Rattner, 2003).

Bald Eagles form monogamous bonds, especially in areas where overwintering occurs (Garrett et al., 1993) and exhibit high site fidelity, meaning nests are reused consecutively during breeding seasons when breeding is successful (Winder & Watkins, 2020). Bald Eagles are also known to have alternate, or satellite nests within their territory (Gerrard & Bortolotti, 1988; Stalmaster, 1987), although this varies depending on the breeding pair. Nest building and maintenance occurs one to three months prior to eggs being laid and are often located less than 2km from a water source in a strong limbed tree (Buehler, 2022; Broley, 1947). In Cape Breton, Bald Eagle nests are known to fall within 2km of a body of water (Cash, 1981). Proximity to water becomes less critical when ample food sources are present nearby (Livingston et al., 1990).

Typically there is only one brood per season, unless eggs are destroyed or lost, in which case a replacement clutch may be laid but this is more common in southern latitudes of the Bald Eagle's breeding range (Broley, 1947). In Nova Scotia the typical schedule for Bald Eagle breeding is as follows: March 1-31st nest repairs and mating occur, April 5th-15th egg laying and the beginning of incubation, May 10th-25th hatching of eggs, and July 15th-30th young fledge (Gittens, 1968). Clutch sizes range from one to three eggs, with two eggs being most common (Stalmaster, 1987). During the beginning of the nesting period, females spend roughly 90% of their time at the nest whereas males are present roughly 50% of the time (Fraser, 1981). Once the young have hatched, both parents feed the young with the male providing the majority of the food until the chicks are 3 to 4 weeks old, at which point feeding is split almost evenly among the male and female (Wallin, 1982; Retfalvi, 1965).

Foraging range amongst Bald Eagles can vary. One study conducted in the Columbia River Estuary found the average foraging range amongst resident pairs to be 22km^2, ranging between 6 km^2 and 47 km^2 (Garrett et al., 1993). Another study conducted in Northern Saskatchewan found a breeding pair's range to be 7 km^2 (male) and 4 km^2 (female) (Gerrard et al.,1992). Food availability is known to influence the density of nests within a region, as well as foraging distance, with nest concentration increasing in regions with ample and easily accessible food (Ogden, 1983; Gittens, 1968).

Historically, Bald Eagle populations have experienced large fluctuations, although the current population is now considered to be stable. Prior to colonization in North America, Bald Eagle populations were believed to have been stable and healthy across the continent (Buehler, 2022). With the arrival of European colonizers came the mentality of dominance over nature, manifested by the killing of apex predators such as wolves, bears, and eagles across North America (Leopold, 2020). Farmers, fishers, and hunters targeted these species believing that by extirpating them, livestock, fish, and game populations across the continent would thrive (Buehler, 2022; USFWS, 2021).

Until the mid-20th century, the killing of Bald Eagles was a regular occurrence as they were perceived as a threat to both livestock and fish stock. Over time, people came to realize the ecological significance of the Bald Eagle. In 1940, the significant population decline, because of these practices, led to the implementation of the *Bald Eagle Protection Act* in the United States which outlawed the disturbance, possession, and killing of Bald Eagles (Buehler, 2022; USFWS, 2021). While no such legislation was implemented at the federal level in Canada, most provincial jurisdictions have enacted laws that prohibit disturbance and killing of eagles, such as the *Wildlife Act* in Nova Scotia.

During this time, the population faced not only the threat of hunting for sport and pest control, but habitat loss due to deforestation as well (Buehler, 2022; USFWS, 2021). Typically, Bald Eagles nest in old growth trees, favouring towering pines and spruces near water sources (Nova Scotia Department of Natural Resources [DNR], 2012; Gittens, 1968). Deforestation, in conjunction with widespread use of DDT (dichloro-diphenyl-trichloroethane) as a pesticide, led to another population decline among Bald Eagles (Nisbet, 1989; USFWS, 2021). DDT moves through the environment via waterways, contaminating aquatic species such as fish. Consumption of DDT-laden fish led to an extreme increase in Bald Eagle nesting failure, as the organochlorine pesticide caused eggshells to be overly thin and prone to breaking during incubation (Nisbet, 1989; USFWS, 2021).

By 1963, after the population decline resulting from the use of DDT, it was estimated that only 417 nesting pairs remained within the lower 48 states (Buehler, 2022; USFWS, 2021). Due to protection provided by legislation and regulations in both Canada and the United States, the Bald Eagle population began a slow and successful recovery. Their resiliency in the wake of significant population declines is a well-known example of conservation success (Buehler, 2022; USFWS, 2021). Despite this drastic decrease in population numbers in the United States, populations in Cape Breton, Nova Scotia were considered stable enough after the DDT epidemic that Bald Eagles were taken from the island to repopulate populations within the eastern United States (Austin-Smith, 1983). The population was assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as Not At Risk in 1984 and is now reported to be stable across the majority of its North American breeding range (Buehler, 2022).

1.2 Bald Eagles on Cape Breton Island

Cape Breton Island is home to Nova Scotia's largest population of Bald Eagles (Gittens, 1968), and has the largest concentration in eastern North America (Erskine, 1992). The unique topography and abundant water features across the island create a unique ecosystem ideal for breeding and foraging (Cash, 1981; Ogden, 1983).

Since the late 1960s, DNRR has been monitoring the Bald Eagle population across Cape Breton Island. In a survey of Nova Scotia conducted in conjunction with DNRR (then known as the Department of Lands and Forests), the density of active nests across the province was 0.03 nests per km of coastline, with the exception of the Bras d’Or Lake, where the density ranged from 0.03 nests per km to 0.3 nests per km of coastline (Gittens, 1968). The high concentration of Bald Eagle nests along the Bras d’Or Lake noted in the 1960s surveys is still evident today, as indicated by DNRR nest records, and citizen science platforms like eBird and iNaturalist (eBird, 2024; iNaturalist, 2024; MacDonald & Austin-Smith, 1989).

DNRR is responsible for the management of Bald Eagles in Nova Scotia, and monitoring efforts are an important component of this. Since the 1980s, regular aerial surveys have been conducted across Cape Breton Island to assess nest activity status, which helps to inform department biologists in reviews of environmental assessments and activities on Crown lands. A Special Management Practice (SMP) for Bald Eagle nests, developed by the department (DNR, 2012) is used to promote the preservation of suitable nesting habitat, including nest and perch trees, and foraging and breeding habitat. The SMP guidelines identify buffer zones and timing windows to ensure protection of both active and inactive nests from human disturbance (DNR, 2012). Additionally, *A Field Guide to Forest Biodiversity Stewardship* (DNR, 2017), offers guidance for private landowners on how to manage forestry activities on private land with similar management measures as outlined in the SMP (DNR, 2012).

Bald Eagles can be found across Cape Breton Island, in various ecosystems. The island is comprised of rocky shores, open farmlands, glacial valleys, barren headlands, highlands, and much more (DNR, 2017). The unique topography in conjunction with ample rivers, streams, lakes, and marine coastline create a unique environment for Bald Eagles. Food sources vary on location across the island, but fish, American eels (*Anguilla rostrata*), and carrion are noted as being significant food sources for the Cape Breton Island Bald Eagle population (Cash, 1981).

1.3 Highly Pathogenic Avian Influenza Virus and Bald Eagles

In December 2021, a strain of highly pathogenic avian influenza virus (HPAI) was first detected in wild birds in Newfoundland and Labrador, Canada (Caliendo et al., 2022). Over the course of 2022, this outbreak spread across Canada with confirmed cases reported from coast to coast to coast in both wild birds and poultry (CFIA Arc Map). In Nova Scotia, the first confirmed case of HPAI in relation to this outbreak was recorded in January of 2022 where a Canada Goose (*Branta canadensis*) was reported on the mainland. Following this, the first confirmed occurrence of HPAI in Cape Breton was a bird of prey collected in the Cape Breton Regional Municipality on January 31st (DNRR pers. comm.). This was followed by two confirmed cases of HPAI positive Bald Eagles on Cape Breton Island during the 2022 HPAI outbreak (DNRR pers. comm.). The confirmation of HPAI in Bald Eagles identified the risk of transmission of the virus due to scavenging on deceased, infected wildlife.

The symptoms of HPAI vary depending on strain and the species infected, with some birds such as raptors being more susceptible to succumbing to the virus while others, such as ducks, can be asymptomatic carriers (Caliendo et al., 2022; Hall et al., 2009). HPAI not only poses a threat to birds but can also affect other wildlife and humans as well (Caliendo et al., 2022). This particular strain of HPAI, H5N1 Clade 2.3.4.4b, is known to spread through waterfowl and other migrating bird populations (Lane et al., 2023) with cases of mammals such as red foxes and seals contracting the virus through scavenging (DNRR pers. comm.). The virus is transmitted by contact with infected tissue and fluids, such as blood, saliva, and fecal secretions, and can remain on infected objects and surfaces for hours in dry and hot conditions or months in wet and cold conditions (The Raptor Centre, 1970; Wood et al., 2010).

DNRR staff were responsible for responding to reports of sick, injured or dead birds suspected to be infected with avian influenza and the collection response efforts were employed to mitigate the spread of HPAI through Nova Scotia's wild and captive bird populations. Cases of suspected HPAI were reported to local DNRR offices across the province; with certain regions receiving more reports than others.

In Eastern Canada, breeding colonies of Northern Gannet (*Morus bassanus*) within the Gulf of St. Lawrence and off the coast of Newfoundland were hit particularly hard by HPAI during the breeding season of 2022 (Lane et al., 2023). HPAI's method of transmission and the close proximity of nests within these large colonies allowed for an environment which exacerbated the spread of the virus rampantly throughout the colony (Lane et al., 2023).

Cape Breton Island had significantly more reports of suspected HPAI infected Northern Gannets than the rest of Nova Scotia, particularly along the island's marine coastline (DNRR, pers. comm.). It is thought that infected individuals had succumbed to their symptoms at sea during foraging, and the ocean currents carried the Northern Gannets to the beaches and shorelines of Cape Breton Island and elsewhere in the Gulf of St. Lawrence (DNRR, pers. comm.). Cleanup efforts ensued, with DNRR and Parks Canada employees working to remove as many suspected HPAI infected seabirds as possible from coastlines. At the time of the 2022 outbreak, the author was employed by DNRR as a summer resource student and was heavily involved in these efforts. The inaccessibility of sites, and the size of the island itself in conjunction with the high rate of mortality in a short period of time made it impossible to collect every reported individual, and so areas of high concern (i.e. public beaches, private beaches, coastlines with human activity) were prioritized during cleanup efforts (DNRR pers. comm.).

Along with responding to reports from the public, aerial surveillance of the coast was conducted by DNRR to identify previously undetected or otherwise inaccessible areas with large numbers of dead or dying seabirds. Reports of infected Northern Gannets were concentrated from the end of May to the beginning of June, with hundreds of reports received daily. Between May 10th and June 10th, 2022, more than 1100 dead and dying seabirds, primarily Northern Gannets, were reported to and/or collected by local government agencies (DNRR pers. comm.). Areas where particularly high numbers of seabird carcasses were found included Aspy Bay in northern Victoria County, Inverness County from Cheticamp south to Port Hood, and much of Cape Breton County including Big Glace Bay Beach, Schooner Pond, Sydney Mines, and South Bar to Victoria Mines (DNRR, pers. comm.).

During survey and cleanup efforts along the Cape Breton coastlines, DNRR staff observed Bald Eagles feeding on Northern Gannet carcasses on multiple occasions (DNRR pers. comm), raising concerns about the potential for transmission of HPAI into the Bald Eagle population of Cape Breton Island. During the spring and summer of 2022, two confirmed cases of HPAI in Bald Eagles were reported, both birds having been collected from known active nests in the 2022 breeding season. The transmission of HPAI from infected birds to raptors, including eagles, was documented in several regions globally during the 2021-22 outbreak of HPAI (Nemeth et al., 2023; Günther et al., 2023). As opportunistic foragers, eagles fed on weakened and dead individuals infected with HPAI (Nemeth et al., 2023; Günther et al., 2023; DNRR pers. comm.). A 2022 study assessed the decrease in Bald Eagle nesting success in areas of Georgia and Florida where HPAI positive waterfowl were recorded. It was found that nests in areas with higher exposure to HPAI had a lower success rate in comparison to areas with little to no prevalence of HPAI (Nemeth et al., 2023).

1.4 Study Purpose and Objectives

With the rising concern regarding the impact of HPAI on the Bald Eagle population on Cape Breton Island, this study aimed to assess how ample HPAI contaminated food sources could impact population numbers across Cape Breton Island. Department records indicate that reports of sick, injured, or deceased Bald Eagles across the island in 2022 increased to 150% of the annual average over the previous 10 years (DNRR Biodiversity Investigation Reporting [BIR] System, accessed 22 March 2024). To address the increase in BIR Bald Eagle reports and the concern of HPAI, two main objectives were outlined for this study: (1) Determine if nesting activity was lower across the Bald Eagle population of Cape Breton Island in the breeding season following a significant HPAI outbreak and (2) to determine if Bald Eagle nests with an expected foraging range that included marine coastline had lower rates of active nests when compared to nests where foraging ranges did not overlap with marine coastline.

As such, two null hypotheses were identified:

> H_0: There is no decrease in nesting activity for Bald Eagles in the 2023 breeding season when compared to the 2022 breeding season for Cape Breton Island.
>
> H_0: Changes in nesting activity from 2022 to 2023 for Bald Eagles nesting within foraging distance of the marine coast are similar to those for Bald Eagles that nest further from the marine coast.

The potential for exposure of Bald Eagles to HPAI is expected to be higher along marine coastlines where large numbers of dead and dying infected seabirds were present, raising the question of whether eagles at coastal nests across Cape Breton Island would be at a higher risk of contracting HPAI in comparison to those at nests situated further from the marine coastline.

It is hypothesized that Bald Eagles nesting along the marine coast will have a lower rate of nesting activity in 2023 when compared to those nesting inland or along non-marine coastlines, as exposure to HPAI is expected to be highest along marine coastlines.

2. Study Area

Surveys were conducted at known Bald Eagle nest sites across Cape Breton Island, on the east coast of Nova Scotia (Figure 1). The island is divided into four counties: Cape Breton, Richmond, Inverness, and Victoria. The major ecodistricts on the island include the expansive taiga of the Northern Plateau and high elevation boreal forest of the Cape Breton Highlands, the rolling topography and steep slopes of the Cape Breton Hills, and the low-lying coastal Victoria Lowlands, Inverness Lowlands, Bras d'Or Lowlands, and Cape Breton Coastal ecodistricts (DNR, 2017).

A notable feature of the Island is the Bras d'Or Lake, a brackish body of water connected to the ocean and fed by many freshwater rivers (BLBRA, 2024). Major freshwater bodies on Cape Breton Island include Lake Ainslie and the Margaree River in the west, and the Mira River in the southeast (Figure 1). Marine coastlines are a mix of sand and gravel beaches, rocky shorelines, and steep inaccessible cliffs.

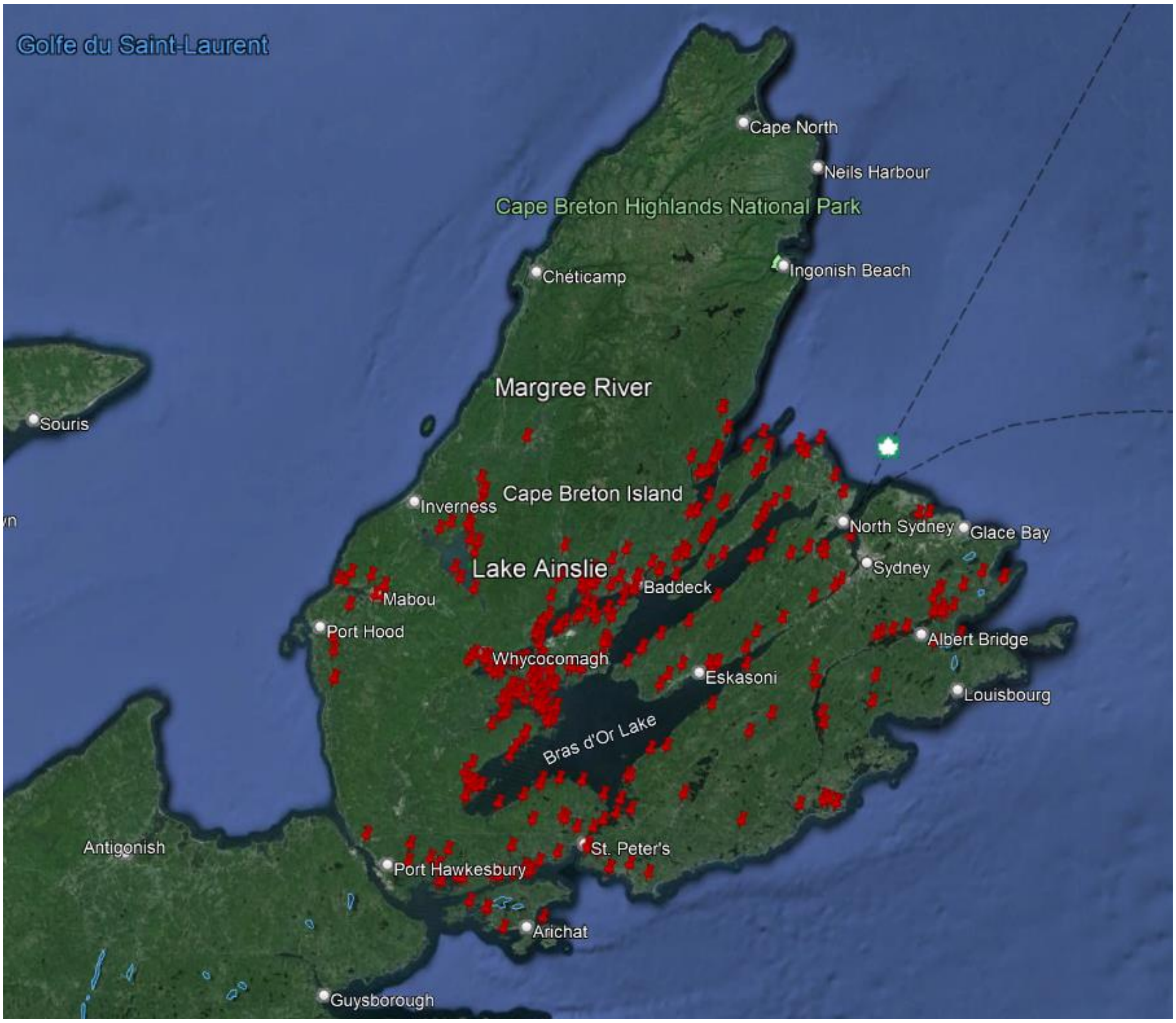


Figure 2.1 All known Bald Eagle nests from 2022 surveys across Cape Breton Island.

3. Methods

3.1 Aerial surveys

DNRR has conducted annual aerial Bald Eagle nest surveys on Cape Breton Island since the 1980s using a standardized protocol. Surveys are conducted by helicopter, ideally between April 1st and June 30th, as when nests are active with young and nest visibility is optimal prior to spring leaf-out; however, this is not always possible due to logistical constraints. Fledging peaks across Nova Scotia the last week of July (Gittens, 1968), therefore by conducting the surveys within the above timeline, the likelihood of the chicks having fledged prior to surveys is reduced.

The longstanding dataset of known Bald Eagle nests across the island, supplemented by newly reported nest records, is used to determine survey routes each spring. Flights are conducted during daylight and in safe weather conditions, ideally during warm, clear or overcast days with little to no wind. These conditions allow for suitable visibility and flight accuracy. Navigation during the 2022 and 2023 surveys was done using ForeFlight software, allowing pilots to navigate to the general area of each nest where a handheld GPS with more precision is used to locate the nest tree.

Each survey team consisted of a pilot, a primary observer, a secondary observer, and when possible a tertiary observer. Typically, the primary and secondary observers sat on the left side of the helicopter in the front and back seats allowing for the best nest visibility. The primary observers for the 2022 and 2023 seasons all had previous experience in Bald Eagle nest surveys, which allowed for efficient nest assessment and data collection. Nest waypoints were approached by flying low enough to see if the adult left the nest, and to see, any eggs or nestlings. Height was maintained for safety and to reduce disturbance to the nest. Nest visits are typically completed in less than ten seconds.

DNRR's protocol recommends one pass of the nest, whether the female Bald Eagle flushes or not, and so it is often not possible to observe eggs and young directly, although the presence and behaviour of adults is itself a reliable indicator of nesting activity. Males typically will be above the machine circling while females will either remain incubating or will flush to the side of the helicopter (DNRR, 2021).

During a nest pass, observers record the nest status (i.e., whether the nest is still present and in good repair), whether or not the nest is active, and breeding evidence (if any). Breeding evidence is determined by presence of one or both territorial adults at the nest site, presence of fresh nest material, incubating or brooding behaviour, and/or presence of eggs or chicks.

It is important to note that the safety of both the eagles and crew members is of the utmost importance, and as a result the direction of approach or specifics in protocol varied depending on the pilot's assessment of wind speed and direction, surrounding terrain, and the behaviour of territorial adults near the helicopter.

In 2022, surveys were conducted over four days between May 2nd and June 2nd. However, in 2023, there were limitations on aircraft availability and poor weather conditions. An extremely active fire season in mainland Nova Scotia required full-time use of Department helicopters over much of the Bald Eagle survey window, and poor weather conditions further limited surveys. As a result, many of the nests could not be visited until mid-July; by this time, visibility of nests is impacted due to leaf-out. Furthermore, fledging of Bald Eagle nestlings is well underway (Gittens, 1968) and so, in the absence of nest occupants, determination of nest activity status was not always possible. In these cases, if new nesting material was observed in the nest, it was inferred to have been active in 2023; otherwise, the activity status was considered ‘unknown’ and the nest was discarded from the analysis.

3.2 Data Collection and Analysis

Survey data from all observers were entered into a master spreadsheet. The master spreadsheet is archived with DNRR for future surveys and population management. Once data was made accessible via Excel, sorting of nests into inclusion or exclusion of this study was completed. For nests to be included in the analysis they had to be surveyed in both 2022 and 2023. Nests that were newly identified in 2023 and those that were inactive in both 2022 and 2023 were removed from the dataset prior to analysis as the status in 2022 and 2023 was used to assess nest activity changes across the two years.

Nests were mapped (ArcPRO) and any nests within 0.5km of the main nest was considered to be a satellite nest. Only one satellite nest was identified from 2022 and 2023 Bald Eagle nests (DNRR pers. comm.).

A 2 km buffer of the marine coast was overlaid to determine which nests were within foraging distance of shoreline. Nests overlapping with the 2 km buffer were classified as “Coastal”, and all other nests (including those situated along the Bras d’Or Lake and freshwater bodies) were classified as “Non-coastal”. Although the Bras d’Or Lake is brackish, this classification is intended to account for the Northern Gannet carcasses that occurred along marine coastlines. The 2 km buffer was selected due to observed foraging behaviour during breeding seasons where home ranges averaged 4 km^2 to 7 km^2 and because the typical foraging range is less than 2km (Buehler, 2022; Gerrard et al., 1992; Garrett et al., 1993).

3.3 Statistical Analysis

Nests were classified as active or inactive based on breeding evidence (or lack thereof) at the time of survey. Nests with territorial adults, incubation, young, or eggs were considered active for the breeding season .

Bald Eagles have high site fidelity, and the nesting population of Cape Breton Island has been the subject of long-term annual surveys, which allowed the opportunity to assess potential impacts as a result of the HPAI outbreak. However, a confounding variable for this study was the impact of Hurricane Fiona in the fall of 2022, which downed thousands of trees throughout Nova Scotia, particularly in coastal areas in the eastern part of Cape Breton (Al-Hakim, 2022; Pasch et al., 2023). Any nest trees determined to be blown down during 2023 surveys were presumed to have been lost due to hurricane damage and were removed from the data set prior to analysis. Nests that were inactive in both 2022 and 2023 were also removed from the data set as they could not be used within the design of this study as an indicator of HPAI impact on nesting activity.

To test the null hypothesis that nest activity was similar before and after the 2022 HPAI outbreak, a chi-squared test was used to compare counts of active and inactive nests in 2022 and 2023, for both the coastal and non-coastal categories; with the null hypothesis we would see that the number of active and inactive nests in 2023 would be the same as in 2022.

To explore the within-nest change in activity between years in coastal and non-coastal nests, a “Status Change” variable was created in which nests were classified as: activated, inactivated, or and no change. “Inactivated” nests were those that were active in 2022 but inactive in 2023, indicating that the breeding pair did not nest in the year following the HPAI outbreak. “Activated” nests were those that were inactive during the 2022 surveys but were active during the 2023 surveys, and “No change” nests were those found to be active in both 2022 and 2023. To test the null hypothesis that changes in nesting activity rates in coastal and non-coastal nests were similar, a chi-squared test was performed to compare the status change categories for coastal nests and non-coastal nests.

4. Results

A total of 361 nests were surveyed in both 2022 and 2023; of these, 206 were inactive in both years and removed from the data set, and a further 5 nests were lost to hurricane damage. Of the remaining 150 nests, 41 were within 2 km of the marine coast (“coastal”) and 109 were not (“non-coastal”) (Figure 2). The number of active and inactive nests observed in 2022 and 2023 is shown in Figure 3; overall, the proportion of active nests decreased for both coastal and non-coastal nests. This decrease in nesting activity was statistically significant ($p < 0.001$) between 2023 and 2022 (Table 1; chi2 = 55, df = 1).

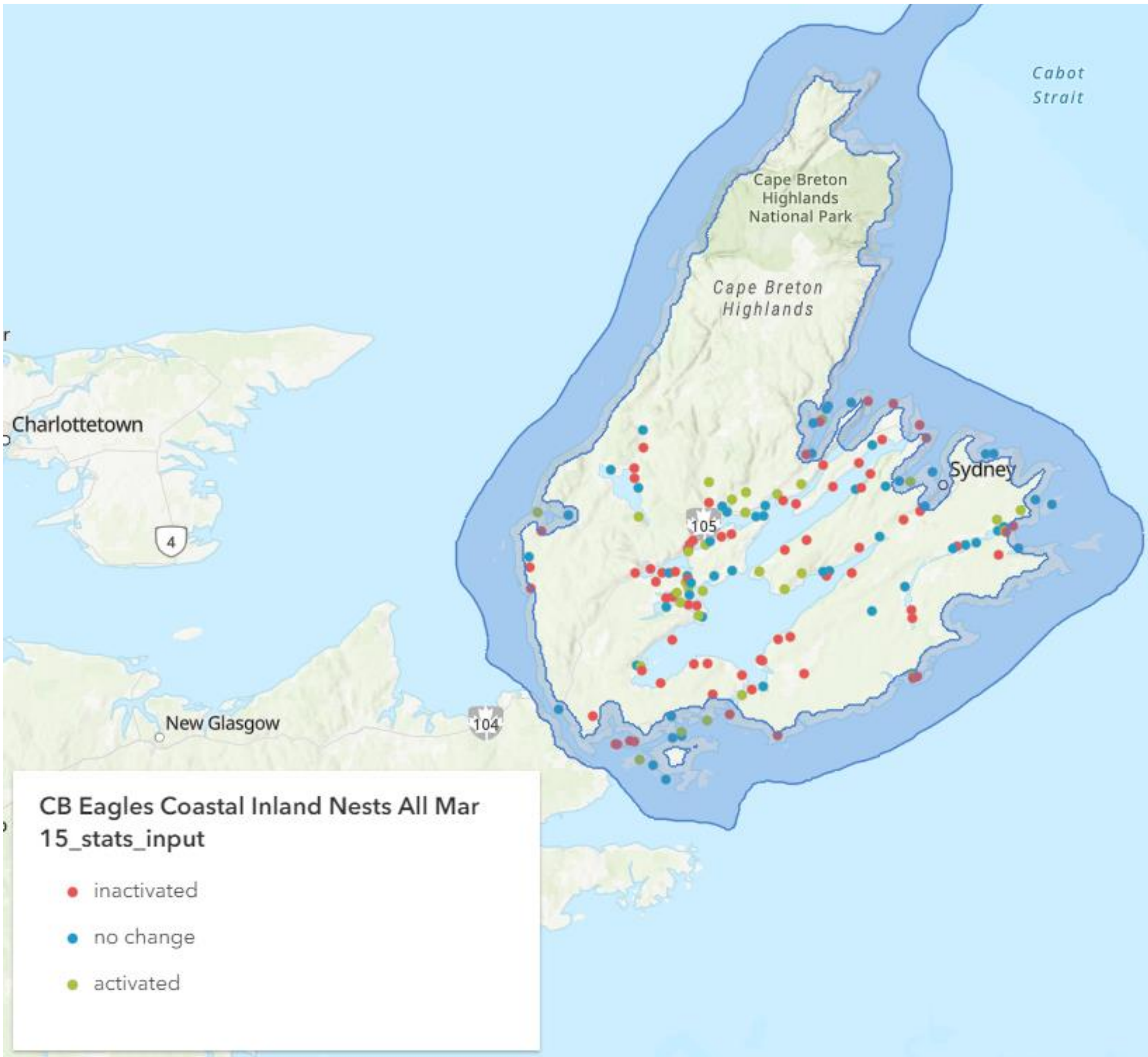
In 2022 there were 34 active coastal nests and 7 inactive coastal nests, and 86 active non-coastal nests and 23 inactive non-coastal nests. In 2023 there were 27 active coastal nests and 14 inactive coastal nests, and 57 active non-coastal nests and 52 inactive non-coastal nests. When the change in activity status from 2022 to 2023 is compared, the distribution among the status change categories is statistically similar for coastal and non-coastal nests ($p = 0.132$) suggesting that the change in nesting activity for nests within foraging distance of the marine coast did not differ from nests that were not within foraging distance (Table 2; chi2 = 4.05, df = 2).

4.1 Table 1. Number of active and inactive Bald Eagle nests for the 2022 and 2023 seasons used for analysis. A Chi-square test was used to determine the validity of the hypothesis. Chi2= 55, df= 1, p value of 0.00.

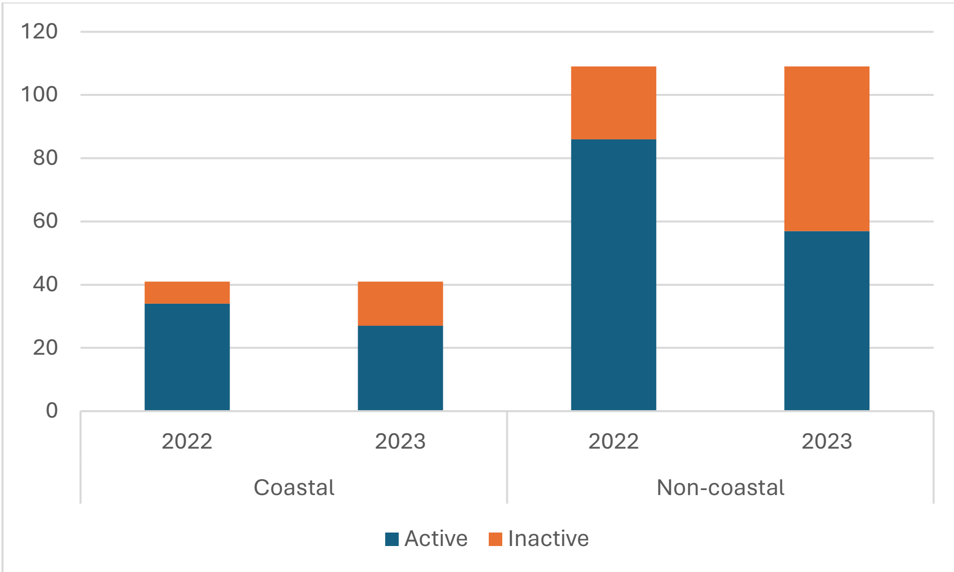
	2023		2022		(2023 - 2022)		(Obs-Exp)2/Exp	
Status	Coastal	Not Coastal	Coastal	Not Coastal	Coastal	Not Coastal	Coastal	Not Coastal
Active	27	57	34	86	-7	-29	1	10
Inactive	14	52	7	23	7	29	7	37
Totals	41	109	41	109				

4.2 Table 2. Nest activity status analysis based on 2022 and 2023 Bald Eagle nest surveys. A Chi-square test was used to determine the validity of the hypothesis. Chi2=4.05, df= 2, p value of 0.130.

		Observed		Expected		Obs - Exp		(Obs-Exp)2/Exp	
Status Change (2022 to 2023)	Totals	Coastal	Not Coastal	Coastal	Not Coastal	Coastal	Not Coastal	Coastal	Not Coastal
No Change	54	20	34	15	39	5	-5	1.860	0.700
Inactivated	66	14	52	18	48	-4	4	0.900	0.340
Activated	30	7	23	8	22	-1	1	0.180	0.070
Totals	150	41	109	41	109				



4.3 Figure 2. Map of Bald Eagle nests used in the statistical analysis after data sorting had occurred with the 2km marine buffer applied. Nests falling within the buffer are considered coastal and those outside of the buffer non-coastal.



4.4 Figure 3. Number of Active and Inactive nests for "Coastal" and "Non-Coastal" category for both the 2022 and 2023 Bald Eagle Nest Surveys.

5. Discussion

There was a significant decrease in nesting success across Cape Breton Island based on 2023 survey results (Table 1). However, results from survey efforts do not indicate a larger proportion of decreased Bald Eagle nesting activity in nests situated in the coastal category (Table 2).

5.1 Comparison of Active Bald Eagle nests in 2022 and 2023

There is a decrease in active Bald Eagle nests across Cape Breton Island. In 2022, there was a total of 120 active nests across Cape Breton Island, whereas in 2023 only 84 active nests were counted. This decrease in active nests could imply that HPAI outbreaks impact nests with foraging ranges outside of the coastal category. The buffer chosen for this study relied on average foraging ranges during breeding seasons for Bald Eagles (Retfalvi, 1965; Dzus & Gerrard, 1993; Gerrard et al, 1992); however, it is possible that this buffer did not encompass the extent of HPAI spread across Cape Breton Island as it was detected in other species such as waterfowl, corvids, seabirds, and other raptors (CFIA, 2024).

The abundance of easily accessible food along coastlines may have also expanded the foraging range of nesting pairs. When ample and easily accessible food is present, foraging behaviour for bald eagles is known to favour these sources over closer, conventional ones that require more effort (Ogden, 1983).

Although the null hypothesis of no relationship between marine coastline foraging was supported, Chi-square tests did indicate that the proportion of active vs inactive Bald Eagle nests across Cape Breton Island was statistically significant, meaning there was a notable change in the proportion of active and inactive nests across the 2022 and 2023 breeding seasons. Without confirmation that inactivated nests were exposed to the HPAI clade 2.3.4.4b, we cannot say with certainty that the decrease in nesting activity between the two years was due to the 2022 HPAI outbreak. However, there was a decrease overall from 120 active nests to 84 active nests from 2022 to 2023, which is cause for concern. A factor that could contribute to this decline in active nests between 2022 and 2023 is lead poisoning. The Department typically receives multiple reports of Bald Eagles across Cape Breton Island that are suffering from lead poisoning each year, however this was not accounted for within the study design (DNRR pers. comm).

5.2 Impact of Avian Influenza on Coastal Bald Eagle Nests

It was hypothesized that coastal Bald Eagle nests would have a lower proportion of nesting activity in the breeding season following a major outbreak of HPAI across Cape Breton Island, during the previous breeding season. Results indicate that coastal nests did not in fact have a lower proportion of active nests in 2023 in comparison to non-coastal nests (Table 2). However, of the two confirmed cases of HPAI in Bald Eagles recorded in Cape Breton during 2022, one nest fell within the coastal category while the other was non-coastal.

In previous studies that assessed the impact of HPAI on Bald Eagles, there is evidence to support that even with exposure to HPAI, Bald Eagles are capable of developing immunity to the virus (Günther et al., 2023) which is a factor not accounted for within this study design and could factor into the assessment of HPAI spread across Cape Breton Island's Bald Eagle population.

Possible reasons for the lack of support for this relationship between proximity to coastline and nesting activity could be (1) Nesting surveys in 2023 were not conducted on a timeline that captured the true active and inactive nest counts, and (2) The spread of HPAI through the Bald Eagle population on Cape Breton Island is not localized to coastal nests.

5.3 Methods Comparison

It is common modern practice to use aircraft, normally helicopters, for Bald Eagle nesting surveys (Gittens, 1968). Helicopters provide an efficient and less invasive survey method in comparison to the use of fixed wing aircraft (Gittens, 1968). However, excessive nest disturbance associated with helicopter use during surveys has been found to have a negative impact on nesting activity during the breeding season following surveys (Austin-Smith, 1983; Gittens, 1968). Delayed Disturbance Response is thought to be a factor in nesting success decrease the year following aerial surveys (Gittens, 1968). However, DNRR has been consistently monitoring the Cape Breton Island Bald Eagle population via aerial surveys without any notable impact from Delayed Disturbance Response, as the survey protocol is designed to be minimally invasive and reduce effects from such disturbances.

Alternative methods for surveying nests can involve blind usage, accessing nests via a ladder, and fixed wing aircraft aerial surveys (Austin-Smith, 1983). Each approach has its own limitations; disturbance rate and efficiency being two large factors. In the case of this study, and DNRR protocol, a limited time window meant helicopter aerial surveys were the most feasible option for obtaining nest data.

Studies assessing the impact of HPAI on Bald Eagles have recently emerged with the 2021-2022 outbreak of clade 2.3.4.4b across North America. A study conducted in Florida and Georgia during the 2022 breeding season found a positive correlation between HPAI positive Bald Eagles and proximity to areas with high amounts of waterfowl mortality. This study combined aerial surveys, reported bald eagle and waterfowl mortality sites, and immunochemistry testing results to assess the impact of HPAI on Bald Eagle nests (Nemeth et al., 2023). These methods, used in conjunction, allowed for a more complete data set, and specific details on positive cases associated with the nests of that year. Immunochemistry tests were not feasible for this project, as testing is normally carried out by the Canadian Wildlife Health Cooperative (CWHC). When possible, DNRR sent viable Bald Eagle samples to CWHC for HPAI testing, with positive tests results indicating that Bald Eagles in Cape Breton were in fact succumbing to HPAI.

5.4 Study Limitations

There were several limitations within the study design. One of the most significant limitations was the aircraft availability during the standard survey window. At the time of surveys in 2023, DNRR was in the midst of combating several wildfires that were spread across the province (DNRR pers. comm.). This issue occurred during the 2022 season as well, when limited aircraft availability in July of 2022 meant late season nest surveys, in the midst of the HPAI outbreak, were not feasible as well. Although limited aircraft availability impacted the ability to survey Bald Eagle nests during ideal periods, peak breeding season in 2022 and post HPAI outbreak in 2022, the study was conducted to the best of the Department's ability with these constraints in place.

This resulted in two separate survey windows, one in May and another in July. The surveys conducted in May were not done consecutively but were all done within the period of the breeding season when the likelihood of the nestlings having fledged is low (Gittens, 1968). July surveys were completed outside of the period listed within DNRR protocol. Therefore, late season surveys have a higher likelihood of nests having been active for the 2023 season but were incorrectly noted as Inactive due to the uncertainty of fledging having possibly occurred.

A large proportion of Bald Eagle surveys are done by surveying during the breeding period, when eagles are more likely to be on their nest or within their smaller home range

(DNRR, n.d.). This is common practice in Bald Eagle surveys but does present a possible variable that was not captured within the study, as juvenile Bald Eagles are more prone to ground foraging and carrion feeding than adult Bald Eagles (Bennetts & McClelland, 1997). A study conducted in Glacier National Park, Montana, found that ground

piracy in Bald Eagles decreased with age, whereas stooping increased with age (Bennetts & McClelland, 1997). Ground piracy is foraging behaviour such as carrion feeding and kleptoparasitism (Elliser et al., 2022). Stooping is the act of diving for prey which is common amongst birds of prey (Buehler, 2022). This could highlight a limitation within the study design, where juveniles, which may be more likely to forage on HPAI positive carcasses and are not accounted for within the data set as surveys count mature breeding bald eagles. This prevents us from assessing the impact of HPAI across the Bald Eagle population for Cape Breton Island as a whole, because there is only data on breeding pairs.

Another possible limitation is the exclusion of four known nests in Northern Victoria and Inverness counties. Surveys in 2022 and 2023 were not conducted in regions north of Indian Brook due to time constraints. Although there is no recent nest data for Bald Eagles in this area, there are Bald Eagles in this region (eBird, 2024; iNaturalist, 2024) and many Northern Gannets were noted along these coastlines, meaning the survey data is not representative of any impact HPAI had on Bald Eagles in this region of Cape Breton Island.

6. Conclusion

An overall decrease in active Bald Eagle nests in the 2023 breeding season in comparison to the 2022 breeding season nest surveys was noted. These results do not directly indicate that HPAI was a factor in this decrease, however the lack of data on HPAI spread through the ecosystems via other means or in remote areas could be a factor, as such we cannot rule out HPAI as a factor in this decrease. Further research is required to identify if this relationship is supported or not, as this study design did not account for inland waterfowl species or inaccessible areas of Cape Breton Island. This study provides a baseline for further research into the resiliency of Cape Breton Island's Bald Eagle population in the face of disease outbreaks.

The study results do not indicate a strong correlation between 2023 nesting status and proximity to marine coastline, thus implying that exposure to HPAI infected Northern Gannet carcasses along marine coastlines of Cape Breton Island in 2022 did not have a direct impact on coastal nests the following year. As mentioned in the discussion, it is possible that HPAI is responsible for the overall decrease, however proximity to coastline did not appear to be a significant factor. The survey timing in conjunction with a lack of juvenile Bald Eagle data could be responsible for the support of the null hypothesis (Gittens, 1968; Bennett & McClelland, 1997).

Where there are few studies thus far regarding the status of Bald Eagles in Nova Scotia, this assessment of the largest breeding population within the province is a key stepping stone in the continued protection and management of Nova Scotia's Bald Eagle population. This project also provides DNRR with information on how the population's distribution and count has changed in the face of a major disease outbreak. Further, documented nest activity can be used to properly inform forestry and land management decisions moving forward, to further the Department's goal of protecting and procuring ideal nesting, foraging, and breeding habitat for Bald Eagles across Cape Breton Island.

Recommendations for future research into HPAI impacts on Bald Eagles would be an extension of the foraging buffer to account for a higher rate of exposure. As discussed in the study limitations, there is the possibility that HPAI in other bird species could be responsible for the decrease in active non-coastal nests. When food sources are easily accessible and in ample supply as the Northern Gannets were, there is the possibility that typical foraging ranges were extended, even during the breeding season. An adjustment to the marine coastline buffer could help to account for this variable in future research into HPAI impacts on Bald Eagles.

For the future of Bald Eagle research across Cape Breton Island, the continued monitoring of the population is vital. Should the Bald Eagle population be subjected to another disease or viral outbreak in the future, having an accurate baseline population count through nest surveys will allow for a better understanding of the potential impacts felt by the population. If we wish to fully understand the extent to which HPAI impacts can be felt by Bald Eagles across Cape Breton Island, maintaining a longstanding dataset of Bald Eagle nest surveys is a foundational step in the process of doing so.

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8. Appendix

Table A.1: Bald Eagle Nest Survey Data 2022-2023

Waypoint	NestID	County	2023_statu	2022_statu	Coastal_Y_	Status_Change
W002	R-162	Richmond	Active	Inactive	N	activated
W005	R-72	Richmond	Active	Active	N	no change
W006	R-142	Richmond	Inactive	Active	N	inactivated
W007	R-164	Richmond	Inactive	Active	N	inactivated
W008	R-2	Richmond	Inactive	Active	N	inactivated
W010	R-73	Richmond	Inactive	Active	N	inactivated
W011	R-143	Richmond	Active	Inactive	Y	activated
W024	R-168	Richmond	Inactive	Active	Y	inactivated
W025	R-130	Richmond	Active	Inactive	Y	activated
W029	R-154	Richmond	Active	Active	Y	no change
W030	R-99	Richmond	Active	Inactive	Y	activated
W031	R-116	Richmond	Active	Active	Y	no change
W032	R-155	Richmond	Active	Active	Y	no change
W038	R-146	Richmond	Active	Active	Y	no change
W039	R-157	Richmond	Active	Active	Y	no change
W041	R-148	Richmond	Active	Inactive	Y	activated
W042	R-61	Richmond	Inactive	Active	Y	inactivated
W043	R-149	Richmond	Inactive	Active	Y	inactivated
W044	R-106	Richmond	Inactive	Active	Y	inactivated
W045	R-172	Richmond	Inactive	Active	Y	inactivated
W050	R-170	Richmond	Inactive	Active	N	inactivated
W051	R-36A	Richmond	Inactive	Active	N	inactivated
W054	R-56	Richmond	Inactive	Active	N	inactivated
W055	R-79	Richmond	Inactive	Active	N	inactivated
W057	R-150	Richmond	Inactive	Active	N	inactivated
W059	R-119	Richmond	Inactive	Active	N	inactivated
W062	CB-147	CB	Inactive	Active	N	inactivated
W063	CB-177	CB	Inactive	Active	N	inactivated
W064	CB-139	CB	Active	Active	Y	no change
W065	CB-189	CB	Active	Active	N	no change
W066	CB-192	CB	Active	Active	Y	no change
W067	CB-161	CB	Active	Inactive	Y	activated
W069	CB-133	CB	Active	Active	Y	no change
W070	CB-167	CB	Active	Active	Y	no change
W071	CB-192	CB	Active	Active	Y	no change
W072	CB-157	CB	Active	Active	Y	no change

W074	CB-194	CB	Active	Active	Y	no change
W075	CB-168	CB	Active	Inactive	N	activated
W078	CB-165	CB	Active	Inactive	N	activated
W080	CB-186	CB	Active	Active	N	no change
W081	CB-185	CB	Active	Active	N	no change
W082	CB-173	CB	Active	Inactive	N	activated
W083	CB-196	CB	Inactive	Active	N	inactivated
W084	CB-197	CB	Inactive	Active	Y	inactivated
W085	CB-109	CB	Active	Active	Y	no change
W086	CB-170	CB	Inactive	Active	N	inactivated
W087	CB-118	CB	Active	Active	N	no change
W088	CB-187	CB	Active	Active	N	no change
W089	CB-188	CB	Inactive	Active	N	inactivated
W090	CB-198	CB	Active	Active	N	no change
W092	CB-158	CB	Active	Active	N	no change
W094	CB-146	CB	Inactive	Active	N	inactivated
W095	CB-132	CB	Inactive	Active	N	inactivated
W098	CB-191	CB	Active	Active	N	no change
W101	CB-172	CB	Inactive	Active	N	inactivated
W102	CB-174	CB	Active	Active	N	no change
W103	CB-202	CB	Inactive	Active	N	inactivated
W105	CB-175	CB	Active	Active	N	no change
W106	CB-53	CB	Inactive	Active	N	inactivated
W107	CB-54	CB	Active	Active	N	no change
W108	CB-162	CB	Active	Inactive	N	activated
W110	CB-203	CB	Active	Inactive	N	activated
W111	CB-63	CB	Active	Inactive	N	activated
W114	CB-89	CB	Inactive	Active	N	inactivated
W115	CB-154	CB	Inactive	Active	N	inactivated
W117	CB-190	CB	Active	Active	N	no change
W118	CB-183	CB	Inactive	Active	N	inactivated
W119	CB-204	CB	Inactive	Active	N	inactivated
W120	CB-83	CB	Inactive	Active	N	inactivated
W121	CB-81	CB	Active	Active	N	no change
W125	CB-164	CB	Inactive	Active	N	inactivated
W126	V-18A4	CB	Inactive	Active	N	inactivated
W128	V-18B3	CB	Inactive	Active	N	inactivated
W131	CB-206	CB	Inactive	Active	Y	inactivated
W133	CB-180	CB	Inactive	Active	Y	inactivated

W134	CB-184	CB	Inactive	Active	Y	inactivated
W135	I-114	Inverness	Inactive	Active	N	inactivated
W140	I-078	Inverness	Inactive	Active	N	inactivated
W142	I-107	Inverness	Inactive	Active	N	inactivated
W145	I-143	Inverness	Inactive	Active	N	inactivated
W146		Inverness	Active	Active	N	no change
W150	I-145	Inverness	Inactive	Active	N	inactivated
W152	I-125 / VI-142	Inverness	Inactive	Active	N	inactivated
W153	I-003	Inverness	Inactive	Active	N	inactivated
W155	I-156	Inverness	Active	Inactive	N	activated
W158	I-091	Inverness	Active	Inactive	N	activated
W161	I-084	Inverness	Active	Active	N	no change
W170	I-039	Inverness	Inactive	Active	N	inactivated
W172	I-171	Inverness	Active	Active	N	no change
W177		Inverness	Active	Inactive	N	activated
W183		Inverness	Inactive	Active	N	inactivated
W184	I-152	Inverness	Active	Inactive	N	activated
W186	I-160	Inverness	Inactive	Active	N	inactivated
W189		Inverness	Active	Inactive	N	activated
W190	I-161	Inverness	Inactive	Active	N	inactivated
W193		Inverness	Active	Active	N	no change
W201	I-064	Inverness	Inactive	Active	N	inactivated
W205		Inverness	Active	Active	N	no change
W207	I-096	Inverness	Active	Inactive	N	activated
W209	I-154	Inverness	Active	Active	N	no change
W212	I-122	Inverness	Active	Active	Y	no change
W213	I-050	Inverness	Inactive	Active	Y	inactivated
W215	I-058	Inverness	Inactive	Active	N	inactivated
W216		Inverness	Active	Active	N	no change
W217		Inverness	Inactive	Active	Y	inactivated
W220	I-124	Inverness	Active	Active	Y	no change
W222		Inverness	Active	Inactive	Y	activated
W227		Inverness	Active	Active	N	no change
W230		Inverness	Inactive	Active	N	inactivated
W231		Inverness	Inactive	Active	N	inactivated
W233		Inverness	Active	Active	N	no change
W234		Inverness	Active	Inactive	N	activated
W235	I-059	Inverness	Inactive	Active	N	inactivated
W239		Inverness	Active	Active	N	no change

W242	VI-114	Victoria	Active	Inactive	N	activated
W245	VI-155	Victoria	Active	Inactive	N	activated
W248	VI-003	Victoria	Active	Active	N	no change
W251		Victoria	Active	Active	N	no change
W252	VI-094	Victoria	Active	Inactive	N	activated
W253	VI-New6	Victoria	Inactive	Active	N	inactivated
W257		Victoria	Inactive	Active	N	inactivated
W265	VI-142 / I-125	Victoria	Inactive	Active	N	inactivated
W268	VI-145	Victoria	Active	Inactive	N	activated
W273		Victoria	Active	Active	N	no change
W276	VI-146	Victoria	Inactive	Active	N	inactivated
W277	VI-120	Victoria	Active	Active	N	no change
W283	VI-122	Victoria	Active	Inactive	N	activated
W284	VI-117	Victoria	Active	Active	N	no change
W289	VI-173	Victoria	Active	Active	N	no change
W296	VI-New7	Victoria	Active	Inactive	N	activated
W299	VI-150	Victoria	Active	Active	N	no change
W301	VI-121	Victoria	Inactive	Active	N	inactivated
W305	VI-087	Victoria	Inactive	Active	N	inactivated
W311	VI-113	Victoria	Active	Active	N	no change
W312	VI-160	Victoria	Active	Active	N	no change
W314	VI-132	Victoria	Active	Active	N	no change
W316	VI-47	Victoria	Active	Inactive	N	activated
W318		Victoria	Inactive	Active	N	inactivated
W321	VI-159	Victoria	Active	Inactive	N	activated
W328		Victoria	Inactive	Active	N	inactivated
W334	VI-163	Victoria	Inactive	Active	Y	inactivated
W336		Victoria	Active	Active	Y	no change
W342	VI-167	Victoria	Active	Active	Y	no change
W344		Victoria	Active	Active	Y	no change
W347	VI-015	Victoria	Active	Inactive	Y	activated
W349	VI-153	Victoria	Inactive	Active	Y	inactivated
W351	VI-102	Victoria	Active	Active	Y	no change
W355	VI-129	Victoria	Active	Active	Y	no change
W356	VI-081	Victoria	Inactive	Active	Y	inactivated