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Pacific Island Landbird Monitoring Report, Kalaupapa National Historical Park, 2021

‘Apapane (*Himatione sanguinea*)
NPS / JANICE WEI

Pacific Island landbird monitoring report, Kalaupapa National Historical Park, 2021

Science Report NPS/SR—2025/322

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Abstract

In 2021, landbird surveys were conducted at Kalaupapa National Historical Park on the island of Moloka‘i to assess changes in species composition, distribution, and population densities since 2005. Point-transect distance sampling surveys were conducted on six transects at 50 landbird monitoring stations within an 1,834-hectare area. A total of nine landbird species were detected, with the ‘Apapane (*Himatione sanguinea*) the only endemic Hawaiian species detected. Sufficient detections of six species allowed for population density and abundance estimates, which were compared to 2005 estimates using a two-sample *z*-test. The abundance of ‘Apapane declined by 57% to 2,476 ± 729 (SE) birds in 2021 compared to 2005. Population densities of the House Finch (*Haemorhous mexicanus*), Japanese Bush Warbler (*Horornis diphone*), Warbling White-eye (*Zosterops japonicus*), and White-rumped Shama (*Copsychus malabaricus*) were also lower in 2021 than in 2005, but comparisons were inconclusive. Since 2005, the Red-billed Leiothrix (*Leiothrix lutea*) irrupted within the survey area to an estimated abundance of 11,088 ± 1,208 birds. The Warbling White-eye was the most abundant species, with an estimated 101,724 ± 11,692 birds. Surveyors failed to detect the Hawai‘i ‘Amakihi (*Chlorodrepanis virens),* which has become increasingly rare on Moloka‘i. The federally threatened ‘I‘iwi (*Drepanis coccinea*) was last seen on Moloka‘i in 2010, further raising concerns about its potential extirpation. The Oloma‘o (*Myadestes lanaiensis*), an endemic thrush, has not been detected since 1980 and is likely extinct. These findings show the ongoing shift toward non-native bird communities and highlight the challenges of conserving native forest birds amidst widespread avian malaria transmission, introduced predators, and extensive habitat degradation.

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Introduction

Hawaii is home to a significant proportion of the nation's imperiled wildlife, with nearly 500 species of plants and animals listed as threatened or endangered—accounting for over 30% of all federally protected species in the United States (USFWS 2024). Approximately 75% of the 142 endemic Hawaiian species of birds have gone extinct since humans first arrived in Hawaii (Olson and James 1982, Banko and Banko 2009, Elphick et al. 2010). Only 21 species of endemic forest birds persist in the main Hawaiian Islands (VanderWerf et al. 2018, Chesser et al. 2022), and, of those, 12 are threatened or endangered (USFWS 2024). On the island of Molokaʻi, the only native forest birds commonly observed are Hawaiʻi ʻAmakihi (*Chlorodrepanis virens*) and ʻApapane (*Himatione sanguinea*). The ʻIʻiwi (*Drepanis coccinea*) was listed as threatened in 2017 (USFWS 2017) and is rarely detected on Molokaʻi, with the last detection in 2010 (Smith et al. 2025). The endangered Olomaʻo (*Myadestes lanaiensis*) was last seen in 1979 and 1980 (Scott et al. 1986) and the species is currently undergoing its fourth five-year review to assess its status (USFWS 2021). Another Molokaʻi endemic, the Kākāwahie (*Paroreomyza flammea*) was recently delisted as an endangered species due to extinction, having not been detected since 1963 (USFWS 2023).

The U.S. Fish and Wildlife Service (USFWS) initiated the first systematic surveys to estimate population densities and abundance in many of the main Hawaiian Islands, including Molokaʻi, in the late 1970s and early 1980s (the Hawaiian Forest Bird Survey (HFBS); Scott et al. 1986). By that time, numerous extinctions had already occurred across Maui Nui, a former single landmass over one million years ago composed of the present-day islands of Molokaʻi, Maui, Lānaʻi, and Kahoʻolawe (Price and Elliott-Fish 2004). Western naturalists began documenting the avifauna of each Maui Nui island in the late 1800s. On Molokaʻi, the first specimens of the Bishop's ʻŌʻō (*Moho bishopi*), Black Mamo (*Drepanis funerea*), ʻĀkohekohe (*Palmeria dolei*), Kākāwahie, and Olomaʻo were collected in the 1880s and 1890s (Olson and James 1994). By 1907, the Bishop's ʻŌʻō was presumed extinct (Bryan 1908) and by the 1930s, the Black Mamo, ʻĀkohekohe, and ʻŌʻū (*Psittirostra psittacea*) were extirpated (Richardson 1949). Similar patterns of extinction occurred on the smaller island of Lānaʻi, where ʻIʻiwi were extirpated by 1929 (Munro 1944) and Hawaiʻi ʻAmakihi by the early 1980s (Lindsey et al. 2020), with ʻApapane being the only extant native passerine remaining (MFBRP 2021). Maui, the largest island in the Maui Nui complex, experienced the 2004 extinction of the Poʻouli (*Melamprosops phaeosoma*; Butchart et al. 2018). In 2023, the Maui ʻĀkepa (*Loxops ochraceus*) and Maui Nukupuʻu (*Hemignathus affinis)* were removed from the endangered species list due to extinction (USFWS 2023). Of the six remaining native forest birds on Maui, two are critically endangered, the ʻĀkohekohe and Kiwikiu (*Pseudonestor xanthophrys*), and occur at very low numbers (Judge et al. 2021).

Across the main Hawaiian Islands, a general pattern has been consistent: low to mid- elevation forests (<1,300 m elevation) are mostly devoid of native forest birds, while high elevation forests (>1,300 m) support the highest biodiversity and abundance of native flora and fauna. This pattern can be traced back to the first arrival of Polynesians to the islands between 780 and 1130 AD (Kirch 2011, Athens et al. 2014). Lowland forests were degraded due to agriculture and development (Kirch

1982). Birds were harvested for food and feathers, while introduced predators such as domestic dogs (*Canis lupus familiaris*) and Polynesian rats (*Rattus exulans*) contributed to the extinction of an estimated 71 bird species before Western contact (Olson and James 1982, 1984, Banko et al. 2001). The first European arrivals in the late 1770s accelerated lowland deforestation and introduced additional stressors. Domestic cats (*Felis catus*) were intentionally introduced, and the Norway rat (*R. norvegicus*), black rat (*R. rattus*), and house mouse (*Mus musculus*) were accidentally introduced and quickly naturalized within most landbird habitat where they posed persistent threats through predation and competition of resources (Atkinson 1977, Witmer and Shiels 2017). In 1883, the small Indian mongoose (*Herpestes javanicus*) was intentionally introduced (Tomich 1986), and the predator became nearly ubiquitous on the islands of Hawaiʻi, Oʻahu, Molokaʻi, and Maui, ranging from sea level to as high as 3,000 m elevation (Kaholoaa et al. 2019). Mongooses are effective predators and cause direct threats to nesting seabirds, water birds, and forest birds (Banko 1992, Hays and Conant 2007, VanderWerf 2020).

Threats to avifauna extended into predominantly native forest with the introduction of the southern house mosquito (*Culex quinquefasciatus*) in 1826, a species that transmits avian malaria (*Plasmodium relictum*; Warner 1968). Hawaiian honeycreepers (Fringillidae) are highly vulnerable to the parasite, which has contributed to many extinctions and significant range reductions (Warner 1968, van Riper et al. 1986, Atkinson et al. 1995). The impact of avian malaria is worsened by climate change as rising temperatures expand the altitudinal range of both *C. quinquefasciatus* and *P. relictum* (Ahumada et al. 2004, LaPointe et al. 2010, Samuel et al. 2011, Atkinson et al. 2014). The upper limit of mosquito distribution and malaria transmission was historically around 1,500 m elevation where mean temperatures were approximately 14°C (Ahumada et al. 2004). Molokaʻi, with a maximum elevation of 1,526 m, is almost entirely within the "malaria-zone," putting species such as the highly susceptible ʻIʻiwi at constant risk of disease exposure (Atkinson et al. 1995, Paxton et al. 2013).

As extinctions continued throughout the 20th century, there was an influx of introduced, non-native species. Over 170 bird species have been introduced to Hawaii and 54 species have become naturalized (Foster 2009, VanderWerf et al. 2018). The Warbling White-eye (*Zosterops japonicus*), Japanese Bush Warbler (*Horornis diphone*), and Red-billed Leiothrix (*Leiothrix lutea*) are nearly ubiquitous, even in predominantly native forests where the remaining native forest birds persist (Richardson 1949, Pyle and Pyle 2017). Aggressive invasive plants such as strawberry guava (*Psidium cattleianum*), Himalayan ginger *(Hedychium gardnerianum),* and Koster's curse (*Miconia crenata*) replaced native forest bird habitat in large areas that were surveyed during HFBS, resulting in degradation and loss of habitat required by specialized native forest birds. The spread of weeds was accelerated by introduced ungulates, contributing to the conversion of more than 50% of lowland native forests to non-native habitat in the state (Leopold and Hess 2017, Gon et al. 2018).

The HFBS on Molokaʻi documented landbird composition, distribution, and abundance in native wet and mesic forests. A total of 22 transects were established across 131 km² of the island's eastern portion, spanning elevations from 250 to 1,510 m. Surveys were conducted in 1979 and 1980 (Scott et al. 1986); however, these efforts did not include the Kalaupapa Peninsula or areas within the current boundaries of Kalaupapa National Historical Park (hereafter Kalaupapa NHP). Comprehensive bird surveys in the park did not occur until 2004 and 2005 (Marshall and Kozar 2008), nearly 25 years after Congress designated the area as Kalaupapa NHP (U.S. Congress 1980). Many original HFBS transects outside the park have been surveyed intermittently, most recently in 2010. In 2021, the Hawaiʻi Department of Land and Natural Resources-Division of Forestry and Wildlife (DOFAW), U.S. Geological Survey-Pacific Island Ecosystems Research Center, Maui Forest Bird Recovery Project, The Nature Conservancy, and the National Park Service-Pacific Island Inventory and Monitoring Network (PACN) coordinated and conducted point-transect distance surveys on prioritized transects on state, federal, and private lands managed for conservation. Results from surveys outside Kalaupapa NHP are provided in Smith et al. (2025), which focused on a core survey area that was mostly dominated by native forest bird habitat. Transects sampled in 2004 and 2005 within Kalaupapa NHP were resurveyed in 2021 to provide an updated assessment of native and non-native bird composition, distribution, and occurrence. For species with sufficient detections to estimate density to characterize detection probability (Buckland et al. 2015), we provide species-specific density estimates and test for differences in abundances between 2005 and 2021.

Methods

Survey Area

Kalaupapa NHP, located on the northern coast of Molokaʻi, Hawaii, was established in 1980 to preserve and interpret traditional Hawaiian sites, cultural values, natural features, and the community of Hansen's disease patients (U.S. Congress 1980). The park encompasses 4,340 hectares (ha), including 809 ha of submerged lands and ocean waters extending 400 meters from shore. Despite its significant management role, the National Park Service (NPS) owns only 9 ha of land. Most of Kalaupapa NHP is state-owned, falling within Kalawao County, and is governed by the State of Hawaii Department of Health. Approximately 505 ha of land is leased from the State of Hawaii Department of Hawaiian Homelands. The park operates under a complex land and administrative arrangement, with cooperative agreements involving NPS and the State of Hawaii Department of Land and Natural Resources (DLNR). Portions of the Puʻu Aliʻi Natural Area Reserve (NAR) and Molokaʻi Forest Reserve (FR) fall within park boundaries and are managed by DLNR Division of Forestry and Wildlife (DOFAW) (Figure 1). Two seabird sanctuaries, the islets Huelo and ʻOkala Island, are co-managed by NPS and DOFAW. Smaller areas of both state- and privately-owned lands are also managed through cooperative agreements with NPS. The residents of the settlement contribute local knowledge, historical perspectives, and cultural insights that enhance the collaborative stewardship of the park's unique ecological and cultural resources.

The geography of Kalaupapa NHP is dominated by the Kalaupapa Peninsula, Kauhakō Crater, and the steep cliffs of three major valleys: Waihānau, Waiʻaleʻia, and Waikolu. This extreme topography, coupled with the area's history of land use, has resulted in a mosaic of vegetation strata across the park. After vegetation surveys in 2013, Green et al. (2014) classified and mapped 46 vegetation communities. Following the U.S. National Vegetation Classification Standard (Grossman et al. 1998), each classification is capitalized for clarity and consitency. Strata levels are separated by "/" in order of dominance and co-dominant strata are indicated by a "-", while strata in parentheses "()" indicate a species that may or may not be present. Vegetation strata are then followed by elevation zone and physiognomy of the vegetation (i.e., sparse vegetation, forest and woodlands, shrublands, and herbaceous).

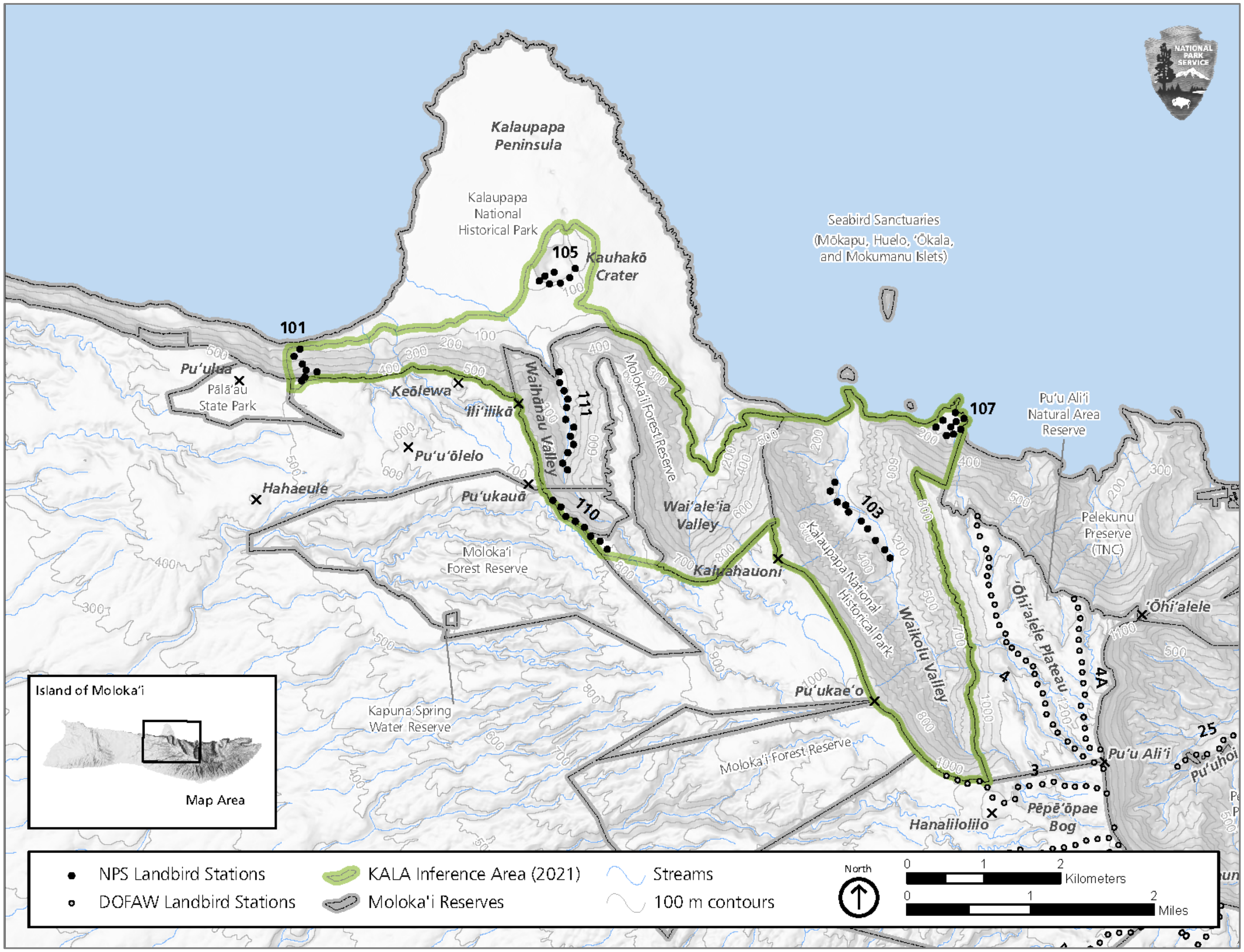

Figure 1. The island of Molokaʻi and Kalaupapa National Historical Park landbird survey area (2021). The 2021 inference area for estimating species abundance is outlined in green. Base map from World Geodetic System 1984 (WGS84) zone 5; coastline from U.S. Geological Survey's National Map (USGS, U.S. Geological Survey 2020).

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Classifications dominated by non-native strata comprised more than 60% of Kalaupapa NHP, such as Christmas Berry (*Schinus terebinthifolia*) Semi-natural Scrub Woodland, Java Plum (*Syzygium cumini*) Lowland Mesic Semi-natural Forest, Strawberry Guava Lowland Wet Semi-natural Forest, Common Guava (*P. guajava*) / Disturbed Understory Semi-natural Forest, Common Ironwood (*Casuarina equisetifolia*) Semi-natural / Planted Forest, Kukui (*Aleurites moluccanus*) Lowland Wet Forest, and Koa Haole (*Leucaena leucocephala*) Lowland Dry Semi-natural Shrubland. These communities were particularly abundant on valley floors, cliffsides, and the lowlands of the peninsula, where the invasive shrubs and grasses such as lantana (*Lantana camara*), Koster's curse, Bermuda grass (*Cynodon dactylon*), and molasses grass (*Schizachyrium condensatum*) were also common, as well as unvegetated areas. These areas were often invaded by non-native feral pigs (*Sus scrofa*), goats (*Capra hircus*), and axis deer (*Axis axis*), especially throughout non-fenced areas.

The largest native plant communities were predominantly in areas above 700 m elevation in the Puʻu Aliʻi NAR and Molokaʻi FR. The Lama (*Diospyros sandwicensis*) Lowland Mesic Woodland and ʻŌhiʻa lehua (*Metrosideros polymorpha*) Montane Wet Forest comprise approximately 25% of the land in the park (Green et al. 2014). These communities can include other native trees, such as ʻōlapa (*Cheirodendron trigynum*) and kōpiko (*Psychotria mariniana*), but can also be encroached by many non-native trees (e.g., strawberry guava, common guava). Non-native ungulates were also present in many of these areas, notably goats on steep cliffsides, where their activity contributed to erosion and increased the risk of rockfall, posing a hazard to human safety.

In 2021, we surveyed six transects which ranged from approximately 100 m to 1,000 m elevation (Figure 1). We defined boundaries of the inference area using transect location, elevation contours, management boundaries, and topographic features (e.g., ridges and streams). The survey area included the Kalaupapa Cliff Trail, Kukaʻiwaʻa Point, Kauhakō Crater, and the valleys of Waihānau, Waiʻaleʻia, Waikolu, with the upper eastern and southern edges following the park boundary and sections of the Molokaʻi FR and Puʻu Aliʻi NAR. We defined the northern edge using the 1,066 m contour line and the Pelekunu Preserve boundary. The lowland coastal areas, shrublands, and settlement areas were excluded from the inference area, as they are not suitable forest bird habitat. Also excluded were transects 3 and 4, located in upper Waikolu and Puʻu Aliʻi NAR, respectively; these areas were surveyed in 2005 (Marshall and Kozar 2008) but were included in the 2021 core survey area described by Smith et al. (2025). The inference area was mapped with a minimum convex polygon using ArcGIS Pro (Environmental Systems Research Institute, CA, USA) and totals 1,834 ha (Figure 1).

Point-Transect Sampling

Bird surveys were conducted using point-transect distance sampling methods to estimate abundance for individuals that are undetected as a function of the distance between the observer and birds (Buckland et al. 2015). Robust estimates are reliant upon the critical assumptions that all birds are detected with certainty at the station center point, birds further from the observer are harder to detect, birds are detected prior to any movement, and distances are measured with low error. Details specific to the sampling design in this survey can be found in Camp et al. (2011). In addition, weather conditions and habitat parameters were recorded at each sampling unit, and weather data were evaluated as covariates in the detection function (Camp et al. 2011).

Landbird surveys were conducted from April 13 through April 17, 2021. A total of 50 stations were surveyed with one station sampled twice for a total of 51 counts. Weeks prior to the start of the survey, primary and secondary surveyors from NPS, DOFAW, and other partners were trained to calibrate for distance estimation and learn bird vocalizations, thereby minimizing variability among observers and standardizing for local conditions (Camp et al. 2011). Detection type (heard, seen, or both) and horizontal distance from the station center point to individual birds detected was recorded during 8-minute counts. Birds only flying over or through the survey area were excluded. Detections of both male and female birds singing and calling were recorded, although the sex of individuals was not noted. Most of the birds encountered were adults because counts were timed during the breeding season and most juveniles had not yet fledged (Camp et al. 2011).

Observers also recorded cloud cover, rain intensity, wind strength, gust strength, and time of day at each station (Camp et al. 2011). Sampling was conducted between dawn and 11:00 a.m. and halted when rain, wind strength, or gust exceeded prescribed levels (light rain and wind level 3 on the Beaufort scale). Weather variables and time of day were included as covariates in the analyses to account for possible differences in the detection probabilities due to the conditions when the count was conducted.

The detectability of forest birds varies throughout the year, due to changes in vocal activity associated with breeding (Best 1981), and birds may move in or out of the study area in response to phenology of food resources (Simon et al. 2002). To minimize biases associated with differences in sampling periods, density estimates were restricted to the breeding season only.

Habitat Surveying

Habitat data were collected following the methods described in Camp et al. (2011). A 50-m radius plot was established at each point-count station using the station as the center. At each plot, the dominant canopy species composition, canopy height and cover and dominant understory species composition was recorded. Habitat surveys were collected at the point-count stations after completing bird counts (either after completing the station count, or after completing the daily counts).

Computer Data Entry and Verification

Microsoft Access was used as the primary software environment for landbird data and the associated metadata. Two separate Access databases with front-end, back-end configuration were developed for the landbirds monitoring data: the PACN Landbird Monitoring Database and the PACN Habitat Monitoring Database, which is available online (DataStore - Pacific Island Network Landbird Monitoring).

Raw data were verified by comparing data sheets to the electronic version on a line-by-line basis to correct transcription errors. After line-by-line proofing was completed, individual data sets were certified by checking for errors. Lastly, field books (copies and originals) and digital data were archived according to PACN standards (Camp et al. 2011).

Data Analysis

Indices

Indices of percent occurrence and birds per count (BPC) were calculated for each species. Percent occurrence was calculated as the number of stations occupied divided by the total number of stations sampled within a year. BPC was calculated as the total number of individuals detected divided by the total number of station counts (*n*=51).

Density Estimation

Species-specific density estimates were calculated for six species—‘Apapane, House Finch, Japanese Bush Warbler, Red-billed Leiothrix, Warbling White-eye, and White-rumped Shama (*Copsychus malabaricus*)—that had sufficient detections to adequately characterize the detection probability (Buckland et al. 2015) using the R (R Core Team 2021) package DISTANCE (Miller et al. 2019) following methods described in Thomas et al. (2010) and Buckland et al. (2015). We limited the candidate detection function models to half normal and hazard-rate detection functions with expansion series of order two. We paired the half normal with cosine and Hermite polynomial adjustments, and the hazard-rate was paired with cosine and simple polynomial adjustments. Model precision was improved by incorporating sampling covariates in the multiple covariate distance sampling (MCDS) engine of DISTANCE (Buckland et al. 2015). Covariates included cloud cover, rain, wind, gust, observer, type of detection, and survey year. Each detectability model in the candidate set was fit to data pooled across years for each species, and the model selected was that with the lowest Akaike’s Information Criterion (AIC) (Buckland et al. 2015). Data were truncated at a distance where the detection probability using a preliminary half-normal detection function model was about 0.1. This procedure facilitates modeling by deleting outliers and reducing the number of parameters needed to modify the detection function. Species-specific densities by year were estimated from the global detection function using the post-stratification procedure, and variances and confidence intervals were derived by bootstrap methods in DISTANCE from 1,000 iterations (Appendix A; Thomas et al. 2010). Absolute abundance was calculated as mean density of estimates weighted by the inference area (1,834 ha). We assessed differences between 2005 and 2021 population densities with a two-sample z-test in an equivalency framework following methods detailed in Camp et al. (2008).

Results

2021 Landbird Detections

A total of 689 detections of nine species (1 native and 8 non-native; Table 1) were counted during the 2021 landbird survey of Kalaupapa NHP. The Red-billed Leiothrix and Warbling White-eye were the most widely distributed species, each occurring at more than 94% of stations surveyed (Table 1). The White-rumped Shama and Northern Cardinal (*Cardinalis cardinalis*) occurred at 70% and 64% of stations surveyed, respectively. The remaining species occurred at 38% or fewer of stations surveyed. Densities, abundance, and trends are described at length in the sections below and we provide a summary for each species with links to maps of occurrence in Appendix B.

Table 1. List of species detected during the 2021 landbird survey of Kalaupapa National Historical Park. Taxonomic classification follows the International Ornithological Congress World Bird List (Gill et al. 2023). Total detections (*n*) were the number of birds recorded during 51 counts at 50 stations on six transects. Stations occupied were the number of stations where one or more individuals of a species was detected. Percent occurrence was computed as stations occupied divided by total stations surveyed. Birds per count (BPC) was computed by dividing total detections of each species by total number of counts.

Common Name	Scientific Name	n	Stations Occupied	% Occurrence	BPC
‘Apapane [A]	*Himatione sanguinea*	18	10	20%	0.36
Common Myna	*Acridotheres tristis*	8	6	12%	0.16
House Finch	*Haemorhous mexicanus*	38	19	38%	0.74
Japanese Bush Warbler	*Horornis diphone*	10	5	10%	0.20
Northern Cardinal	*Cardinalis cardinalis*	75	32	64%	1.49
Red-billed Leiothrix	*Leiothrix lutea*	221	48	96%	4.33
Spotted Dove	*Spilopelia chinensis*	30	17	34%	0.58
Warbling White-eye	*Zosterops japonicus*	233	47	94%	4.57
White-rumped Shama	*Copsychus malabaricus*	56	35	70%	1.10

[A] Species endemic to Hawaii.

Population Density, Abundance, and Change

There were sufficient detections of six species, one native and five non-native, to estimate density and abundance (Table 2). The density of the single native species, ‘Apapane, was estimated at 1.35 ± 0.40 (SE) birds/ha, for an abundance of 2,476 ± 729 (95% CI = 1,167–4,007). The density of the Warbling White-eye was the highest of all species detected, which we estimated at 29.12 ± 4.72 birds/ha for an abundance of 53,407 ± 8,653 (38,307–72,242). The Red-billed Leiothrix was the second most abundant species with a density of 6.05 ± 0.66 birds/ha and abundance of 11,088 ± 1,208 (8,740–13,505). The density of the White-rumped Shama was 1.44 ± 0.29 birds/ha for an abundance of 2,643 ± 537 birds. The density of the Japanese Bush Warbler was the least abundant species with 0.26 ± 0.09 birds/ha and an abundance of 484 ± 157 birds (202–808). Estimates of density and abundance were higher in 2005 for every species except Red-billed Leiothrix, which wasn't detected within the survey area in 2005 (difference not evaluated; Table 3). The density of ‘Apapane was significantly lower in 2021, while differences for the non-native species were inconclusive.

Table 2. Density and abundance estimates of ‘Apapane, House Finch, Japanese Bush Warbler, Red-billed Leiothrix, Warbling White-eye, and White-rumped Shama in the 2005 and 2021 Kalaupapa National Historical Park survey area.

Common Name	Year	Density ± SE (95% CI)	Abundance ± SE (95% CI)
‘Apapane	2005	3.12 ± 0.73 (1.78–4.60)	5,726 ± 1,344 (3,262–8,439)
	2021	1.35 ± 0.40 (0.64–2.18)	2,476 ± 729 (1,167–4,007)
House Finch	2005	3.15 ± 1.42 (1.15–6.68)	5,771 ± 2,606 (2,109–12,247)
	2021	2.25 ± 0.97 (0.83–4.75)	4,134 ± 1,771 (1,513–8,706)
Japanese Bush Warbler	2005	1.42 ± 0.21 (1.03–1.86)	2,605 ± 391 (1,897–3,413)
	2021	0.26 ± 0.09 (0.11–0.44)	484 ± 157 (202–808)
Red-billed Leiothrix	2005	0	0
	2021	6.05 ± 0.66 (4.77–7.36)	11,088 ± 1,208 (8,740–13,505)
Warbling White-eye	2005	55.47 ± 6.38 (43.95–68.05)	101,724 ± 11,692 (80,600–124,810)
	2021	29.12 ± 4.72 (20.89–39.39)	53,407 ± 8,653 (38,307–72,242)
White-rumped Shama	2005	1.62 ± 0.37 (1.08–2.47)	2,973 ± 670 (1,974–4,530)
	2021	1.44 ± 0.29 (0.99–2.20)	2,643 ± 537 (1,823–4,038)

Table 3. Population density differences of ‘Apapane, House Finch, Japanese Bush Warbler, Warbling White-eye, and White-rumped Shama in the Kalaupapa National Historical Park survey area in 2005 and 2021. Differences in Red-billed Leiothrix were not evaluated as it was not detected in 2005. Values shown include the difference in density between years, the standard error (SE), the lower confidence limit (LCL), upper confidence limit (UCL), z-score, p-value for the z-score, lower equivalence limit (LEL), upper equivalence limit (UEL), the p-value for the lower equivalence limit (LELp), and the p-value for the upper equivalence limit (UELp).

Species	Difference	SE	LCL	UCL	Z-score	Z p-value	LEL	UEL	LELp	UELp	Result
‘Apapane	-1.77	0.83	-3.14	-0.40	-2.13	0.03	1.90	-2.31	0.97	0.01	Significant difference in density
House Finch	-0.90	1.42	-3.23	1.43	-0.63	0.53	0.50	-0.74	0.69	0.23	Inconclusive result
Japanese Bush Warbler	-1.16	1.04	-2.86	0.54	-1.12	0.26	0.94	-1.26	0.83	0.10	Inconclusive result
Warbling White-eye	-26.35	48.66	-106.4	53.70	0.59	0.59	0.54	-0.54	0.70	0.29	Inconclusive result
White-rumped Shama	-0.18	1.47	-2.59	2.23	0.90	0.90	-0.01	-0.22	0.50	0.41	Inconclusive result

Species Summaries

'Apapane

There were 18 detections of 'Apapane, occurring at 20% of stations surveyed and at 0.36 BPC (Table 1). The detections were on transects 103, 110, and 111 (Figure 2). Estimated density was 1.35 ± 0.4 birds/ha for an estimated abundance of 2,476 ± 729 birds in the 1,834-ha survey area (Table 2), which was a significant decrease since 2005 (Table 3; Figure 3).

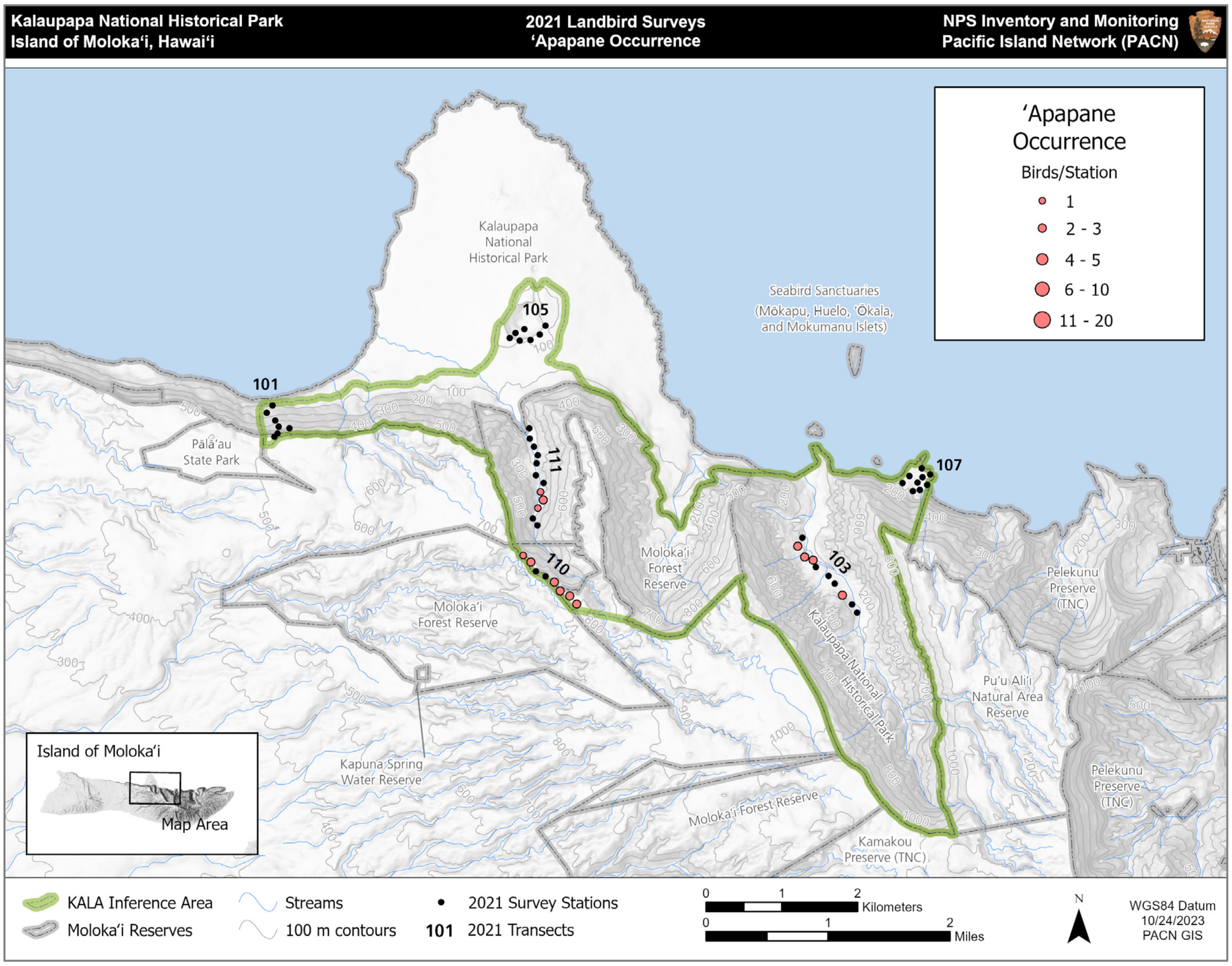

Figure 2. 'Apapane detections during the 2021 Kalaupapa National Historical Park landbird survey. *NPS / MARK W. WASSER*

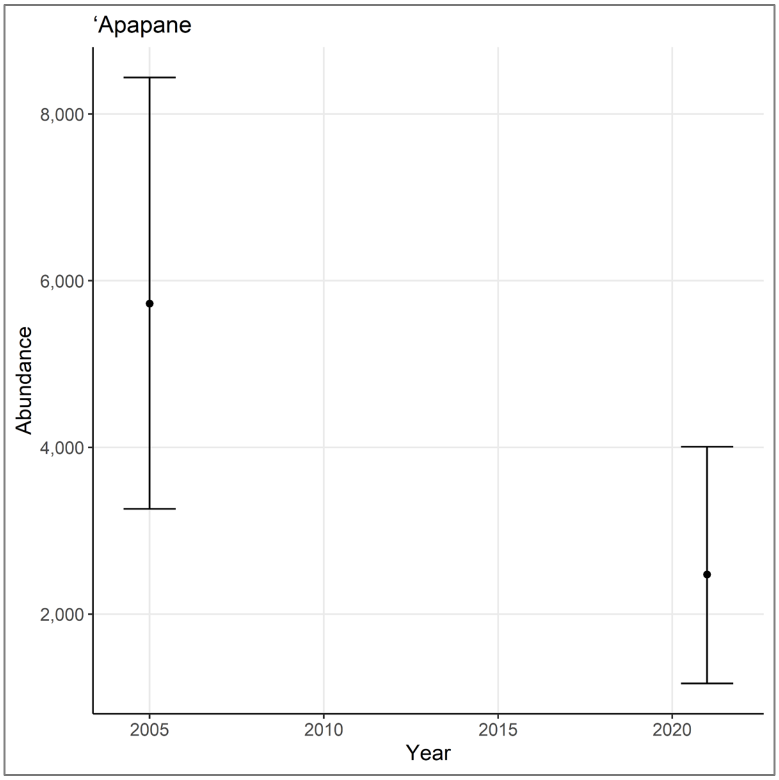

Figure 3. Abundance estimates of ‘Apapane in the Kalaupapa National Historical Park survey area in 2005 and 2021. Whisker bars are the abundance 95% confidence interval.

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Common Myna

There were eight detections of the Common Myna (*Acridotheres tristis*). The species occurred at 12% of the stations surveyed at 0.16 BPC (Table 1). The detections were on transects 103, 110, and 111 (see figures in Appendix B).

House Finch

There were 38 detections of the House Finch. The species occurred at 38% of the stations surveyed at 0.74 BPC (Table 1). The species was detected on every transect surveyed, with the highest occurrence on transects 105 and 107 (Appendix B). The 2021 density was 2.25 ± 0.97 birds/ha for an estimated abundance of 4,134 ± 1,771 birds, which was lower than 2005, but the difference was inconclusive due to a small difference in detections between the two surveys (Table 2; Figure 4).

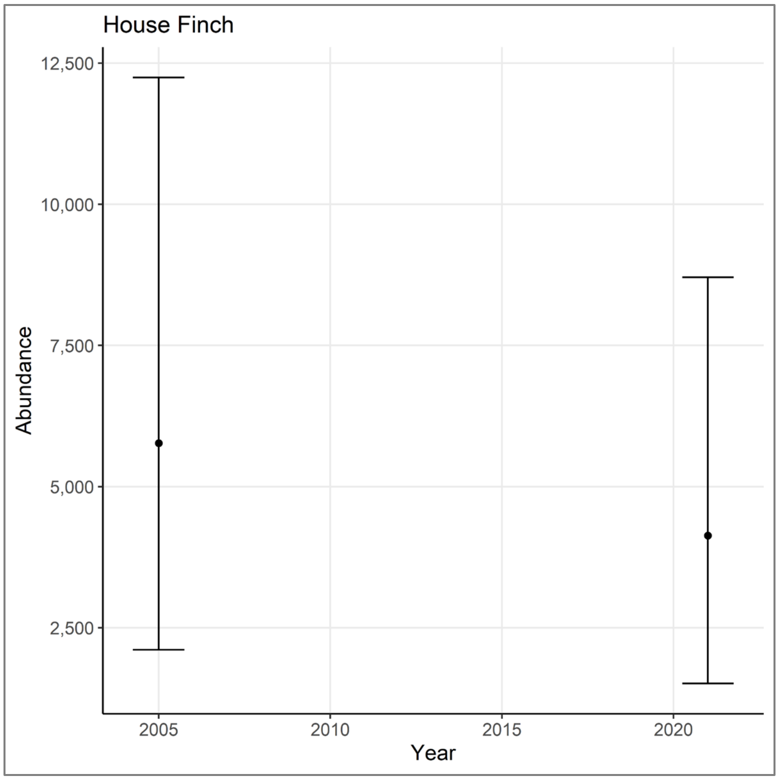

Figure 4. Abundance estimates of House Finch in the Kalaupapa National Historical Park survey area in 2005 and 2021. Whisker bars are the abundance 95% confidence interval.
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Japanese Bush Warbler
There were 10 detections of the Japanese Bush Warbler. The species was detected at 10% of the stations surveyed at 0.20 BPC (Table 1). The majority of detections were clustered on Transect 110, with one detection on Transect 103 on the Kukaʻiwaʻa Point (Appendix B). The 2021 density was 0.26 ± 0.09 birds/ha for an estimated abundance of 484 ± 157 birds, an 81% decrease since 2005; however, the difference was inconclusive because of high variance relative to the rate of change (Table 2; Figure 5).

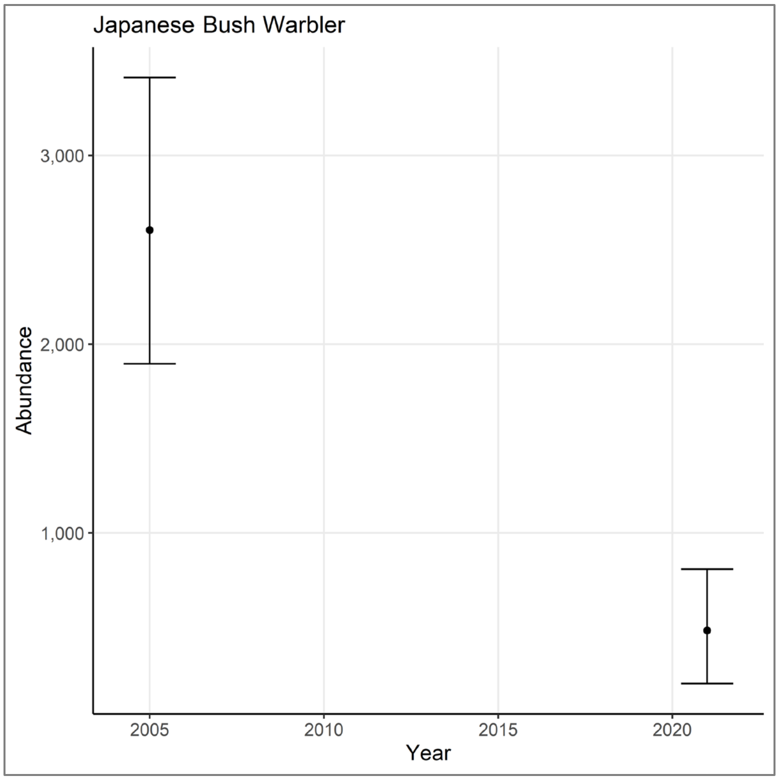

Figure 5. Abundance estimates of Japanese Bush Warbler in the Kalaupapa National Historical Park survey area in 2005 and 2021. Whisker bars are the abundance 95% confidence interval.
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Northern Cardinal

There were 75 detections of the Northern Cardinal. The species was detected at 64% of stations surveyed at 1.49 BPC (Table 1). The species occurred on every transect (Appendix B).

Red-billed Leiothrix

There were 221 detections of Red-billed Leiothrix. The species was broadly detected at 96% of the stations surveyed at 4.33 BPC (Table 1; Appendix B). The 2021 density was 6.05 ± 0.66 birds/ha for an estimated abundance of 11,088 ± 1,208 birds (Table 2). In 2005, the species was not detected within the 2021 survey area, thus there is no population density or abundance estimate for that year.

Spotted Dove

There were 30 detections of the Spotted Dove (*Spilopelia chinensis).* The species occurred at 34% of stations surveyed at 0.58 BPC (Table 1). Most of the detections were on transects 105, 110, and 111 (Appendix B).

Warbling White-eye

The Warbling White-eye was the most broadly distributed and abundant species detected in the 2021 survey, occurring at 97.5% of stations surveyed at 9.13 BPC (Table 1; Appendix B). The 2021 density was 29.12 ± 4.72 birds/ha for an estimated abundance of 53,407 ± 8,653 birds, which was a

47% decrease since 2005 (Table 2). Since 2005, the estimated density was 26.3 birds/ha lower, but the difference was inconclusive (Table 3, Figure 6).

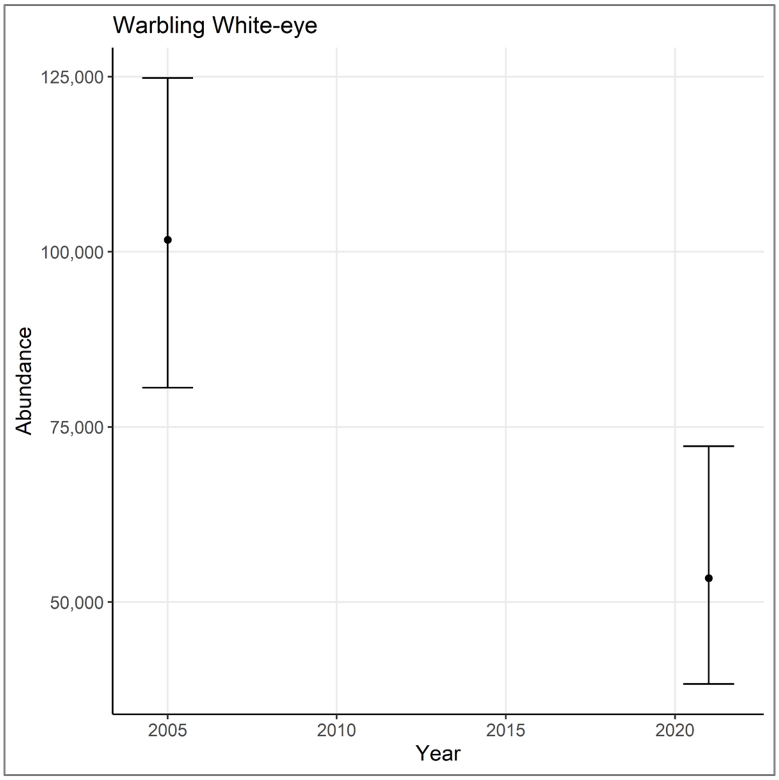

Figure 6. Abundance estimates of Warbling White-eye in the Kalaupapa National Historical Park survey area in 2005 and 2021. Whisker bars are the abundance 95% confidence interval.
USGS / RICHARD J. CAMP

White-rumped Shama

There were 56 detections of the White-rumped Shama. It occurred at 70% of the stations surveyed at 1.10 BPC (Table 1). The species occurred on every transect surveyed (Appendix B). The 2021 estimated density was 1.44 ± 0.29 birds/ha for an estimated abundance of 2,643 ± 537 birds, which was lower, but an inconclusive difference compared to the 2005 estimate (Table 2; Figure 7).

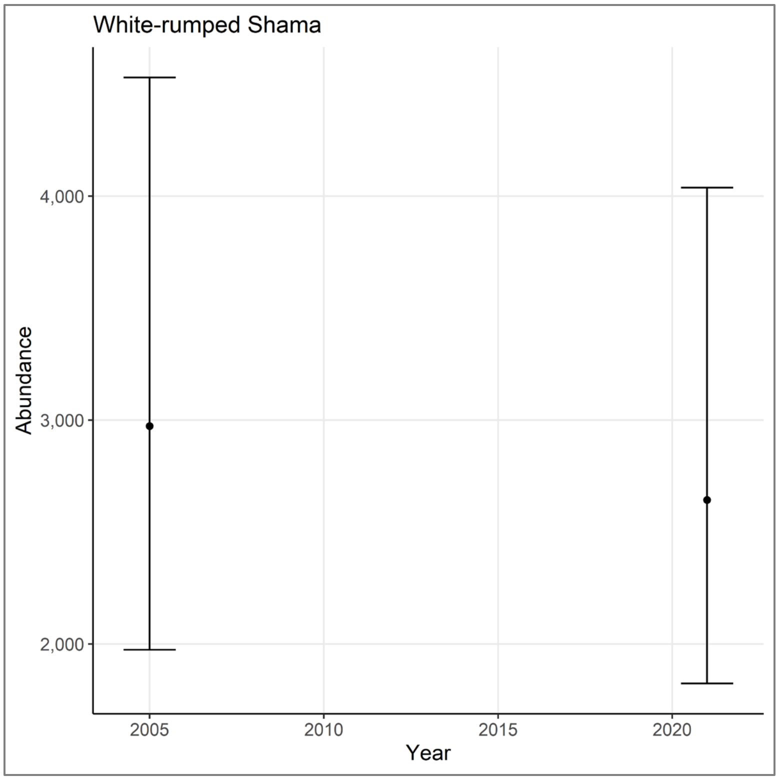

Figure 7. Abundance estimates of White-rumped Shama in the Kalaupapa National Historical Park survey area in 2005 and 2021. Whisker bars are the abundance 95% confidence interval.
USGS / RICHARD J. CAMP

Habitat Results

Habitat variables were measured at all 50 of the stations surveyed in 2021. The dominant canopy height was >10 m at 46% of stations, 6–10 m at 42% of stations, and 2–5 m at 14% of stations surveyed (Table 4). A closed canopy dominated the majority of survey plots, with 82% of stations having a closed canopy, and 16% with an open canopy (Table 5). There were 27 unique canopy composition classes recorded, with the "Mixed Non-native" class accounting for 28% of stations surveyed (Table 6). The Mixed Non-native class was a combination of species that included: kukui, Java plum, Christmas berry, ironwood, common guava, and strawberry guava. The remaining 26 classes were recorded at < 8% of stations, including ʻōhiʻa lehua and hala (*Pandanus tectorius*), which were the only native tree canopy species recorded. There were 26 unique understory composition classes recorded (Table 7). The "Bare Ground" class accounted for 28% of stations surveyed and a combination of Bare Ground and Mixed Non-native shrubs accounted for 8% in areas disturbed by ungulates and dense monotypic canopies.

Table 4. Canopy height classes recorded in Kalaupapa National Historical Park during the 2021 landbird monitoring survey.

Canopy Height	Count	%
2–5 m	7	14%
6–10 m	21	42%
> 10 m	23	46%
No Trees	1	2%

Table 5. Canopy cover classes recorded in Kalaupapa National Historical Park during the 2021 landbird monitoring survey.

Canopy Cover	Count	%
Closed	41	82%
Open	8	16%
Scattered	1	2%
Very Scattered	1	2%
No Trees	1	2%

Table 6. Dominant canopy composition classes recorded within Kalaupapa National Historical Park during the 2021 landbird survey. Tree species or grouped classes (e.g., Mixed Non-native) are separated by a comma in order of dominance. Classes that are separated by a dash are co-dominant with the other species, meaning both occurred equally throughout the habitat plot around the survey station.

Canopy Class	Count	%
Mixed Non-native	14	28%
Hala	4	8%
Guava spp., ʻŌhiʻa lehua	3	6%
Guava spp. – Kukui – Mixed Non-native	3	6%
ʻŌhiʻa lehua	2	4%
ʻŌhiʻa lehua, Mixed Non-native	2	4%
Mixed Non-native, ʻŌhiʻa lehua	2	4%
Guava spp.	2	4%
Guava spp., Kukui	2	4%
Kukui – Mixed Non-native	1	2%
Kukui – Guava spp., Java plum	1	2%
Kukui-Java plum	1	2%
Kukui-Java plum – Guava spp.	1	2%
Common Ironwood	1	2%
Mango (*Mangifera indica*), Guava spp.	1	2%

Table 6 (continued). Dominant canopy composition classes recorded within Kalaupapa National Historical Park during the 2021 landbird survey. Tree species or grouped classes (e.g., Mixed Non-native) are separated by a comma in order of dominance. Classes that are separated by a dash are co-dominant with the other species, meaning both occurred equally throughout the habitat plot around the survey station.

Canopy Class	Count	%
Mixed Non-native, Native Ferns	1	2%
Non-native Shrubs, Guava spp.	1	2%
Hala, Coconut Palm (*Cocos nucifera*)	1	2%
Hala, Mixed Non-native	1	2%
Guava spp., Kukui, Coffee Tree (*Coffea* spp.)	1	2%
Guava spp., Kukui, Mixed Non-native	1	2%
Guava spp., Mixed Non-native	1	2%
Guava spp., Hala	1	2%
Guava spp., Java plum	1	2%
Guava spp., Java plum, ʻŌhiʻa lehua	1	2%
Guava spp. – Kukui	1	28%
Christmas berry, Mixed Non-native	1	8%

Table 7. Understory classes recorded within Kalaupapa National Historical Park during the 2021 landbird survey. Classes are separated by a comma in order of dominance. Classes separated by a dash are co-dominant within the habitat plot around the survey station.

Understory Class	Count	%
Bare Ground	14	28%
Bare Ground, Non-native Shrubs	4	8%
Non-native Shrubs, Native Ferns	4	8%
Non-native Shrubs	3	6%
Non-native Shrubs, Bare Ground	3	6%
Bare Ground, Native Ferns	2	4%
Non-native Ferns	2	4%
Non-native Ferns, Non-native Herbaceous	2	4%
Bare Ground, Native Ferns, Non-native Shrubs	1	2%
Bare Ground, Non-native Shrubs, Native Ferns	1	2%
Koster's curse, Himalayan ginger, Native Ferns	1	2%
Koster's curse, Himalayan ginger, *Pluchea carolinensis*	1	2%
Koster's curse, Native Ferns	1	2%
Koster's curse, Native Ferns, Bare Ground	1	2%
Himalayan ginger, Non-native Shrubs	1	2%

Table 7 (continued). Understory classes recorded within Kalaupapa National Historical Park during the 2021 landbird survey. Classes are separated by a comma in order of dominance. Classes separated by a dash are co-dominant within the habitat plot around the survey station.

Understory Class	Count	%
Non-native Herbaceous	1	2%
Native Ferns, Koster's curse, Himalayan ginger	1	2%
Non-native Grasses, Non-native Herbaceous – Matted Ferns	1	2%
Non-native Grasses – Non-native Herbaceous, Non-native Trees	1	2%
Non-native Herbaceous – Non-native Grasses, Native Grasses	1	2%
Non-native Herbaceous – Non-native Grasses	1	2%
Non-native Shrubs – Non-native Herbaceous, Non-native Grasses	1	2%
Non-native Shrubs, Non-native Grasses	1	2%
Non-native Trees, Bare Ground	1	2%
Non-native Trees, Native Shrubs – Native Trees	1	2%
Non-native Trees – Bare Ground, Matted Ferns	1	2%

Discussion

The 2021 landbird survey of Kalaupapa NHP provides an update of the forest bird composition, population density, and estimates of abundance relative to the 2005 survey effort. There was evidence of reduced abundances of four non-native species; and of ʻApapane, which had a significantly lower density since 2005. There was an apparent sudden increase of the Red-billed Leiothrix population, jumping to over 11,000 birds in 2021, after not being detected in 2005. The results reveal shifts in the avifauna within Kalaupapa NHP since the 2005 survey, particularly with the decline or absence of native species and dominance of non-native species.

The absence of Hawaiʻi ʻAmakihi and ʻIʻiwi, plus the decrease in the ʻApapane population, with an estimated 57% decline in abundance, may be attributed to a combination of habitat degradation, competition with non-native birds (VanderWerf et al. 2018), depredation by non-native predators (Atkinson et al. 1977 and others), and the persistent threat of avian malaria (Warner 1968, van Riper et al. 1986). With Kalaupapa NHP situated almost entirely below the traditional "malaria-free" elevation threshold of 1,500 m, the exposure of native birds to mosquito-borne diseases is probable (LaPointe et al. 2010). ʻIʻiwi, not observed on Molokaʻi since 2010, are particularly vulnerable to avian malaria (Atkinson 1995) and its potential extirpation is likely linked to disease. It is unknown if Olomaʻo is vulnerable to disease—its congeners such as ʻŌmaʻo (*M. obscurus*) have demonstrated tolerance (Atkinson 2001) and thrive in many windward forests on the Island of Hawaiʻi (Judge et al. 2012).

Habitat degradation caused by invasive plant species and non-native ungulates is likely a primary driver of decline and loss of native bird species in Kalaupapa NHP. More than 60% of Kalaupapa NHP is dominated by non-native vegetation, including highly invasive species such as strawberry guava, Christmas berry, and Java plum, which displace native plants like ʻōhiʻa lehua and lama (Smith 1985, Hawaiʻi Invasive Species Council 2023). These invasive plants alter the forest structure and reduce the availability of food and nesting resources for native birds (Pratt and Jacobi 2009). Additionally, non-native ungulates, including feral pigs, goats, and axis deer, exacerbate habitat degradation by trampling vegetation, rooting for food, and by spreading invasive plants (Leopold and Hess 2017). Pigs facilitate the spread of strawberry guava by consuming and dispersing its seeds (Strauch et al. 2016). Pigs also create larval mosquito habitat by disturbing the soil and creating muddy wallows (Baker 1975). These conditions provide the stagnant water necessary for mosquitoes to breed, increasing the risk of avian malaria transmission (LaPointe et al. 2009). The cumulative effects of invasive plants and ungulates create a negative feedback loop of habitat degradation, making it increasingly difficult for resource managers to maintain and protect native habitat important for Hawaiian birds.

The survey results also show the dominance of non-native bird species, such as Warbling White-eye and Red-billed Leiothrix. The Warbling White-eye remains the most abundant species in the park, with an estimated population exceeding 53,000 birds. The irruption of the Red-billed Leiothrix demonstrates the rapid establishment and expansion potential of non-native species, posing additional challenges for conservation. While differences were inconclusive, the lower densities of

House Finch, Japanese Bush Warbler, Warbling White-eye, and White-rumped Shama could be associated to severe drought conditions in 2020 and 2021. After decreasing rainfall from 2018 through 2020, populations of axis deer experienced widespread mortality events in Hawaiʻi (Hess et al. 2022). Notably, annual precipitation in years preceding the 2004–2005 survey period was nearly twice the totals recorded from 2017 through 2021 (Western Regional Climate Center 2021). On the Island of Hawai'i, droughts contributed to reduced seed crops and population declines of non-native species and of the critically endangered Palila *(Loxioides bailleui*; Banko et al. 2013). Elsewhere, droughts have led to reductions of other avian food sources such as insects, plants, and water; leading to malnutrition, lower productivity, and population declines (George et al. 1992, Meyers et al. 2019, Goldstein et al. 2024).

Quantifying the influence of non-native species on native bird population trends remains challenging, yet several mechanisms contribute to declines. Non-native birds, resistant to avian malaria, act as reservoirs that amplify disease transmission to native species (McClure et al. 2020). On Molokaʻi, non-native birds exhibited an average disease prevalence of 64%, underscoring their role in sustaining pathogen cycles (Paxton 2022). They may also facilitate the spread of other infectious agents, such as avian pox and novel *Plasmodium* strains, further threatening native forest birds (van Riper et al. 1986, Atkinson and LaPointe 2009). Beyond disease transmission, non-native generalist birds degrade habitat by dispersing some of Hawaii's most invasive plants (Foster and Robinson 2007, Chimera and Drake 2010, Vizentin-Bugoni et al. 2019). Some species, such as the Warbling White-eye and Common Myna, also exhibit aggressive behaviors that displace native birds from foraging areas and nesting sites, reducing reproductive success and survival rates (Freed and Cann 2009), with the Common Myna also documented preying on eggs (Byrd and Moriarty 1980). Additionally, dietary overlap between native and non-native passerines suggests that competition for limited foraging resources may further exacerbate native species declines (Banko et al. 2015).

Interpreting these population trends is complicated by several methodological and temporal factors. Although point-transect distance sampling is a robust method when applied consistently (Buckland et al. 2015), the 16-year interval between surveys limits the capacity to detect population changes. This long interval fails to capture short- to medium-term fluctuations in bird populations that can result from changes in food availability, climatic events, or disease outbreaks (Scott et al. 1986). High variance in density estimates for some species further complicates interpretation, particularly for species with patchy distributions or low detection rates. Increasing survey frequency to intervals of two, three, or five years following PACN survey protocols (Camp et al. 2011; Kalaupapa NHP and Molokaʻi were not currently included in the PACN monitoring protocol) could help track population trajectories (Brinck et al. 2012). More frequent surveys could also enhance the ability to correlate population changes with potential stressors, such as climate variability, disease dynamics, and shifts in vegetation structure and composition, providing a more comprehensive understanding of the ecological drivers of population change.

Moving forward, conservation efforts in Kalaupapa NHP may prioritize the restoration of native-dominated habitats, particularly in higher-elevation portions of the Puʻu Aliʻi NAR and Molokaʻi FR. Measures such as fencing, ungulate control, and the removal of invasive plants can help promote the regeneration of native vegetation and reduce sediment runoff (Jacobi and Stock 2017). Additionally, proactive mosquito control strategies, such as the Incompatible Insect Technique (Zheng et al. 2019, Beebe et al. 2021) and mosquito larvicides, such as *Bacillus thuringiensis israelenis* (Després et al. 2011, Tetreau et al. 2012), could suppress southern house mosquitoes and reduce avian malaria transmission to vulnerable species. Collaborative management involving state agencies, private landowners, Native Hawaiian communities, and settlement residents could increase the likelihood of conservation success.

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Appendix A. Model Selection- Akaike's Information Criterion (AIC) Statistics

Detection function model parameters and model-selection results for forest birds of the 2021 Kalaupapa National Historical Park landbird survey. For each species, models were sorted by differences in second-order Akaike's information criterion corrected for small sample size (ΔAIC) between each candidate model and the model with the lowest AIC value. Models examined included half-normal (HN) and hazard-rate (HR) key detection functions and with cosine (COS), Hermite polynomial (Hpoly), and simple polynomial (Spoly) series expansions. Covariates were incorporated with the most parsimonious key detection function model to improve model precision. Covariates included the categorical variables cloud cover (Cloud), amount of rain (Rain), Beaufort wind scale (Wind), Beaufort gust scale (Gust), observer (Obs), time of day (Time), survey month (Month), survey year (Year). Detection type (1=heard, 2=seen, 4=heard and seen) was also evaluated as a categorical variable, indicated as "Detection", and based on pooling detection type by combination of types (e.g., "Detect 2, 4" pools all detections that were seen and both heard and seen, while "Detect 1, 4" pools detections that were heard and both heard and seen). Time of day (Time) was evaluated as a continuous variable. The number of estimated parameters (Num params), and negative log-likelihood (-LogL) are presented. The Akaike model weight (w) is the likelihood that each model is the best of the converged models evaluated for each species. Model selection criteria are provided in Tables 8–13 below.

Table 8. Model selection results for 'Apapane (truncation=69 m).

Key Function	Adjustment Term/ Covariate	Df	AIC	Delta	Weight
HR	Spoly	4	31115.83	0	0.932261
HN	Cos	2	31121.08	5.243893	0.067739
HR	None	2	31183.28	67.44964	2.10E-15
HN	None	1	31191.59	75.76068	3.30E-17

Table 9. Model selection results for House Finch (truncation=50 m).

Key Function	Adjustment Term/ Covariate	Df	AIC	Delta	Weight
HR	None	2	1352.169	0	0.818545
HN	None	1	1355.182	3.013042	0.181455

Table 10. Model selection results for Japanese Bush Warbler (truncation=99 m).

Key Function	Adjustment Term/ Covariate	Df	AIC	Delta	Weight
HR	None	2	31010.12	0	1
HN	None	1	31042.3	32.17975	1.03E-07

Table 11. Model selection results for Red-billed Leiothrix (truncation=96 m).

Key Function	Adjustment Term/ Covariate	Df	AIC	Delta	Weight
HN	Year	6	11559.14	0	1
HN	Tract	2	11635.07	75.9287	3.25E-17
HN	Rain	2	11645.04	85.90098	2.22E-19
HN	Gust	2	11645.94	86.80101	1.42E-19
HN	Wind	2	11647.97	88.83529	5.12E-20
HN	Cloud	2	11651.56	92.41873	8.54E-21
HN	Cos	3	11652.95	93.81186	4.26E-21
HN	Null	1	11653.17	94.02871	3.82E-21
HR	Simple	3	11656.61	97.46946	6.84E-22
HR	Null	2	11656.69	97.54979	6.57E-22

Table 12. Model selection results for Warbling White-eye (truncation=39 m).

Key Function	Adjustment Term/Covariate	Df	AIC	Delta	Weight
HR	Dtype 2+4	3	25740.51	0	1
HR	Year	8	26249.29	508.7751	3.32E-111
HR	Cos	3	26287.3	546.7896	1.85E-119
HN	Cos	2	26293.37	552.8543	8.90E-121
HR	Wind	3	26296.52	556.0058	1.84E-121
HR	Cloud	3	26315.18	574.6647	1.63E-125
HR	Gust	3	26320.18	579.6685	1.34E-126
HR	Null	2	26322.88	582.3667	3.47E-127
HN	Null	1	26327.98	587.4622	2.72E-128

Table 13. Model selection results for White-rumped Shama (truncation=65 m).

Key Function	Adjustment Term/Covariate	Df	AIC	Delta	Weight
HR	None	2	1167.642	0	0.659307
HN	Hpoly	2	1169.445	1.803014	0.267651
HN	None	1	1172.043	4.400297	0.073042

Appendix B. Non-native Species Occurrence Maps

Occurrence maps for non-native species detected during the 2021 landbird survey of Kalaupapa National Historical Park can be seen in Figures 8–15.

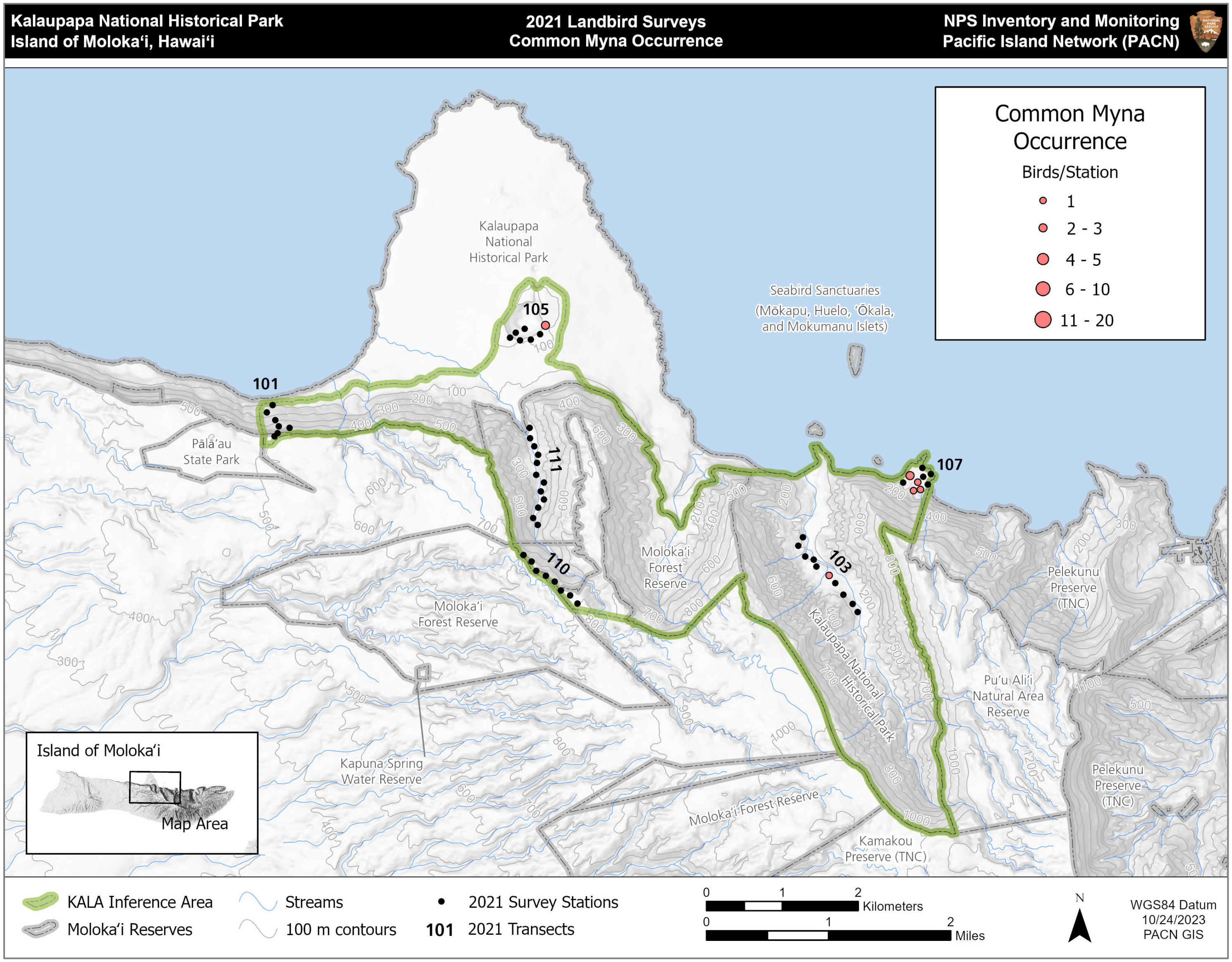

Figure 8. Common Myna detections during the 2021 Kalaupapa National Historical Park landbird survey.
NPS / MARK W. WASSER

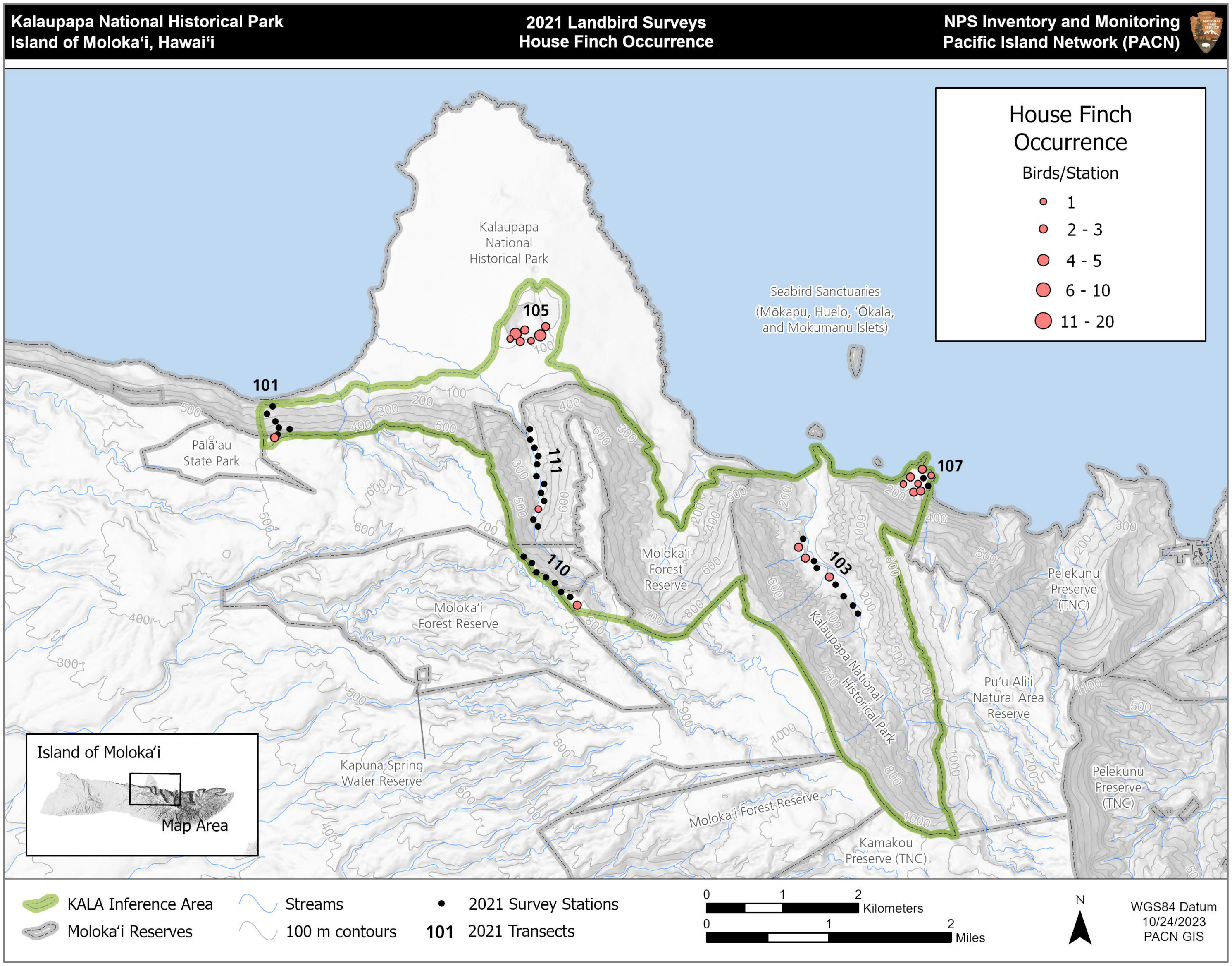

Figure 9. House Finch detections during the 2021 Kalaupapa National Historical Park landbird survey.
NPS / MARK W. WASSER

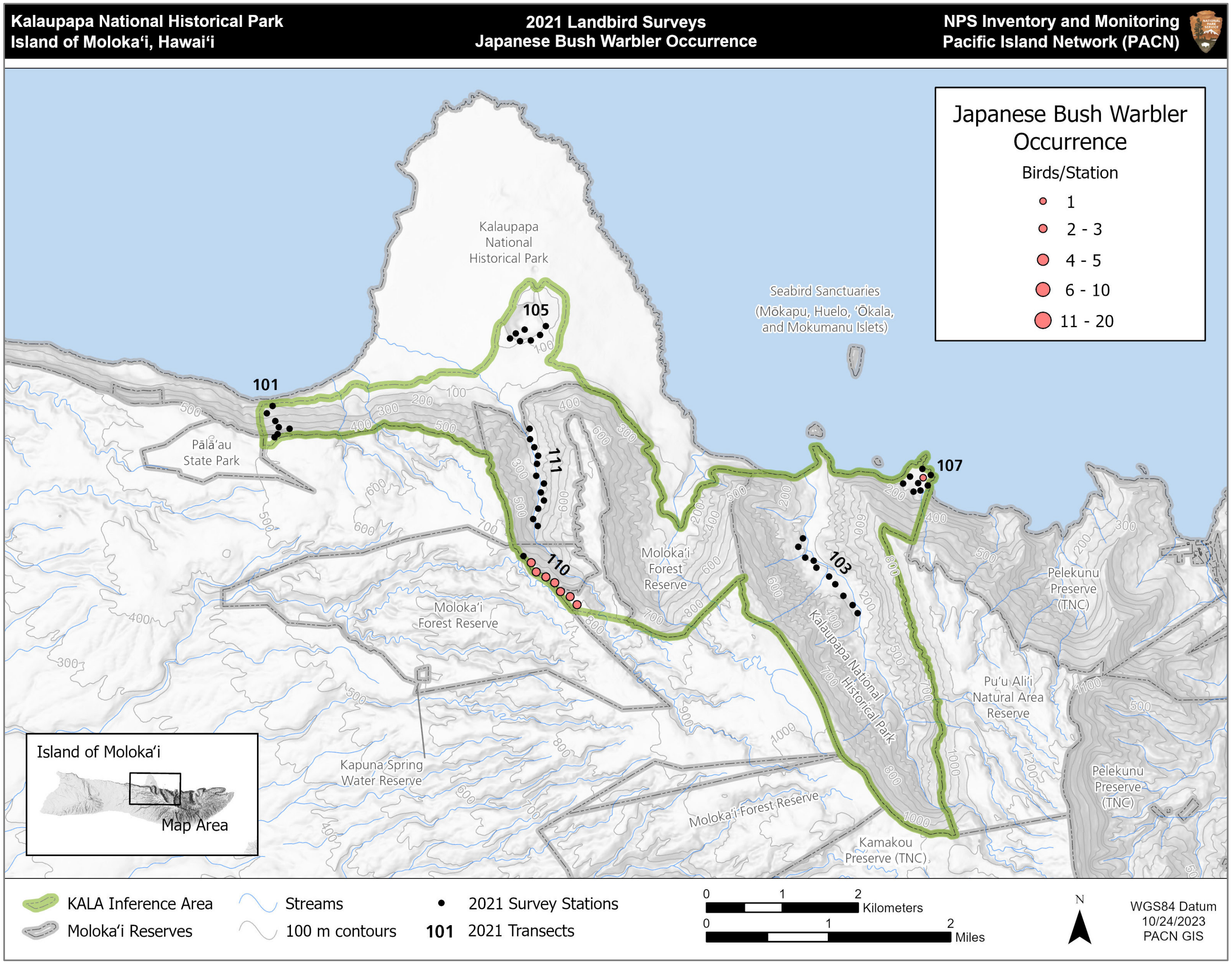

Figure 10. Japanese Bush Warbler detections during the 2021 Kalaupapa National Historical Park landbird survey.
NPS / MARK W. WASSER

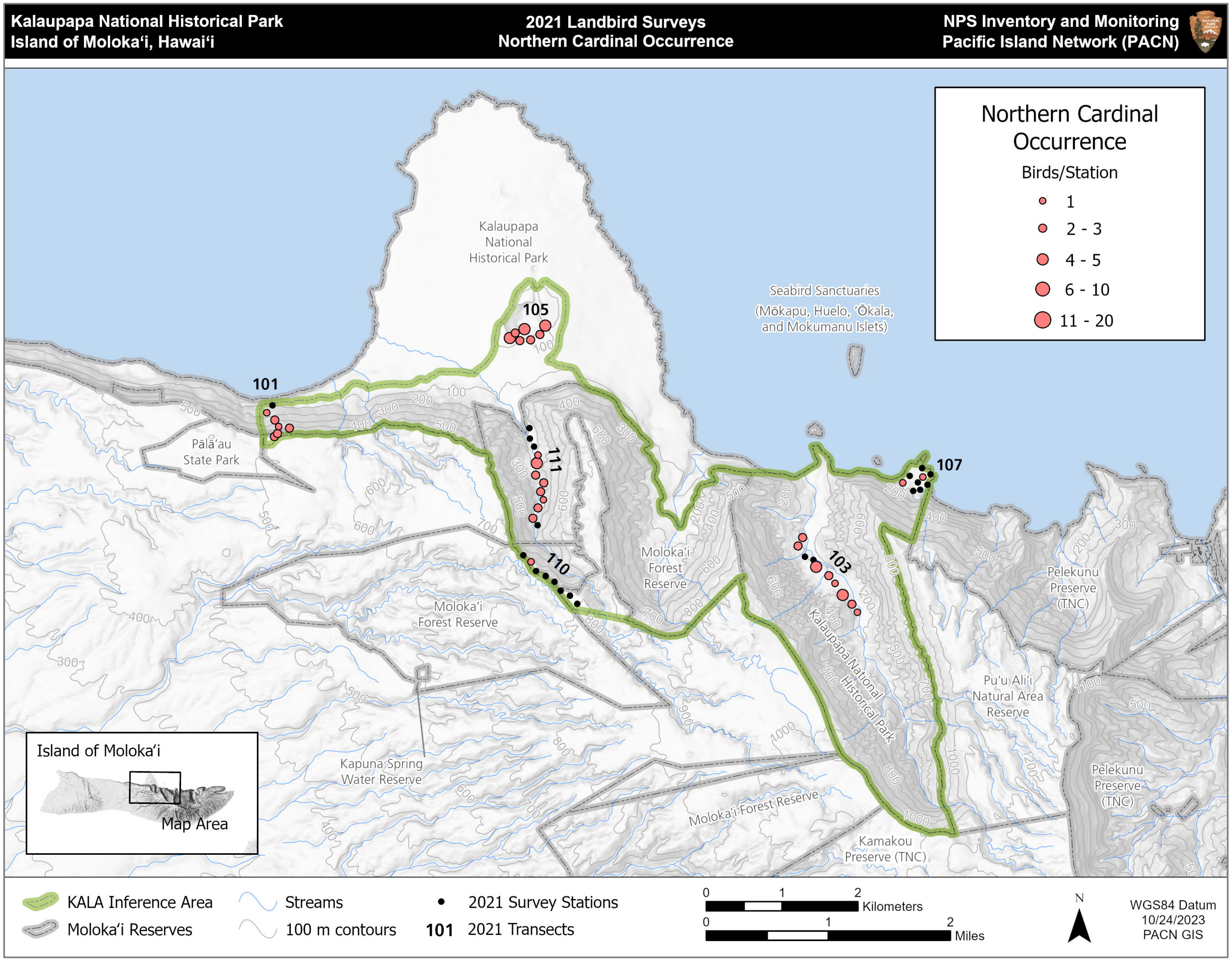

Figure 11. Northern Cardinal detections during the 2021 Kalaupapa National Historical Park landbird survey.
NPS / MARK W. WASSER

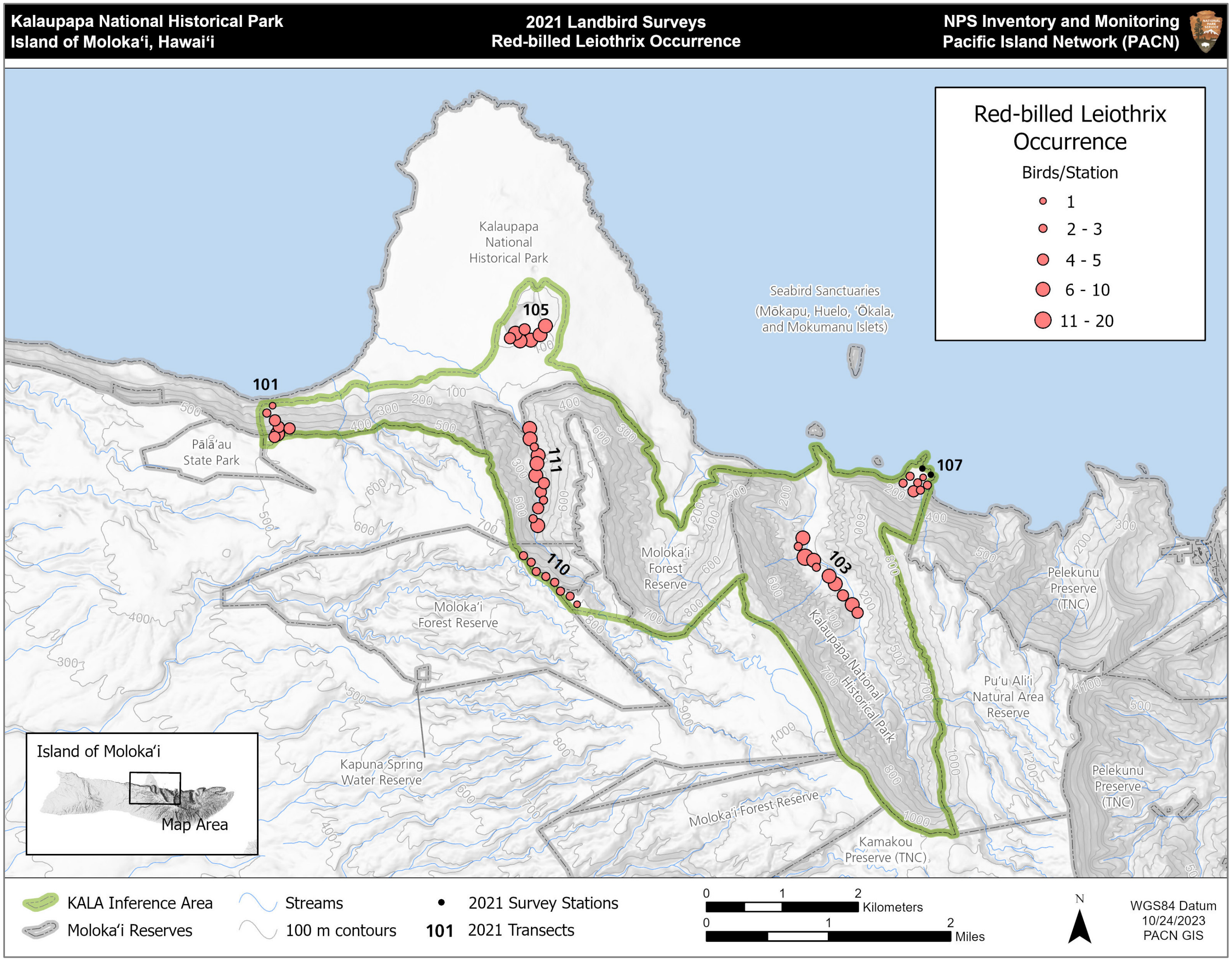

Figure 12. Red-billed Leiothrix detections during the 2021 Kalaupapa National Historical Park landbird survey.

NPS / MARK W. WASSER

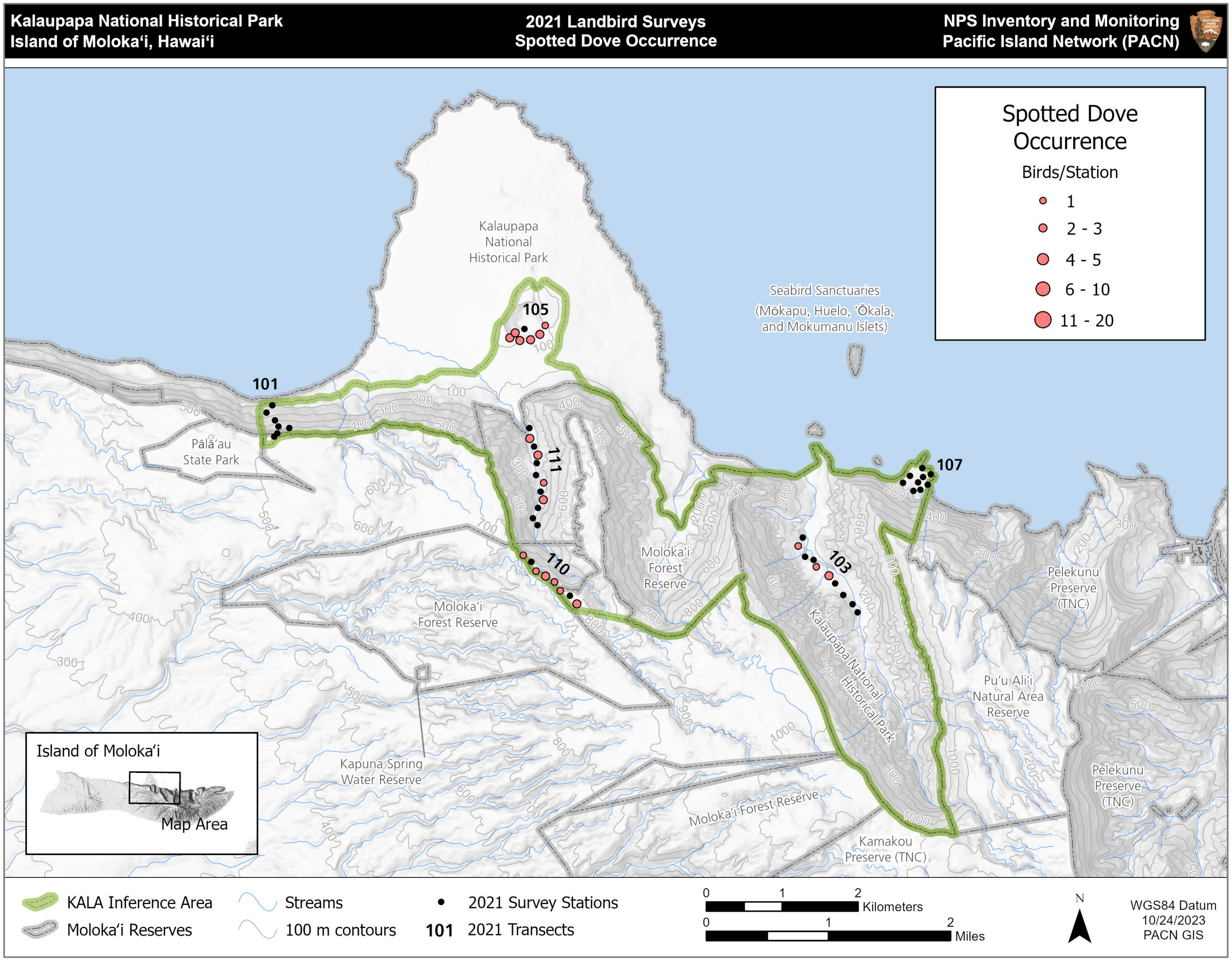

Figure 13. Spotted Dove detections during the 2021 Kalaupapa National Historical Park landbird survey.
NPS / MARK W. WASSER

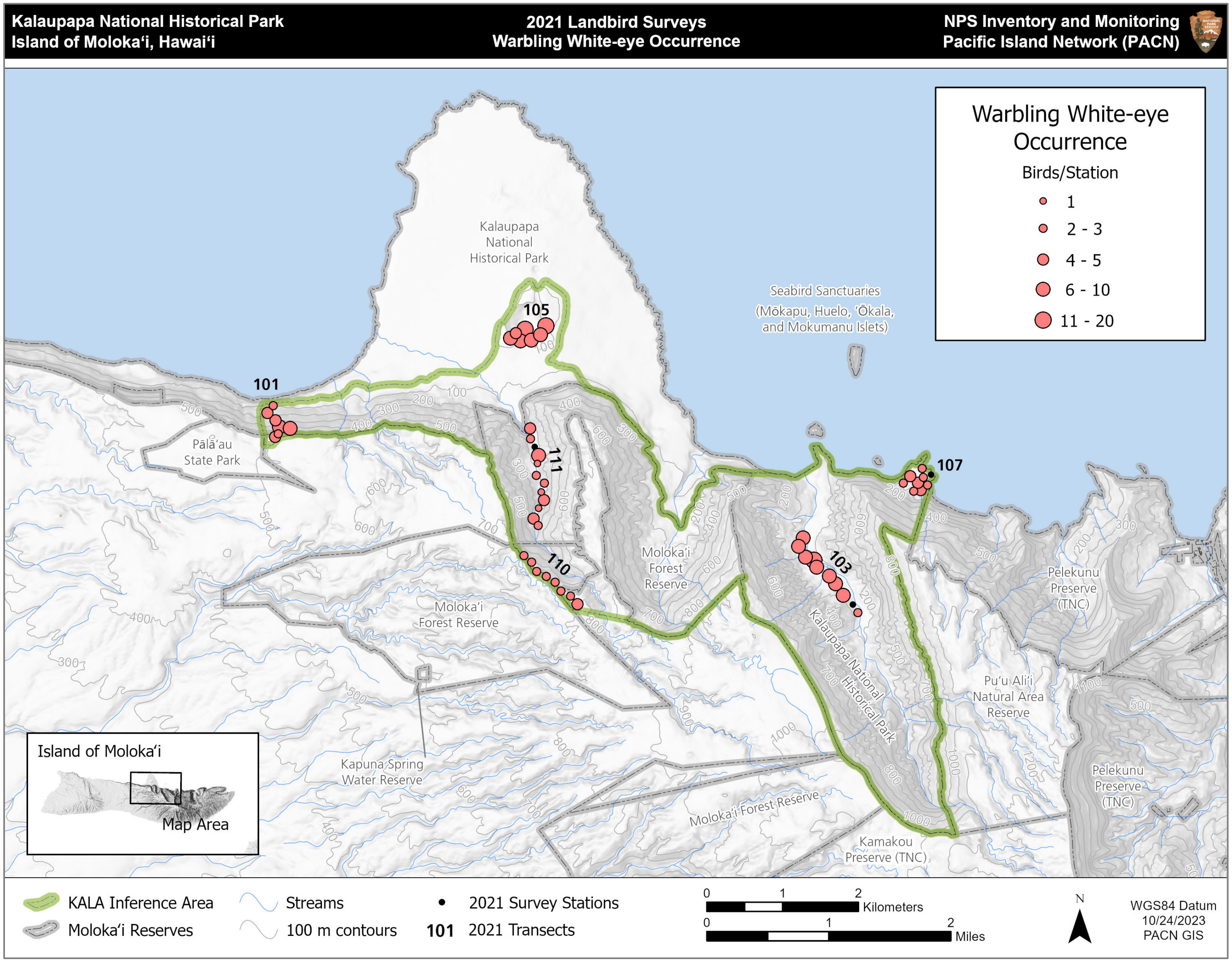

Figure 14. Warbling White-eye detections during the 2021 Kalaupapa National Historical Park landbird survey.
NPS / MARK W. WASSER

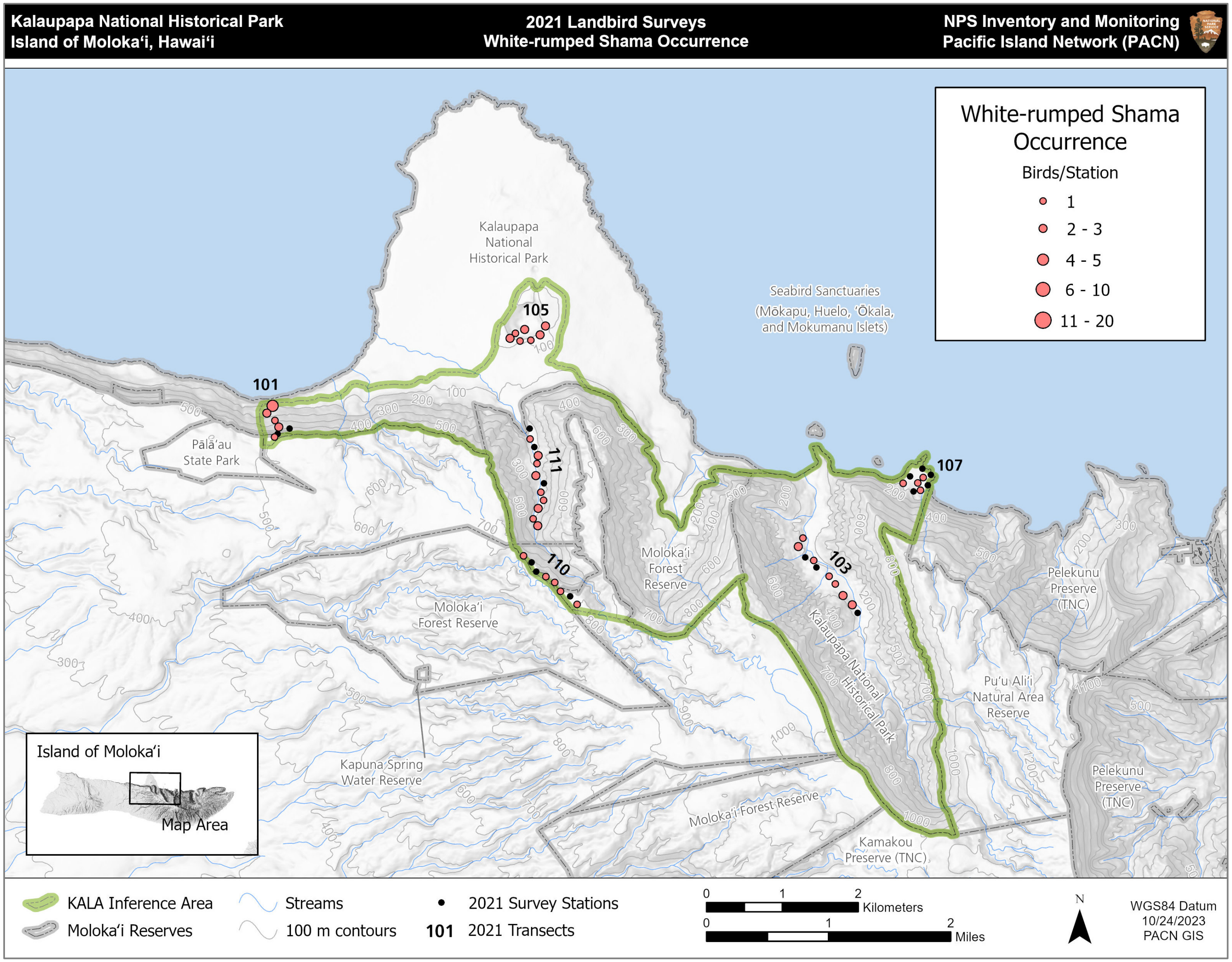

Figure 15. White-rumped Shama detections during the 2021 Kalaupapa National Historical Park landbird survey. *NPS / MARK W. WASSER*

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