FOREST BIRD DISTRIBUTION, DENSITY AND TRENDS AT HAKALAU FOREST NATIONAL WILDLIFE REFUGE, HAWAII

REPORT TO
HAKALAU FOREST NATIONAL WILDLIFE REFUGE
U. S. FISH & WILDLIFE SERVICE

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EXECUTIVE SUMMARY

The Hawaii Forest Bird Interagency Database Project has produced a centralized and relational database of forest bird survey data collected in Hawaii since the mid-1970s. The database contains more than 800,000 records from over 400 surveys on all the major Hawaiian Islands. We synthesized information from 66 separate variable circular plot (VCP) surveys for forest birds on the north Hamakua Region of the Island of Hawaii from 1977-2000. The objectives of this study were to (1) estimate the distribution, abundance, and status of native and exotic forest birds in HFNWR; (2) examine trends in forest bird densities over time; and (3) evaluate the effectiveness of the current monitoring program to detect changes in forest bird populations. The present study represents a milestone for the HFBIDP, because it was the test case for developing and testing methods in landcover classification, point density estimation, species habitat modeling, and power analysis that will be used for HFBIDP's future work throughout the islands.

The study area encompasses 648-km^2 of mid- to high-elevation montane rain forest on the northeastern slope of Mauna Kea volcano, including Hakalau Forest National Wildlife Refuge (HFNWR) and surrounding public and private lands. Survey sites were mapped and linked to habitat information derived from digital elevation models, rainfall and temperature isopleths, and land-cover classification of Landsat 7 imagery. Classified imagery provided data on vegetation composition and structure, including forest canopy closure, canopy height, and the richness (i.e., heterogeneity) of land-cover types. Understory components including native tree- and matted-ferns and invasive species such as banana poka (*Passiflora mollissima*) and guava (*Psidium* spp.) were obtained from Jacobi (1989). Point estimates of bird densities were calculated with program DISTANCE from VCP surveys. Regression was used to model density and habitat associations, to predict density in surveyed and unsurveyed habitats, and to estimate population sizes for 13 native and introduced bird species (Table 1). We examined trends in population sizes since 1977, and examined the ability of the current monitoring protocol to detect trends in populations over time.

Population Status

Hakalau Forest NWR was established to protect some of the best remaining habitat for forest birds in Hawaii, and contains relatively high densities of many native forest birds. In particular, although HFNWR comprises only 20% of the land area within the north Hamakua study area, this study showed that it harbors fully 50% of the area's Akiapolaau, 49% of its Hawaii Creeper, 72% of its Hawaii Akepa, and 30% of the area's Iiwi population. Moreover, populations of 6 native species – Hawaii Amakihi, Akiapolaau, Hawaii Creeper, Hawaii Akepa, Iiwi, and Apapane – have shown significant increases in density since the area was first surveyed during the Hawaii Forest Bird Surveys in 1977. Only one alien species, the Northern Cardinal, was found to have increased in density, whereas Japanese White-eye density has declined since 1977. The refuge appears to be succeeding in its goal of protecting populations of native Hawaiian forest birds within its boundaries. Unfortunately, the current monitoring program can detect downward trends in density for most species only if they are sufficiently severe

(greater than or equal to 10% per annum). Additional reasonable sampling effort would not result in sufficient increase in statistical power. Moreover, our analyses demonstrated that the current sampling effort could be reduced by approximately 1/3 without significant loss of statistical power, allowing sampling effort to be redirected to provide more extensive sampling of surrounding or low-elevation habitats that are currently inadequately surveyed.

The majority of native forest birds of Hakalau Forest NWR are forest specialists whose densities are positively associated with high-stature, closed-canopy forests of ohia and koa, and are negatively associated with landcover richness (e.g., areas where different habitat types meet, such as forest and pasture). These findings emphasize the importance of employing refuge management practices that increase the amount of closed-canopy native forest, but that also minimize fragmentation and the creation of edge habitats.

Species Accounts

Elepaio (*Chasiempis sandwichensis*)

- Approximately 138,900 (± 605 SE) Elepaio occur in the north Hamakua study area.
- HFNWR currently protects 27% of the Elepaio population in the study area (approximately 38,000 Elepaio).
- No trends in Elepaio densities were detected for either the 24-year (1977-2000) or 14-year (1987-2000) study periods.
- The current survey effort is capable of detecting declines in Elepaio density of ≥10% per year with 84% power for a prospective 10-year monitoring period. Low to moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- Elepaio are common, widespread, and occur at highest densities in upper elevation, closed-canopy, high-stature forests.

Omao (*Myadestes obscurus*)

- Approximately 57,500 (± 191 SE) Omao occur in the north Hamakua study area.
- HFNWR currently protects 29% of the Omao population in the study area (approximately 16,900 Omao).
- No trends in Omao densities were detected for either the 24-year (1977-2000) or 14-year (1987-2000) study periods.
- The current survey effort is capable of detecting declines in Omao density of ≥10% per year with 89% power for a prospective 10-year monitoring period. Low to moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- Omao are fairly common, widespread, and occur at highest densities in upper elevation, closed-canopy, high-stature forests.

Hwamei (*Garrulax canorus*)

- Approximately 5,400 (± 43 SE) Hwamei occur in the north Hamakua study area.
- Approximately 300 Hwamei (6%) occur in HFNWR.
- No trends in Hwamei densities were detected for either the 24-year (1977-2000) or 14-year (1987-2000) study periods.

- The species is uncommon but widespread, and occur at highest densities in lower elevation, open-canopy, mid-stature forests.

Red-billed Leiothrix (*Leiothrix lutea*)
- Approximately 82,000 (± 480 SE) Leiothrix occur in the north Hamakua study area.
- Approximately 24,200 Leiothrix (30%) occur in HFNWR.
- No trends in Leiothrix densities were detected for either the 24-year (1977-2000) or 14-year (1987-2000) study periods.
- The species is common, widespread, and occur at highest densities in upper elevation, closed-canopy, high-stature forests.

Japanese White-eye (*Zosterops japonicus*)
- Approximately 460,400 (± 1,417 SE) Japanese White-eye occur in the north Hamakua study area.
- Approximately 68,300 Japanese White-eye (15%) occur in HFNWR.
- No trends in White-eye densities were detected for either the 24-year (1977-2000) or 14-year (1987-2000) study periods.
- The species is common, widespread, and occur at highest densities in lower elevation, open-canopy, mid-stature forests, and heterogeneous vegetation types.

Northern Cardinal (*Cardinalis cardinalis*)
- Approximately 8,700 (± 93 SE) Northern Cardinal occur in the north Hamakua study area.
- Approximately 500 Northern Cardinal (6%) occur in HFNWR.
- A positive trend in Northern Cardinal density was observed for the 24-year study period (1977-2000); no trends in Northern Cardinal densities were detected for the 14-year study period (1987-2000).
- The species is uncommon but fairly widespread, and occur at highest densities in the lower- and uppermost-elevation, open-canopy, high-stature forests, and heterogeneous vegetation types.

House Finch (*Carpodacus mexicanus*)
- Approximately 64,800 (± 568 SE) House Finch occur in the north Hamakua study area.
- Approximately 8,300 House Finch (13%) occur in HFNWR.
- No trends in House Finch densities were detected for either the 24-year (1977-2000) or 14-year (1987-2000) study periods.
- The species is common, and occur at highest densities in grassland, drier koa-dominated woodland and forests, and heterogeneous vegetation types.

Hawaii Amakihi (*Hemignathus virens virens*)
- Approximately 200,800 (± 990 SE) Amakihi occur in the north Hamakua study area.
- HFNWR currently protects 26% of the Amakihi population in the study area (approximately 51,600 Amakihi).

- A positive trend in Amakihi density was observed for the 24-year study period (1977-2000); no trends in Amakihi densities were detected for the 14-year study period (1987-2000).
- The current survey effort is capable of detecting declines in Amakihi density of ≥10% per year with 89% power for a prospective 10-year monitoring period. Low to moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- The species is common, widespread and occurs at highest densities in drier koa-dominated woodland and forests, and heterogeneous vegetation types.

Akiapolaau (*Hemignathus munroi*)

- Approximately 1,600 (± 44 SE) Akiapolaau occur in the north Hamakua study area.
- HFNWR currently protects 50% of the Akiapolaau population in the study area (approximately 800 Akiapolaau).
- A positive trend in Akiapolaau density was observed for the 24-year study period (1977-2000); no trends in Akiapolaau densities were detected for the 14-year study period (1987-2000).
- The current survey effort is capable of detecting declines in Akiapolaau density of ≥10% per year with 52% power for a prospective 10-year monitoring period. Low to moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- The species is very uncommon and restricted to a narrow belt of habitat of upper elevation, closed-canopy, high-stature forests.

Hawaii Creeper (*Oreomystis mana*)

- Slightly more than 17,800 (± 221 SE) Creeper occur in the north Hamakua study area.
- HFNWR currently protects 49% of the Creeper population in the study area (approximately 8,700 Creeper).
- Positive trends in Creeper density were observed for the 24-year (1977-2000) and 14-year (1987-2000) study periods.
- The current survey effort is capable of detecting declines in Creeper density of ≥10% per year with 79% power for a prospective 10-year monitoring period. Low to moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- The species is uncommon and restricted to upper elevation, closed-canopy, high-stature forests.

Hawaii Akepa (*Loxops coccineus coccineus*)

- Approximately 8,300 (± 144 SE) Akepa occur in the north Hamakua study area.
- HFNWR currently protects 72% of the Akepa population in the study area (approximately 6,000 Akepa).
- A positive trend in Akepa density was observed for the 24-year study period (1977-2000); no trends in Akepa densities were detected for the 14-year study period (1987-2000).
- The current survey effort is capable of detecting declines in Akepa density of ≥10% per year with 80% power for a prospective 10-year monitoring period. Low to

moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- The species is uncommon and restricted to upper elevation, closed-canopy, high-stature forests.

Iiwi (*Vestiaria coccinea*)
- Approximately 285,400 (± 1,267 SE) Iiwi occur in the north Hamakua study area.
- HFNWR currently protects 35% of the Iiwi population in the study area (approximately 100,300 Iiwi).
- A positive trend in Iiwi density was observed for the 24-year study period (1977-2000); no trends in Iiwi densities were detected for the 14-year study period (1987-2000).
- The current survey effort is capable of detecting declines in Iiwi density of ≥10% per year with 99% power for a prospective 10-year monitoring period. Low to moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- The species is common, fairly widespread, and occurs at highest densities in upper elevation, closed-canopy, high-stature forests.

Apapane (*Himatione sanguinea*)
- Approximately 255,900 (± 1,037 SE) Apapane occur in the north Hamakua study area.
- HFNWR currently protects 29% of the Apapane population in the study area (approximately 75,200 Apapane).
- A positive trend in Apapane density was observed for the 24-year study period (1977-2000); no trends in Apapane densities were detected for the 14-year study period (1987-2000).
- The current survey effort is capable of detecting declines in Apapane density of ≥10% per year with 81% power for a prospective 10-year monitoring period. Low to moderate (1-5%) rates of decline in density cannot be reliably detected with the present monitoring scheme.
- The species is common, widespread, and occurs at highest densities in upper elevation, closed-canopy, high-stature forests.

Management Recommendations
- Hakalau Forest NWR should continue its efforts and progress at forest restoration. Our species habitat association models indicate that increasing the amount of high-stature, closed-canopy native forest will result in higher densities of native forest birds.
- Variable-circular plot methods (and other count data) are relatively ineffective at tracking changes in species that occur at very low densities. Thus, it is of limited use in determining the status of rare or uncommon species, particularly Akiapolaau, Hawaii Creeper, and Akepa. Demographic studies should be considered for these species, and may follow BBIRD protocols (Martin *et al*. 1997).
- Alternative methods for surveying Akiapolaau (e.g., capture-recapture/resight, spot-mapping, etc.) should be evaluated; an examination of seasonal and year-to-year

variability in Akiapolaau vocalization should be initiated to improve density and variance estimates based on count surveys; and Akiapolaau surveys should coincide with greatest seasonal levels of vocalizing.

- We evaluated the feasibility of improving the ability (power) of the monitoring program to detect trends in bird populations by increasing sample size. Although power increases with increasing sample size, the relationship is not linear, so that a very large increase in sample size is necessary to obtain only a minimal increase in power. Thus, we judged that increasing sampling size was not a feasible or desirable method for improving trend detection of forest birds in HFNWR.
- Power analyses indicate that sampling effort within the HFNWR could be reduced from the current 339 to approximately 200 stations, with minimal reduction in ability to detect trends. The savings in sampling effort could be utilized to increase either the geographic coverage, or the frequency of sampling, as discussed below. Specifically, we recommend dropping from breeding season forest bird surveys transects: 2, 4, 6, 11, 15/1001 (1A), 7001 (7A), and 8001 (8A).
- We recommend that an effort be made to expand the sampling of bird populations on surrounding public lands, where significant populations of endangered species persist, and at middle elevations, where population declines due to disease are of concern. Specifically, we recommend:
  1. Establishing and annually surveying one transect that parallels HFNWR transect 14 immediately north of the refuge boundary.
  2. Reestablishing and surveying annually the upper portions (above 1,300 m) of HFBS transects 21 and 22
  3. Establish two additional transects between HFBS transects 21 and 22 to provide thorough and consistent spatial coverage of the area.
- We recommend that an effort be made to expand sampling of bird populations at middle elevations, where low density populations of Akepa and Creeper exists, and population declines due to disease are of concern. Specifically, we recommend that several of the existing transects spaced 3-4 km apart (similar to HFBS) be extended downslope to approximately 1,300 m elevation and sampled every 3-5 years.
- We encourage HFNWR and neighboring land managing agencies to develop a regional approach for species monitoring and conservation.
- Observers vary in their ability to detect birds. Observer training and pre-survey calibration exercises should be continued to reduce inter-observer variability.
- Vegetation should be periodically described (e.g., decadal) for all survey stations. Vegetation information could be used as a covariate in detection function modeling and would substantially benefit remote sensing classification efforts.
- Sampling covariates (e.g., weather conditions and time of day) affect the detectability of birds. Covariate fields left blank on data forms are treated as missing data. All data form fields should be completed during surveys, especially gust.

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INTRODUCTION

The 13,252 ha Hakalau Forest National Wildlife Refuge (HFNWR; 19° 51'N, 155° 18'W) on the windward slope of Mauna Kea volcano, is the largest protected area of mid- to high-elevation rain forest on the island of Hawaii. The forest harbors important populations of native forest birds, including three endangered species, the Akiapolaau (*Hemignathus munroi*), Akepa (*Loxops coccineus coccineus*), and Hawaii Creeper (*Oreomystis mana*), and more than 30 species of rare and endangered Hawaiian plants.

The primary mission of the refuge is the preservation and recovery of Hawaii's native avifauna, and the current management strategy is to protect refuge lands from further degradation and to restore them as much as possible to their natural state. Inventory and monitoring of bird populations and their response to land management activities (feral ungulate removal, forest restoration and alien species control) are an important component of the management strategy. As part of the monitoring program, the refuge conducted variable circular plot (VCP) surveys along established transects each year from 1987 to the present. Additional surveys have been conducted in limited areas as part of specific research projects (USGS/PIERC unpubl. data). Data analyzed in this study include the Hawaii Forest Bird Surveys conducted in 1977 (HFBS; Scott *et al*. 1986) and all VCP surveys conducted in the study area from 1987 to 2000.

The objectives of this study were to (1) estimate the distribution, abundance, and status of native and exotic forest birds in HFNWR; (2) examine trends in forest bird densities over time; and (3) evaluate the effectiveness of the current monitoring program to detect changes in forest bird populations.

BACKGROUND

Bird Surveys in Hawaii

Monitoring bird populations is a critical component of conservation efforts and much effort has been expended on the development of appropriate survey methods (Thomas 1996, Rosenstock *et al*. 2002). Bird surveys in Hawaii have the distinct benefit of having been established with a consistent and standardized methodology. Distance sampling has been applied to almost all forest bird surveys conducted on the six main islands over the past quarter century.

In 1976-1981, the U.S. Fish and Wildlife Service conducted systematic surveys of forest birds and plant communities on all of the main Hawaiian Islands as part of the HFBS (Scott *et al*. 1986). Results of this monumental effort have guided conservation efforts and provided the basis for many plant and bird recovery plans and land acquisition decisions in Hawaii during the past two decades. Unfortunately, these estimates and range maps are now outdated, hindering modern conservation decision-making efforts and recovery plan development.

Nearly 400 different surveys of forest birds have been conducted in Hawaii since the HFBS by many organizations, including the U.S. National Park Service, U.S. Fish and Wildlife Service, U.S. Forest Service, U.S. Department of Defense, Hawaii Department of Land and Natural Resources, Kamehameha Schools, the University of Hawaii, The Nature Conservancy, U.S. Geological Survey - Pacific Island Ecosystems Research Center, and private consultants. These survey data represent a phenomenal informational resource that has not previously been widely available.

The Hawaii Forest Bird Interagency Database Project

The Hawaii Forest Bird Interagency Database Project was established in 1999 to accomplish four primary objectives: (1) create a centralized, standardized database of all forest bird surveys collected since and including the HFBS; (2) estimate current population size, and produce distribution maps for all native and alien forest birds in Hawaii; (3) examine population trends in species of concern; and (4) make these results available to cooperators throughout Hawaii through written reports and on the Internet.

Since October 1999, the HFBIDP has been gathering, compiling, proofing, and standardizing data from all forest bird surveys conducted throughout Hawaii over the past quarter century. The database now contains over 800,000 bird records from more than 400 surveys. Data analysis, species-habitat modeling, and trend detection analysis are now in progress. Once analyzed, the data will elucidate trends in distribution and density of species of concern, allow hypothesis testing for the causes of decline, examine the results of management actions, and guide future survey effort, conservation planning and decision-making. The present study represents a milestone for the HFBIDP, because it was the test case for developing and testing methods in landcover classification, point density estimation, species habitat modeling, and power analysis that will be used for HFBIDP's future work throughout the islands.

Advances in Analysis of Bird Density and Distribution

There has been keen interest and much research activity in recent years focused on improving methods for obtaining density estimates from survey data. Specifically, advances have been made in the following areas: (1) accounting for effects of sampling conditions and observers; (2) developing methods that avoid assuming strata homogeneity; and (3) predicting densities in areas that have not been sampled. The procedures presented here utilize these new developments in distance sampling analysis.

Previous methods (e.g., Sauer *et al*. 1994, Pendleton 1995, Kendall *et al*. 1996, Fancy 1997) did not directly adjust for the effects of variables (e.g., weather conditions or observer effects) that can significantly bias density estimates. Fancy (1997) detailed a procedure where effects of variables were quantified in separate analyses and used to adjust density estimates *a posteriori*. His approach represented a marked improvement over previous methods that did not adjust for sampling conditions. However, Fancy's method adjusts the actual distance estimates, and results in interpretative difficulties similar to that of transforming data prior to analysis; i.e., the association of response and transformed predictor variables are not straightforward. Modeling covariate parameters can now be conducted in Distance 4.0 through a log link function that directly adjusts the

detection function, thereby avoiding the need of manipulating the actual detection distances (Buckland *et al.* in preparation).

A second area of analysis that has improved in recent years involves translating count data for particular stations into a density estimate for an entire area. Habitats are rarely homogeneous, particularly within large study areas. To account for differences in population densities across study areas, Buckland *et al*. (1993, 2001) and Fancy (1997) recommended stratifying model parameters by habitat type or other factors (e.g., ohia forest, open canopy sites, etc.). This procedure assigns each bird survey station to a stratum and produces abundance estimates for the area of each stratum. Total population estimates are then calculated by summing abundances over all strata. The difficulty with this method is that complex combinations of habitat variables are not readily translated into strata and modeling species response to several variables with numerous classes requires an inordinate number of strata combinations. For example, an area of ohia on flat terrain within a 3,000 to 4,000 mm rain belt would constitute a stratum distinct from that of similar habitat within a 2,000 to 3,000 mm rain belt. Instead of using a strata approach, we used regression techniques to incorporate multiple habitat factors in the estimation of bird densities at known locations (i.e., sampling stations). We then applied the habitat association regression models to estimate bird densities to unsampled areas (Stauffer 2002).

Advances are also currently ongoing in the science of predicting species occurrence across the landscape. The species-habitat models developed here are an extension of the widely used regression techniques applied elsewhere (see Stauffer 2002, and references cited therein). The models operationally depend on the assumption that bird populations respond in a predictable manner to combinations of biotic (e.g., vegetation type, canopy closure) and abiotic (e.g., elevation, precipitation) factors. Regression modeling and geographic information systems (GIS) allow for predicting densities in a systematic manner across the entire study area. Through this integration, estimates of population size and variance are reproducible and applicable to other study areas and species.

METHODS

Study Area

The north Hamakua study area (64,843 ha) is located on the eastern flank of Mauna Kea, Hawaii Island, between 300 to 2,400 m (1,000 to 8,000 ft) elevation (Figure 1). Mean daily air temperature average 15°C with an annual variation of <5°C. Annual rainfall averages 2,500 mm with an annual maximum of about 6,100 mm (Juvik and Juvik 1998). The montane forest, where most surveys were conducted, has a canopy dominated by old growth ohia (*Metrosideros polymorpha*) and koa (*Acacia koa*). Olapa (*Cheirodendron trigynum*), pukiawe (*Styphelia tameiameiae*), ohelo (*Vaccinium calycinum*), akala (*Rubus hawaiiensis*), and *Cibotium* tree ferns are the most common subcanopy trees and shrubs. The study area is steeply dissected by ridges and erosion gullies, with frequent major tree falls. Vegetation at low elevations (0 – 600 m) consists of exotic trees, shrubs and grasses in agriculture and urban/exurban settings (Figure 2). Vegetation at middle

elevations (600 – 1,900 m) is dominated by native ohia and koa/ohia forest, whereas the highest elevations (>1,900 m) are comprised of pasture, subalpine native shrubland, and mamane (*Sophora chrysophylla*) and koa woodland. Non-native plant species may be found throughout parts of the native forest at all elevations. Scott *et al*. (1986) provides a more detailed description of the region.

Field Methods

A total of 66 variable circular plot surveys were conducted between 1977 and 2000 in the Hakalau Forest National Wildlife Refuge (HFNWR) and environs (Figure 1). The 1977 Hawaii Forest Bird Survey was the first systematic bird survey of the region and sampled an extensive area, including 1,366 stations on 12 transects covering 648 km². Following the creation of HFNWR, refuge staff conducted annual surveys between 1987 and 2000 covering 350 stations, 15 transects, and an area of 55 km². Three smaller study areas at Maulua, Nauhi, and Pua Akala (250 stations, 23 transects, 3 km²) were surveyed approximately quarterly from 1994 to 1999 by USGS/PIERC as part of a larger research project. The World Union Parcel, an extension of the HFNWR transects (110 stations, 12 transects, 11 km²), was sampled in 1999 and 2000. A number of the transects and stations were sampled by more than one survey effort.

Surveys were conducted throughout the year, with most occurring during January to July (69.7%; 46 of 66 surveys). Surveys were comprised of 63 unique transects with a total of 1,984 point-count stations (Table 2). The distance among stations varied between 134 m and 250 m. However, most studies established a 150-m interval between stations to reduce the likelihood of double-counting birds (Reynolds *et al*. 1980, Scott *et al*. 1986). Observers received pre-survey training to calibrate for distance estimation and bird vocalizations, thereby minimizing variability among observers and standardizing for local conditions (Kepler and Scott 1981, Scott *et al*. 1986, Verner and Milne 1989).

Observers recorded the detection type (aural, visual, or both) and horizontal distance from the station center point to individual birds detected during an 8-min count. They also recorded cloud cover, rain, wind, gust, and time of day at each station. Sampling was typically conducted between dawn and 11:00 hours, and halted when rain, wind, or gust exceeded pre-specified levels (see Scott *et al*. 1986).

Data Handling

Survey data were evaluated for content and completeness. A quality assurance/quality control protocol verified data accuracy, all records were line-item proofed and standardized, and error rate (< 1%) in data entry was determined through spot-checking before the data were added to the database. Metadata was produced in a data set and error-checking summary, and returned to the survey coordinator for verification. Once the data were validated the dataset was integrated into the database.

Detectability of forest birds varies throughout the year, due to vocal activity associated with breeding and non-breeding seasons. To minimize biases associated with differences in sampling periods, we restricted density estimates to breeding season surveys only (i.e., January to July) (*sensu* Fancy and Ralph 1997, Lepson and Freed 1997, Fancy and Ralph

1998, Lindsey *et al*. 1998, Male *et al*. 1998, VanderWerf 1998, Halkin and Linville 1999, Wakelee and Fancy 1999, van Riper 2000, Pratt *et al*. 2001).

We defined a primary observer as a qualified, trained observer who partook in pre-survey calibration. In some cases, a station was sampled more than once during a given survey. When two or more individuals conducted sampling on the same day, we used only the data from the first observer in our analysis. If sampling was conducted on multiple days within a single survey, the increased effort at that station was accounted for in the analysis procedures by dividing the number of observations by the sampling effort (Buckland *et al*. 2001; see below).

Estimating Population Density and Size from VCP Counts

Variable circular plot counts are a form of distance sampling in which sampling points (i.e., stations) are placed at intervals along transects, and these stations serve as the centers for estimating radial distances to birds (i.e., distance measures) during a count period. Ultimately, our goal is to use these counts to estimate the population size for the entire area, by extrapolating from density estimates at each of the stations (i.e., density per station; DPS). To determine the density of a particular species at a given station, one must know the total number of individuals of that species that were detected at that station and the effective area sampled. The effective area (EA) is determined by the species (the frequency and volume of vocalizations) as well as the habitat (where denser habitats decrease detectability of birds and lead to smaller EA). EA is a function of the effective detection radius (EDR), which is defined as the point where the number of birds detected beyond the point equals the number missed within the point. The final parameter needed is the species-specific detection probability, or the probability of detecting an individual at a given distance. The detection probability is determined by plotting distance measures and fitting a curve (i.e., detection function) to the histogram. The number of stations, number of birds detected, the EA and the detection probability are used to calculate species-specific density estimates ($\hat{D}$).

Once density has been estimated, it can be used to estimate the population size ($\hat{N}$) in an area of size (A) by the equation $\hat{N} = \hat{D} * A$. Further discussion of the statistical framework for distance sampling, including estimating variance parameters, can be found in Buckland *et al*. (2001).

Covariables

As discussed above, the probability of detection is a function of distance from the station, species, and habitat type; however, many other factors such as wind, rain, cloud cover, and time of day, may also influence detectability. These factors, or covariables, can therefore affect density estimates from count data unless they are accounted for during analysis. Accounting for these covariables reduces the variation in the detected distances and the resulting models possess greater precision. We explored the following covariables: cloud cover, rain, wind, gust, time of detection, observer, and year.

Reliable density estimates require fairly large sample sizes (i.e., detections) of individual species. Increasing the number of variables (i.e., number of sampling covariables and

habitat-association factors) increases model complexity and requires greater amounts of data (i.e., bird observations). Buckland *et al*. (2001) suggest that for each variable combination there be 60-80 observations. However, as few as 50 observations per variable combination may be possible for species that respond favorably to distance sampling methodologies (L. Thomas, pers. comm.). Maximal models incorporate all possible parameters of interest and require the greatest amount of data. However, saturating a model with all possible parameters does not necessarily produce the most descriptive or explanatory model. Simplified models that include only the most important parameters and which require less data than maximal models may produce the best approximating model in many cases.

Model Selection

Model selection is the process of assessing simplified models to identify the best approximating model, that is, the 'best-fit' model. As stated above, a detection form *g(y)* must be specified for a given data set. Typically, uniform, half-normal and hazard-rate key function models are most appropriate for VCP data (Buckland *et al.* 1993:150). The key function is a mathematical curve that can take a variety of shapes and should be matched to the general shape of the distance histogram. Expansion terms, also called adjustment terms, may be used with the key functions to adjust the curve fit of the model. We used the cosine and simple polynomial expansion terms with uniform and hazard-rate key functions, and a hermite and simple polynomial expansion term with half-normal detection key function. Previous research of Hawaiian birds showed a marked decline with distance from the center point and a long right tail (Nelson and Fancy 1999, Reynolds *et al*. in press, Foster *et al*. in press, USGS/PIERC unpubl. data). This general shape most closely matches the half-normal and hazard-rate key functions; however, the uniform key function with appropriate series expansion may adequately fit these data. Truncating the largest distances typically improves model fit by deleting outliers. Truncation prior to analysis is advised by Buckland *et al*. (2001: 16) and they suggest removing 5 – 15% for point transect data. We explored *a priori* 10% truncation before model fitting and applied further truncation when necessary based on assessment of model fit.

We selected the model with the best fit to the observed data based on four parameters: $h(0)$ %CV; var($\hat{D}$) ; correlation; and Akaike's information criterion (AIC) (Buckland *et al.* 1993, 2001, Burnham and Anderson 1998).

h(0)%CV

The parameter $h(0)$ %CV is the "slope of the probability density function of detected distances from the point, evaluated at zero distance" (Buckland *et al*. 2001:18). In order to be accepted, a model had to have a coefficient of variation at $h(0)$ less than or equal to 10%; the lower the value, the better the fit of the model to the data, so that lower values were preferred.

var(D)

Model variance is comprised of variability in the detection form and variability from the distance data such that

$$\text{var}(\hat{D}) = \text{var(model)} - \text{var(distance data)}$$

where the parameter $\text{var}(\hat{D})$ is the proportion of variance in the model due to variability in the *g(y)* detection form. Only models with $\text{var}(\hat{D})$ of less than 70% were considered (K. Burnham, pers. comm.).

Correlation
The correlation parameter varies from –1 to 1. Detection form features that are strongly correlated with each other should be avoided; however, because of the nature of bird distance distributions some models will have very high levels of correlation (e.g., > |.80|).

Akaike's information criterion (AIC)
AIC provides a quantitative value for model assessment, where the model with the lowest value is chosen. A limitation to using AIC is that comparisons are valid only for models based on the same data (i.e., the same amount of truncation). AIC should not be used as the sole model selection criteria as it is insensitive to $h(0)$ %CV and $\text{var}(\hat{D})$. Therefore, AIC was the last parameter evaluated in the model selection process.

Further parameterization of a model to account for differences in sampling conditions can be accomplished through covariates. This is achieved through a generalized linear model framework where the linear function of a covariate is modeled to the logarithm of the effective area searched (Ramsey *et al*. 1987, Fancy 1997, Buckland *et al*. 2001, Buckland *et al*. in preparation). The effective area is treated as a scale parameter and is related to the covariates through a log link function (Ramsey *et al*. 1987, Buckland *et al*. 2001). Covariate modeling is only possible for the half-normal and hazard-rate key functions (Buckland *et al*. 2001, Thomas *et al*. 2001). Covariate analysis is accomplished in the Multiple Covariates Distance Sampling module in Distance 4.0 (Thomas *et al*. 2001).

Correlating population densities to habitat types may be accomplished through the production of unstratified bird densities per station (DPS). EDR was calculated under standard conditions, accounting for covariates, from pooled data sets using program Distance 4.0 (Thomas *et al*. 2001). Standard error about the EDR was calculated empirically, providing a measure of the variance associated with model fit. EDR was converted to an effective area (EA) surveyed by

$$EA = \pi EDR^2$$

the equation for a circle with units of m^2. EA is then converted to ha or km^2 (dividing the value by 10,000 or 1,000,000, respectively).

Density per station is the product of the number of observations at an individual station (n_i) multiplied by EA and dividing by E_i sampling effort:

$$DPS = \left(n_i * EA\right) / E_i$$

where sampling effort is defined as the sum of times an individual station was sampled independently by primary observers (see METHODS: Data Handling).

Habitat Variables

The 64,843 hectare (= 648 km^2) north Hamakua study area was delineated with a minimum concave polygon at a distance of 1-kilometer around all survey stations. The 1-kilometer buffer ensured that density predictions were not applied to habitat areas >1 km beyond the range of those used to generate the models.

We selected habitat variables for investigation based on published ecological studies in Hawaii and elsewhere (e.g., Scott *et al.* 1986, Dettmers *et al.* 2002), knowledge of the prominent features of Hawaiian forests, and discussions with other biologists. We were constrained to using only those variables for which digital landscape-scale information was available. These included the coverage of ohia, koa, mamane, grass, and exotic vegetation types, the presence/absence of tree ferns, matted ferns, *Psidium* spp, and *Passiflora mollissima*, the richness of landcover types, canopy closure and height, elevation, slope, rainfall, and temperature.

Habitat values were generated as either point- or area-based measures centered at each of the 1,984 distinct VCP station locations sampled within the study area. In addition, point- and area-based values were derived for a lattice of 64,843 points spaced 100 meters apart and used for prediction of densities for the entire study area. The 100-meter spacing was selected so as to match the 1-hectare (i.e., 100 x 100 meter) area used for bird density estimation. Point-based values were obtained by querying a GIS layer with the overlying lattice using the ArcView (Version 3.2) script "Pt2Z". Area-based measures used a 129-meter radius area (= 5.2 hectare circular sample) centered on each lattice point to quantify habitat. This radius was calculated as twice the maximum EDR for the native bird species with the greatest detectability (Omao, *Myadestes obscurus*). This radial extent was a compromise between sampling habitats across either too large or too small an area. More specifically, the extent of the area used for habitat sampling ensured that it exceeded the spatial resolution of digital grid-based imagery (900 square meters) and included the habitat conditions that most likely determine local bird abundance. We limited the extent of the habitat sample area to reduce overlap (and therefore correlation) in habitat measures between neighboring stations. The 129-meter radius was used to generate a buffer area from which habitat features were queried with the ArcView Spatial Analyst module. The tabulated output was subsequently converted to a percent of total area within each sample. This step standardized and accounted for the slight differences in total area among samples produced as an artifact of the process of a circular sample "cookie-cutting" a grid of square pixels.

Landcover classes as defined by dominant vegetation composition and structure were classified from Landsat ETM satellite imagery for the scene located at Path 62 Row 46

and dated 12/30/2000 (Figure 2). Vegetation structure is a composite measure of such characteristics as plant species composition and biomass, forest and woodland canopy closure and height, the amount of exposed soil or rock, and moisture. Classification was accomplished with a supervised method that involved identifying sets of spectral signatures characteristic of specific landcover and vegetation types. Classification incorporated ground-truth sampling and image interpretation of ancillary data sources such as air-borne acquired imagery (e.g., USDA Emerge Program Digital Orthophotos), digital vegetation maps (e.g., Jacobi 1989), and vegetation survey transects produced for other projects (e.g., HFBS; Scott *et al*. 1986). The vegetation structure types identified in classified satellite imagery were parsed into three components (dominant vegetation type, canopy closure, and canopy height), and exported as grid themes for use in subsequent analyses.

Coverage of the ohia, koa, mamane, grass, and exotic vegetation types were calculated as the proportional area within each 5.2-hectare circular sample. The proportional areas for canopy closure categories (closed [>60% closure], open [>25-60%], and sparse [< 25%]), and canopy height categories (high [>10 m], mid [>5-10 m], and low stature [<5 m]) were calculated in the same manner.

Although the proportional areas are typically correlated among vegetation types (i.e., the presence of one vegetation type implies the absence of other types), the values do not always sum to 100% because of co-dominance. For example, koa and ohia may occur syntopically either as co-dominants or single dominants. Therefore, the total area of ohia is the sum of "ohia-only" and koa-ohia areas. Likewise, koa is represented by the combined "koa-only" and koa-ohia areas. Consequently, a point-based query in which a mixture of ohia, koa and koa-ohia occur may result in values that sum to more than 100%.

Richness measured the heterogeneity of vegetation surrounding survey stations (Figure 3). The index was an area-based count of the structural vegetation types identified with classified satellite imagery, and was generated with the ArcView extension Spatial Analyst (menu command "Neighborhood Statistics"). The presence or absence of dominant understory components (Figure 4) were derived from point-based queries of grids developed from polygon-based digital vegetation maps (Jacobi 1989), and include tree ferns, matted ferns, *Psidium* spp. (i.e., guava), and *Passiflora mollissima* (i.e., banana poka).

Measures of elevation were generated from point-based queries of 10-meter digital elevation models. Slope was calculated as an area-based mean (Figure 5), and was obtained with the ArcView extension Spatial Analyst (menu command "Neighborhood Statistics"). Temperature and rainfall were point-based values of grids interpolated from isopleth contours (Figures 6 and 7). Isopleth contours were derived from digitized temperature and rainfall maps in Juvik and Juvik (1998).

Spatial Autocorrelation and Autoregressive Models
"Spatial autocorrelation" refers to the situation where the values of some parameter (say, bird density or presence of tree fern) are not distributed randomly across the landscape, but rather are more likely to be similar to those in neighboring areas (e.g., Akepa densities are related not only to landscape or habitat features but also to the density of Akepa in neighboring areas). This situation may be caused by conspecific attraction (Smith and Peacock 1990) and dispersal limitations, or for other demographic reasons related to population interactions. In addition, autocorrelation may arise as a result of collinearity among explanatory variables (i.e., habitat). For example, rainfall may be closely linked to elevation. These relationships may occur at fine- and coarse-scales (Kaluzny *et al*. 1998). Fine-scale autocorrelation corresponds to that which occurs among interacting neighbors (e.g., individual birds). Coarse-scale spatial autocorrelation occur in cases where broad geographic trends exist in habitat patterns that in turn may structure biotic responses (e.g., demes centered in an area with an optimum range of habitat conditions).

Analysis of autocorrelated data is problematic for conventional statistics, and may result in the overstatement of explanatory variable significance and tests of significance in models that assume independent errors (Haining 1990, Legendre 1993). To address this issue, we analyzed species-habitat relationships with spatial autoregressive models (Haining 1990), a technique only recently applied by ecologists (e.g., Lichstein *et al*. 2002a,b). Fine-scale spatial relationships were incorporated in an autoregressive model with a distance-based weight matrix that described the covariance among neighboring observations (Kaluzny *et al*. 1998). Coarse-scale spatial autocorrelation was accounted for by including in the regression models terms that described how density changed as a function of geographic location independent of the direct effect of habitat. More specifically, location was described in models by use of second-degree monomials (X^2, XY and Y^2) of the X and Y geographic coordinates. Second-degree monomials permit a response variable to exhibit a quadratic (i.e., unimodal) form as a function of location (Legendre and Legendre 1998). This form may occur where abundance increases, then decreases across a study area. Higher order monomials (e.g., cubic, etc.) can describe more complex forms. However, these terms come at the cost of diminished degrees of freedom, the need for considerably larger sample sizes and a loss of parsimony, and were not included in model development. X and Y coordinates were standardized to zero mean and unit variance to reduce collinearity between first order and higher order terms (Legendre and Legendre 1998). The second-degree monomials (X^2, XY and Y^2) were calculated from the standardized X and Y coordinates.

Model Development
Statistical models are sensitive to the skewness (i.e., non-normality) in response variable data (e.g., density, counts, etc.). The data used to develop predictive regression models exhibited skewness because of the high incidence of zero densities from observations that occurred in areas outside species' regional range. Exploratory models in these cases showed a poor fit to the data. To reduce the effects of high numbers of zero densities on dependent variable distribution and thereby improve model performance, portions of the study area for which a species was absent were excluded from the subset of data used in

model development. This was accomplished by initially identifying all survey stations with densities greater than zero. These stations were buffered with a 1-kilometer radius area, and a minimum concave polygon encompassing the buffers was used to delineate the area of each species' occurrence (hereafter referred to as "presence area"). The subsetting of stations with a presence area was accomplished with the "Intersect Themes" utility of the ArcView extension Xtools. Species for which models were developed for a presence area include Omao, House Finch, Hawaii Amakihi, Akiapolaau, Hawaii Creeper, Hawaii Akepa, and Iiwi. All other species had distributions that spanned the study area, and models were developed to this 64,843 hectare extent.

Model development initially entailed identifying the relative importance of habitat variables in accounting for variance in observed density. This was accomplished by calculating the deviance for single habitat variable models in S-Plus (Version 6; 2001). Variables were subsequently entered in the species-habitat model in the order in which deviance was most reduced (i.e., strongest correlation to density). Models were developed with ordinary least square (OLS) regression in S-Plus, with a significance level for variable entry and retention set at 0.05. A variable was retained in the model if its inclusion did not increase the p-value of variables already in the model to over 0.05. This criterion ensured that important variables were not "bumped out" by inclusion of variables with collinear effects. To further avoid the effects of multicollinearity, habitat variables were excluded as candidates if they were strongly correlated (i.e., $r \geq |0.8|$) to any other variable already included in the model. An exception to the variable entry threshold was made for the model developed for Akiapolaau. The infrequent occurrence, and low and highly variable density of this species rendered difficult the development of a habitat model with even a modicum of explanatory power. Therefore, the variable entry threshold and retention was relaxed to $p < 0.10$. Univariate correlation analysis was also used to identify predictor variables significantly ($p < 0.01$) correlated to bird density but not selected for model inclusion because of the effects of multicollinearity.

To determine if spatial autocorrelation was present in the relationship between bird density and habitat, the residuals from the OLS models developed for each species were examined with Moran's I correlograms (Legendre and Legendre 1998). This step was performed with a custom S-Plus program written and made available by Lichstein *et al*. (2002a: Supplementary Material, and pers. comm.). A randomization test with 999 permutations was used to test for the significance of autocorrelation at lag distances (e.g., 0 – 500 meters, 500 – 1000 meters, etc) spanning a species' presence area. The maximum lag distance at which the randomization test was not significant indicated the extent at which spatial autocorrelation was no longer present; that is, the size of the spatial autocorrelation "neighborhood". This value was subsequently incorporated in the autoregressive models and determined the distance to which a value at any one point was weighted by the values at all other points within a neighborhood. Weights were set to zero if location j was not within the neighborhood of location i, and were weighted as $1/\text{distance}_{ij}$ if otherwise. Habitat variables included in an OLS model were dropped if shown to be non-significant in the autoregressive model output.

Estimation of Density, Population Size and Variance

The autoregressive model for each species was used to predict densities for the entire study area. This was accomplished by multiplying the habitat values derived from the lattice of 100-meter spaced points by the autoregressive model coefficients for significant variables, as given by:

$$\mu = X * \beta$$

where μ was the vector of predicted mean densities, X was the matrix of significant habitat values, and β was the matrix of autoregressive model coefficients.

Negative densities predicted by the models were set to zero in subsequent analyses. To derive area-based estimates of population size for each species, the lattice of point predictions was converted to grid (i.e., raster) themes with the ArcView "Convert to Grid" utility. Grids of estimated densities were clipped to include only the species' presence area. This ensured that predicted densities that were produced for areas outside of the range of model parameters (i.e., extrapolated densities) were not used to estimate population size and variance. The clipping of the predicted density grid was accomplished with the "Extract grid theme using polygon" utility of the ArcView extension Grid Analyst. Descriptive statistics of the resulting grid cell values were summarized. A species' population estimate entailed summing the predicted densities for all grid cells within the presence area (or for the entire study area if its distribution was not limited to a presence area), and was obtained with the "Calculate grid statistics" utility.

The variance around population estimates was calculated as a function of the model mean square error (MSE) and prediction error (Neter *et al*. 1996), as given by:

$$s^2_{\text{prediction}} = \text{MSE}(1 + X'_h (X'X)^{-1} X_h)$$

where X_h was the matrix of significant habitat values, X'_h was the transposed form of the matrix, and $(X'X)^{-1}$ was the variance-covariance matrix generated by the autoregressive model. The product of the above terms was a variance-covariance matrix of the predicted values, and the variance associated with each prediction was extracted from the diagonal of the matrix. Variance associated with the population estimate was obtained by summing the variance for all density predictions. For reasons of computational efficiency, the S-Plus code used to compute variance subset the X matrix into an *x* by 1,000-element matrix, where *x* was the number of significant variables (including intercept) comprising the autoregressive model. Therefore, the variance estimates do not include the effects of all the covariance values, and resulted in estimates slightly higher (i.e., more conservative) than that obtainable from computation capable of processing the entire original *x* by 64,843-element matrix.

Population estimates for the HFNWR were obtained by clipping the predicted density grid to the area coincident with the refuge boundary (and species presence area, if applicable). These estimates were subsets of density predictions for a larger area (i.e.,

either study area or presence area); consequently, they do not have associated variance estimates.

Population Trend and Power Analyses

We examined trends in density over time to determine whether populations were stable, declining, or increasing. A population trend was defined as a positive or negative directional change in density over a specific time interval for a specific area. A trend is conventionally viewed as a directional dominance and may be characterized with simple linear measures (Urquhart *et al*. 1998). Therefore, we used linear regression methods to detect trends, and did not attempt to quantify non-linear patterns or distinguish short-term trajectories in density. Because of differences in transect locations and the 10 year gap in survey data between the 1977 HFBS and subsequent surveys, trends in density were modeled for two periods of surveys: 14-year (1987-2000) and 24-year (1977-2000) intervals. This permitted us to examine trends inclusive and exclusive of the spatially distinct and temporally disjunct HFBS.

Trends were modeled with the linear regression of log transformed mean annual density per station (DPS) and survey year. To compare densities and trends between HFBS and subsequent surveys we subset the HFBS data to include only those stations within and immediately adjacent to HFNWR (n = 95 stations). Subsequent surveys (1987-2000) include only those stations sampled within HFNWR. The slope coefficient of the linear regression was used to characterize the direction of trend. One problem in trend detection is that count data are temporally autocorrelated (counts spaced closer in time are more similar than those spaced farther apart). We set the alpha level for a significant trend at 0.01, to mitigate autocorrelation in the counts and therefore achieve a reasonable actual Type I error rate (e.g., alpha < 0.05; Hatfield *et al*. 1996).

Power analyses were conducted to determine the effectiveness of sampling efforts given the observed variability in native bird densities. Power is the ability to detect a change over time when one actually exists (Steidl *et al*. 1997), and consists of four parameters: variance, magnitude, sample size, and alpha. Variance is a measure of variability in density over time. Magnitude (i.e., effect size) may refer either to the proportional rate of change in mean densities over time (e.g., 1% decline per year) or an absolute change over a time period (e.g., 30% decline in 10 years). Sample size is the number of stations surveyed. Alpha is the significance of a statistical test and corresponds to the probability of incorrectly rejecting a true null hypothesis (i.e., stating that density has changed when it has not; Type I error).

An analysis of the power to detect negative trends in bird density was examined for prospective 10-year monitoring period with the program TRENDS (Gerrodette 1987, 1993). In general, a prospective power analysis seeks to answer the question: What is the likelihood of observing a certain trend over a specific time period? Although the analysis used the variance observed during the 1987-1999 surveys in the HFNWR as a guide, its inference was limited to certain conditions (e.g., negative trend only) of a hypothetical future monitoring program. A prospective 10-year monitoring period was

used to measure power because it is sufficiently brief to satisfy management and monitoring objectives without unduly reducing power.

Variance was estimated by regression of mean annual DPS by year for each species (Hatch 2003). This was done for a series of 10-year periods (i.e., years 1987-1996, 1988-1997, 1989-1998 and 1990-1999) and averaged so as to capture "typical" variability in density as observed from past surveys. This step avoided the use of any particular time period for which variance was higher or lower than average. Regression standard error was converted to coefficient of variation (CV) for input in the program TRENDS. The program did not require specifying sample size because its effect is already incorporated in the variance observed in mean annual densities.

Population declines corresponding to low, moderate, high and very high rates of change were produced by selection of a 1%, 3%, 5% and 10% decrease in mean annual DPS. These annual rates of decline in density correspond to absolute declines of 9%, 24%, 37% and 61% for a 10-year period, respectively. The range of rates includes that used for bird population monitoring by the North American Breeding Bird Survey (i.e., -2.7% per year, or 50% decline over a 25-year period; Peterjohn *et al*. 1995).

Power was calculated for significance levels (i.e., alpha) of 0.05, 0.10 or 0.20. An alpha of 0.05 reflects a fairly stringent statistical standard that ensures against Type I error. However, it may also be advantageous to assess power given a "relaxed" alpha of 0.10 and 0.20. The approach increases the risk of stating that a trend exists when in fact it does not, but reduces the risk of missing an existing trend. From a management perspective, it may be more important to ensure that no declines in species of concern are missed.

Although a model of exponential change in density was available as a program option, a preliminary examination of density changes over time for native bird species did not reveal such trends. Moreover, trends are fit about equally well with either linear or exponential models for short time periods and result in similar power estimates (Hatch 2003). Therefore, we selected linear trend as a TRENDS program option.

Power analysis was performed as a one-sided test of the null hypothesis H_o "the trend in mean annual DPS is not decreasing" versus the alternative hypothesis H_1 "the trend in mean annual DPS is decreasing". This test is specific to an assessment of the power of detecting trend declines, and has no power to detect differences in the opposite direction. A one-tailed test was used because it is appropriate to the monitoring objective of detecting declines and has greater statistical power than a two-tailed test (Sokal and Rohlf 1995:164).

The program TRENDS allows a choice of variance structures corresponding to the relationship of the variance and the mean. Statistical power increases as a function of the proportionality of the variance and the power of the mean (i.e., mean, mean^2, and mean^3), and reflects a positive correlation of precision with the mean (Hatch 2003). That is, variances that diminish rapidly with decreasing means are more powerful statistically

than relationships in which variance diminishes moderately or remain constant. The variance structure options available in TRENDS are those for which the CV is proportional to 1/√mean, constant relative to mean, and proportional to √mean. These structures are equivalent to a variance that is proportional to the mean, $mean^2$, and $mean^3$, respectively (Gerrodette 1987, Hatch 2003). Variance structure was assessed by calculating the correlation of variance versus mean, $mean^2$, and $mean^3$, and examining the scatterplot of variance on the mean of annual DPS observations.

To assess the effect of sample size (i.e., number of survey stations) on the power to detect declining trends in mean annual densities, a custom program was written in the software package S+ to resample observations of densities made during a 10 year period (1991 to 2000). This was simulated for 100 iterations over a range of sample sizes (50, 100, 200, 300, 400, 800, 1,200, and 2,000 stations) for Iiwi, Creeper and Akiapolaau (i.e., species with low, moderately high and very high variability in mean annual densities). For each iteration, variance was estimated by the regression of mean annual DPS by year, converted to CV, and the mean CV for all iterations was input into the program TRENDS. The exercise used an alpha of 0.2 and a 10% decline per year in mean annual density to examine power under a scenario conducive to high power (i.e., a relaxed alpha and a severe decline).

SPECIES ACCOUNTS

Elepaio (*Chasiempis sandwichensis*)

Elepaio occupy both native and alien forests and occur from low to high elevations on the islands of Hawaii, Kauai, and Oahu; however, recent evidence indicates that population on Oahu (*C. s. ibidis*) is declining (VanderWerf 1998) and the species' range may be undergoing contraction at low elevations on Hawaii Island (Reynolds *et al*. in press, USGS/PIERC unpubl. data). Accounts of this species can be found in Scott *et al*. (1986) and VanderWerf (1998).

Surveys conducted between February and July in 1977-2000 resulted in 5,537 Elepaio observations. Distance estimates ranged from 0 to 304 m with a mean distance of 34.1 m (SD = 21.8 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 3). The hazard-rate key function with truncation at 52.1 m (4,677 observations) provided the best fit to the detection distances (Figure 8). This model was further parameterized with covariates representing gust, observer and year (Table 4). This parameterized model was used to calculate an effective detection radius of 33.81 m ± 0.61 %CV and an effective area surveyed of 0.36 hectares.

Regression analysis identified a suite of habitat variables accounting for 32% of the variance in Elepaio density (Table 5). Elepaio were positively associated with closed canopy forest and the trend term XY, and negatively associated with exotic vegetation types, presence of tree fern, richness and the trend term X. Correlation analysis identified additional variables with which density was significantly and positively associated: ohia, high-stature forests, and elevation; and negatively associated: grass, open or sparse

canopy, mid-stature forest, presence of matted fern and *Passiflora*, *Psidium*, slope, temperature, rainfall, and the trend terms Y and X^2.

Densities of Elepaio are highest in high-elevation wet forests within the study area (Figures 2, 9, and 10). However, low densities were also observed and predicted at low elevations and in open and drier habitats of the study area. The spatial distribution of densities predicted from regression models is similar to that described by Scott *et al*. (1986). Both distribution maps indicate that Elepaio are concentrated in the southerly portion of the upper elevation forest within the study area. The species habitat model predicts that the area of highest Elepaio density is centered just south of the refuge.

We estimated that the Elepaio population within the north Hamakua study area numbers 138,930 $\pm$ 605 (SE), of which approximately one-quarter (38,000 birds; 27%) occurs within the HFNWR (Table 6). Mean density of Elepaio for the 14-year period of surveys within the HFNWR (1987-2000) was 2.57 birds/hectare (SD = 2.90; Table 7). Elepaio populations did not show a positive or negative trend in density over the 24- or 14-year survey periods (24-year: $P = 0.72$, slope = 0.002, $r^2 = 0.01$; 14-year: $P = 0.49$, slope = 0.005, $r^2 = 0.04$; Table 8; Figure 11). Elepaio demonstrate fairly low within-year but high between-year variability in density. As a result of the high variability among years, power to detect trends in Elepaio populations is fairly low. Adequate power ($\geq$ 80%) exists to detect only a 10% annual decline in density at significance levels $\geq$ 0.20 given current sampling efforts (Table 9); the overall moderately high variance (mean CV = 0.654 for a 10-year period) around the annual estimates precludes detecting smaller reductions (i.e., 1 - 5% annual decline) in Elepaio densities.

Omao (*Myadestes obscurus*)

The Omao is a relatively common species on Hawaii, occupying montane rain forests and mesic forests above 1,000 m (Wakelee and Fancy 1999). Although the Omao is the only Hawaiian thrush that is not endangered, it has been extirpated from leeward Hawaii (Scott *et al.* 1986, USGS/PIERC unpubl. data). Accounts of this species can be found in van Riper and Scott (1979), Scott *et al*. (1986), and Wakelee and Fancy (1999).

Surveys conducted between February and July in 1977-2000 resulted in 11,466 Omao observations. Distance estimates ranged from 0 to 799 m with a mean distance of 57.1 m (SD = 38.2 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 10). The hazard-rate single simple-polynomial adjustor function with truncation at 88.2 m (9,834 observations) provided the best fit to the detection distances (Figure 12). This model was further parameterized with covariates representing wind, observer and year (Table 4). This parameterized model was used to calculate an effective detection radius of 61.49 m ± 0.40 %CV and an effective area surveyed of 1.19 hectares.

Regression analysis identified a suite of habitat variables accounting for 36% of the variance in Omao density (Table 5). Omao were positively associated with ohia, closed canopy forest and the trend term XY, and negatively associated with presence of tree fern and *Passiflora* and the trend term X. Correlation analysis identified additional variables with which density was significantly and positively associated: koa, high canopy, and

elevation; and negatively associated: grass, exotic species, open or sparse canopy, mid-stature forest, presence of matted fern, richness, slope, temperature, rainfall, and the trend terms X^2 and Y^2.

Omao densities are highest in wet forests at high elevations within the study area (Figures 2, 13, and 14). However, low densities were also observed and predicted at mid elevations and in open and drier habitats. The spatial distribution of densities predicted from regression models is comparable to that described by Scott *et al.* (1986). Both distribution maps indicate that Omao are concentrated in upper elevation forest. The HFNWR encompasses one-third of the population and distributional extent predicted within the species' presence area. The species habitat model predicts that the area of highest density is centered just south of the refuge.

We estimated that the Omao population within the 473 km^2 species' presence area was 57,533 $\pm$ 191 (SE), of which approximately 17,000 birds (29%) were predicted to occur within the HFNWR (Table 6). Mean density of Omao for the 14-year period of surveys within the HFNWR (1987-2000) was 1.80 birds/hectare (SD = 1.22; Table 11). Omao populations did not show a positive or negative trend in density over the 24- or 14-year survey periods (24-year: $P = 0.41$, slope = 0.004, $r^2 = 0.05$; 14-year: $P = 0.41$, slope = -0.005, $r^2 = 0.06$; Table 8; Figure 15). The Omao demonstrates low within-year but high between-year variability in density. As a result, adequate power ($\geq$ 80%) exists to detect only a 10% annual decline in density at significance levels of $\geq$ 0.10 given current sampling efforts (Table 9), and the moderate variance (mean CV = 0.549 for a 10-year period) around the annual estimates precludes detecting small reductions (i.e., 1 - 5% annual decline) in Omao densities.

Hwamei (*Garrulax canorus*)

The Hwamei or Melodious Laughing-thrush is a common introduced species on all main Hawaiian Islands, except Lanai. Hwamei occupy both native and alien habitats from sea level to 2,900 m (Scott *et al*. 1986). Accounts of this species can be found in Berger (1981) and Scott *et al*. (1986).

Surveys conducted between February and July in 1977-2000 resulted in 428 Hwamei observations. Distance estimates ranged from 0 to 304 m with a mean distance of 93.3 m (SD = 57.0 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 12). The hazard-rate key function with truncation at 183.0 m (404 observations) provided the best fit to the detection distances (Figure 16). This model was further parameterized with covariates representing observer and year (Table 4). Because of few observations, the year covariate was divided into HFBS and pooled subsequent surveys (1987-2000). This parameterized model was used to calculate an effective detection radius of 94.23 m $\pm$ 2.53 %CV and an effective area surveyed of 2.79 hectares.

Regression analysis identified a suite of habitat variables accounting for 17% of the variance in Hwamei density (Table 5). Hwamei were positively associated with sparse canopy cover and the trend term Y^2, and negatively associated with elevation. Correlation analysis identified additional variables with which density was significantly

and positively associated: ohia, exotic species, open canopy, mid-stature forest, presence of tree fern and matted fern, temperature, rainfall, and the trend terms X and X^2; and negatively associated: koa, grass, closed canopy, presence of *Passiflora*, and the trend terms Y and XY.

Correlation and regression analyses for Hwamei were complicated by the widely dispersed occurrence and low abundance of the species. In general, the analyses indicate that densities of Hwamei are highest in open to sparse canopy forests at low to mid elevations within the study area (Figures 2, 17, and 18). However, low densities were also observed in closed canopy forests. The spatial distribution of densities predicted from regression models corresponds to that described by Scott *et al*. (1986). Both distribution maps indicate that Hwamei are concentrated in low to mid elevation forest. The HFNWR appears to encompass little of the population and distributional extent predicted within the study area.

The population estimated to occur within the study areas was 5,421 $\pm$ 43 (SE), of which 336 birds (6%) were predicted to occur within the HFNWR (Table 6). Mean density of Hwamei for the 14-year period of surveys within the HFNWR (1987-2000) was 0.002 birds (SD = 0.020; Table 13). Hwamei populations did not show a positive or negative trend in density over the 24- or 14-year survey periods (24-year: $P = 0.67$, slope = -0.027, $r^2 = 0.01$; 14-year: $P = 0.17$, slope = -0.122, $r^2 = 0.15$; Table 8; Figure 19). As with correlation and regression analyses, trend analysis for Hwamei proved to be difficult. No individuals were observed during several years of surveys, and for years in which there were detections, densities were very low and confidence intervals extremely large.

Red-billed Leiothrix (*Leiothrix lutea*)

The Red-billed Leiothrix is a common introduced species on all main Hawaiian Islands, but is not present on Lanai, Kahoolawe, and Niihau, and is presumably absent from Kauai. Red-billed Leiothrix (referred herein as Leiothrix) occupy both native and alien habitats, including urban areas, from sea level to more than 4,000 m (Male *et al*. 1998). Accounts of this species can be found in Scott *et al*. (1986) and Male *et al*. (1998).

Surveys conducted between February and July in 1977-2000 resulted in 8,139 Leiothrix observations. Distance estimates ranged from 0 to 400 m with a mean distance of 45.5 m (SD = 29.3 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 14). The half-normal key function with truncation at 72.9 m (6,852 observations) provided the best fit to the detection distances (Figure 20). This model was further parameterized with all covariates: cloud, rain, wind, gust, time, observer, and year (Table 4). This parameterized model was used to calculate an effective detection radius of 42.21 m ± 0.55 %CV and an effective area surveyed of 0.56 hectares.

Regression analysis identified a suite of habitat variables accounting for 34% of the variance in Leiothrix density (Table 5). Leiothrix were positively associated with closed canopy forest, high canopy, presence of *Passiflora*, elevation and the trend terms XY, and negatively associated with the presence of tree fern and the trend term X^2. Correlation analysis identified additional variables with which density was significantly

and positively associated: ohia and the trend term Y; and negatively associated: grass, open canopy, mid-stature forest, presence of matted fern and *Psidium*, richness, temperature, rainfall, and the trend terms X and Y^2.

Leiothrix densities are highest in closed canopy, high stature ohia and ohia-koa forests at high elevations within the study area (Figures 2, 21, and 22). The spatial distribution of densities predicted from this study differed slightly from that described by Scott *et al*. (1986). This study predicted a fairly uniform distribution of Leiothrix spanning a broad contiguous expanse of upper elevation forest, whereas Scott *et al*. indicated several density peaks within the same area. The HFNWR harbors about one-third of the predicted range.

The population estimated to occur within the study area was 82,006 $\pm$ 480 (SE), of which 24,239 birds (30%) were predicted to occur within the HFNWR (Table 6). Mean density of Leiothrix for the 14-year period of surveys within the HFNWR (1987-2000) was 2.67 birds (SD = 3.03; Table 15). Leiothrix populations within and near the HFNWR did not show a positive or negative trend in density over the 24- or 14-year survey periods (24-year: $P = 0.97$, slope < 0.001, $r^2 < 0.001$; 14-year: $P = 0.78$, slope = 0.002, $r^2 = 0.01$; Table 8; Figure 23).

Japanese White-eye (*Zosterops japonicus*)

The Japanese White-eye is a common introduced species on all main Hawaiian Islands. Japanese White-eye (referred herein as White-eye) occupy all habitats from urban to wet forest, from sea level to tree line (van Riper 2000). Accounts of this species can be found in Berger (1981), Scott *et al*. (1986), and van Riper (2000).

Surveys conducted between February and July in 1977-2000 resulted in 6,700 White-eye observations. Distance estimates ranged from 0 to 304 m with a mean distance of 26.3 m (SD = 17.5 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 16). The hazard-rate key function with truncation at 43.0 m (6,032 observations) provided the best fit to the detection distances (Figure 24). This model was further parameterized with the covariate year (Table 4). This parameterized model was used to calculate an effective detection radius of 29.04 m ± 0.49 %CV and an effective area surveyed of 0.27 hectares.

Regression analysis identified a suite of habitat variables accounting for 28% of the variance in White-eye density (Table 5). White-eye were positively associated with open canopy, mid-stature forest, presence of tree fern and *Passiflora*, slope and the trend terms X^2 and Y^2, and negatively associated with elevation and the trend term XY. Correlation analysis identified additional variables with which density was significantly and positively associated: exotic vegetation, sparse canopy cover, presence of *Psidium*, richness, temperature, rainfall, and the trend term X; and negatively associated: closed canopy and high-stature forest.

Densities of White-eye are highest in mid-stature open to sparse canopy forests at low to mid elevations within the study area (Figures 2, 25, and 26). However, relatively low to

moderate densities were also observed in closed canopy forest habitats. The spatial distribution of densities predicted from regression models is similar to that described by Scott *et al.* (1986). Both distribution maps indicate that White-eye are concentrated in low to mid elevation forest, particularly in the northern and southern portion of the study area. The HFNWR harbors about one-quarter of the predicted range.

A population of 460,373 $\pm$ 1,417 (SE) White-eye was estimated to occur within the study area, of which 68,253 birds (15%) were predicted to occur within the HFNWR (Table 6). Mean density of White-eye for the 14-year period of surveys within the HFNWR (1987-2000) was 3.16 birds (SD = 3.82; Table 17). White-eye populations within and near the HFNWR did not show a significantly positive or negative trend in density over the 24- or 14-year survey periods (24-year: $P = 0.06$, slope = -0.008, $r^2 = 0.25$; 14-year: $P = 0.12$, slope = -0.009, $r^2 = 0.19$; Table 8; Figure 27).

Northern Cardinal (*Cardinalis cardinalis*)

The Northern Cardinal is a common introduced species on all main Hawaiian Islands. Northern Cardinal (referred herein as Cardinal) occupy native and alien grasslands with shrubs, woodland and open to sparse forest habitats, and urban areas with greatest numbers at low elevations (Halkin and Linville 1999); however, established populations are found at higher elevations (> 3,000 m; Berger 1981, Scott *et al*. 1986). Accounts of this species can be found in Scott *et al*. (1986), and Halkin and Linville (1999).

Surveys conducted between February and July in 1977-2000 resulted in 1,130 Cardinal observations. Distance estimates ranged from 0 to 850 m with a mean distance of 67.4 m (SD = 59.8 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 18). The half-normal key function with truncation at 114.0 m (1,002 observations) provided the best fit to the detection distances (Figure 28). This model was further parameterized with the covariates observer and year (Table 4). This parameterized model was used to calculate an effective detection radius of 58.11 m ± 1.46 %CV and an effective area surveyed of 1.06 hectares.

Regression analysis identified a suite of habitat variables accounting for 16% of the variance in Cardinal density (Table 5). Cardinal were positively associated with koa, exotic vegetation, presence of *Passiflora*, slope, temperature and the trend terms X^2 and Y^2, and negatively associated with the trend term XY. Correlation analysis identified additional variables with which density was significantly and positively associated: open canopy, high-stature forests, presence of *Psidium*, richness, and the trend terms X and Y; and negatively associated: ohia, mid-stature forest, presence of matted fern, and elevation.

Densities of Cardinal are highest in open canopy forests at low to mid elevations within the study area (Figures 2, 29, and 30). However, relatively low densities were also observed and predicted in upper elevation forests within the HFNWR. The spatial distribution of densities predicted from regression models is comparable to that described by Scott *et al*. (1986). Both distribution maps indicate that Cardinals are found primarily

in low elevation forest, and in the northern portion of the study area. The HFNWR harbors less than one-quarter of the predicted range.

A population of 8,677 ± 93 (SE) Cardinal was estimated to occur within the study area, of which 484 birds (6%) were predicted to occur within the HFNWR (Table 6). Mean density of Cardinal for the 14-year period of surveys within the HFNWR (1987-2000) was 0.19 birds (SD = 0.48; Table 19). Cardinal populations within and near the HFNWR did not show a significantly positive or negative trend in density over the 14-year interval ($P = 0.57$, slope = 0.004, $r^2 = 0.03$; Table 8). However, Cardinal density did increase over the 24-year period ($P = 0.002$, slope = 0.043, $r^2 = 0.53$; Table 8; Figure 31). The increase in density since the HFBS may be associated with range expansion. The HFBS showed this species to be established in areas outside the HFNWR (Berger 1981, Scott *et al*. 1986), and subsequent surveys have demonstrated an incursion of Northern Cardinals into the HFNWR.

House Finch (*Carpodacus mexicanus*)

The House Finch is a common introduced species on all main Hawaiian Islands. House Finch occupy a wide range of habitats and extend from sea level to over 3,000 m (Scott *et al*. 1986, Hill 1993). Berger (1981) noted House Finch were absent in wet forests; however, House Finch were recorded in low densities in wet forests during the HFBS (Scott *et al*. 1986), possible evidence of range expansion. Accounts of this species can be found in Scott *et al*. (1986) and Hill (1993).

Surveys conducted between February and July in 1977-2000 resulted in 1,854 House Finch observations. Distance estimates ranged from 0 to 500 m with a mean distance of 66.4 m (SD = 51.1 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 20). The hazard-rate key function with truncation at 60.9 m (1,066 observations) provided the best fit to the detection distances (Figure 32). This model was further parameterized with the covariates cloud, rain, wind and year (Table 4). This parameterized model was used to calculate an effective detection radius of 41.84 m ± 1.29 %CV and an effective area surveyed of 0.55 hectares.

Regression analysis identified a suite of habitat variables accounting for 34% of the variance in House Finch density (Table 5). House Finch were positively associated with grass, exotic vegetation and the trend term Y, and negatively associated with koa and the trend term X. Correlation analysis identified additional variables with which density was significantly and positively associated: sparse canopy, richness, slope, and the trend terms X^2 and Y^2; and negatively associated: ohia, closed canopy, high-stature forest, presence of tree fern, temperature, rainfall and the trend term XY.

Densities of House Finch are highest in the western and northern portions of the study area in grassland, sparse canopy forest (i.e., woodland), exotic forest, and heterogeneous habitats (Figures 2, 3, 33, and 34). The spatial distribution of densities predicted from regression models corresponds to that described by Scott *et al*. (1986) in which distributions are primarily restricted to the margins of native forest and open habitats. The HFNWR harbors about one-quarter of the predicted range.

A population of 64,799 ± 568 (SE) House Finch was estimated to occur within the study area, of which 8,331 birds (13%) were predicted to occur within the HFNWR (Table 6). Mean density of House Finch for the 14-year period of surveys within the HFNWR (1987-2000) was 0.54 birds (SD = 1.61; Table 21). House Finch populations within and near the HFNWR did not show a significantly positive or negative trend in density over the 24- or 14-year survey periods (24-year: $P = 0.58$, slope = -0.008, $r^2 = 0.02$; 14-year: $P = 0.22$, slope = -0.024, $r^2 = 0.12$; Table 8; Figure 35).

Hawaii Amakihi (*Hemignathus virens*)

The Hawaii Amakihi is a locally common species on the island of Hawaii. The species is found primarily in xeric and mesic montane forests and woodland above 1,500 m (Lindsey *et al*. 1998); however, local populations are also found down to sea level (USGS/PIERC unpubl. data). Accounts of this species (referred to herein as Amakihi) can be found in Scott *et al*. (1986) and Lindsey *et al*. (1998).

Surveys conducted between February and July in 1977-2000 resulted in 17,863 Amakihi observations. Distance estimates ranged from 0 to 437 m with a mean distance of 34.4 m (SD = 23.3 m). A set of potential submodels was assessed for model fit and parsimony (Table 22). The hazard-rate key function with truncation at 45.9 m (13,753 observations) provided the best fit to the detection distances (Figure 36). This model was further parameterized with covariates representing rain, wind, observer, and year (Table 4). This parameterized model was used to calculate an effective detection radius of 30.59 m ± 0.35 %CV and an effective area surveyed of 0.29 hectares.

Regression analysis identified a suite of habitat variables accounting for 42% of the variance in Amakihi density (Table 5). Amakihi were positively associated with koa and richness, and negatively associated with exotic vegetation and rainfall. Correlation analysis identified additional variables with which density was significantly and positively associated: closed canopy, presence of *Passiflora*, slope, elevation, and the trend terms Y and X^2; and negatively associated: ohia, open or sparse canopy, mid-stature forest, presence of tree fern and matted fern, temperature, and the trend terms X and Y^2.

Amakihi attained highest densities in the higher elevation portion of the study area in a range of habitats including grassland, closed canopy forest with a koa component, *Passiflora* infested stands, and heterogeneous habitats along the forest margins (Figures 2, 3, 4, 37, and 38). The species was absent or occurred at low densities in the wet forest with tree fern and matted fern. The spatial distribution of densities predicted from regression models is similar to that described by Scott *et al*. (1986) in which distributions are primarily restricted to the margins of native forest and open habitats. The HFNWR harbors about one-third of the predicted range within the study area.

A population of 200,760 ± 990 (SE) Amakihi was estimated to occur within the study area, of which 51,600 birds (26%) were predicted to occur within the HFNWR (Table 6). Mean density of Amakihi for the 14-year period of surveys within the HFNWR (1987-2000) was 12.91 birds (SD = 7.63; Table 23). Amakihi populations within and near the

HFNWR did not show a significantly positive or negative trend in density over the 14-year survey period ($P = 0.46$, slope = -0.004, $r^2 = 0.05$; Table 8). However, Amakihi density increased over the 24-year survey period ($P = 0.02$, slope = 0.017, $r^2 = 0.33$; Table 8; Figure 39). Amakihi demonstrates low within-year but moderately high between-year variability in density. Because of this, and despite the low overall variance (mean CV = 0.465 for a 10-year period), adequate power ($\geq$ 80%) exists to detect only a 10% annual decline in density at significance levels $\geq$ 0.10 given current sampling efforts (Table 9), and small reductions (i.e., 1 - 5% annual decline) in Amakihi densities cannot be detected with sufficient power.

Akiapolaau (*Hemignathus munroi*)

The Akiapolaau is an uncommon forest bird on the island of Hawaii. It occurs in greatest numbers in montane mesic ohia-koa forest above 1,100 m. Accounts of this species can be obtained from Scott *et al*. (1986) and Pratt *et al*. (2001).

Surveys conducted between February and July in 1977-2000 resulted in 539 Akiapolaau observations. Distance estimates ranged from 0 to 200 m with a mean distance of 50.3 m (SD = 29.1 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 24). The half-normal key function with truncation at 88.0 m (485 observations) provided the best fit to the detection distances (Figure 40). This model was further parameterized with covariates representing observer and year (Table 4). To increase the number of detections, the covariate year was pooled into HFBS and subsequent years by 2-year intervals. This parameterized model was used to calculate an effective detection radius of 51.63 m ± 2.08 %CV and an effective area surveyed of 0.84 hectares.

Regression analysis identified three habitat variables accounting for 4% of the variance in Akiapolaau density (Table 5). Akiapolaau were positively associated with koa and closed canopy, and negatively associated with the trend term Y. Correlation analysis identified additional variables with which density was significantly and positively associated: ohia, high-stature forest, and rainfall; and negatively associated: grass and presence of *Passiflora*.

Akiapolaau attained highest densities in the upper elevation with a koa component and heterogeneous habitats along the forest margins (Figures 2, 3, 4, 41, 42). The spatial distribution of densities predicted from regression models is comparable to that described by Scott *et al*. (1986) in which distributions are primarily restricted to the margins of native forest and open habitats. The HFNWR harbors about one-half of the predicted range within the species' presence area.

A population of 1,585 $\pm$ 44 (SE) Akiapolaau was estimated to occur within the study area, of which 789 birds (50%) were predicted to occur within the HFNWR (Table 6). Mean density of Akiapolaau for the 14-year period of surveys within the HFNWR (1987-2000) was 0.11 birds (SD = 0.39; Table 25). Akiapolaau populations within and near the HFNWR did not show a significantly positive or negative trend in density over the 14-year survey period ($P = 0.06$, slope = 0.026, $r^2 = 0.27$; Table 8); however, density did

increase over the 24-year survey period ($P = 0.03$, slope = 0.021, $r^2 = 0.31$; Table 8; Figure 43). Akiapolaau demonstrates high within-year and between-year variability in density. The resulting high overall variance (mean CV = 1.346 for a 10-year period) precludes detecting even a 10% annual decline in Akiapolaau density with adequate power ($\geq$ 80%) at significance levels $\leq$ 0.20 given current sampling efforts (Table 9).

Hawaii Creeper (*Oreomystis mana*)

The Hawaii Creeper (referred herein as Creeper) is an uncommon forest bird on the island of Hawaii. Creeper occur in higher-elevation ohia and ohia/koa forests on Kau, north Kona, the north slope of Hualalai Mountain, and windward Hawaii Is. Accounts of this species can be found in Scott *et al*. (1986), Ralph and Fancy (1994), Woodworth *et al*. (2001), and Lepson and Woodworth (2002).

Surveys conducted between February and July in 1977-2000 resulted in 2,375 Creeper observations. Distance estimates ranged from 0 to 152 m with a mean distance of 35.7 m (SD = 20.8 m). A set of potential submodels was assessed for model fit and parsimony (Table 26). The half-normal key function with truncation at 58.5 m (2,002 observations) provided the best fit to the detection distances (Figure 44). This model was further parameterized with covariates representing observer and year (Table 4). This parameterized model was used to calculate an effective detection radius of 34.65 m ± 0.98 %CV and an effective area surveyed of 0.38 hectares.

Regression analysis identified a suite of habitat variables accounting for 20% of the variance in Creeper density (Table 5). Creeper were positively associated with ohia, closed canopy, elevation and trend term XY, and negatively associated with the trend terms Y and Y^2. Correlation analysis identified additional variables with which density was significantly and positively associated: high-stature forest; and negatively associated: the presence of grass, tree fern and *Passiflora*, richness, temperature, and the trend term X.

Densities of Creeper are highest in upper elevation, high stature, ohia forest (Figures 2, 45, and 46). The species was absent or occurred at low densities in grasslands, in heterogeneous habitats along the grass-forest interface, and in mid elevation wet forest. The spatial distribution of densities predicted from regression models corresponds to that described by Scott *et al*. (1986) in which distributions are primarily restricted to upper elevation native forest. The HFNWR encompasses about one-half of the species' presence area.

A population of 17,842 $\pm$ 221 (SE) Creeper was estimated to occur within the study area, of which 8,659 birds (49%) were predicted to occur within the HFNWR (Table 6). Mean density of Creepers was 0.28 birds/ha (SD = 0.97) for the 1977 HFBS survey, and was 1.26 birds/ha (SD = 2.44) for the 14-year period of subsequent surveys within the HFNWR (1987-2000; Table 27). Creeper populations within and near the HFNWR showed a positive trend in density over both the 24- and 14-year survey periods (24-year: $P < 0.001$, slope = 0.030, $r^2 = 0.73$; 14-year: $P = 0.009$, slope = 0.021, $r^2 = 0.44$; Table 8; Figure 47). Creeper demonstrates moderately high within- and between-year variability

in density. The high overall variance (mean CV = 0.730 for a 10-year period) only marginally permits detecting a 10% annual decline in Creeper density (power = 79%) at significance levels of 0.20 given current sampling efforts (Table 9), and precludes detecting smaller reductions (i.e., 1 - 5% annual decline) in densities.

Hawaii Akepa (*Loxops coccineus*)

The Akepa is an uncommon forest bird on the island of Hawaii, and is considered rare on Maui. On Hawaii Is., Akepa occur in greatest numbers in montane mesic ohia-koa forest above 1,400 m. Accounts of this species can be found in Scott *et al*. (1986), and Lepson and Freed (1997).

Surveys conducted between February and July in 1977-2000 resulted in 2,396 Akepa observations. Distance estimates ranged from 0 to 152 m with a mean distance of 33.2 m (SD = 16.5 m). A set of potential submodels was assessed for model fit and parsimony (Table 28). The hazard-rate key function with truncation at 55.0 m (2,182 observations) provided the best fit to the detection distances (Figure 48). This model was further parameterized with covariates representing cloud, rain, wind, observer, and year (Table 4). This parameterized model was used to calculate an effective detection radius of 41.48 m ± 0.78 SE and an effective area surveyed of 0.54 hectares.

Regression analysis identified a suite of habitat variables accounting for 42% of the variance in Akepa density (Table 5). Akepa were positively associated with ohia, koa, elevation and the trend term Y^2, and negatively associated with the presence of *Passiflora*, richness and the trend term Y. Correlation analysis identified additional variables with which density was significantly and positively associated: closed canopy and high-stature forest; and negatively associated: grass, open or sparse canopy, temperature, and the trend terms X, XY and X^2.

Densities of Akepa are highest in upper elevation koa-ohia and ohia forests of high stature and closed canopy (Figures 2, 49, and 50). The species was absent or occurred at low densities in heterogeneous habitats along the grass-forest interface and in mid elevation forest. The spatial distribution of densities predicted from regression models is similar to that described by Scott *et al*. (1986) in which distributions are restricted to a limited area in upper elevation native forest. The HFNWR harbors almost the entire distribution predicted to lie within the species' presence area.

A population of 8,311 $\pm$ 144 (SE) Akepa was estimated to occur within the study area, of which 6,015 birds (72%) were predicted to occur within the HFNWR (Table 6). Akepa mean density was 0.12 birds/ha (SD = 0.58) for the 1977 HFBS survey, and was 0.97 birds/ha (SD = 2.03) for the 14-year period of subsequent surveys within the HFNWR (1987-2000) (Table 29). Akepa density did not demonstrate a positive or negative trend over the 14-year survey period ($P = 0.06$, slope = 0.014, $r^2 = 0.27$; Table 8), but did increase over the 24-year survey period ($P < 0.001$, slope = 0.035, $r^2 = 0.66$; Table 8; Figure 51). Akepa demonstrates moderately high within- and between-year variability in density. This high overall variance (mean CV = 0.718 for a 10-year period) only permits detection of a $\geq$ 10% annual decline in density with adequate power ($\geq$ 80%) at

significance levels ≥ 0.20 given current sampling efforts (Table 9), and precludes detecting smaller reductions (i.e., 1 - 5% annual decline) in Akepa densities.

Iiwi (*Vestiaria coccinea*)

The Iiwi is a common forest bird in mesic and wet forest above 1,500 m on Hawaii, Maui and Kauai. Although nesting is restricted to upper elevation forest, Iiwi show considerable movement in and out of the study region in response to seasonal and patchy distribution of ohia flowering (Ralph and Fancy 1995, Fancy and Ralph 1998). It occurs in low numbers at lower elevations on Oahu and Molokai (Fancy and Ralph 1998). Accounts of this species can be found in Scott *et al*. (1986), and Fancy and Ralph (1998).

Surveys conducted between February and July in 1977-2000 resulted in 28,921 Iiwi observations. Distance estimates ranged from 0 to 640 m with a mean distance of 32.1 m (SD = 25.6 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 30). The half-normal single simple-polynomial adjustor function with truncation at 55.1 m (25,865 observations) provided the best fit to the detection distances (Figure 52). This model was further parameterized with all covariates: cloud, rain, wind, gust, time, observer and year (Table 4). This parameterized model was used to calculate an effective detection radius of 30.25 m ± 0.28 %CV and an effective area surveyed of 0.29 hectares.

Regression analysis identified a suite of habitat variables accounting for 61% of the variance in Iiwi density (Table 5). Iiwi were positively associated with koa, presence of *Passiflora* and elevation, and negatively associated with grass, exotic vegetation and presence of tree fern. Correlation analysis identified additional variables with which density was significantly and positively associated: ohia, closed canopy, high-stature forest, richness, and the trend term Y; and negatively associated: open or sparse canopy, presence of matted fern, temperature, rainfall, and the trend terms X, X^2 and Y^2.

Densities of Iiwi are highest in upper elevation koa-ohia and ohia forests of high stature and closed canopy (Figures 2, 4, 53, and 54). The positive association with *Passiflora mollissima* may be due to the use of its copious nectar by Iiwi (Fancy and Ralph 1998). The species occurred at low densities in heterogeneous habitats along the grass-forest interface and in mid elevation forest. The spatial distribution of densities predicted from regression models is similar to that described by Scott *et al*. (1986) in which distributions are concentrated in upper elevation native forest. The HFNWR harbors about half the distribution predicted to lie within the species' presence area.

A population of 285,422 ± 1,267 (SE) Iiwi was estimated to occur within the study area, of which 100,347 birds (35%) were predicted to occur within the HFNWR (Table 6). Iiwi mean density for the 14-year period of surveys within the HFNWR (1987-2000) was 20.87 birds (SD = 9.27; Table 31). Iiwi populations did not show a positive or negative trend in density over the 14-year survey period ($P = 0.14$, slope = 0.006, $r^2 = 0.19$; Table 8). However, a moderate increase in density did occur over the 24-year survey period ($P = 0.02$, slope = 0.008, $r^2 = 0.37$; Table 8; Figure 55). Iiwi density demonstrates little variance in within-year densities and only moderate between-year variation. Thus,

adequate power (≥ 80%) exists to detect a ≥ 10% annual decline in density at significance levels ≥ 0.05 given current sampling efforts (Table 9). The relatively low overall variance (mean CV = 0.345 for a 10-year period) around the annual estimates also permits detecting a 5% annual decline in Iiwi density with marginal power (= 79%) at significance levels of 0.20.

Apapane (*Himatione sanguinea*)

The Apapane is a common forest bird on Hawaii, Maui and Kauai, and is the most abundant of Hawaiian honeycreepers. Apapane occur in mesic and wet forests above 1,000 m on Hawaii, Maui and Kauai, and are locally common at higher elevations on Oahu (Fancy and Ralph 1997). Recent surveys indicate that Apapane persist at low elevations on Hawaii Is. (Reynolds *et al*. in press, USGS/PIERC unpubl. data). Like Iiwi, Apapane move widely in response to seasonal and patchy distribution of ohia flowering (Ralph and Fancy 1995, Fancy and Ralph 1997), and show considerable movement in and out of the study region. Accounts of this species can be found in Scott *et al*. (1986), and Fancy and Ralph (1997).

Surveys conducted between February and July in 1977-2000 resulted in 23,089 Apapane observations. Distance estimates ranged from 0 to 750 m with a mean distance of 36.6 m (SD = 31.8 m). A set of potential submodels was assessed for detection function fit and parsimony (Table 32). The hazard-rate single simple-polynomial adjustor function with truncation at 61.0 m (21,152 observations) provided the best fit to the detection distances (Figure 56). This model was further parameterized with covariates observer and year (Table 4). This parameterized model was used to calculate an effective detection radius of 38.74 m ± 0.30 %CV and an effective area surveyed of 0.47 hectares.

Regression analysis identified a suite of habitat variables accounting for 39% of the variance in Apapane density (Table 5). Apapane were positively associated with koa, closed canopy and elevation, and negatively associated with sparse canopy and the trend term X^2. Correlation analysis identified additional variables with which density was significantly and positively associated: ohia, high-stature forest, and the trend terms Y and XY; and negatively associated: grass, exotic vegetation, open canopy, mid-stature forest, presence of tree fern, matted fern and *Psidium*, richness, temperature, rainfall, and the trend terms X and Y^2.

Densities of Apapane are highest in upper elevation koa-ohia and ohia forests of high stature and closed canopy (Figures 2, 57, and 58). The species occurred at low densities in grassland, heterogeneous habitats along the grass-forest interface, and in mid to low elevation forest. The spatial distribution of densities predicted from regression models corresponds to that described by Scott *et al*. (1986) in which distributions span the length of upper elevation native forest in the study area. The HFNWR harbors about one-third of the distribution predicted to lie within the study area.

A population of 255,898 ± 1,037 (SE) Apapane was estimated to occur within the study area, of which 75,165 birds (29%) were predicted to occur within the HFNWR (Table 6). Mean density of Apapane for the 14-year period of surveys within the HFNWR (1987-

2000) was 9.85 birds (SD = 5.61; Table 33). Apapane populations did not show a positive or negative trend in density over the 14-year survey period ($P = 0.76$, slope = 0.002, $r^2 = 0.008$; Table 8). However, a marginally significant increase in density did occur over the 24-year survey period ($P = 0.04$, slope = 0.013, $r^2 = 0.30$; Table 8; Figure 59). Apapane density demonstrates low within-year, but high between-year variation in density. The moderately high overall variance (mean CV = 0.694 for a 10-year period) only permits detection of a $\geq$ 10% annual decline in density with adequate power ($\geq$ 80%) at significance levels $\geq$ 0.20 given current sampling efforts (Table 9), and precludes detecting smaller reductions (i.e., 1 - 5% annual decline) in Apapane densities.

DISCUSSION

The analyses presented in this report are the latest synthesis of bird survey data and habitat information, and constitute an update of the landmark study by Scott *et al.* (1986). Species-habitat models determined the relationship of bird density to a variety of habitat variables, and allowed for the prediction of densities to areas not surveyed, the generation of distribution maps, and the estimation of population size. Trends in densities were examined for the 14-year (1987-2000) and 24-year (1977-2000) periods as an indication of population status. Power analyses evaluated the effectiveness of the current monitoring program to detect changes in forest bird populations. Management and monitoring recommendations are provided based on the results of the analyses.

Species Distribution

There was broad agreement in the distributions predicted by this study and that of Scott *et al*. (1986). This is not surprising given that survey observations for a major portion of the study area (i.e., outside of the HFNWR) were limited to HFBS data in both studies. Surveys subsequent to the HFBS were located entirely within the HFNWR and served primarily to reinforce the habitat associations observed regionally.

With the exception of the Amakihi, the observed and predicted distributions of native species were centered on upper elevation forest. Amakihi distribution included both upper elevation forest and open grassland/woodland at higher elevations. The distributions of Elepaio and Apapane, and to a lesser extent, Omao and Iiwi, spanned the study area, and included native forest at a range of elevations and open grassland and woodland at higher elevations. The predicted distributions for Akiapolaau, Creeper, Akepa were restricted to upper elevation forest.

The distribution of exotic species showed three general patterns. Red-billed Leiothrix were concentrated in upper elevation forest. Hwamei, Japanese White-eye and Northern Cardinal densities were highest at lower elevations, although the latter two species and Leiothrix did demonstrate patches of higher densities associated with *Passiflora mollissima* infestations. House Finch occurred in high numbers in open grassland and woodland habitats, primarily at the western portion of the study area.

General Species-Habitat Associations
With the exception of the Hawaii Amakihi, the native species are primarily forest specialists whose densities were correlated significantly and positively to high-stature, closed-canopy forests of ohia and koa. Amakihi densities were high in both forested and non-forested upper elevation habitat. The exotic bird species exhibited a variety of responses to habitat. For example, the Red-billed Leiothrix was most common in forest habitats, whereas the House Finch was found mostly in grassland and open woodland. In addition, species such as the Japanese White-eye demonstrated generalist habits and a fairly ubiquitous distribution. The Northern Cardinal's distribution (highest at the edges of the study area, as indicated by the positive association of density with X^2 and Y^2 terms) in combination with increasing trends since 1977, suggest that the species is expanding its range inward from the edges of the study area. In this case, the habitat association model should be interpreted with caution, as it will be overly influenced by the historical pattern of colonization, rather than habitat affinities.

Trends in Density
One of the most significant, and positive, findings of this study was that densities of two endangered species, the Hawaii Creeper and Akiapolaau, have increased within Hakalau Forest NWR over the 14-year period 1987-2000. Moreover, when the analysis is expanded to include the 1977 HFBS data (a 24-year span), we detected significant increases in another endangered species, the Akepa, one special-concern species, the Iiwi, and two additional native forest birds, the Amakihi and Apapane. Only one exotic species, the Northern Cardinal, was found to be increasing in density in the refuge.

No native species were found to have declined in density in Hakalau Forest NWR over the 14- or 24-year survey periods. One exotic species, the Japanese White-eye, showed a marginally significant ($P = 0.06$) decrease in density over the 24-year survey period.

Five species – Elepaio, Omao, Hwamei, Red-billed Leiothrix, and House Finch – did not demonstrate significant increasing or decreasing trends in density over either the 14-year or 24-year survey period. These species exhibited high inter-annual variation in densities that may have contributed to a lack of statistical power to detect trends (discussed in the next section).

Power Analyses
Annual survey data were examined for the purpose of detecting declines in density over time as a function of the trend and the desired risk of Type I error (i.e., concluding a change occurred when it actually did not). Specifically, we assessed the power of detecting a decrease in density given four rates of annual declines (low [1%], moderate [3%], high [5%] and very high [10%]) and three levels of Type I error (alpha = 0.05, 0.10 and 0.20) over a prospective 10-year monitoring period.

In general, the results of the power analyses were somewhat discouraging. The detection of a small to moderate (1 – 3%) decline in density within a 10-year period is not possible for any species given observed variability in densities and current level of sampling. Analyses indicated that only very high ($\geq$ 10%) negative trends could be detected with

certainty. For Iiwi, an abundant species for which intra- and inter-annual variability was relatively low, the power to detect a very high (10%) rate of annual decline was adequate (i.e., power = 100%) but only marginal (i.e., power = 79%) for declines of 5% per annum. Surveys of rare to uncommon species that exhibit highly variable intra- and inter-annual mean densities, such as Akiapolaau and Creeper, have little to no power to detect declines within a 10-year period.

Acceptance of a higher risk of Type I error (e.g., from 0.05 to 0.10 or 0.20) typically increases power for any given magnitude of change (Allen 1980, Taylor and Gerrodette 1993). That is, if one wishes to be certain of detecting a density decline when it occurs, one must be willing to commit a greater degree of error in stating a decline exists when it may not be the case. However, higher alpha levels yielded only moderate gains in power for native species. The relaxation of alpha from 0.05 to 0.20 increased power, but sufficient increases occurred only for situations in which densities undergo a substantially negative decline (i.e., 10% annual decrease).

Estimated power may also be overly optimistic because the analyses do not account for positive autocorrelation of densities over time (i.e., observations close together in time may be more similar than observations farther apart). Positive autocorrelation may result in underestimated variance and inflated power (Gerrodette 1987).

We did not conduct a power analysis of the observed 14-year survey period because a power value that is estimated with the same data used to test the null hypothesis of a change in density is inappropriate (Steidl *et al*. 1997). Although this type of "retrospective" analysis is commonly conducted, it provides no information beyond that of the *P*-value for situations in which the null hypothesis is rejected (i.e., a trend is detected). For situations in which the original hypothesis test does not reject the null hypothesis, retrospective power cannot exceed 50%.

Statistical power is partly a function of sample size (as well as alpha and magnitude of change; Steidl *et al*. 1997), and studies that lack sufficient power to detect an existing effect (e.g., trend) may seek to augment power by increasing sample size (e.g., number of survey stations). The relationship of sample size and power was examined for Iiwi, Hawaii Creeper and Akiapolaau, species with low, moderately high and very high variability in mean annual densities, respectively (Table 34). Power calculations based on simulated sample sizes demonstrated that species with low variability in observed densities have high power to detect trends. Power was consistently 100% for Iiwi given sample sizes ranging from 50 to 2,000 stations. That is, as few as 50 stations would be adequate for detecting a 10% decline in mean annual density during a 10-year monitoring period assuming an alpha of 0.2. For those species with moderately high between- and within-year variability in observed densities, power is not adequate to detect declining trends, even with very large sample sizes. Power for Creeper only approaches 75% with sample sizes upwards of 2,000 stations. Likewise, power is 56% for a similar sampling effort of the Akiapolaau, a species with very high between- and within-year variability in observed densities. Most notably, power increased only modestly as a function of sample size. For example, there was little difference in power between samples of 200 and those

of 300 stations for all three species (51 to 54% for Akiapolaau; 71 to 73% for Hawaii Creeper; and 100% in both cases for Iiwi).

The modest gain in statistical power between 200 and 300 stations sampled was due to the ability to detect trends in population size depends more on the variability *between* years than it does on the variability among stations *within* a given year. Analyses of the relative proportion of variance attributable to between- versus within-year variance demonstrate ratios of 2:1 for Iiwi, 3:2 for Creeper, and 5:4 for Akiapolaau. That is, Iiwi exhibit twice as much variance in density between years as they do within years. The implication of the sample size-dependent power analysis is that a sampling effort of 200 stations is sufficient for measuring within-year variation within the current survey area. However, between-year variance can only be improved (i.e., reduced) by longer sampling periods (i.e., more years) or more frequent sampling within a year. Furthermore, the difference in effort between 200 stations and the current *intensive* sampling effort of >300 stations may be better reallocated to conducting a more *extensive* sample in areas beyond the current survey area.

Caveats and Cautions

Estimating Population Size

Population estimates did not include those areas that occurred outside of a species' presence area (if applicable). However, some of these areas may harbor birds where they are located in proximity to a species' presence area. For example, a modest number of Akepa may occur in the upper elevation koa-ohia forest south of the presence area used for modeling distribution.

Changes in habitat conditions may also result in inaccurate density predictions and population estimates. For example, mechanical, chemical, and biocontrol efforts in the refuge and adjacent state lands have reduced *Passiflora mollissima* infestations in some areas (J. Jacobi, pers. comm.), and species-habitat models that included the exotic plant may have over-predicted densities if it is no longer present in these areas.

Comparisons with Scott et al. (1986)

Population size estimates differed widely between this study and that of Scott *et al*. (1986). A number of factors contribute to these dissimilarities, including different analysis methods, sampling periods and study areas. The analytical methods employed herein and by Scott *et al*. are fundamentally different and are not directly comparable. The method of Scott *et al*. is based on the extrapolation of mean density-per-station to the aerial extent of strata comprised of eight vegetation types and elevation (200-m elevation intervals). In contrast, the species-habitat regression models applied in our study draw on potentially up to 19 habitat variables, many of which are continuous quantitative descriptors. Consequently, the numbers of habitat "strata" combinations from which densities are estimated are much greater. Moreover, predicted densities were derived from point- or area-based measures of local (1 hectare) habitat conditions. This approach avoids the assumption that the entire area of each stratum contains uniform habitat conditions. Differences in the study area size (i.e., 1,112 km^2 in Scott *et al*. vs. 648 km^2 in this study) also contribute to differences in population estimates. Moreover, our study

area was located in the northern two-thirds of the Hamakua area, a region that Scott *et al*. identified as harboring greater densities and a larger proportion of regional populations for many bird species than the more southerly portion (i.e., Waiakea region). In addition, their results were based on observations from a single survey (1977), whereas our species-habitat models and estimates have the advantage of 15 years of data (1977 and 1987-2000). Significant trends in density were detected for several species, and the longer time period may account, in part, for the differences in population estimates.

Interpreting Species-Habitat Models

The problem of multicollinearity of habitat variables

The inter-relationship (i.e., multicollinearity) of many habitat variables requires that their associations to density be examined for complementary relationships with other variables. For example, a positive association with closed canopy, high-stature forest may imply negative correlations to grassland, exotic forest, open and sparse canopies, and lower stature forests. In addition, a habitat variable may simply serve as a "substitute" for other variables to which density is correlated. For example, most native species demonstrated a negative correlation with tree fern and matted fern, variables that occurred at mid- to low elevations. However, because range contractions have limited most native species distributions to areas above the avian malaria zone (van Riper and Scott 2001), the negative relationship with tree fern and matted ferns may simply be the result of the positive correlation of density with elevation.

Species with a strong association to closed canopy and high-stature forest also often show a negative correlation with richness (i.e., the heterogeneity of landcover types). Landcover rich areas usually are found at the margins of forest and may also include stands of exotic forest and invasive plants such as *Passiflora mollissima*. The exceptions to this response include Hawaii Amakihi and Iiwi, both of which show a positive correlation between density and richness. Interestingly, both of these species forage on *P. mollissima* (Fancy and Ralph 1998; Lindsey *et al*. 1998), and this response may account in part for their association with landcover rich areas.

Mamane occurred too infrequently within the study area to account for a significant amount of the variation in density for any of the species examined. Analyses that encompass the higher elevation portions of species' range may be expected to elicit stronger associations between density and mamane cover. Likewise, *Psidium* spp. did not occur where most native species were present; however, for Elepaio and Apapane, the only two native species whose distributions did span the study area, density was negatively correlated to *Psidium*. However, this relationship may in part be due to the species' low densities at low elevations where *Psidium* spp. occurs.

Slope was identified as a significant predictive variable for several species. Within the study area, forest habitat occurs on gradients of lesser relief, while grassland and woodland habitats are found in steeper areas. Thus, we propose that this relationship reflects the degree to which a species is associated with forest versus woodland (sparse canopy) or grassland habitats.

Interpreting geographic trend terms
Species that demonstrate a correlation with the geographic trend term X do so, in part, because of the term's association with elevation. This is the result of the fact that as one moves east or west across the study area, one is moving across an elevational gradient. More specifically, lower values of X occur in westerly directions and are coincident with both higher elevations and density for many species. Likewise, the term Y increases in northerly directions; therefore, negative correlations with density indicate that bird number decrease towards the north. A negative correlation with the term X^2 describes a modal pattern in which density is lowest at the western and easternmost edges of the study area and peak towards the middle. This pattern is exhibited by many of the birds that attain highest densities in the upper elevation forests, and whose densities decrease above and below this area. Conversely, a positive correlation with X^2 describes a distribution pattern, as seen in the House Finch, in which density is highest at the east and west margins and decrease towards the center. Similarly, the association of density with term Y^2 also describes a pattern in which the orientation runs in a north-south direction (a negative correlation indicates that densities are highest at north and south edges; positive correlation indicates modal pattern with highest densities in the middle). The term XY describes a more complicated "saddle" pattern, such as that seen in the Japanese White-eye, in which the highest densities occur at the margins of the study area on either a northwest-southeast or southwest-northeast axis (with the lowest densities at the other orientation). Although the geographic trend terms describe broad-scale population processes (e.g., interacting birds and clusters of territories), the terms are introduced in species-habitat models primarily to correct for large-scale spatial autocorrelation.

Predicted distribution maps
The predicted distributions that extended beyond the species' presence area for Omao, Akiapolaau, Creeper, Akepa and Iiwi are model "extrapolations". These areas should only be considered as indicative of potentially occupied habitat. For example, the scattered occurrence of Creeper detections at mid-elevations resulted in a convoluted presence area that may have excluded some potential habitat. Since the excluded habitat is in proximity to the species' presence area and is comprised of habitat similar to that with observed occurrences, it is likely that this area supports Creeper, although at low densities. On the other hand, predicted densities 2-4 km southwest of the Creeper presence area reflect the extrapolation of the species' positive correlation with elevation. Because this area is moderately distant from the species' presence area and is located in habitat dissimilar to that with the highest densities, it is likely to support few or no Creeper.

Trend detection
Linear regression, applied over the 14-year and 24-year sampling periods, tested for *increasing* and *decreasing* patterns over the survey interval. The advantages of linear regression are that the patterns are easily understood and interpreted, and widely used in monitoring programs. However, the method does not indicate the "normal" or benchmark density from which to infer trends, is heavily influenced by the initial and final densities, and does not describe patterns that change over time (Steidl *et al*. 1997, Urquhart *et al*. 1998). For example, linear regression does not capture the unimodal

pattern expressed in the Amakihi 14-year sampling period (Figure 39) in which the end point densities are lower than the intervening years. In addition, because there is no information between 1977 (HFBS) and 1987 surveys, patterns cannot be fully described for the entire 24-year sampling period.

Analytical Improvements and Limitations

The analytical methods applied in this study include improvements in the estimation of densities from count data and in the use of species-habitat modeling. The methods address several shortcomings inherent in previous studies: (1) densities are directly adjusted for such covariates as observer and weather effects; (2) regression models incorporate complex combinations of habitat variables not amenable to a stratification-based approach; (3) regression models provide a direct link between digitally mapped habitat variables and quantitatively generated population estimates; and (4) the autoregressive approach to model development directly addresses spatial autocorrelation in bird densities.

Despite the analytical improvements of the current study, a number of limitations in the available data required assumptions that complicated or precluded certain analyses. Firstly, the low detection rates of uncommon species made it necessary to pool observations over a 24-year survey period for purposes of developing detection functions and species-habitat models. Consequently, models may incorporate densities from surveys early in the 24-year study period that no longer reflect current conditions. For example, Creeper densities appear to have significantly increased since the 1977 HFBS survey, and the absences and low densities detected in the Maulua Unit of the HFNWR at this time may no longer be accurate because of population recovery and may result in underestimating densities. Secondly, because repeat observations were unavailable for the area outside of the HFNWR, we were unable to examine trends at large scales or correct for temporal autocorrelation for the study area as a whole. Thirdly, habitat information in digital formats was limited to recent conditions, and it was therefore necessary to assume that land-cover types and other habitat factors did not change considerably over the survey period.

Finally, the species-habitat models do not include all the variables capable of determining bird density and distribution. Limiting factors that were not incorporated in these analyses may include introduced avian parasites and diseases (e.g., avian malaria and pox), potential predators (e.g., rats [*Rattus* spp.], feral cats [*Felis catus*], mongoose [*Herpestes auropunctatus*]), competitors (e.g., Japanese white-eye [*Zosterops japonicus*]), and fine-scale habitat modification (e.g., understory destruction caused by feral pigs [*Sus scrofa*] and cattle [*Bos taurus*]). These and other factors are described in van Riper and Scott (2001). The omission of these variables in model development may lead to the misinterpretation of model results. For instance, a species' absence in portions of its historical range may be the direct consequence of disease impacts (an omitted variable) rather than habitat selectivity.

MANAGEMENT RECOMMENDATIONS

The Hakalau Forest NWR has one of the most consistent, widespread, long-term monitoring programs in Hawaii, and serves as a model for other management organizations in the state. Our work sought to find ways of improving field methods and monitoring program design to improve the quality and usefulness of future surveys.

Habitat Management

The native forest birds of Hakalau Forest NWR are forest specialists whose densities are positively associated with high-stature, closed-canopy forests of ohia and koa (Amakihi, which were common in both forested and non-forested upper elevation habitat, were the only exception). Moreover, most native species (including two endangered species – Creeper and Akepa) were negatively associated with landcover richness or heterogeneity. Landcover rich areas usually are found at the margins of forest, where several habitat types come together. In addition, at least two exotic species, Northern Cardinal and House Finch, respond positively to landcover richness, being most commonly found in forest openings and edges. Thus, our findings suggest that forest edges support lower numbers of native forest birds and increased numbers of exotic birds than intact forest.

These findings lend quantitative support to the general expectation that increasing the amount of high-stature, closed-canopy native forest should ultimately result in increased populations of native forest birds. Thus, these findings support the refuge's substantial efforts and progress at reforestation. However, they also indicate the importance of minimizing fragmentation of closed-canopy forests within the refuge (e.g., it is not only the acreage but the configuration of forest that is important). Creation of edge habitats through road or building construction, helicopter landing pads, or forest management practices should be considered carefully in light of the impact on native and exotic birds.

Improving Field Methods

A number of factors affect the detectability of birds in the field, including sampling conditions (e.g., weather), time of day, observer and year. As detailed in the methods, these factors are included in analysis models as covariates, and their inclusion allows us to account for the variability resulting from these conditions and thereby better estimate the true density of birds in the sampled area. For all 13 species included in this report, one or more covariate variables improved the final model. The variables most frequently found to be significant were Observer and Year.

It is well established that observers vary in their ability to detect birds in the field (e.g., Kepler and Scott 1981, Ramsey and Scott 1981, Bennetts *et al*. 1999). This leads to differences in detection functions among observers. In the present study, such differences were detected for 11 of the 13 species. Although training and pre-survey calibration exercises are routine prior to most VCP counts in Hawaii, these results suggest that these efforts be strengthened to further reduce inter-observer variability.

Secondly, the covariate Year improved the final model for all species. Year may have accounted for differences in annual detection probabilities due to year-to-year differences

in seasonality of breeding and vocalization patterns, and over the longer term, changes in habitat composition and structure, and/or changes in population sizes. Bird breeding and vocalization patterns may change from year-to-year depending upon annual weather patterns (e.g., ENSO events). It is therefore critical that breeding bird surveys be timed to fall within the peak breeding season each year; the current schedule of conducting surveys in March or April is probably ideal. We recommend against expending survey effort at other times of year. Accounting for changes in habitat conditions over time is more problematic. Current habitat conditions were expressed through classification of recent satellite imagery (December 2000 satellite image). Future analyses should include classification of up-to-date satellite imagery to account for additional habitat changes. Periodic sampling of vegetation at survey stations would provide detailed site-specific habitat information and a better understanding of habitat changes (e.g., sampling vegetation every 10 years). Vegetation surveys would substantially benefit remote sensing classification efforts and could be used as a covariate in detection function modeling (if all survey stations were sampled for vegetation).

Two variables, Time of Day and Gust, appeared to account for little variability in the final models. Time of Day may have provided only minor improvements because surveys were conducted when the birds are most vocal and all surveys ceased sampling by 11 am. Gusty conditions can reduce the ability of observers to detect birds, especially aural detections. For this analysis, a blank "gust" field in a field notebook was treated as missing data, not an absence of gusts; to remove any ambiguity, we recommend that the "gust" field should be filled in during future surveys.

Monitoring Program Design

Monitoring Rare or Highly Variable Species

The assessment of population status and trends of rare or uncommon species are made difficult by the combination of small sample size with highly variable density estimates resulting from poor and variable detectability. In such cases, determining changes in the density of rare or uncommon species may require considerably greater sampling effort than is feasible given other monitoring and management priorities. Long-term programs specifically designed to monitor demography (i.e., nesting success, productivity, juvenile and adult survival, natal dispersal; Conant and Morin 2001, Woodworth *et al*. 2001) should be considered in these situations.

Akiapolaau are both rare and demonstrate high year-to-year variability in population size, making it particularly difficult to monitor populations of this endangered species. High variability in estimated densities of Akiapolaau might be caused in part by the broad time period during which birds are reproductively and vocally active (Pratt *et al*. 2001). Considerable year-to-year differences in the peak of these activities coupled to surveys that are not conducted during peak activity may contribute to apparent annual density fluctuations. Research should be initiated to better monitor Akiapolaau, and may include: (1) a demographic study; (2) an examination of the seasonal and year-to-year variability in vocalization; and (3) an evaluation of other monitoring methods for surveying Akiapolaau (e.g., capture-recapture/resight, spot-mapping, etc.). We recommend that demographic studies follow the protocols established by the Breeding Biology Research

and Monitoring Database (BBRID) program (Martin *et al.* 1997; http://pica.wru.umt.edu/BBIRD/protocol/protocol.htm). The research currently being conducted by Liba Pechar, University of California, will be of great assistance to the refuge as they strive to understand, monitor, and manage Akiapolaau.

Reallocating Sampling Effort

Our analyses have demonstrated that current sampling effort can be reduced from about 340 to about 200 stations within the current sampling area without a significant loss in ability to detect trends in density. This sampling effort could then be reallocated to areas that are not currently surveyed. Because travel time between stations can entail much of the effort dedicated to surveying transects, it may be more efficient to reduce sampling effort by dropping transects rather than changing the spacing interval of stations. The resulting transects should be spaced fairly consistently across the landscape (our recommendations result in 1 to 1 1/2 km spacing). We recommend that the following transects be dropped from breeding season forest bird surveys: 2, 4, 6, 11, 15/1001 (1A), 7001 (7A), and 8001 (8A). The proposed change eliminates a total of 113 stations from the 339 stations sampled in 2000 (Figure 60). We recommend that reallocated survey effort be used to survey lower elevations within the refuge and upper elevation forest outside the refuge, as per the recommendations below.

Improving Ability to Monitor Range Contraction

Monitoring the margins of a species' distribution is essential for detecting range contraction or expansion (Thomas 1996, Rodriguez 2002). Currently, surveys extend to approximately 1,500 m and adequately sample the distribution of Akiapolaau within the HFNWR. However, low densities of Akepa and Creeper are predicted to occur beyond the area presently surveyed to as low as 1,300 m elevation. These populations are of particular concern because of the potential impact of avian disease on birds at middle elevations. Surveys in these areas may better determine the extent of the current range, monitor range expansion/contraction, improve species-habitat models, and permit predicted densities to be included in population estimates. It is these objectives, rather than an increase the power to detect trends, to which the recommended survey extensions would apply. Determining species occurrence at the margins of a range does not require the degree of survey effort applied to measuring density for the purposes of estimating trends. The extension of surveys to mid-elevation areas can be limited to transects spaced 3-4 km apart (i.e., similar to the HFBS). These extensions may also be sampled less frequently than current surveys in the HFNWR (e.g., every 3-5 years).

Improving Ability to Monitor Regional Trends

Species-habitat models indicate that areas managed by the Hawaii Department of Hawaiian Homelands and the Department of Lands and Natural Resources likely support significant populations of native species. For example, about one-quarter of the Akepa and one-half of the Creeper and Akiapolaau populations within the north Hamakua study area may occur within the Piihonua Unit of the Hilo Forest Reserve south of the HFNWR. In addition, low densities were predicted for Akepa, Creeper, and Akiapolaau in the upper Piha Unit and the Laupahoehoe Unit immediately north of the HFNWR. Thus, we recommend establishing and annually surveying one transect that parallels

HFNWR transect 14 immediately north of the refuge boundary (Figure 60). The upper portions (above 1,300 m) of HFBS transects 21 and 22 should be reestablished and surveyed annually (Figure 60). Two additional transects should be established between HFBS transects 21 and 22 to provide a thorough and consistent spatial coverage of the area. Depending on the length of the newly established transects, the number of stations may range from about 30 to 45 stations apiece. The transect recommended for placement north of the HFNWR may be established with as few as 30 stations, and the four transects south of the refuge may include about 35, 40, 45 and 45 stations (north to south, respectively).

The case for dropping transects within the HFNWR is made stronger if transects are established outside the current survey area and are sampled annually. However, eliminating transects within HFNWR does not directly depend on establishing transects outside the refuge. The recommendation to reduce sampling effort within the refuge is based on the conclusion that there is little difference between 200 and 300 stations in the statistical power to detect declining densities. The establishment of transects outside the refuge is aimed at meeting objectives other than statistical power. These objectives include: (1) delineating relatively high density areas; (2) determining of the size of regional populations; (3) monitoring range expansion and contraction; (4) defining the aerial extent of population recovery efforts for threatened and endangered bird species; (5) expanding the range of bird densities and habitats sampled to improve predictive models; and (6) assessing the performance of predictive models. Conservation strategies for preventing or slowing population declines should focus in high-abundance areas (Rodriguez 2002), and as such, the extension of surveys to areas outside the refuge contributes to this effort. We strongly encourage HFNWR and neighboring land managing agencies to develop a regional approach for species monitoring and conservation.

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Table 1. Names and origin of species analyzed for the Hakalau Forest National Wildlife Refuge. Organized by American Ornithologists' Union (1983) nomenclature.

Common Name	Scientific Name	Origin
Elepaio	*Chasiempis sandwichensis sandwichensis*	Native
Omao	*Myadestes obscurus*	Native
Hwamei	*Garrulax canorus*	Alien
Red-billed Leiothrix	*Leiothrix lutea*	Alien
Japanese White-eye	*Zosterops japonicus*	Alien
Northern Cardinal	*Cardinalis cardinalis*	Alien
House Finch	*Carpodacus mexicanus*	Alien
Hawaii Amakihi	*Hemignathus virens virens*	Native
Akiapolaau	*Hemignathus munroi*	Native
Hawaii Creeper	*Oreomystis mana*	Native
Hawaii Akepa	*Loxops coccineus coccineus*	Native
Iiwi	*Vestiaria coccinea*	Native
Apapane	*Himatione sanguinea sanhuinea*	Native

Table 2. Sampling effort by variable circular plot survey. Data only includes surveys conducted between February and July.

Survey & Year		#Transects Sampled	#Stations Sampled
Hawaii Forest Bird Survey			
	1977 JUL	13	1366
USFWS –			
Refuges			
Hakalau National Wildlife Refuge			
	1987 MAY	14	239
	1988 JUN	14	228
	1989 MAR	14	232
	1990 MAR	14	232
	1991 APR	14	232
	1992 MAR	14	199
	1993 MAR	14	196
	1994 APR	14	196
	1995 APR	14	197
	1996 MAR	14	233
	1997 MAR	14	204
	1998 MAR	14	232
	1999 MAR	14	233
	2000 MAR	15	339
PIERC			
Maulua			
	1995 FEB	6	36
	1995 MAY	6	36
	1996 FEB	6	36
	1996 MAY	6	36
	1997 FEB	6	36
	1997 MAY	6	32
	1998 FEB	6	36
	1998 MAY	6	36
Nauhi			
	1994 FEB	8	39
	1994 MAY	8	48
	1995 FEB	8	48
	1995 MAY	8	48
	1996 FEB	7	36
	1996 MAY	6	35
	1997 FEB	7	48
	1997 MAY	8	48
	1998 FEB	8	48
	1998 MAY	8	48
	1999 FEB	8	48

Survey & Year		#Transects Sampled	#Stations Sampled
	1999 MAY	8	48
Pua Akala			
	1994 FEB	4	26
	1994 MAY	8	49
	1995 FEB	8	46
	1995 MAY	8	40
	1996 FEB	6	36
	1996 MAY	6	36
	1997 FEB	7	40
	1997 MAY	6	36
	1998 FEB	8	48
	1998 MAY	8	52
World Union Parcel			
	1999 MAR	12	110

Table 3. Model parameters of Elepaio detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	5005	1	1.63	46.1	-	40322	35.045	0.81
				54.8 m	4698	1	1.79	49.6	-	36917	32.823	0.89
				52.1 m[2]	4677	1	1.80	49.7	-	36485	33.563	0.90
	H-rate[3]	None[4]				2	3.00	73.3	0.78	36460	34.091	1.50
		Cos Term 2[4]				3	4.64	86.8	0.81 – 0.93	36448	32.010	2.32
		S-poly[4]				2	3.00	73.3	0.78	36460	34.091	1.50
Covariate Analysis												
	H-rate	None	Cloud[5]	52.1 m	4677	3	1.10	27.0	-0.39 – 0.47	36484	34.347	0.55
			Rain[5]			3	1.10	27.0	-0.39 – 0.47	36483	34.341	0.55
			Wind[5]			3	1.10	27.0	-0.39 – 0.47	36481	34.327	0.55
			Gust			3	1.11	27.2	-0.91 – 0.18	36275	34.140	0.55
			Time[5]			3	1.10	27.1	-0.98 – 0.07	36485	34.212	0.55
			Year			16	1.15	28.7	-0.86 – 0.71	36420	33.820	0.57
			Observer			32	1.35	35.9	-0.48 – 0.22	36319	30.293	0.68
Final Model												
	H-rate	None	Gust Year Observer	52.1 m	4677	47	1.23	31.4	-0.73 – 0.70	36202	33.810	0.61

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Hazard-rate function selected over other functions because of Elepaio behavior of attraction to observer. See text for explanation.
[4] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[5] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.

Table 4. Akaike's Information Criterion (AIC) for detection function model (BASE), model of individual covariate variable, and final model by species. Covariate included in final model when the variable AIC is less than the function model AIC. Bold text indicates a covariate variable included in the final model. Dash indicates model failed to converge. Species names are organized by AOU (1983) nomenclature within native and exotic sub-groups.

Covariate	Native Species[b]								Exotic Species[b]				
Variables[a]	ELEP	OMAO	HAAM	AKIP	HCRE	AKEP	IIWI	APAP	HWAM	RBLE	JAWE	NOCA	HOFI
BASE	36460	85833	102631	4313	16017	16981	204457	170156	4133	57923	44199	9209	8558
CLOUD	36484	85837	102633	4297[c]	16017	**16979**	**204397**	170090[c]	4135	**57895**	44205	9182[c]	**8552**
RAIN	36483	85837	**102555**	4304[c]	16017	**16979**	**204404**	170090[c]	4135	**57895**	44206	9184[c]	**8545**
WIND	36481	**85824**	**102560**	4308[c]	16017	**16980**	**204401**	170144[c]	4134	**57903**	44206	9183[c]	**8551**
GUST	**36275**	85835	102672	–	–	–	**204416**	170174	4141	**57915**	44203	9210	8569
TIME	36485	85834	102672	4314	16018	16983	**204446**	170174	4141	**57917**	44208	9210	8563
YEAR	**36420**	**85433**	**102282**	**4293**[d]	**15953**	**16916**	**203443**	**168924**	**4142**[e]	**57770**	**44111**	**9164**	**8486**
OBS	**36319**	**85588**	**102244**	**4301**	**15985**	**16916**	**203451**	**169260**	**4083**	**57709**	–	**9206**	8518[c]
FINAL	36202	85145	102001	4295	15919	16833	202457	168661	4091	57463	44111	9162	8489

[a] Covariate variables: BASE – function model; CLOUD – cloud cover; RAIN – amount of rain; WIND – strength of wind; GUST – strength of gusts; TIME – time of detection; YEAR – year survey was conducted; OBS - observer.

[b] Species acronyms: ELEP – Elepaio; OMAO – Omao; HAAM - Hawaii Amakihi; AKIP – Akiapolaau; HCRE - Hawaii Creeper; AKEP - Hawaii Akepa; IIWI – Iiwi; APAP – Apapane; HWAM – Hwamei; RBLE - Red-billed Leiothrix; JAWE - Japanese White-eye; NOCA - Northern Cardinal; HOFI - House Finch.

[c] Covariate not included in final model due to convergence failure.

[d] Year covariate pooled to increase number of detections.

[e] Covariate included in final model because of data pooling concerns.

Table 5. Coefficients of univariate correlation between each species' density and habitat variable. Species names are organized by AOU (1983) nomenclature within native and exotic sub-groups. Bold text indicates a correlation *p*-value < 0.01. A dash (–) indicates the variable did not occur within a species' presence area. Variables highlighted with borders were retained in the final spatial autoregression model. The R^2 is the percent variance in density accounted for by the model.

Habitat	Native Species[b]								Exotic Species[b]				
Variables[a]	ELEP	OMAO	HAAM	AKIP	HCRE	AKEP	IIWI	APAP	HWAM	RBLE	JAWE	NOCA	HOFI
OHIA	**0.11**	**0.12**	**-0.18**	**0.12**	**0.14**	**0.24**	**0.13**	**0.07**	**0.08**	**0.13**	-0.06	**-0.06**	**-0.39**
KOA	0.05	**0.10**	**0.36**	**0.04**	0.06	**0.25**	**0.46**	**0.12**	**-0.10**	-0.04	0.01	**0.14**	**-0.20**
MAMA	-0.04	-0.06	-0.04	-0.02	–	-0.04	-0.05	-0.02	-0.02	–	-0.05	-0.01	0.02
GRASS	**-0.06**	**-0.12**	0.05	**-0.10**	**-0.11**	**-0.15**	**-0.22**	**-0.07**	**-0.08**	**-0.13**	0.00	-0.04	**0.34**
EXOTIC	**-0.11**	**-0.13**	**-0.06**	-0.04	–	-0.05	**-0.12**	**-0.11**	**0.08**	-0.05	**0.07**	**0.14**	**0.36**
CLOSED	**0.43**	**0.38**	**0.08**	**0.12**	**0.15**	**0.21**	**0.31**	**0.44**	**-0.17**	**0.39**	**-0.33**	-0.05	**-0.28**
OPEN	**-0.36**	**-0.27**	**-0.09**	-0.09	-0.08	**-0.15**	**-0.18**	**-0.32**	**0.18**	**-0.28**	**0.35**	**0.11**	0.03
SPARSE	**-0.25**	**-0.26**	**-0.19**	-0.07	-0.05	**-0.12**	**-0.22**	**-0.34**	**0.16**	-0.05	**0.13**	-0.04	**0.09**
HIGH	**0.14**	**0.15**	-0.01	**0.10**	**0.12**	**0.12**	**0.20**	**0.15**	0.01	**0.17**	**-0.09**	**0.06**	**-0.33**
MID	**-0.13**	**-0.08**	**-0.08**	-0.03	-0.02	0.05	0.04	**-0.14**	**0.08**	**-0.11**	**0.15**	**-0.06**	-0.01
LOW	-0.02	-0.03	0.01	-0.03	–	0.03	0.00	0.03	-0.02	–	-0.03	-0.02	0.01
TF	**-0.11**	**-0.18**	**-0.39**	-0.03	**-0.13**	-0.08	**-0.45**	**-0.16**	**0.06**	**-0.18**	**0.18**	-0.04	**-0.11**
MF	**-0.18**	**-0.17**	**-0.13**	–	-0.06	–	**-0.07**	**-0.27**	**0.11**	**-0.14**	0.04	**-0.07**	–
PM	**-0.12**	**-0.15**	**0.17**	**-0.07**	**-0.10**	**-0.11**	**0.20**	-0.05	**-0.07**	**0.25**	**0.06**	**0.24**	-0.04
PSC	**-0.10**	-0.06	–	–	–	–	–	**-0.16**	0.00	**-0.13**	**0.06**	**0.09**	–
RICH	**-0.27**	**-0.18**	**0.27**	-0.05	**-0.09**	**-0.15**	**0.17**	**-0.19**	0.04	**-0.15**	**0.22**	**0.21**	**0.13**
SLOPE	**-0.07**	**-0.08**	**0.08**	-0.06	0.07	0.03	-0.05	-0.01	-0.03	-0.04	**0.05**	**0.11**	**0.19**
TEMPC	**-0.36**	**-0.33**	**-0.33**	0.03	**-0.18**	**-0.25**	**-0.28**	**-0.37**	**0.23**	**-0.32**	**0.29**	**0.11**	**-0.13**
RAIN	**-0.28**	**-0.30**	**-0.48**	**0.13**	-0.08	-0.05	**-0.39**	**-0.45**	**0.22**	**-0.33**	**0.27**	0.02	**-0.29**
ELEV	**0.34**	**0.37**	**0.45**	-0.08	**0.22**	**0.27**	**0.50**	**0.47**	**-0.27**	**0.39**	**-0.38**	**-0.11**	-0.03
X	**-0.36**	**-0.37**	**-0.39**	0.02	**-0.15**	**-0.18**	**-0.24**	**-0.46**	**0.17**	**-0.32**	**0.28**	**0.07**	**-0.37**
Y	**-0.18**	-0.05	**0.23**	**-0.12**	**-0.14**	**-0.41**	**0.11**	**0.12**	**-0.07**	**0.09**	-0.02	**0.11**	**0.24**
XY	**0.29**	**0.35**	-0.03	0.06	**0.13**	**-0.16**	0.01	**0.10**	**-0.18**	**0.17**	**-0.24**	**-0.18**	**-0.30**

Habitat	Native Species[b]								Exotic Species[b]				
Variables[a]	ELEP	OMAO	HAAM	AKIP	HCRE	AKEP	IIWI	APAP	HWAM	RBLE	JAWE	NOCA	HOFI
X^2	**-0.23**	**-0.24**	**0.13**	-0.06	0.04	**-0.17**	**-0.11**	**-0.42**	**0.07**	**-0.34**	**0.17**	**0.16**	**0.37**
Y^2	-0.05	**-0.14**	**-0.26**	0.04	**-0.19**	**0.12**	**-0.47**	**-0.11**	**0.32**	**-0.19**	**0.31**	**0.14**	**0.43**
R^2	32	36	42	4	20	42	61	39	17	34	28	16	34

[a] Habitat variables: OHIA – percent ohia cover; KOA - percent koa cover; MAMA - percent mamane cover; GRASS - percent grass cover; EXOTIC - percent exotic forest cover; CLOSED - percent closed canopy; OPEN - percent open canopy; SPARSE - percent sparse canopy; HIGH - percent high stature canopy; MID - percent mid stature canopy; LOW - percent low stature canopy; TF – presence of tree fern; MF – presence of matted fern; PM - presence of *Passiflora mollissima*; PSC – presence of *Psidium* spp.; RICH – number of dominant land-cover types; SLOPE – percent slope; TEMPC – temperature Celsius; X, Y, XY, X^2 and Y^2 are standardized geographic trend terms.

[b] Species acronyms: ELEP – Elepaio; OMAO – Omao; HAAM - Hawaii Amakihi; AKIP – Akiapolaau; HCRE - Hawaii Creeper; AKEP - Hawaii Akepa; IIWI – Iiwi; APAP – Apapane; HWAM – Hwamei; RBLE - Red-billed Leiothrix; JAWE - Japanese White-eye; NOCA - Northern Cardinal; HOFI - House Finch.

Table 6. Population and standard error estimates derived from predicted densities within the study area or species' presence area, and the population size and percent proportion that lies within the Hakalau Forest National Wildlife Refuge (HFNWR). Extent refers to the area encompassed by either the 648 km^2 study area or species' presence area.

	Study/Presence Area			HFNWR	
Species	Population Size	Standard Error	Extent (km^2)	Population Size	Proportion
Elepaio	138,930	605	648	38,056	27%
Omao	57,533	191	473	16,902	29%
Hwamei	5,421	43	648	336	6%
Red-billed Leiothrix	82,006	480	648	24,239	30%
Japanese White-eye	460,373	1,417	648	68,253	15%
Northern Cardinal	8,677	93	648	484	6%
House Finch	64,799	568	201	8,331	13%
Hawaii Amakihi	200,760	990	416	51,600	26%
Akiapolaau	1,585	44	108	789	50%
Hawaii Creeper	17,842	221	167	8,659	49%
Hawaii Akepa	8,311	144	108	6,015	72%
Iiwi	285,422	1,267	384	100,347	35%
Apapane	255,898	1,037	648	75,165	29%

Table 7. Elepaio detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	102	2.62	2.86
1987	239	172	2.00	2.55
1988	228	327	3.52	3.68
1989	232	186	2.23	2.80
1990	232	191	2.29	2.80
1991	232	126	1.51	2.24
1992	199	150	2.10	2.75
1993	196	195	2.77	3.13
1994	301	415	3.16	3.20
1995	332	589	3.45	3.02
1996	379	474	2.81	2.94
1997	358	438	2.59	2.89
1998	369	565	2.71	3.11
1999	391	484	2.76	3.04
2000	339	253	2.08	2.50
Grand Mean	288	326	2.57	2.90

Table 8. Observed trends in log-transformed mean annual density per station (DPS) for the 14-year period from 1987-2000 (i.e., excluding 1977 HFBS data) and 24-year period from 1977-2000 (i.e., including 1977 HFBS data). Slope is the coefficient of the linear regression of DPS and survey year, *P* is the significance of the regression, and R^2 is the proportion of the variation in mean annual density accounted for by survey year. Significant ($P \leq 0.05$) trends are highlighted in bold.

	14-yr Trend			24-yr Trend		
Species	Slope	P	R^2	Slope	***P***	R^2
Elepaio	0.005	0.49	0.04	0.002	0.72	0.01
Omao	-0.005	0.41	0.06	0.004	0.41	0.05
Hwamei	-0.122	0.17	0.15	-0.027	0.67	0.01
Red-billed Leiothrix	0.002	0.78	0.01	<0.001	0.97	<0.01
Japanese White-eye	-0.009	0.12	0.19	-0.008	0.06	0.25
Northern Cardinal	0.004	0.57	0.03	**0.043**	**0.002**	**0.53**
House Finch	-0.024	0.22	0.12	-0.008	0.58	0.02
Hawaii Amakihi	-0.004	0.46	0.05	**0.017**	**0.02**	**0.33**
Akiapolaau	0.026	0.06	0.27	**0.021**	**0.03**	**0.31**
Hawaii Creeper	**0.021**	**0.01**	**0.44**	**0.030**	**<0.001**	**0.73**
Hawaii Akepa	0.014	0.06	0.27	**0.035**	**<0.001**	**0.66**
Iiwi	0.006	0.19	0.14	**0.008**	**0.02**	**0.37**
Apapane	0.002	0.76	0.01	**0.013**	**0.04**	**0.30**

Table 9. Power to detect a negative trend in density for native bird species of the Hakalau Forest National Wildlife Refuge. Power (percentage) is the probability of detecting a trend when one actually occurs. Declines of 1%, 3%, 5% and 10% in the mean annual density per station (DPS) were calculated for a prospective 10-year monitoring period with the program TRENDS, given linear trends, 1-tailed significance levels (alpha) of 0.05, 0.10 and 0.20, and observed coefficient of variation (CV) and variance structure of mean annual DPS over time. The types of variance structures applicable for each species include: (a) CV proportional to 1/√DPS; and (b) CV constant relative to mean. Bold text indicates adequate power (≥ 80%) to detect a negative trend.

			Alpha 0.05				Alpha 0.10				Alpha 0.20			
Species	CV	type	1%	3%	5%	10%	1%	3%	5%	10%	1%	3%	5%	10%
Elepaio	0.654	a	7	11	18	53	13	20	30	69	24	34	47	**84**
Omao	0.549	b	7	13	25	78	13	23	39	**89**	25	39	57	**96**
Hawaii Amakihi	0.465	a	7	14	26	78	14	25	41	**89**	26	41	60	**96**
Akiapolaau	1.346	a	6	7	10	21	11	14	18	34	22	27	32	52
Hawaii Creeper	0.730	a	6	10	16	46	12	18	27	62	24	33	44	79
Hawaii Akepa	0.718	a	6	10	16	47	12	19	27	63	24	33	44	**80**
Iiwi	0.345	b	8	21	45	**99**	15	34	62	**100**	28	52	79	**100**
Apapane	0.694	a	6	10	17	49	12	19	28	65	24	33	45	**81**

Table 10. Model parameters of Omao detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	10328	1	1.25	53.7	-	91340	59.428	0.63
				88.2 m[2]	9834	1	1.35	56.3	-	85951	55.790	0.68
	H-rate	None				2	1.31	54.7	0.75	85870	63.808	0.65
		Cos				2	1.31	54.7	0.75	85870	63.808	0.65
		S-poly Term 4[3,4]				3	1.80	69.6	-0.21 – 0.80	85833	62.434	0.90
	H-norm	Cos Term 2,3[5]				3	4.87	94.4	-0.48 – 0.26	85849	66.410	2.43
		S-poly Term 4,6[5]				3	2.55	82.1	-0.99 – 0.93	85869	59.764	1.27
		H-poly[3]										
	Unif	Cos Term 1,2[5,6]				2	2.67	83.5	0.85	85864	62.323	1.34
		S-poly Term 2,4[6]				2	1.38	57.5	-0.99	85846	59.172	0.69
Covariate Analysis												
	H-rate	S-poly Term 4[4]	Cloud[7]	88.2 m	9834	4	0.70	25.7	-0.73 – 0.30	85837	63.499	0.35
			Rain[7]			4	0.70	25.7	-0.74 – 0.30	85837	63.493	0.35
			Wind			4	0.71	26.1	-0.66 – 0.29	85824	62.910	0.35
			Gust[7]			4	0.70	25.7	-0.87 – 0.31	85835	63.532	0.35
			Time[7]			4	0.71	26.1	-0.97 – 0.30	85834	62.960	0.35
			Year			17	0.78	29.8	-0.77 – 0.60	85433	61.548	0.39
			Observer			31	0.73	27.4	-0.65 – 0.40	85588	63.284	0.37
Final Model												
	H-rate	S-poly Term 4[4]	Wind Year Observer	88.2 m	9834	46	0.81	31.6	-0.98 – 0.98	85145	61.492	0.40

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Fully parameterized model failed to converge.
[4] Model restricted to single adjustment factor.
[5] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[6] Model rejected because function does not allow covariate parameterization.
[7] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.

Table 11. Omao detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	142	1.17	1.02
1987	239	564	1.99	1.30
1988	228	745	2.51	1.76
1989	232	502	1.82	1.65
1990	232	503	1.83	1.29
1991	232	309	1.12	1.03
1992	199	364	1.54	1.19
1993	196	407	1.75	1.18
1994	301	923	2.13	1.05
1995	332	1158	2.10	1.08
1996	379	966	1.72	1.17
1997	358	889	1.65	1.09
1998	369	1142	1.81	1.06
1999	391	943	1.75	1.14
2000	339	620	1.53	1.05
Grand Mean	288	717	1.80	1.22

Table 12. Model parameters of Hwamei detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$var(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%[2]	404	1	5.16	41.2	-	4149	101.12	2.58
	H-rate	None[3]				2	9.78	71.6	0.79	4133	98.367	4.89
		Cos[3]				2	9.78	71.6	0.79	4133	98.367	4.89
		S-poly Term 4,6[3]				4	26.15	94.7	-0.95 – 0.81	4120	90.452	13.08
	H-norm	Cos Term 2,3[3]				3	15.06	85.7	-0.23 – 0.13	4143	97.705	7.53
		S-poly Term 4,6				3	7.34	58.6	-0.85 – -0.13	4128	101.76	3.67
		H-poly[4]										
	Unif	Cos Term 1,2[5]				2	6.68	54.0	0.77	4129	92.177	3.34
		S-poly Term 2,4[5]				2	3.47	24.1	-0.98	4121	101.73	1.73
Covariate Analysis												
	H-rate[3,6]	None	Cloud[7]	10%	404	3	4.17	31.4	-0.89 – 0.17	4135	101.71	2.09
			Rain[7]			3	4.16	31.3	-0.89 – 0.16	4135	101.86	2.08
			Wind[7]			3	4.20	31.8	-0.89 – 0.17	4134	100.21	2.10
			Gust[7]			3	4.23	32.0	-0.99 – 0.11	4141	96.273	2.12
			Time[7]			3	4.23	32.1	-0.98 – 0.08	4141	96.177	6.16
			Year[8]			3	4.23	32.0	-0.96 – 0.07	4142	96.462	2.11
			Observer			7	5.18	41.4	-0.74 – 0.55	4083	90.059	2.59
Final Model												
	H-rate	None	Year[8] Observer	10%	404	8	5.06	40.3	-0.90 – 0.57	4091	94.228	2.53

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model failed to converge.
[5] Model rejected because function does not allow covariate parameterization.
[6] Although model parameters exceeded threshold levels, Hazard-rate model selected due to variance near station center point.
[7] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.
[8] Too few observations were made annually to model; therefore, year covariate pooled into HFBS (1977) and Hakalau NWR (1987-2000) data sets.

Table 13. Hwamei detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	1	0.004	0.037
1987	239	0	-	-
1988	228	2	0.003	0.047
1989	232	1	0.002	0.024
1990	232	0	-	-
1991	232	0	-	-
1992	199	0	-	-
1993	196	0	-	-
1994	301	5	0.006	0.046
1995	332	4	0.003	0.026
1996	379	5	0.004	0.038
1997	358	0	-	-
1998	369	4	0.002	0.025
1999	391	1	0.001	0.018
2000	339	5	0.005	0.051
Grand Mean	288	2	0.002	0.020

Table 14. Model parameters of Red-billed Leiothrix detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	7383	1	1.33	36.1	-	64030	47.565	0.66
				72.9 m[2]	6852	1	1.47	38.7	-	57923	43.770	0.74
	H-rate	None				2	2.65	67.2	0.80	58007	42.987	1.33
		Cos Term 2,3[3] S-poly[4]				4	5.90	91.1	0.65 – 0.96	57875	36.617	2.95
	H-norm	Cos Term 2,3[3]				3	3.46	77.8	-0.27 – 0.01	57844	37.447	1.73
		S-poly Term 4,6 H-poly[4]				3	2.71	68.2	-0.96 – 0.54	57829	38.153	1.36
	Unif	Cos Term 1,2[5]				2	2.21	58.8	0.77	57979	43.304	1.11
		S-poly Term 2,4[5]				2	1.40	36.5	-0.99	57989	46.620	0.70
Covariate Analysis												
	H-norm	None	Cloud	72.9 m	6852	2	0.97	21.6	-0.50	57895	43.690	0.49
			Rain			2	0.97	21.6	-0.49	57895	43.690	0.49
			Wind			2	0.97	21.6	-0.48	57903	43.712	0.49
			Gust			2	0.97	21.5	-0.92	57915	43.745	0.48
			Time			2	0.97	21.5	-0.99	57917	43.749	0.48
			Year			15	1.01	22.9	-0.80 – 0.62	57770	43.267	0.50
			Observer			33	1.03	23.8	-0.91 – 0.69	57709	42.985	0.52
Final Model												
	H-norm	None	All	72.9 m	6852	52	1.10	26.1	-0.81 – 0.85	57463	42.205	0.55

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model failed to converge.
[5] Model rejected because function does not allow covariate parameterization.

Table 15. Red-billed Leiothrix detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	162	2.75	2.96
1987	239	344	2.55	2.99
1988	228	459	3.41	3.62
1989	232	402	3.10	4.63
1990	232	221	1.70	2.34
1991	232	253	1.95	2.83
1992	199	286	2.57	3.24
1993	196	268	2.44	3.10
1994	301	595	2.97	2.66
1995	332	789	3.23	3.15
1996	379	678	2.68	3.24
1997	358	770	2.95	2.64
1998	369	829	2.74	2.34
1999	391	715	2.80	3.18
2000	339	439	2.30	2.46
Grand Mean	288	503	2.67	3.03

Table 16. Model parameters of Japanese White-eye detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%[2]	6032	1	1.64	46.8	-	44209	26.778	0.82
	H-rate	None				2	1.89	53.9	0.76	44199	29.789	0.95
		Cos Term 2,3[3]				4	5.99	92.1	-0.65 – 0.98	44196	28.405	2.99
		S-poly Term 4,6[3]				4	2.76	71.3	-0.99 – 0.83	44194	29.096	1.38
	H-norm	Cos Term 2,3[3]				3	5.46	90.7	-0.43 – 0.24	44195	29.512	2.73
		S-poly				1	1.64	46.8	-	44209	26.778	0.82
		H-poly[4]										
	Unif	Cos Term 1,2[3,5]				2	2.92	73.6	0.83	44180	27.930	1.46
		S-poly Term 2,4[5]				2	1.57	44.4	-0.99	44180	27.452	0.78
Covariate Analysis												
	H-rate	None	Cloud[6]	10%	6032	3	0.95	22.7	-0.68 – 0.27	44205	29.081	0.47
			Rain[6]			3	0.95	22.7	-0.67 – 0.27	44206	29.061	0.47
			Wind[6]			3	0.95	22.7	-0.67 – 0.27	44206	29.066	0.47
			Gust[6]			3	0.95	22.9	-0.97 – 0.09	44203	29.072	0.48
			Time[6]			3	0.95	22.6	-0.98 – 0.07	44208	29.207	0.47
			Year			16	0.99	24.1	-0.95 – 0.70	44111	29.036	0.49
			Observer[4]									
Final Model												
	H-rate	None	Year	10%	6032	16	0.99	24.1	-0.95 – 0.70	44111	29.036	0.49

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected because data matched theoretical distribution.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model failed to converge.
[5] Model rejected because function does not allow covariate parameterization.
[6] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.

Table 17. Japanese White-eye detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	105	3.93	5.74
1987	239	273	4.27	4.75
1988	228	210	3.39	4.17
1989	232	213	3.47	4.05
1990	232	174	2.83	3.73
1991	232	178	2.90	3.76
1992	199	192	3.64	4.20
1993	196	226	4.35	4.34
1994	301	211	2.15	3.08
1995	332	346	2.91	3.50
1996	379	347	3.07	4.02
1997	358	297	2.56	3.33
1998	369	318	2.47	3.08
1999	391	303	2.62	3.53
2000	339	330	3.65	4.01
Grand Mean	288	258	3.16	3.82

Table 18. Model parameters of Northern Cardinal detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$var(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	1023	1	3.41	45.6	-	9503	61.956	1.71
				114.0 m[2]	1002	1	3.65	48.3	-	9209	60.273	1.82
	H-rate	None				2	5.03	64.0	0.80	9225	64.539	2.51
		Cos Term 2,3[3]				4	20.32	96.7	0.89 – 0.99	9212	62.417	10.16
		S-poly[4]										
	H-norm	Cos				1	3.65	48.3	-	9209	60.273	1.82
		S-poly				1	3.65	48.3	-	9209	60.273	1.82
		H-poly				1	3.65	48.3	-	9209	60.273	1.82
	Unif	Cos Term 1,2[5]				2	4.94	63.2	0.87	9215	61.641	2.47
		S-poly[4]										
Covariate Analysis												
	H-norm	None	Cloud[6]	114.0 m	1002	2	2.78	35.2	-0.64	9182	59.507	1.39
			Rain[6]			2	2.77	35.1	-0.64	9184	59.546	1.39
			Wind[6]			2	2.77	35.1	-0.64	9183	59.543	1.39
			Gust[7]			2	2.68	33.6	-0.96	9210	60.254	1.34
			Time[7]			2	2.68	33.6	-0.99	9210	60.243	1.34
			Year			15	2.86	36.6	-0.96 – 0.85	9164	58.583	1.43
			Observer			9	2.74	34.5	-0.79 – 0.58	9206	59.801	1.37
Final Model												
	H-norm	None	Year Observer	114.0 m	1002	23	2.92	37.5	-0.95 – 0.76	9162	58.113	1.46

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model failed to converge.
[5] Model rejected because function does not allow covariate parameterization.
[6] Covariate provides better fit, but failed to converge in final model.
[7] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.

Table 19. Northern Cardinal detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	2	0.01	0.10
1987	239	50	0.20	0.52
1988	228	40	0.15	0.47
1989	232	38	0.15	0.46
1990	232	34	0.14	0.42
1991	232	32	0.13	0.40
1992	199	44	0.21	0.51
1993	196	52	0.25	0.55
1994	301	81	0.22	0.47
1995	332	97	0.23	0.53
1996	379	115	0.26	0.54
1997	358	85	0.18	0.45
1998	369	127	0.26	0.52
1999	391	66	0.14	0.41
2000	339	49	0.14	0.40
Grand Mean	288	65	0.19	0.48

Table 20. Model parameters of House Finch detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	1670	1	2.33	10.7	-	15848	63.887	1.17
				60.9 m[2]	1066	1	4.44	28.0	-	8569	43.559	2.22
	H-rate	None				2	4.25	26.3	0.72	8558	48.332	2.13
		Cos				2	4.25	26.3	0.72	8558	48.332	2.13
		S-poly				2	4.25	26.3	0.72	8558	48.332	2.13
	H-norm	Cos Term 2[3]				2	12.10	74.3	-0.59	8559	52.142	6.05
		S-poly Term 4				2	5.87	40.4	-0.87	8563	46.359	2.93
		H-poly[4]										
	Unif	Cos Term 1,2[3,5]				2	10.46	68.3	0.78	8554	51.173	5.23
		S-poly Term 2[5]				1	2.45	10.6	-	8553	46.256	1.23
Covariate Analysis												
	H-rate	None	Cloud	60.9 m	1066	2	2.22	8.9	-0.39	8552	43.241	1.11
			Rain			2	2.25	9.1	-0.34	8545	43.123	1.13
			Wind			2	2.23	8.9	-0.36	8551	43.232	1.11
			Gust[6]			2	2.15	8.4	-0.99	8569	43.515	1.08
			Time[6]			3	2.19	8.6	-0.99	8563	43.416	1.09
			Year			8	2.55	11.3	-0.65 – 0.31	8486	41.870	1.27
			Observer[7]			18	2.49	10.9	-0.92 – 0.81	8518	42.149	1.25
Final Model												
	H-rate	None	Cloud Rain Wind Year	60.9 m	1066	11	2.57	11.5	-0.96 – 0.36	8489	41.837	1.29

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model failed to converge.
[5] Model rejected because function does not allow covariate parameterization.
[6] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.
[7] Covariate provides better fit, but failed to converge in final model.

Table 21. House Finch detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	18	0.35	1.36
1987	239	128	0.97	2.28
1988	228	134	0.99	2.65
1989	232	100	0.78	1.78
1990	232	80	0.63	1.97
1991	232	57	0.45	1.32
1992	199	74	0.68	1.69
1993	196	32	0.30	1.11
1994	301	23	0.14	0.79
1995	332	26	0.12	0.55
1996	379	96	0.45	1.62
1997	358	52	0.25	1.44
1998	369	98	0.47	1.74
1999	391	131	0.59	1.66
2000	339	148	0.79	1.88
Grand Mean	288	84	0.54	1.61

Table 22. Model parameters of Amakihi detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	16181	1	0.94	37.4	-	129020	34.593	0.47
				51.0 m^2	15141	1	1.06	41.9	-	116538	33.726	0.53
				45.9 m^2	13753	1	1.19	45.7	-	102674	31.369	0.60
	H-rate	None				2	1.08	41.1	0.72	102631	35.723	0.54
		Cos Term 2,3[3]				4	3.89	90.0	-0.85 – 0.88	102579	33.135	1.94
		S-poly[4]										
	H-norm	Cos Term 2,3[3]				3	3.57	88.3	-0.54 – 0.26	102589	32.261	1.78
		S-poly Term 4,6[3]				3	2.19	74.0	-0.99 – 0.93	102589	33.563	1.10
		H-poly Term 4[3]				2	2.59	80.0	0.93	102589	34.247	1.30
	Unif	Cos Term 1,2[3;5]				2	2.42	77.6	0.78	102618	34.865	1.21
		S-poly Term 2,4[5]				2	1.37	52.5	-0.99	102576	32.916	0.68
Covariate Analysis												
	H-rate	None	Cloud[6]	45.9 m^2	13753	3	0.57	16.4	-0.33 – 0.33	102633	34.446	0.29
			Rain			2	0.64	19.4	-0.46	102555	31.245	0.32
			Wind			2	0.64	19.3	-0.46	102560	31.251	0.32
			Gust[6]			2	0.62	18.7	-0.95	102672	31.364	0.31
			Time[6]			2	0.62	18.7	-0.99	102672	31.363	0.31
			Year			15	0.66	20.7	-0.70 – 0.60	102282	30.964	0.33
			Observer			41	0.56	15.8	-0.90 – 0.80	102244	35.736	0.28
Final Model												
	H-rate	None	Rain Wind Observer Year	45.9 m^2	13753	56	0.70	22.4	-0.70 – 0.68	102001	30.590	0.35

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over previous level based on AIC and other parameters.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model failed to converge.
[5] Model rejected because function does not allow covariate parameterization.
[6] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.

Table 23. Hawaii Amakihi detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	91	3.13	4.26
1987	239	780	11.80	6.12
1988	228	767	10.65	6.75
1989	232	783	11.48	7.38
1990	232	1027	15.06	8.38
1991	232	1009	14.80	7.67
1992	199	891	15.23	7.70
1993	196	1053	18.28	8.08
1994	301	1277	12.51	7.08
1995	332	1587	12.42	7.29
1996	379	1810	14.50	10.83
1997	358	1585	12.29	6.94
1998	369	1861	12.82	7.97
1999	391	1492	11.35	8.64
2000	339	833	8.31	6.09
Grand Mean	288	1197	12.91	7.63

Table 24. Model parameters of Akiapolaau detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%[2]	485	1	5.66	52.0	-	4313	53.615	2.83
	H-rate	None				2	6.94	62.0	0.77	4317	59.151	3.47
		Cos Term 2[3]				3	12.72	84.5	0.56 – 0.85	4316	52.669	6.36
		S-poly				2	6.94	62.0	0.77	4317	59.151	3.47
	H-norm	Cos				1	5.66	52.0	-	4313	53.615	2.83
		S-poly				1	5.66	52.0	-	4313	53.615	2.83
		H-poly				1	5.66	52.0	-	4313	53.615	2.83
	Unif	Cos Term 1[4]				1	3.74	32.1	-	4306	54.015	1.87
		S-poly Term 2,4[4]				2	5.42	49.8	-0.99	4307	55.991	2.71
Covariate Analysis												
	H-norm	None	Cloud	10%	485	6	3.90	34.0	-0.69 – 0.47	4297	52.447	1.95
			Rain			4	3.81	32.9	-0.79 – 0.46	4304	52.860	1.91
			Wind			4	3.78	32.6	-0.75 – 0.50	4308	52.919	1.89
			Gust[5]									
			Time[6]			2	3.60	30.5	-0.99	4314	53.602	1.80
			Year[7]			8	3.94	34.4	-0.78 – 0.56	4293	52.156	1.97
			Observer			7	3.90	33.9	-0.77 – 0.50	4301	52.477	1.95
Final Model[8]												
	H-norm	None	Year[7] Observer	10%	485	14	4.15	36.8	-0.58 – 0.56	4295	51.628	2.08

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over previous level based on AIC and other parameters.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model rejected because function does not allow covariate parameterization.
[5] Model failed to converge.
[6] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.
[7] Year covariate pooled to increase number of detections: 1977 data and subsequent years by 2-year intervals.
[8] Final model with all significant covariate variables was over parameterized; therefore, only the most explanatory covariates were used.

Table 25. Akiapolaau detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	5	0.06	0.30
1987	239	21	0.11	0.43
1988	228	24	0.10	0.35
1989	232	9	0.05	0.28
1990	232	14	0.07	0.31
1991	232	12	0.06	0.31
1992	199	10	0.06	0.31
1993	196	10	0.06	0.29
1994	301	62	0.18	0.53
1995	332	66	0.14	0.40
1996	379	101	0.25	0.58
1997	358	61	0.15	0.53
1998	369	70	0.14	0.36
1999	391	46	0.13	0.44
2000	339	27	0.10	0.37
Grand Mean	288	38	0.11	0.39

Table 26. Model parameters of Creeper detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	2153	1	2.50	38.9	-	17699	38.290	1.25
				63.8 m	2122	1	2.55	39.5	-	17350	37.666	1.28
				58.5 m[2]	2002	1	2.75	41.9	-	16017	35.766	1.37
	H-rate	None				2	4.09	61.5	0.78	16029	37.384	2.05
		Cos Term 2[3]				3	10.10	90.7	0.78 – 0.94	16019	36.423	5.05
		S-poly Term 4[3]				3	6.32	79.3	0.31 – 0.76	16018	35.577	3.16
	H-norm	Cos Term 2[3]				2	6.04	77.7	-0.33	16016	34.302	3.02
		S-poly Term 4[3]				2	5.48	74.2	-0.99	16016	34.595	2.74
		H-poly				1	2.75	41.9	-	16017	35.766	1.37
	Unif	Cos Term 1[4]				1	1.86	24.8	-	16013	36.076	0.93
		S-poly Term 2,4[4]				2	2.60	39.1	-0.99	16019	36.994	1.30
Covariate Analysis												
	H-norm	None	Cloud[5]	58.5 m	2002	2	1.77	23.0	-0.33	16017	35.753	0.88
			Rain[5]			2	1.77	23.0	-0.32	16017	35.753	0.88
			Wind[5]			2	1.77	23.0	-0.34	16017	35.751	0.89
			Gust[6]									
			Time[5]			2	1.77	23.0	-0.99	16018	35.755	0.88
			Year			15	1.88	25.3	-0.67 – 0.44	15953	35.117	0.94
			Observer			14	1.84	24.5	-0.59 – 0.33	15985	35.346	0.92
Final Model												
	H-norm	None	Year Observer	58.5 m	2002	28	1.96	26.8	-0.64 – 0.61	15919	34.648	0.98

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over previous level based on AIC and other parameters.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model rejected because function does not allow covariate parameterization.
[5] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.
[6] Model failed to converge.

Table 27. Hawaii Creeper detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	12	0.28	0.97
1987	239	89	0.99	2.42
1988	228	86	0.90	2.45
1989	232	59	0.67	1.80
1990	232	124	1.42	2.93
1991	232	79	0.90	2.08
1992	199	96	1.28	2.46
1993	196	61	0.83	1.96
1994	301	246	1.76	2.55
1995	332	233	1.26	2.33
1996	379	297	1.75	3.20
1997	358	238	1.42	2.36
1998	369	246	1.19	2.17
1999	391	278	1.64	2.58
2000	339	206	1.60	2.85
Grand Mean	288	167	1.26	2.44

Table 28. Model parameters of Akepa detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$var(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%[2]	2182	1	2.99	44.1	-	17013	36.769	1.49
	H-rate	None				2	2.74	40.0	0.74	16981	41.753	1.37
		Cos				2	2.74	40.0	0.74	16981	41.753	1.37
		S-poly				2	2.74	40.0	0.74	16981	41.753	1.37
	H-norm	Cos Term 2[3]				2	8.13	85.4	-0.51	16980	44.960	4.07
		S-poly Term 4,6				3	1.84	23.1	-0.99 – 0.00	16982	41.143	0.92
		H-poly[4]										
	Unif	Cos Term 1,2[3;5]				2	6.59	79.3	0.83	16979	43.046	3.29
		S-poly Term 2,4[5]				2	3.18	47.2	-0.99	16998	38.106	1.59
Covariate Analysis												
	H-rate	None	Cloud	10%	2182	3	1.41	14.9	-0.28 – 0.20	16979	41.583	0.70
			Rain			3	1.40	14.8	-0.27 – 0.19	16979	41.672	0.70
			Wind			3	1.40	14.8	-0.27 – 0.20	16980	41.645	0.70
			Gust[4]									
			Time[6]			3	1.39	14.7	-0.99 – 0.03	16983	41.731	0.70
			Year			16	1.49	16.4	-0.80 – 0.50	16916	41.206	0.75
			Observer			22	1.52	16.9	-0.74 – 0.71	16916	41.062	0.76
Final Model												
	H-rate	None	Cloud Rain Wind Year Observer	10%	2182	39	1.57	17.8	-0.74 – 0.71	16833	41.481	0.78

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over previous level based on AIC and other parameters.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model failed to converge.
[5] Model rejected because function does not allow covariate parameterization.
[6] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.

Table 29. Hawaii Akepa detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	7	0.12	0.58
1987	239	122	0.94	2.04
1988	228	126	0.76	1.85
1989	232	86	0.69	1.78
1990	232	81	0.65	1.68
1991	232	80	0.64	0.75
1992	199	108	1.00	2.01
1993	196	149	1.41	2.48
1994	301	252	1.28	2.29
1995	332	235	1.02	2.24
1996	379	283	1.23	2.58
1997	358	207	0.91	1.86
1998	369	267	0.99	1.91
1999	391	229	1.04	1.82
2000	339	205	1.09	2.14
Grand Mean	288	174	0.97	2.03

Table 30. Model parameters of Iiwi detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%	26133	1	0.70	32.5	-	208088	31.307	0.35
				55.1 m[2]	25865	1	0.72	33.3	-	204457	31.316	0.36
	H-rate	None				2	1.04	51.3	0.78	204500	33.178	0.52
		Cos Term 2[3]				3	1.59	71.2	0.71 – 0.90	204320	29.818	0.80
		S-poly Term 4,6[3]				4	2.67	87.4	-0.99 – 0.73	204330	29.472	1.34
	H-norm	Cos Term 2,3[3]				3	2.01	79.7	-0.25 – 0.07	204388	30.774	1.00
		S-poly Term 4,6				3	1.34	63.6	-0.88 – 0.47	204334	30.444	0.67
		H-poly				1	0.72	33.3	-	204457	31.316	0.36
	Unif	Cos Term 1,2[4]				2	1.04	51.4	0.82	204098	30.508	0.52
		S-poly Term 2,4[4]				2	0.58	24.8	-0.99	204240	32.682	0.29
Covariate Analysis												
	H-norm	None	Cloud	55.1 m	25865	2	0.51	20.4	-0.38	204397	31.284	0.26
			Rain			2	0.51	20.4	-0.37	204404	31.287	0.26
			Wind			2	0.51	20.4	-0.38	204401	31.286	0.26
			Gust			2	0.51	20.4	-0.93	204416	31.294	0.26
			Time			2	0.51	20.3	-0.99	204446	31.309	0.26
			Year			15	0.54	22.3	-0.82 – 0.64	203443	30.764	0.27
			Observer			25	0.54	22.0	-0.94 – 0.82	203451	30.798	0.27
Final Model												
	H-norm	None	All	55.1	25865	44	0.57	23.9	-0.74 – 0.83	202457	30.254	0.28

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[4] Model rejected because function does not allow covariate parameterization.

Table 31. Iiwi detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	421	14.53	12.21
1987	239	978	14.18	8.98
1988	228	1295	18.61	13.73
1989	232	1452	21.77	12.14
1990	232	1255	18.81	11.98
1991	232	1341	20.10	9.27
1992	199	1421	24.83	9.05
1993	196	1420	25.20	8.61
1994	301	2423	23.58	7.05
1995	332	2698	21.93	7.25
1996	379	2465	19.04	8.43
1997	358	2794	21.76	7.42
1998	369	3201	22.23	8.87
1999	391	2504	19.59	7.41
2000	339	2013	20.51	9.51
Grand Mean	288	1947	20.87	9.27

Table 32. Model parameters of Apapane detections for the Hakalau region from program Distance. Data only includes surveys conducted between February and July by primary observers.

Analysis	Model [1]	Adjusters [1]	Covariables	Truncation	No. Birds	No. Param.	H(0) %CV	$\mathrm{var}(\hat{D})$	Correlation (range)	AIC	EDR	EDR %CV
Model Fitting												
	H-norm	None		10%[2]	21152	1	0.82	35.2	-	170395	36.244	0.41
				51.8 m	19386	1	0.96	40.4	-	150065	34.175	0.48
	H-rate	None				2	1.04	46.8	0.77	170156	39.752	0.52
		Cos				2	1.04	46.8	0.77	170156	39.752	0.52
		S-poly Term 4,6[3]										
	H-norm	Cos Term 2,3[4]				3	2.74	85.9	-0.34 – 0.15	170290	41.049	1.37
		S-poly Term 4,6				3	1.10	49.5	-0.95 – 0.16	169665	39.692	0.55
		H-poly				1	0.82	35.2	-	170395	36.244	0.41
	Unif	Cos Term 1,2[5]				2	1.34	59.1	0.85	169994	36.142	0.67
		S-poly Term 2,4[5]				2	0.66	26.0	-0.98	169642	35.977	0.33
Covariate Analysis												
	H-rate	None	Cloud[6]	10%	21152	3	0.54	18.8	-0.39 – 0.36	170090	38.775	0.27
			Rain[6]			3	0.54	18.8	-0.39 – 0.36	170090	38.756	0.27
			Wind[6]			3	0.53	18.4	-0.39 – 0.37	170144	39.155	0.26
			Gust[7]			3	0.52	18.2	-0.93 – 0.10	170174	39.416	0.26
			Time[7]			3	0.52	18.2	-0.99 – 0.04	170174	39.416	0.26
			Year			16	0.58	21.6	-0.77 – 0.62	168924	38.836	0.29
			Observer			42	0.57	20.9	-0.41 – 0.19	169260	38.372	0.29
Final Model[8]												
	H-rate	None	Year Observer	10%	21152	49	0.59	22.1	-0.70 – 0.57	168661	38.743	0.30

[1] Model codes: Half-normal = H-norm; H-rate = Hazard-rate; Unif = Uniform; Cos = Cosine expansion term; S-poly = Simple polynomial expansion term; H-poly = Hazard polynomial expansion term.
[2] Truncation level selected over other levels.
[3] Model failed to converge.
[4] Model rejected due to one or more parameters exceeding threshold values (i.e., Var(D) > 70.0).
[5] Model rejected because function does not allow covariate parameterization.
[6] Covariate provides better fit, but failed to converge in final model.
[7] Covariate parameter rejected for inclusion in final model because Covariate model AIC > Function model AIC.
[8] Final model with H-norm S-poly Term 4,6 was over parameterized; therefore, built more parsimonious model.

Table 33. Apapane detections, mean density and standard deviation (birds per hectare) by year for surveys conducted within the Hakalau Forest NWR. Stations selected for the HFBS (1977) were within and in proximity to the Hakalau Forest NWR boundary. Grand mean was calculated only for the Hakalau Forest NWR surveys (1987-2000).

Year	Number Stations Surveyed	Number Birds Detected	Mean Density	Standard Deviation
1977	95	202	4.03	4.68
1987	239	1206	10.70	6.16
1988	228	605	5.20	4.73
1989	232	1223	11.18	6.51
1990	232	1063	9.72	6.16
1991	232	1151	10.52	6.75
1992	199	1361	14.50	6.10
1993	196	1077	11.65	5.88
1994	301	1306	7.85	4.50
1995	332	2158	8.73	4.59
1996	379	1977	7.36	4.79
1997	358	2059	9.40	5.09
1998	369	2513	10.43	5.36
1999	391	2235	10.71	6.33
2000	339	1591	9.89	5.50
Grand Mean	288	1538	9.85	5.61

Table 34. Power to detect a negative trend in density as a function of sample size. Densities observed during a 10-year period (1991 to 2000) were resampled to simulate a range of sample sizes (50, 100, 200, 300, 400, 800, 1,200, 2,000 stations) for Iiwi, Creeper and Akiapolaau (i.e., species with low, moderately high and very high variability in density per station). At each of 100 iterations, variance was estimated by the regression of mean annual density by year, and the mean coefficient of variation for all iterations were input into the program TRENDS. The exercise used an alpha of 0.2 and a 10% decline in mean annual density (see Methods section "Population Trends and Power Analyses" for further explanation.)

	Coefficient of Variation			Power		
Sample Size	Iiwi	Hawaii Creeper	Akiapolaau	Iiwi	Hawaii Creeper	Akiapolaau
50	0.32	1.08	2.01	100	61	40
100	0.31	0.95	1.65	100	66	45
150	0.31	0.88	1.51	100	70	48
200	0.31	0.86	1.41	100	71	50
300	0.30	0.83	1.39	100	73	51
400	0.29	0.81	1.28	100	74	54
800	0.29	0.81	1.20	100	74	56
1200	0.29	0.80	1.20	100	74	56
2000	0.29	0.79	1.20	100	75	56

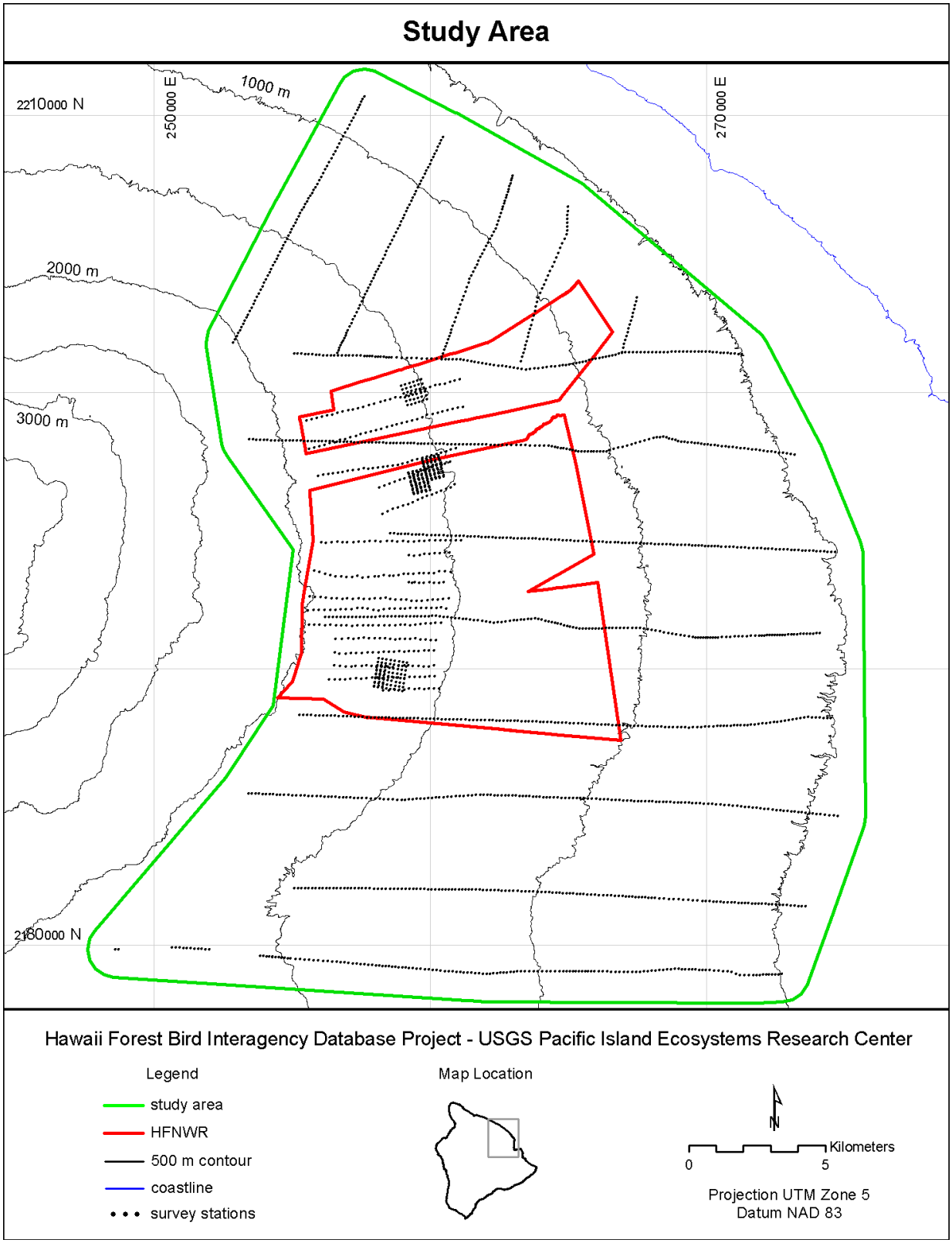

Figure 1. Survey transects and stations in the north Hamakua study area.

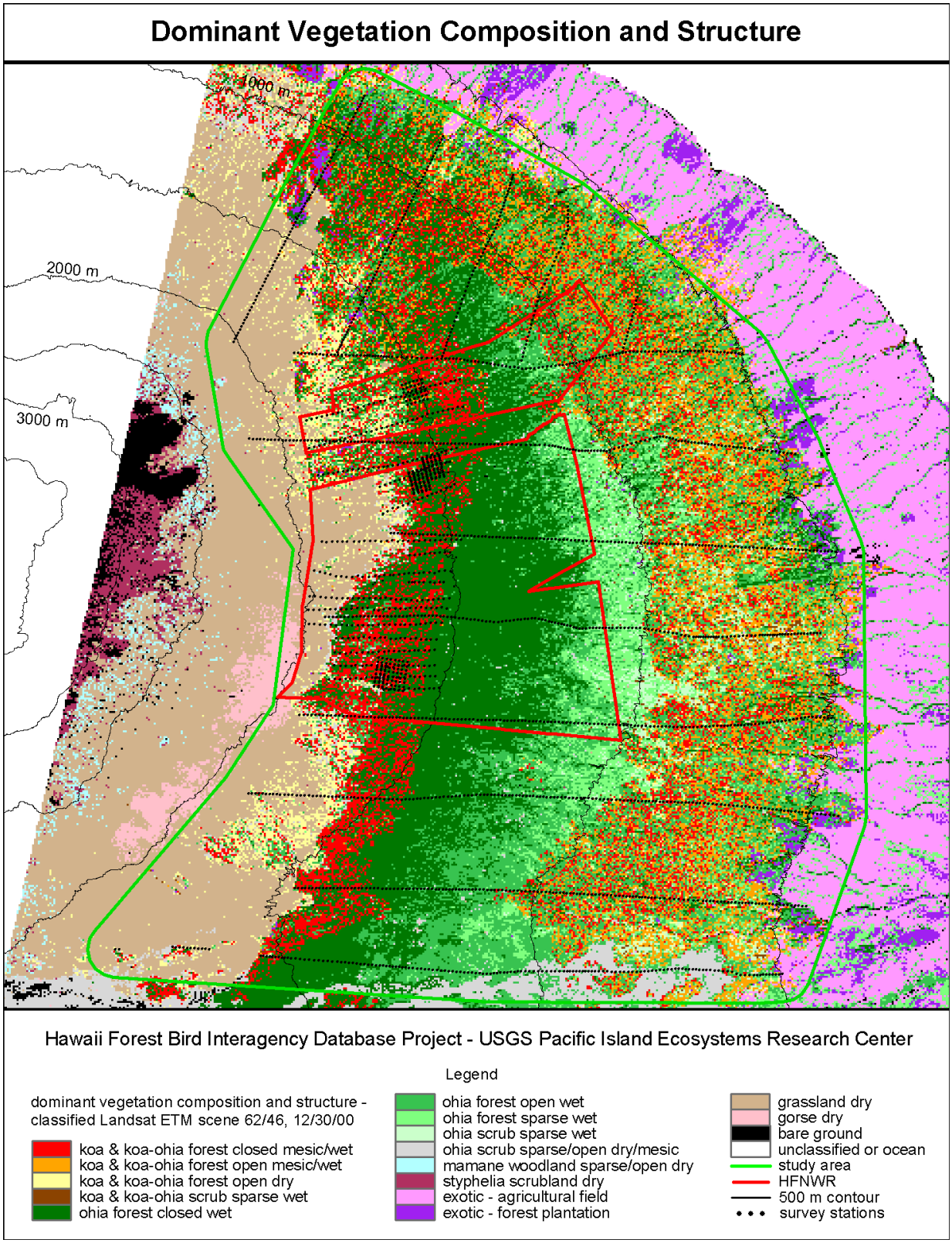

Figure 2. Dominant land-cover types derived from classification of Landsat Enhanced Thematic Mapper imagery of the north Hamakua study area.

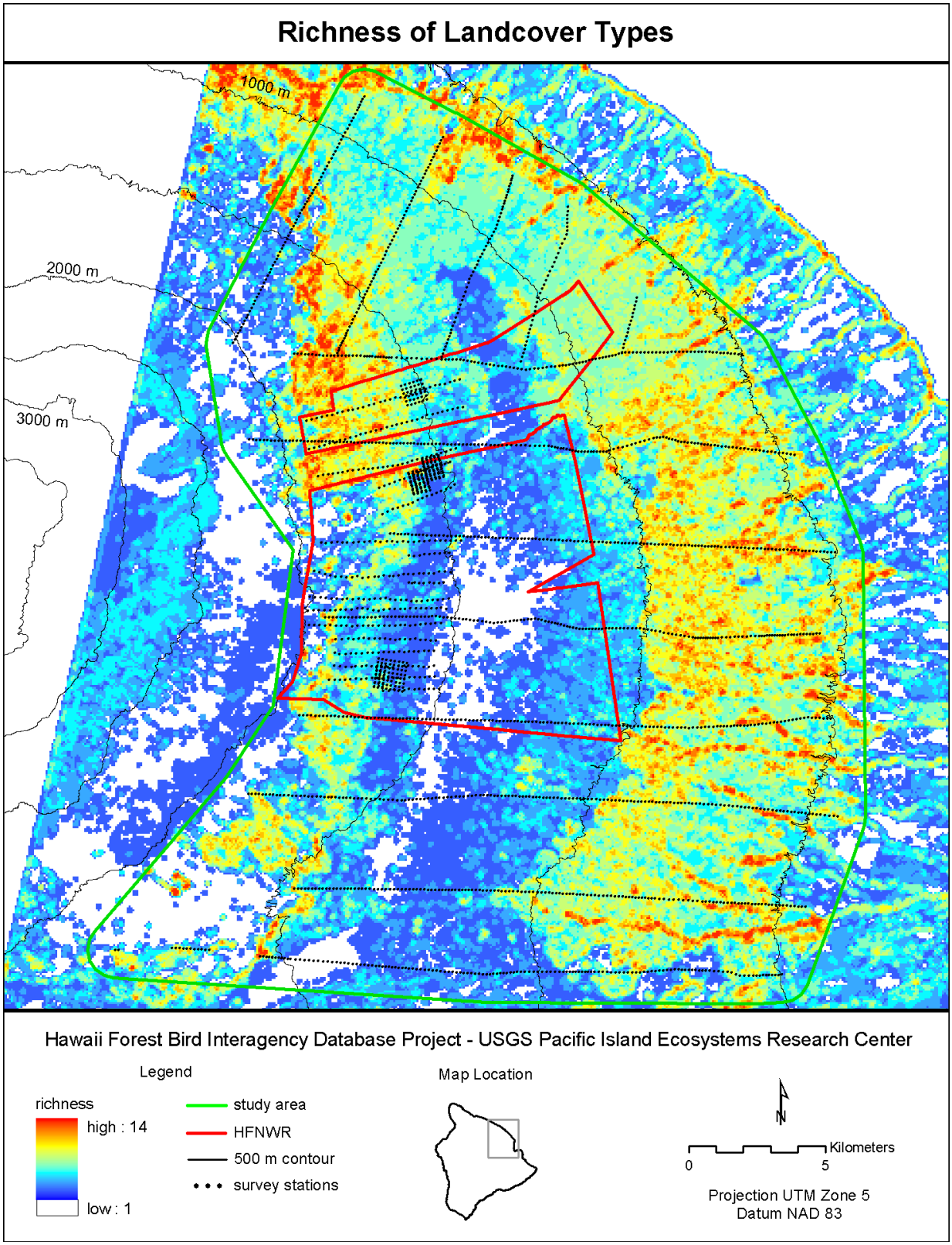

Figure 3. Richness of dominant land-cover types in the north Hamakua study area.

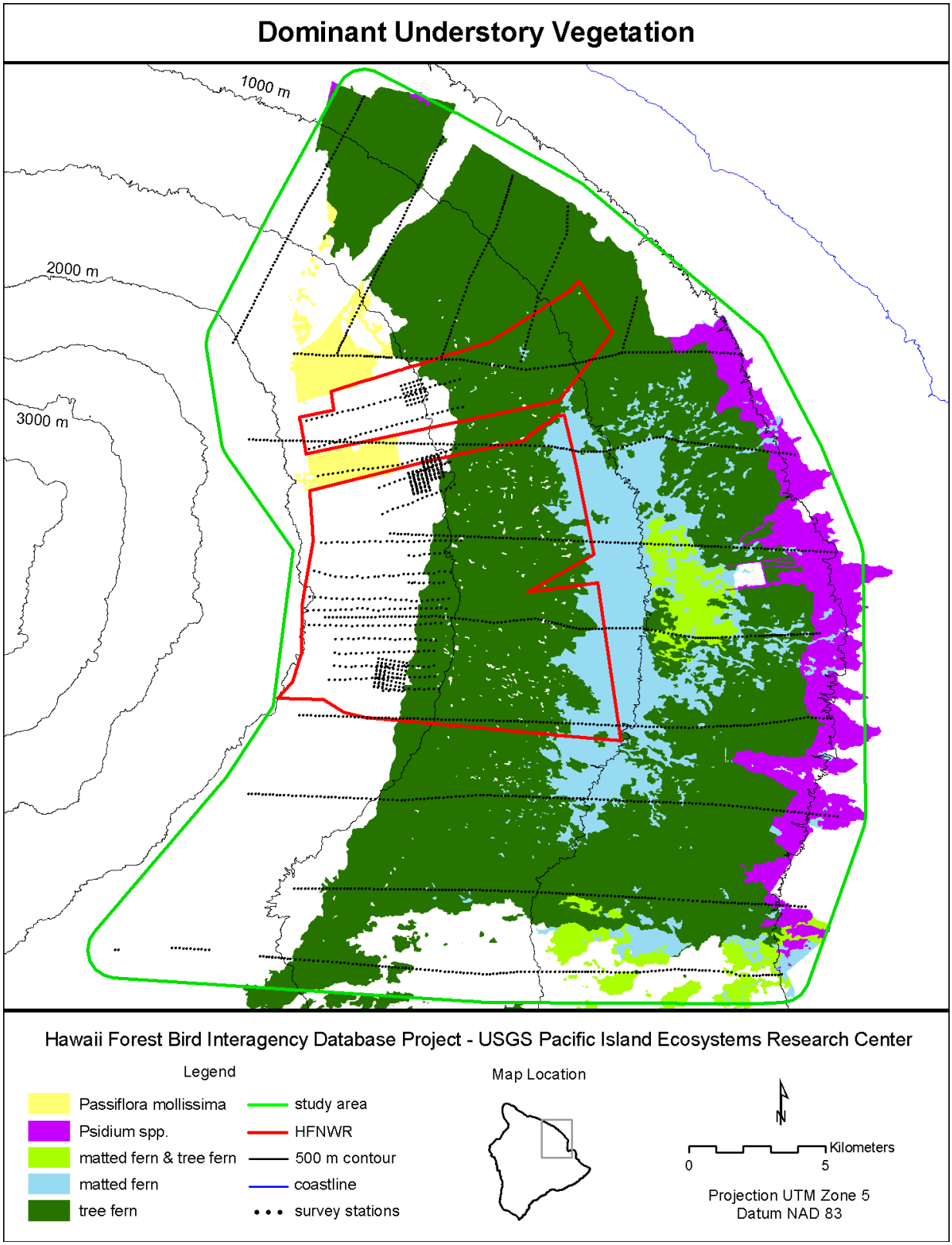

Figure 4. Selected dominant understory components for the north Hamakua study area.

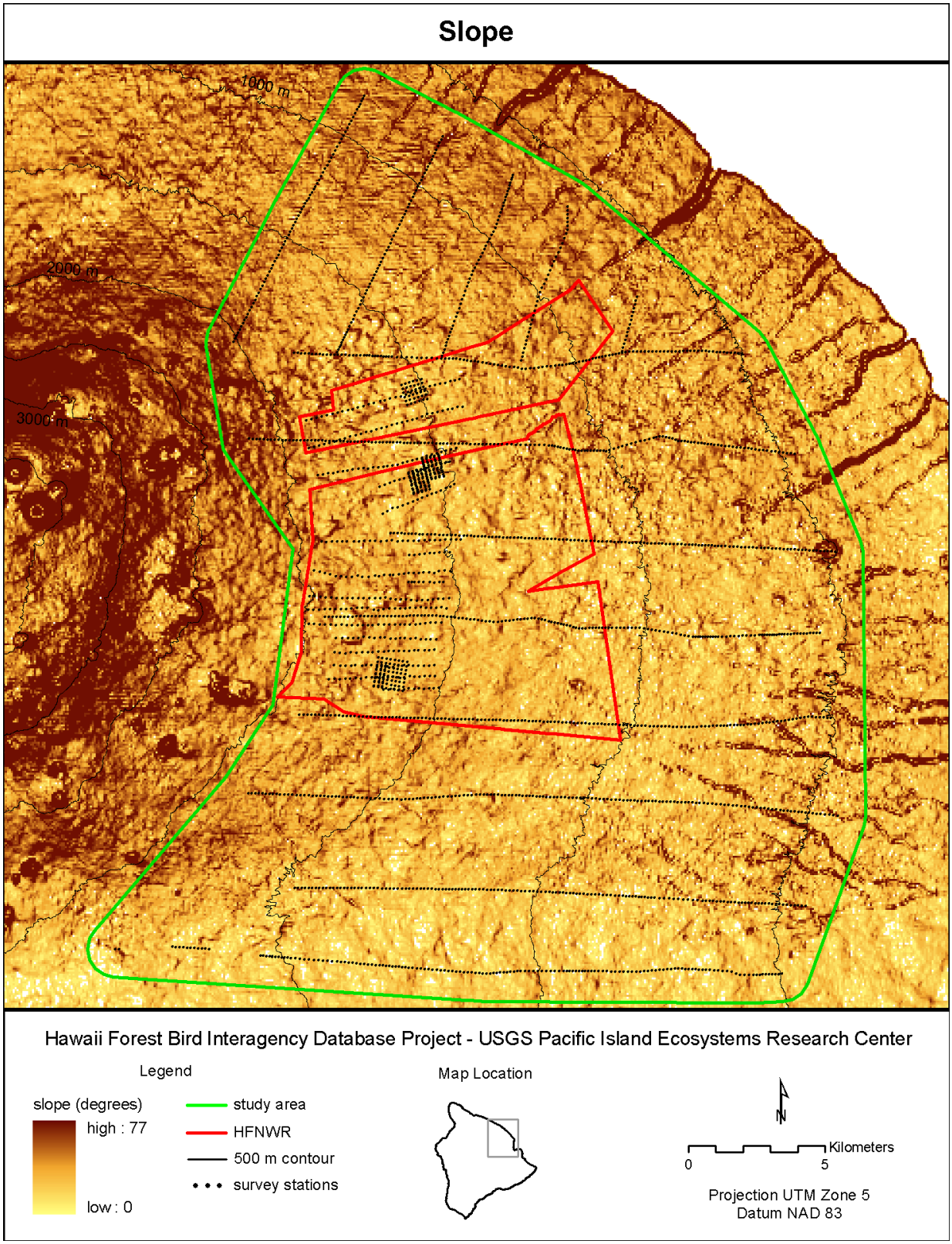

Figure 5. Slope (degrees) derived from 10m Digital Elevation Models for the north Hamakua study area.

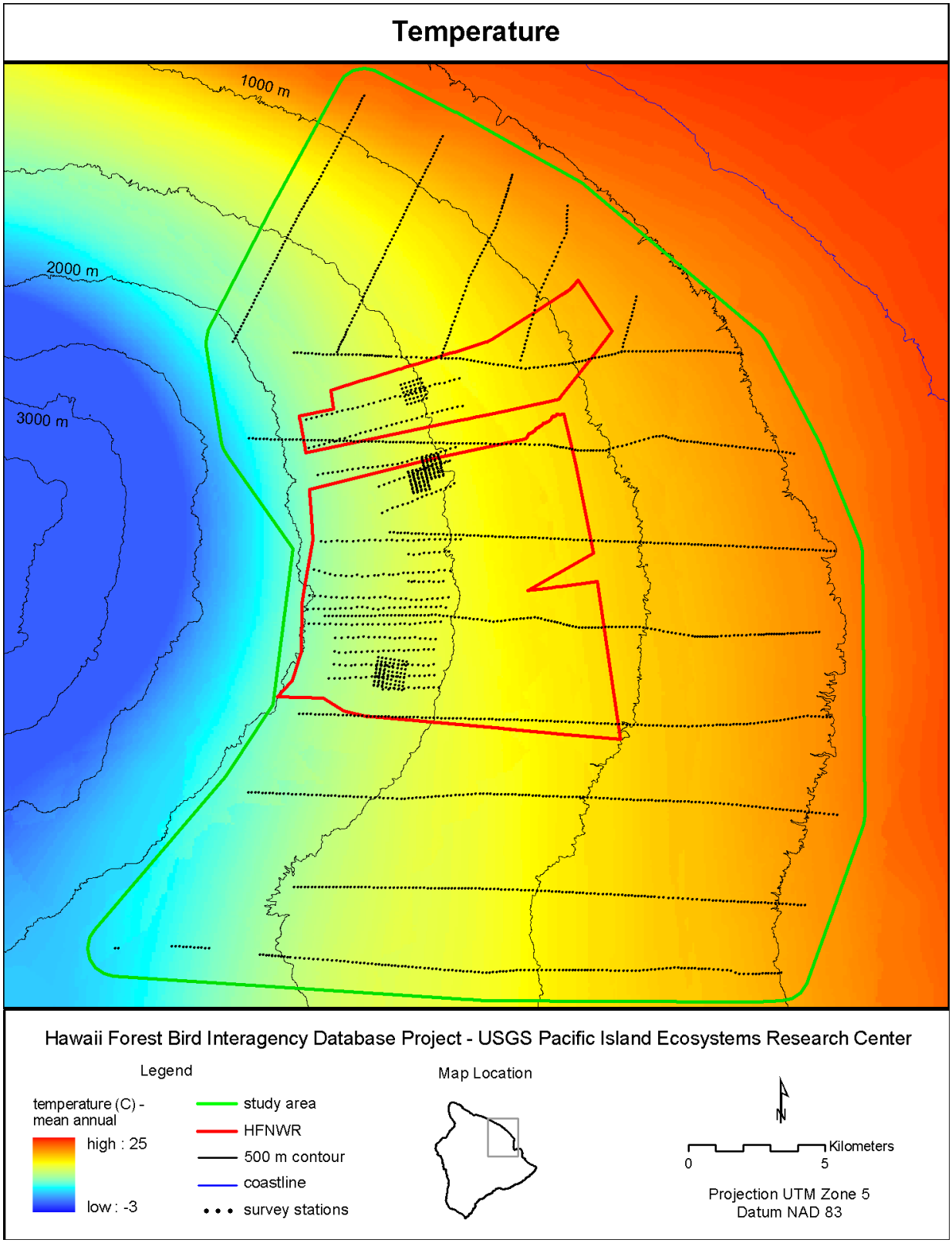

Figure 6. Mean annual temperature (Celsius) for the north Hamakua study area.

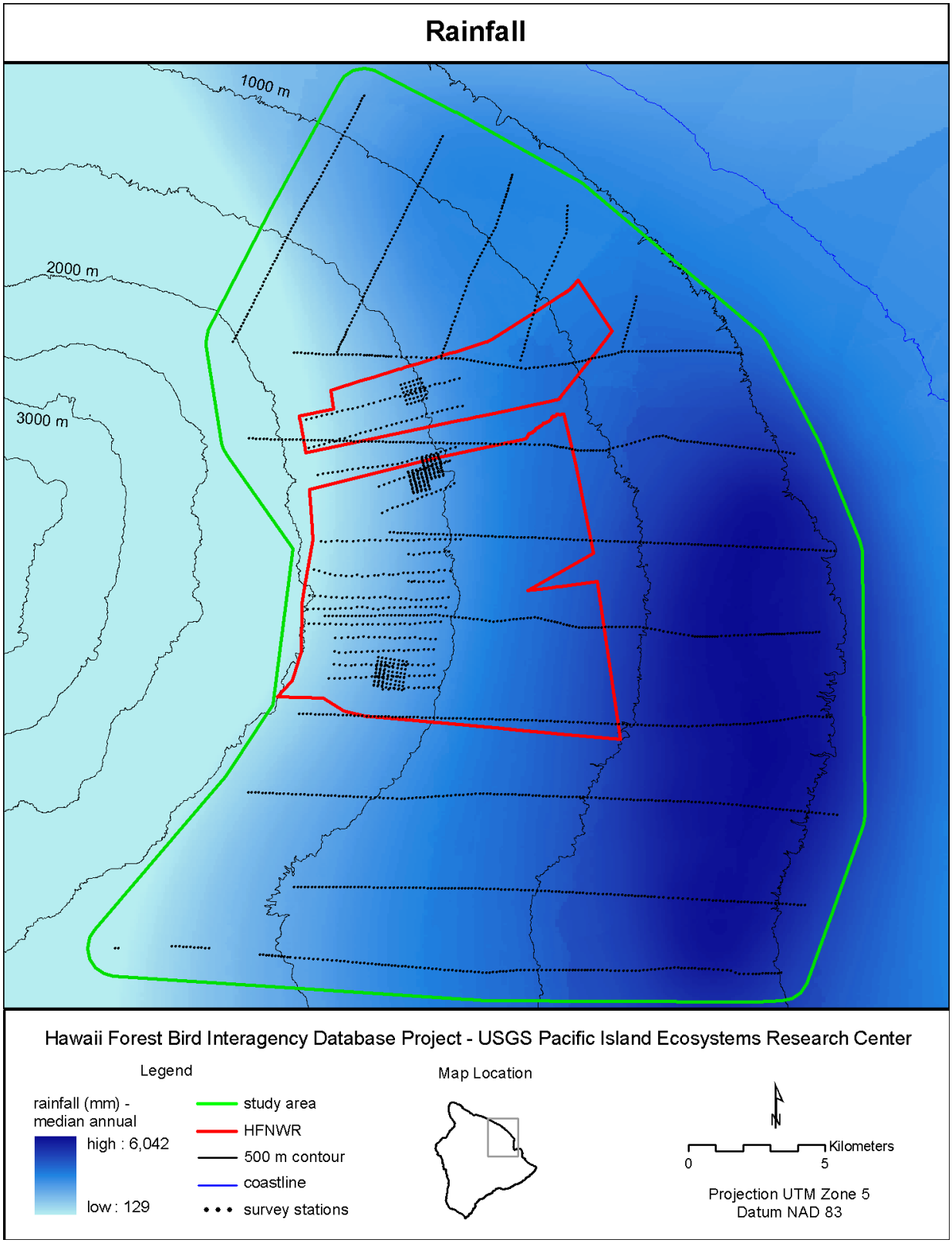

Figure 7. Median annual rainfall (millimeters) for the north Hamakua study area.

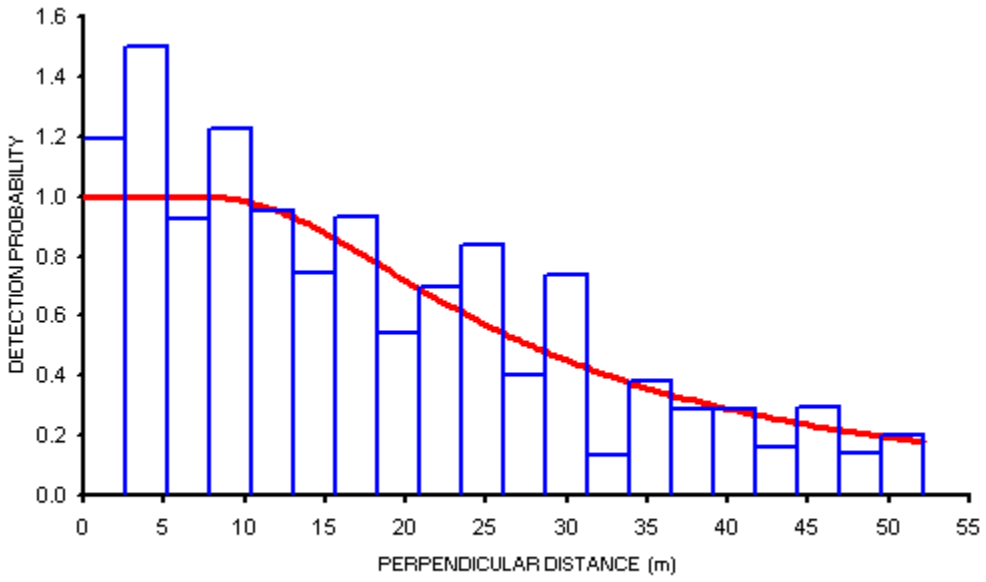

Figure 8. Hazard-rate key detection function and Elepaio distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 52.1 m.

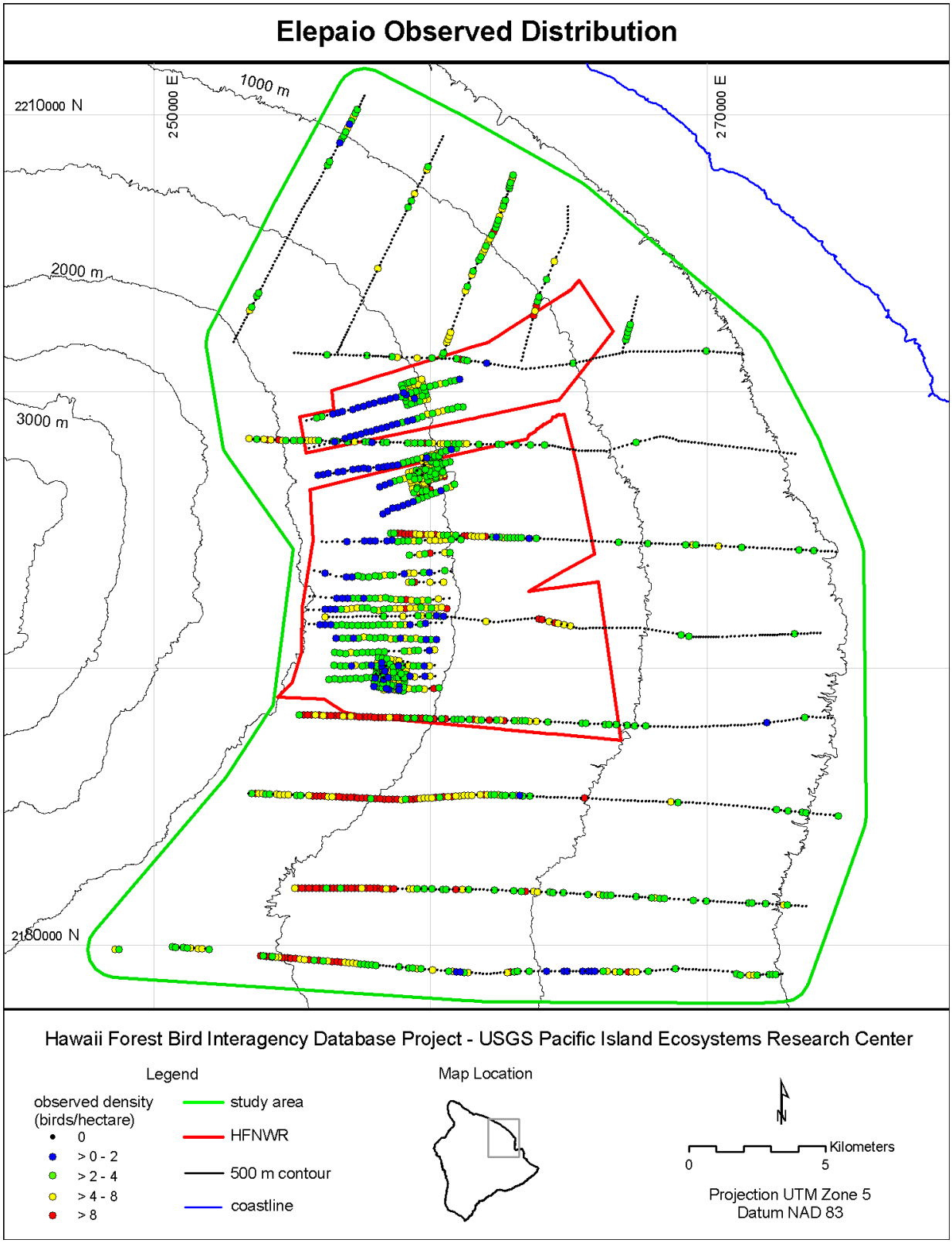

Figure 9. Observed distribution and density of Elepaio in the north Hamakua study area.

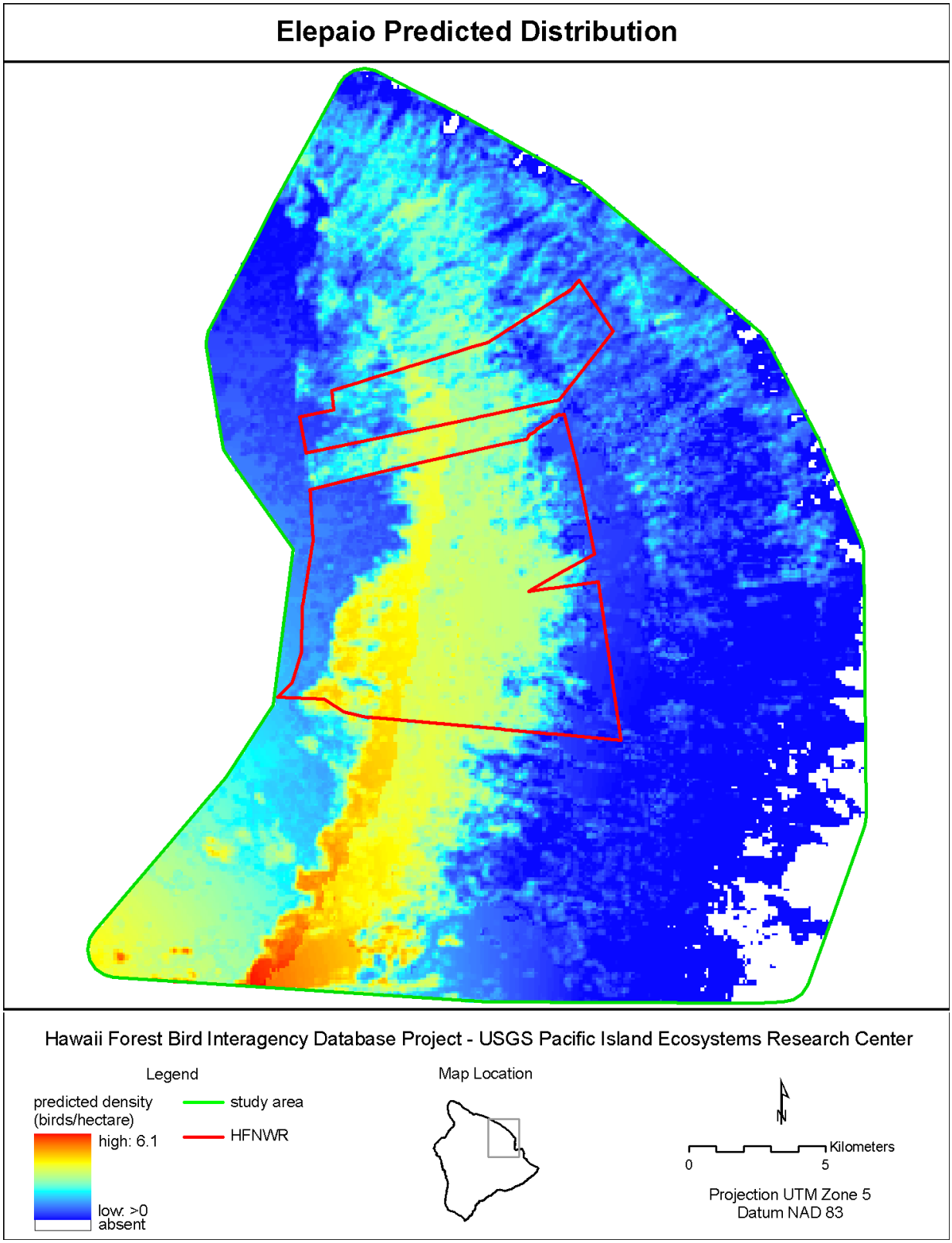

Figure 10. Predicted distribution and density of Elepaio in the north Hamakua study area.

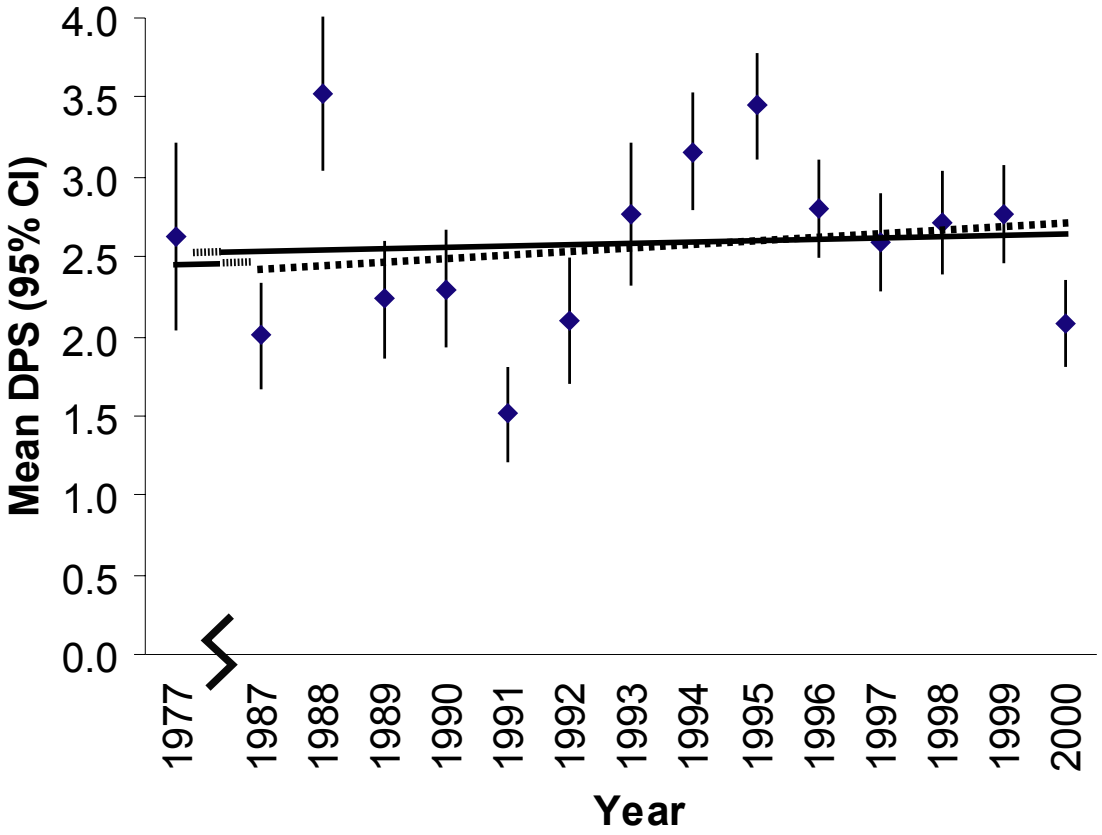

Figure 11. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Elepaio. Regression of log-transformed densities were non-significant for the 14-year (dashed line; slope = 0.005, 95% confidence limit = -0.010 – 0.020, $r^2 = 0.04$, $P = 0.49$) and the 24-year survey periods (solid line; slope = 0.002, 95% confidence limit = -0.008 – 0.012, $r^2 = 0.01$, $P = 0.72$).

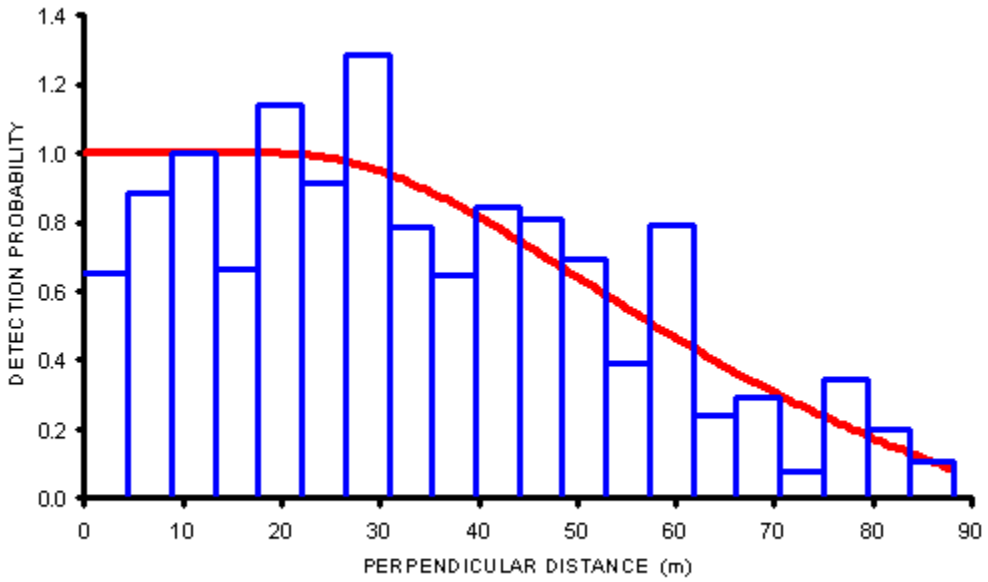

Figure 12. Hazard-rate detection function with a single simple-polynomial adjustment term and Omao distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 88.2 m.

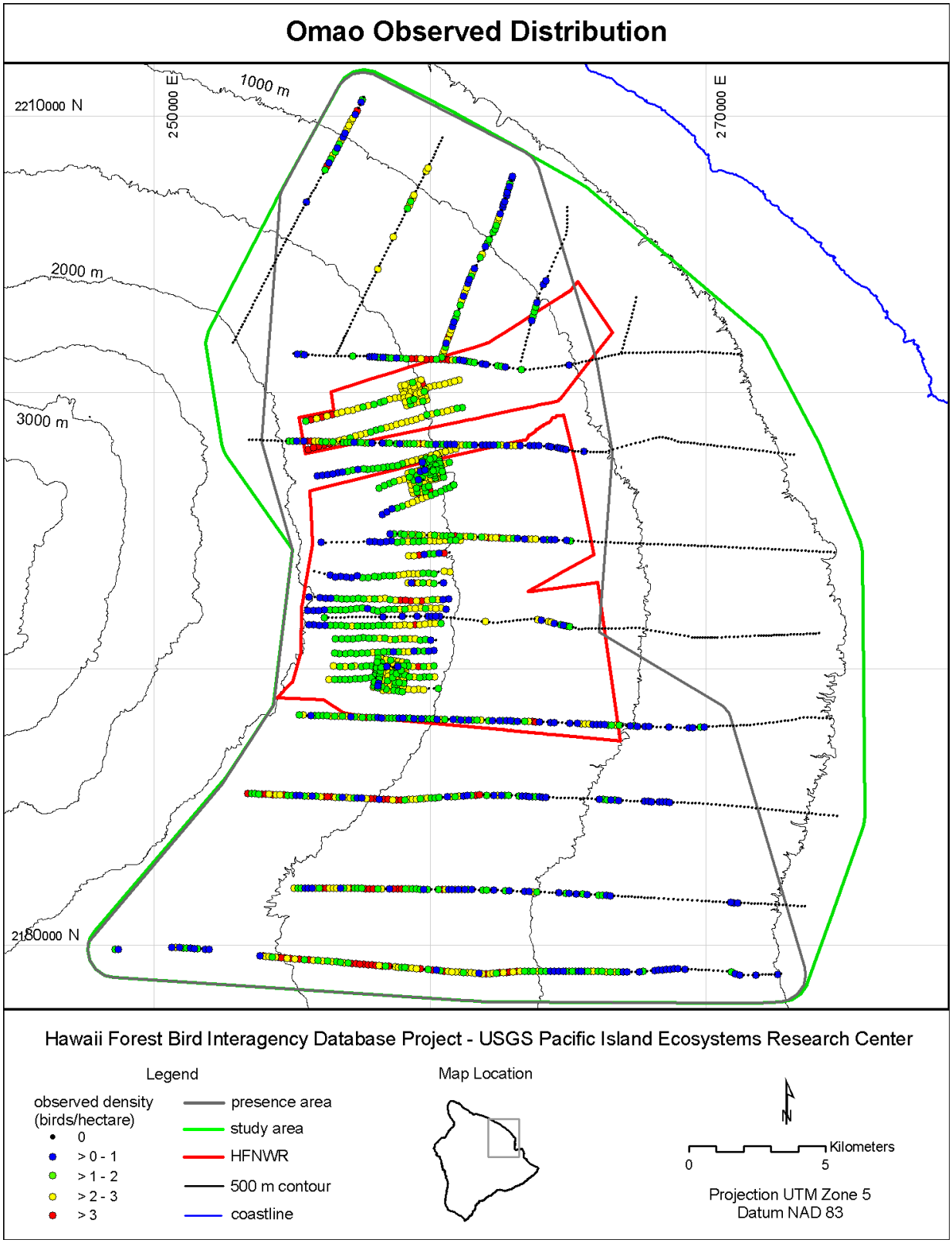

Figure 13. Observed distribution and density of Omao in the north Hamakua study area.

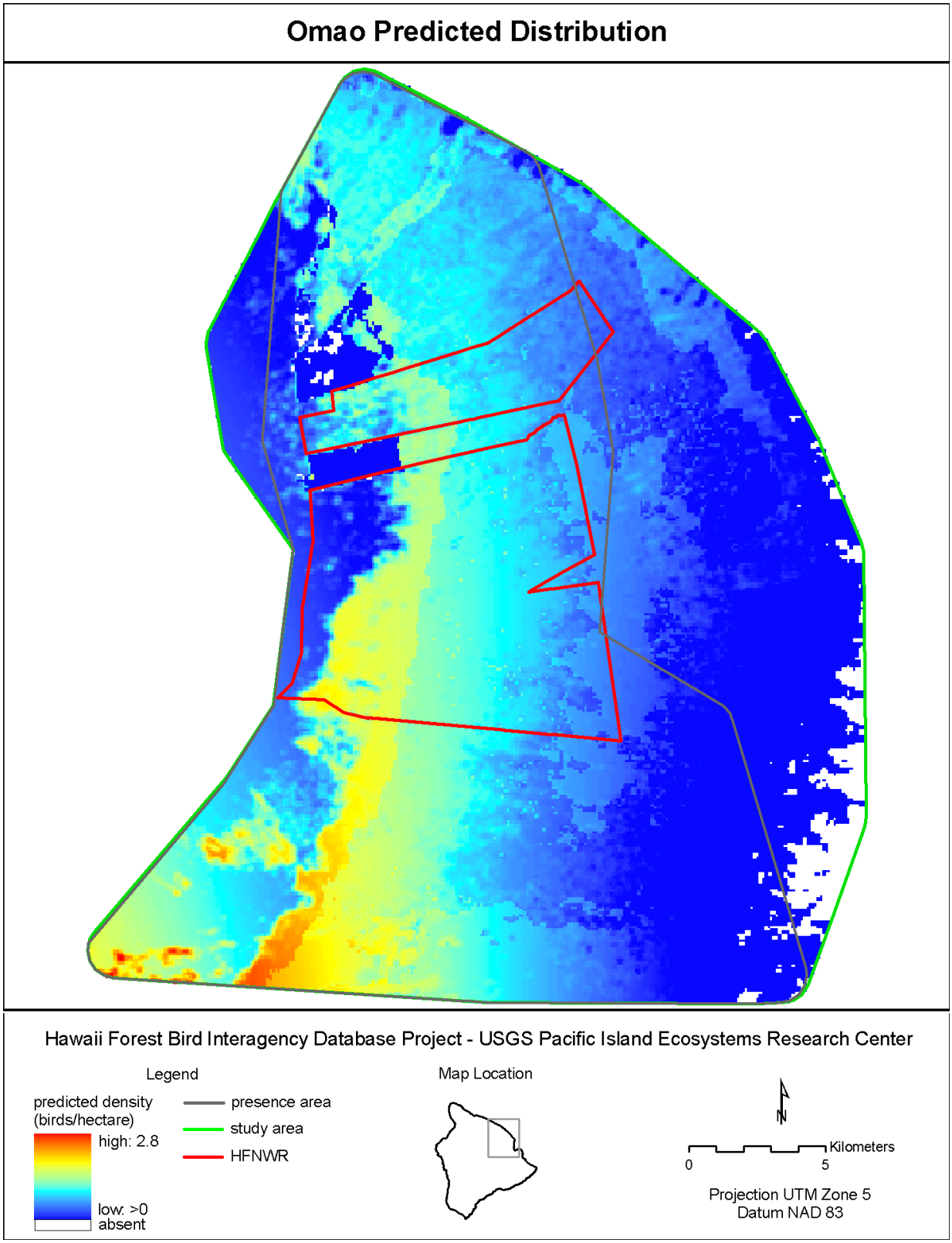

Figure 14. Predicted distribution and density of Omao in the north Hamakua study area.

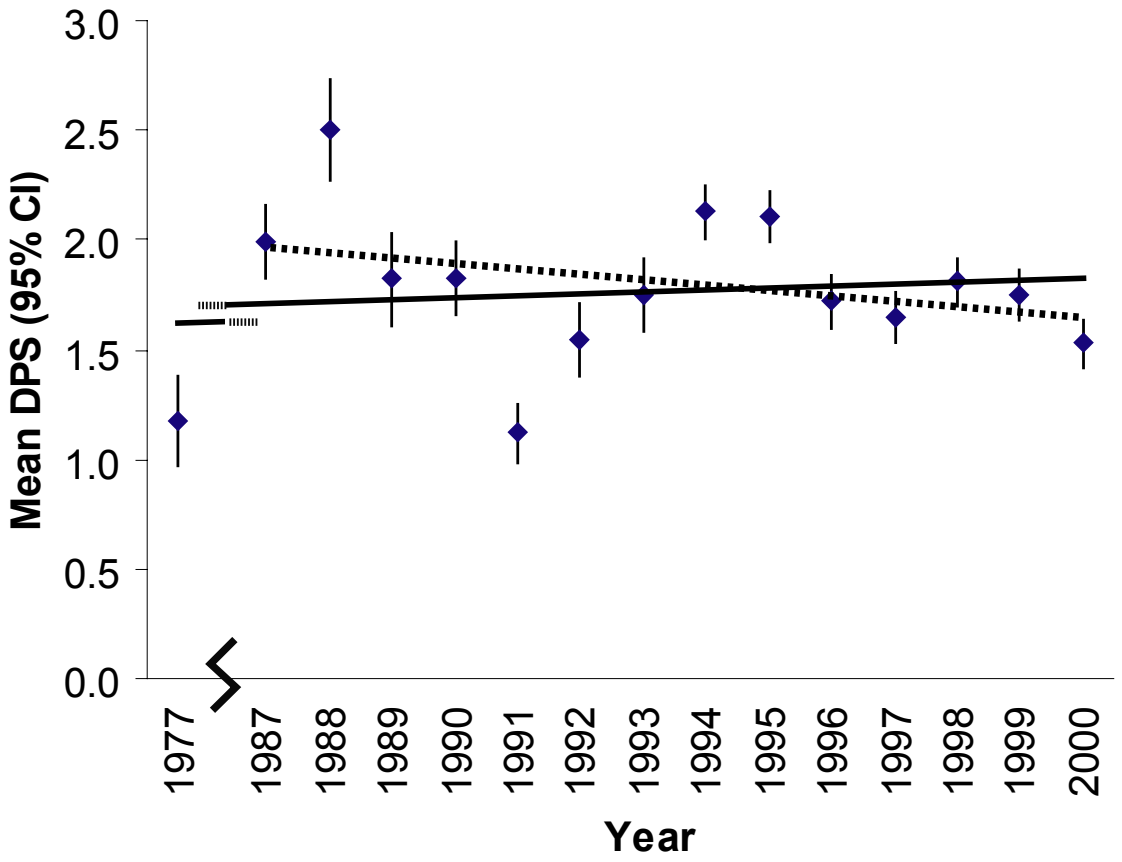

Figure 15. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Omao. Regression of log-transformed densities were non-significant for the 14-year (dashed line; slope = -0.005, 95% confidence limit = -0.016 – 0.007, r^2 = 0.06, P = 0.41) and the 24-year survey periods (solid line; slope = 0.004, 95% confidence limit = -0.006 – 0.013, r^2 = 0.05, P = 0.41).

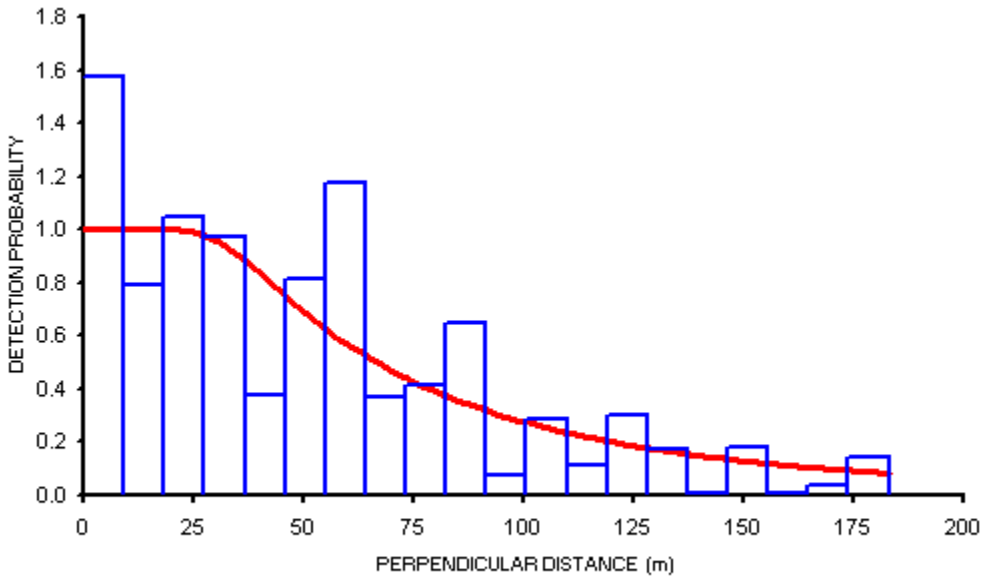

Figure 16. Hazard-rate key detection function and Hwamei distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 183.0 m.

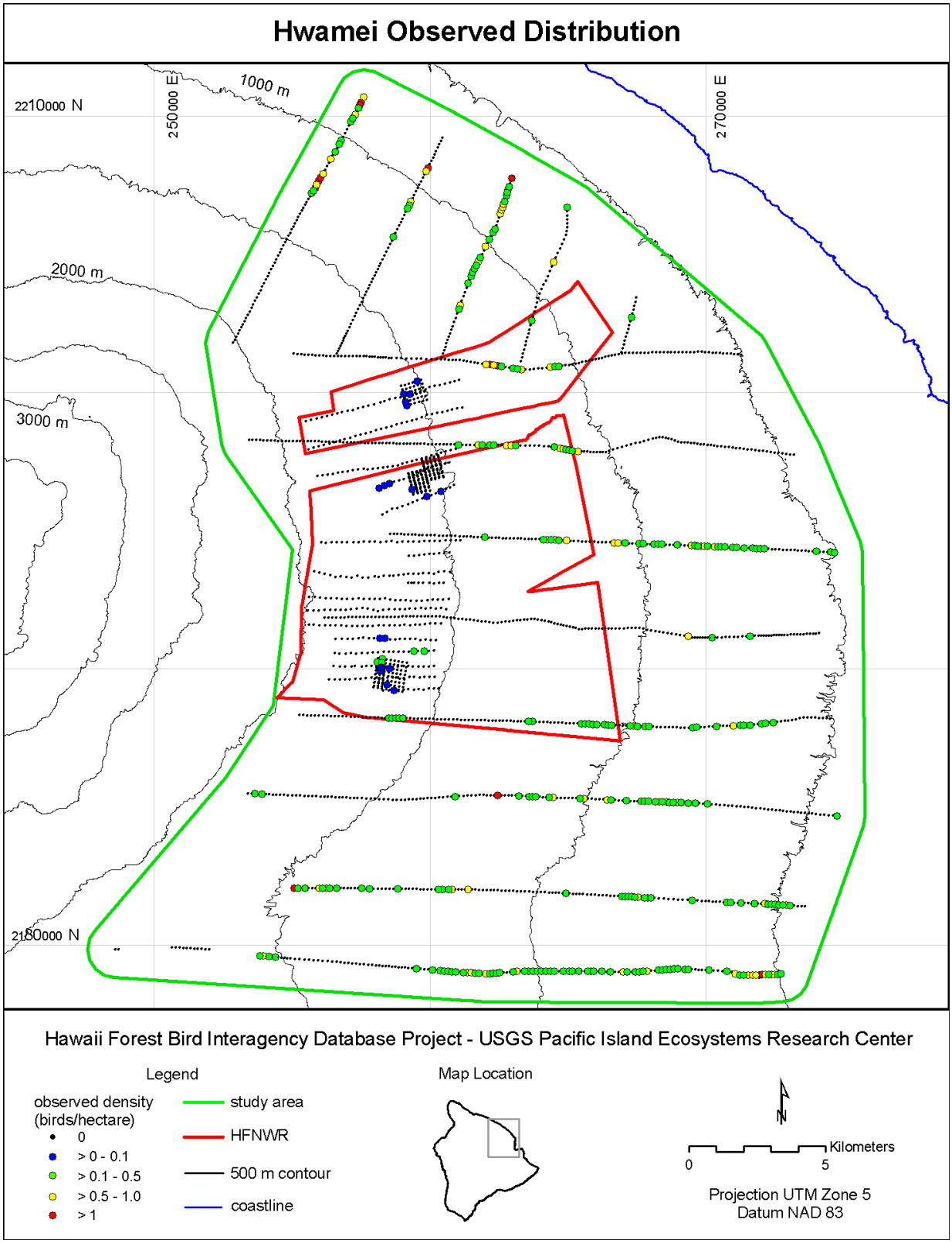

Figure 17. Observed distribution and density of Hwamei in the north Hamakua study area.

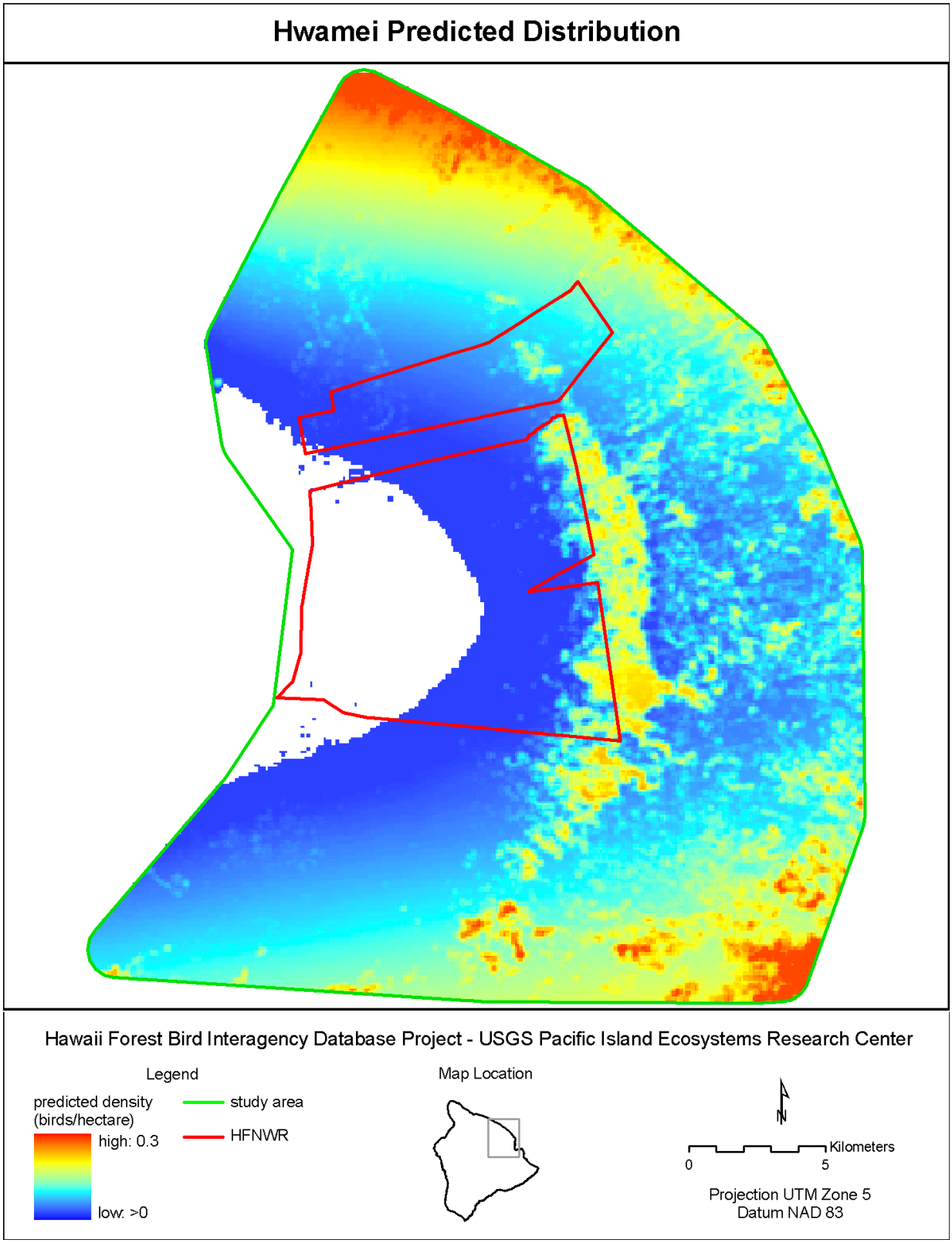

Figure 18. Predicted distribution and density of Hwamei in the north Hamakua study area.

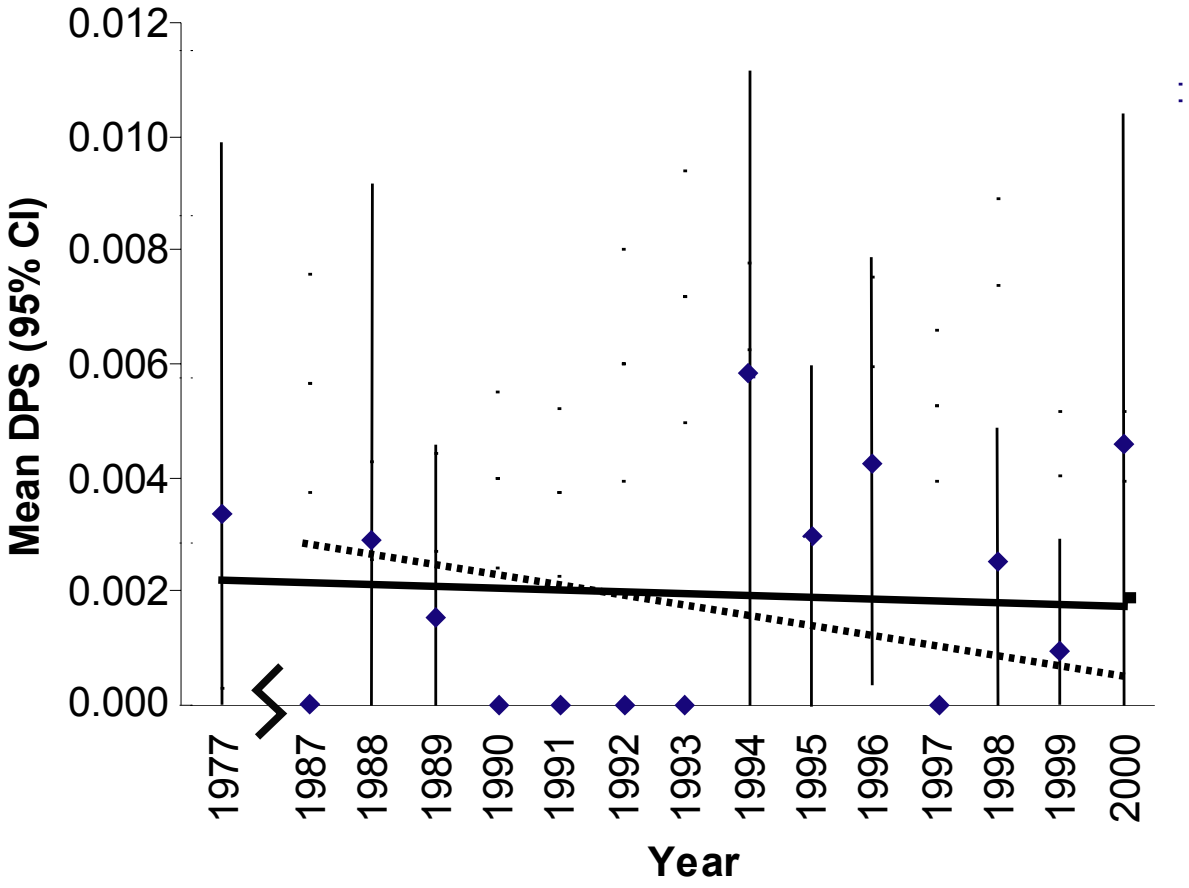

Figure 19. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Hwamei. Regression of log-transformed densities were non-significant for the 14-year (dashed line; slope = -0.122, 95% confidence limit = -0.306 – 0.062, $r^2 = 0.15$, $P = 0.17$) and the 24-year survey periods (solid line; slope = -0.027, 95% confidence limit = -0.159 – 0.105, $r^2 = 0.01$, $P = 0.67$).

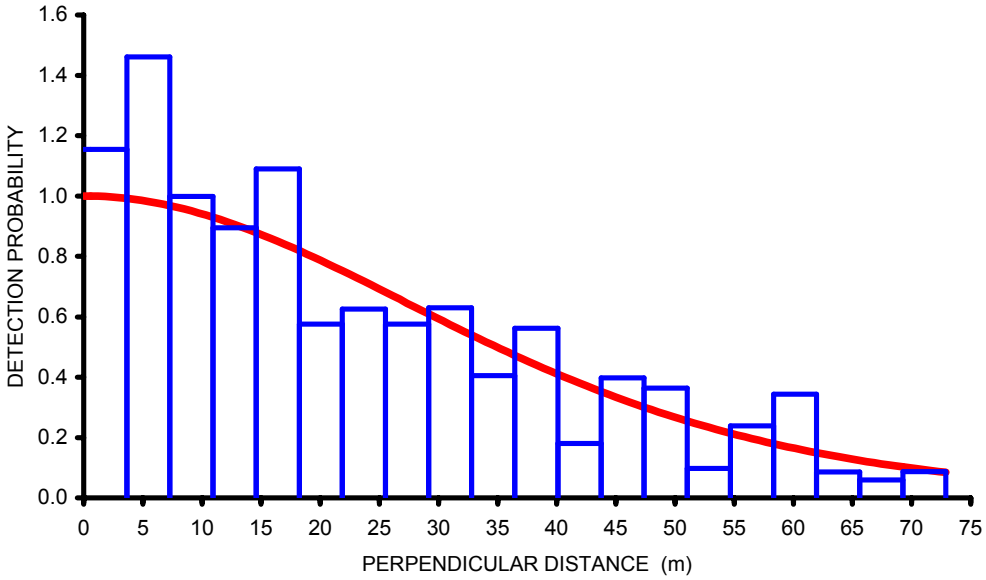

Figure 20. Half-normal key detection function and Red-billed Leiothrix distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 72.9 m.

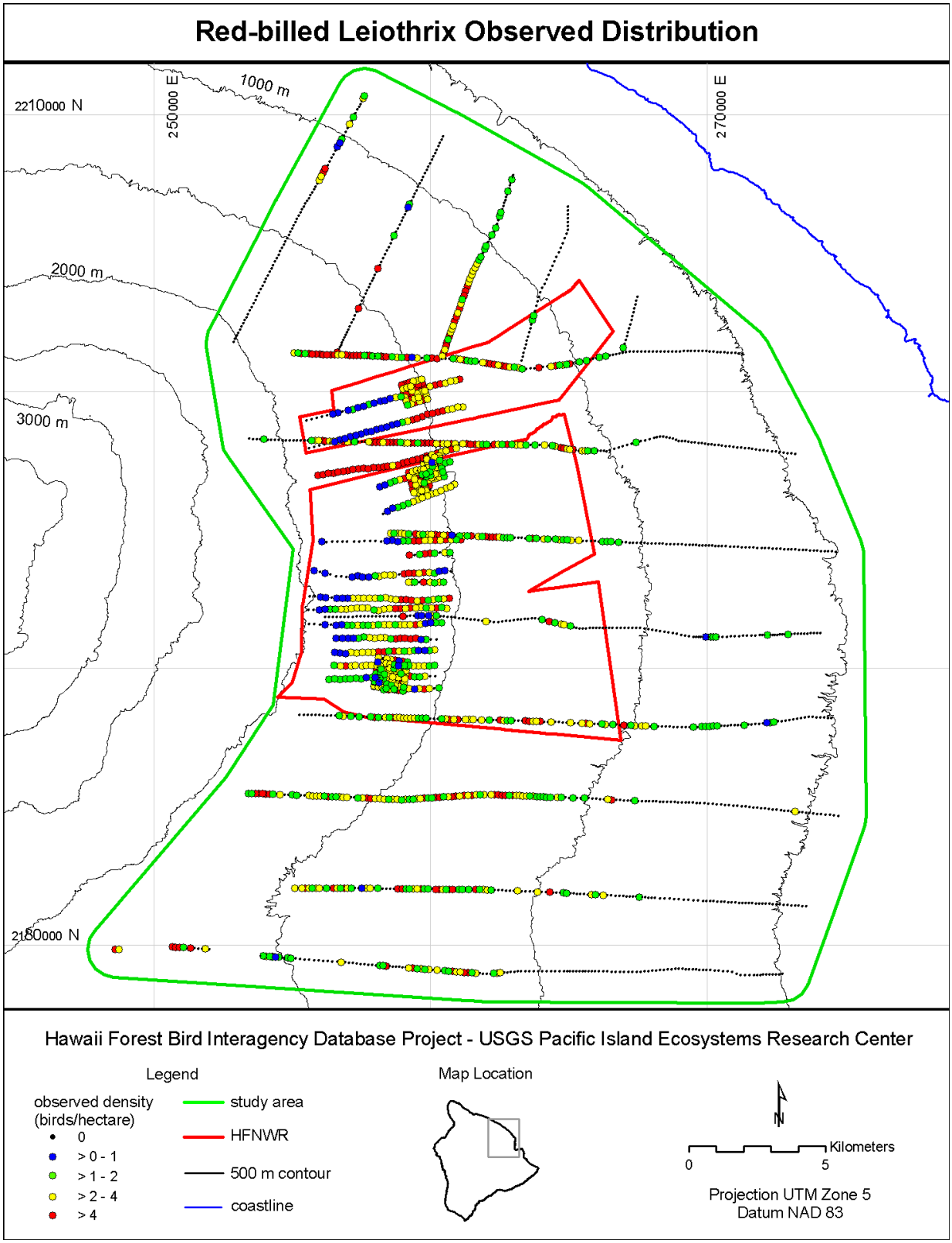

Figure 21. Observed distribution and density of Red-billed Leiothrix in the north Hamakua study area.

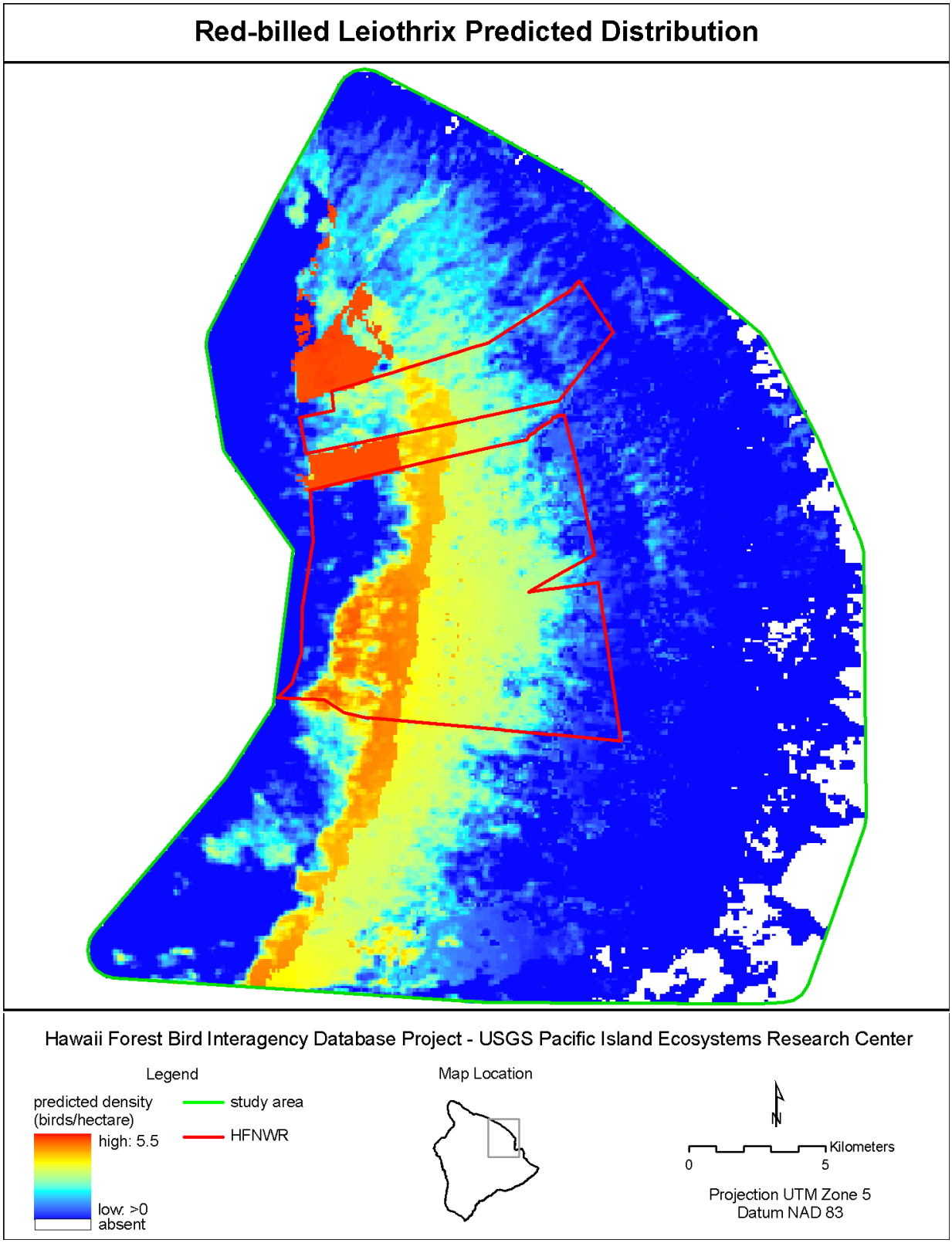

Figure 22. Predicted distribution and density of Red-billed Leiothrix in the north Hamakua study area.

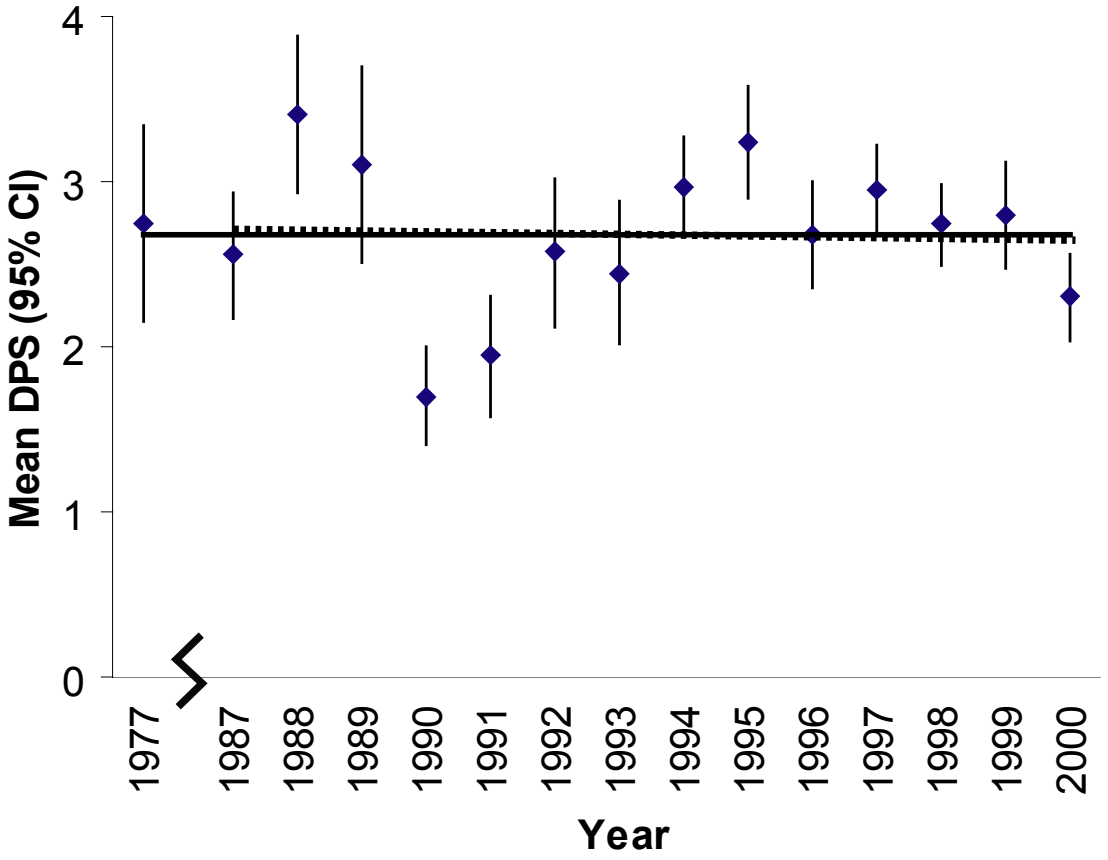

Figure 23. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Red-billed Leiothrix. Regression of log-transformed densities were non-significant for the 14-year (dashed line; slope = 0.002, 95% confidence limit = -0.011 – 0.014, $r^2 = 0.01$, $P = 0.78$) and the 24-year survey periods (solid line; slope < 0.001, 95% confidence limit = -0.008 – 0.008, $r^2 < 0.001$, $P = 0.97$).

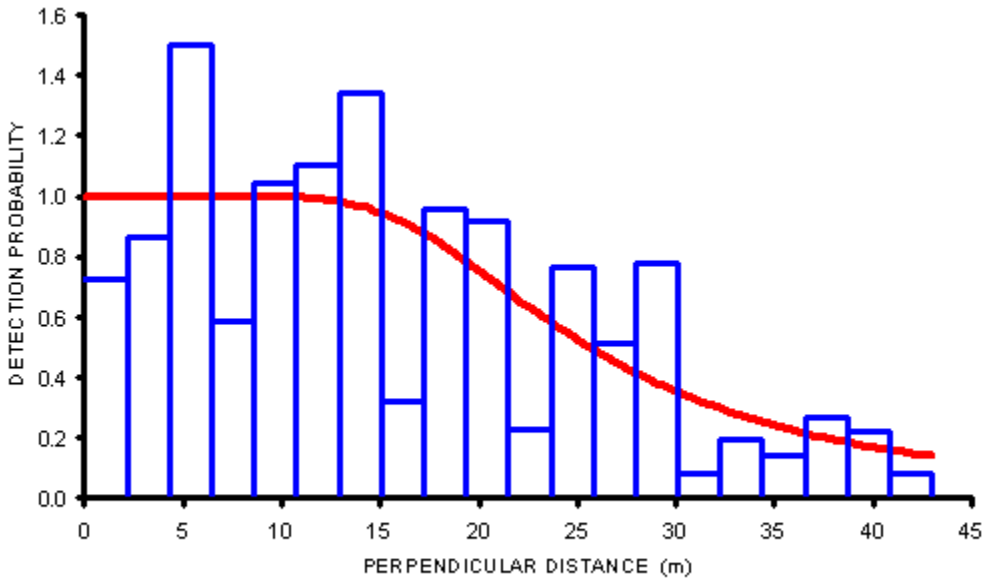

Figure 24. Hazard-rate key detection function and Japanese White-eye distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 43.0 m.

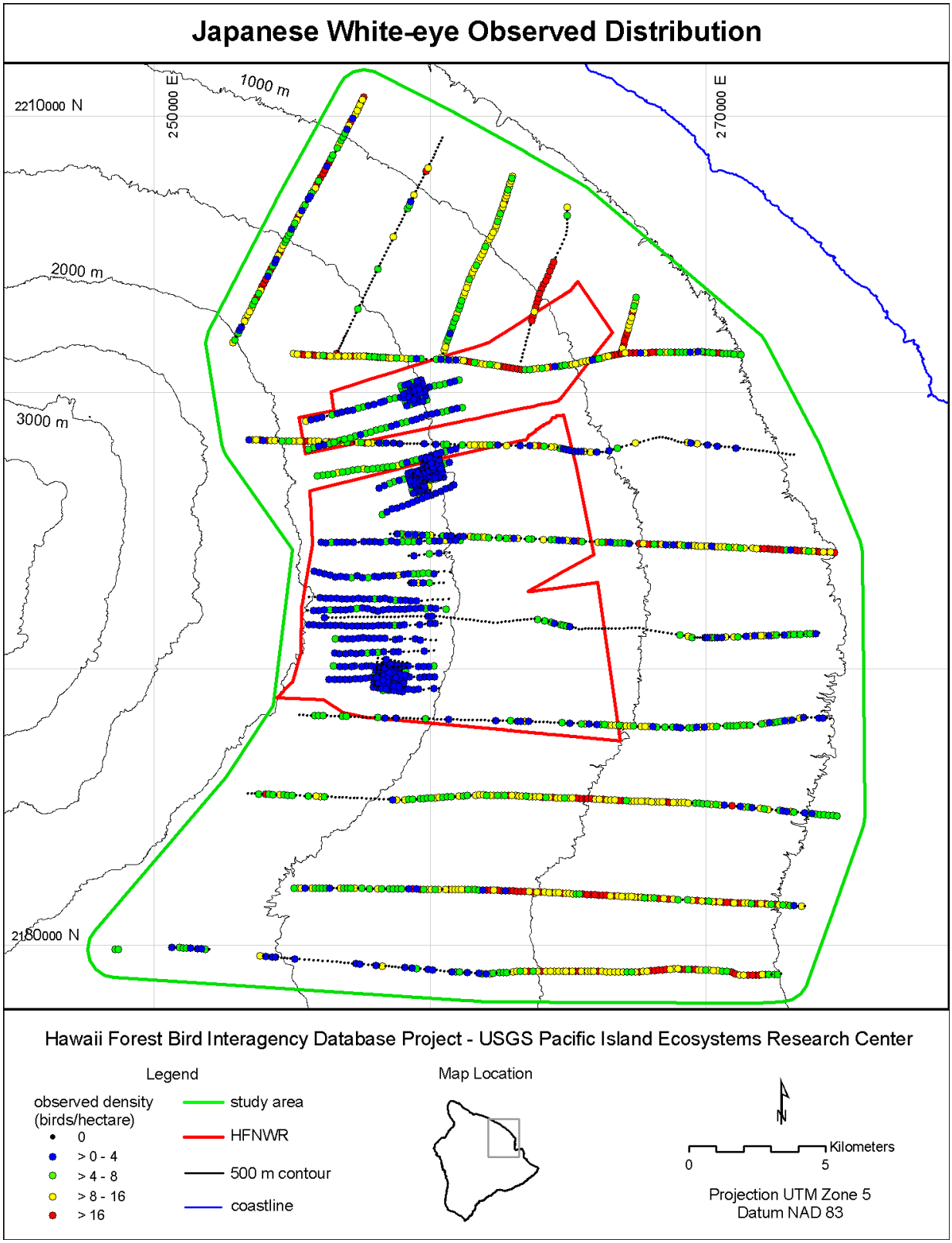

Figure 25. Observed distribution and density of Japanese White-eye in the north Hamakua study area.

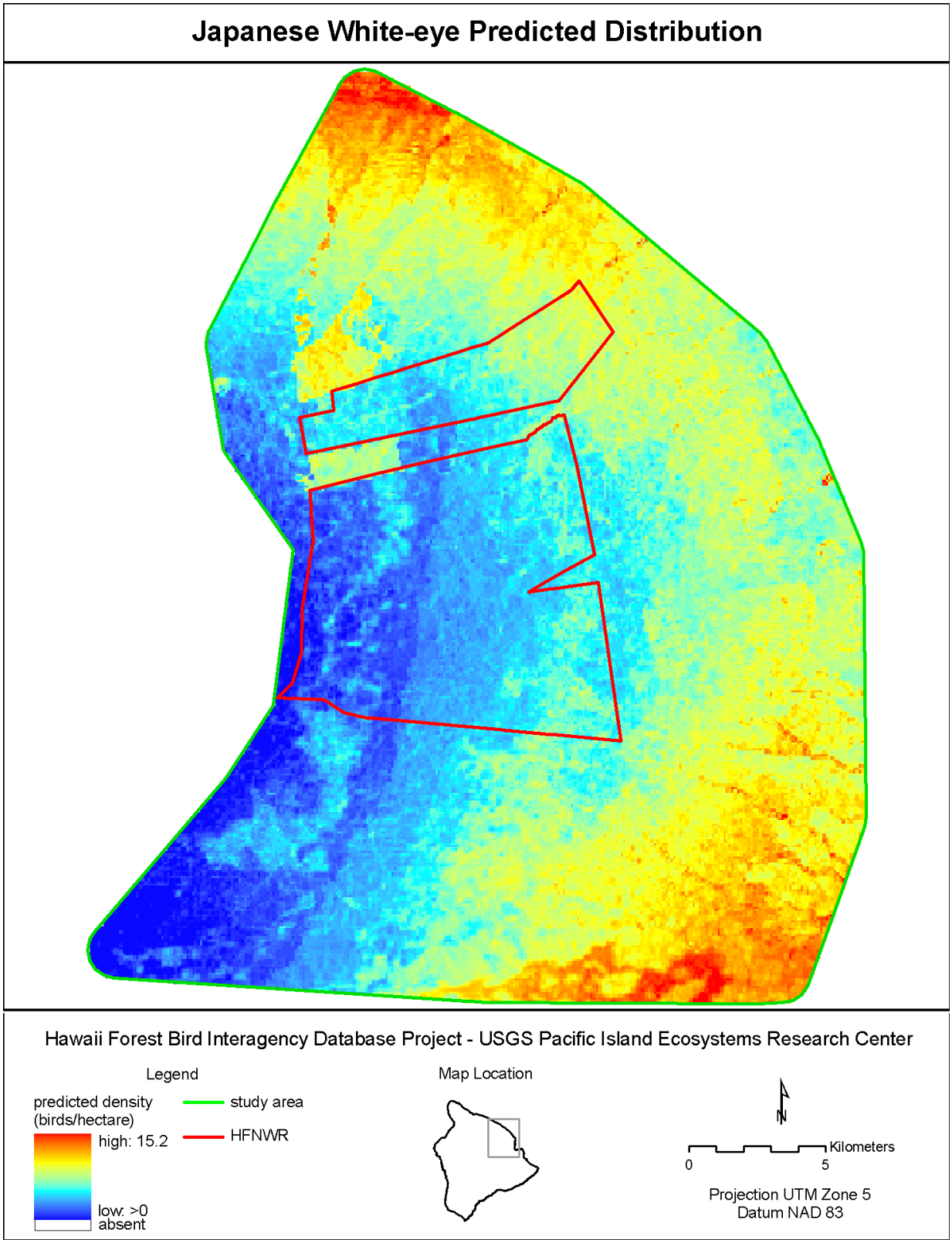

Figure 26. Predicted distribution and density of Japanese White-eye in the north Hamakua study area.

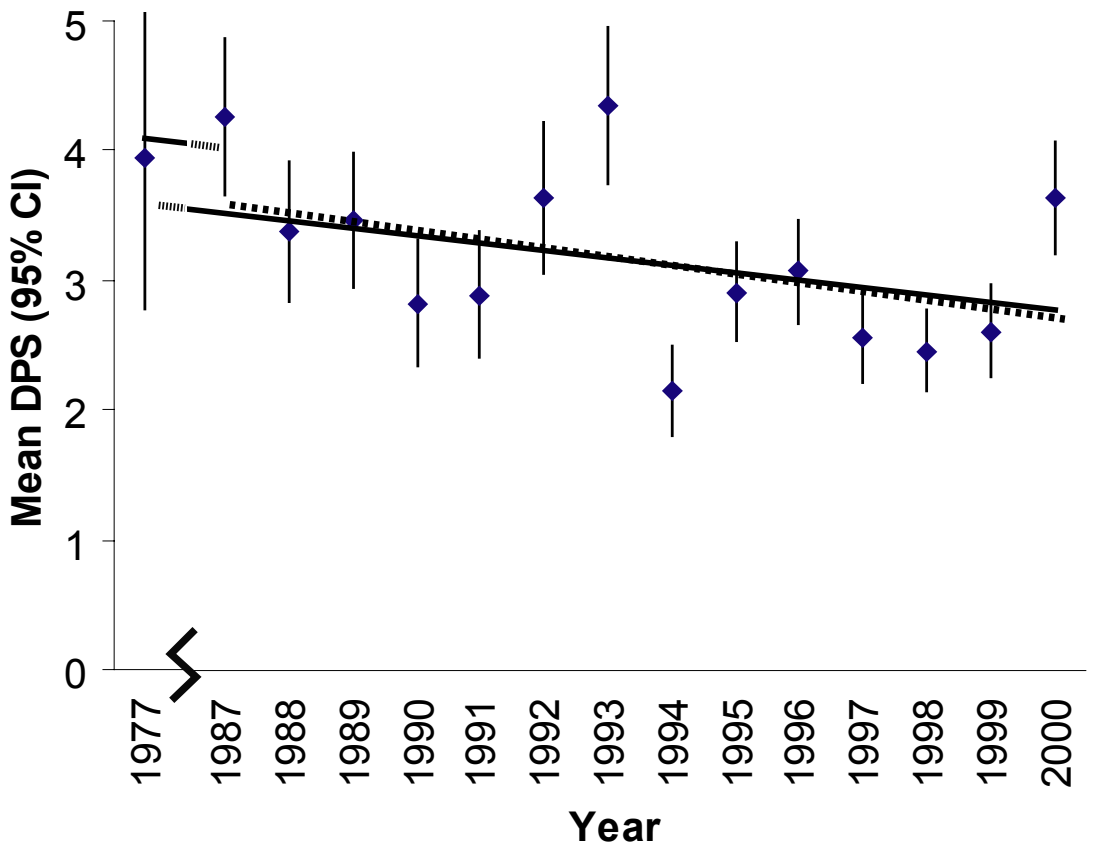

Figure 27. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Japanese White-eye. Regression of log-transformed densities were non-significant for the 14-year (dashed line; slope = -0.009, 95% confidence limit = -0.021 – 0.003, $r^2 = 0.19$, $P = 0.12$) and the 24-year survey periods (solid line; slope = -0.008, 95% confidence limit = -0.016 – 0.001, $r^2 = 0.25$, $P = 0.06$).

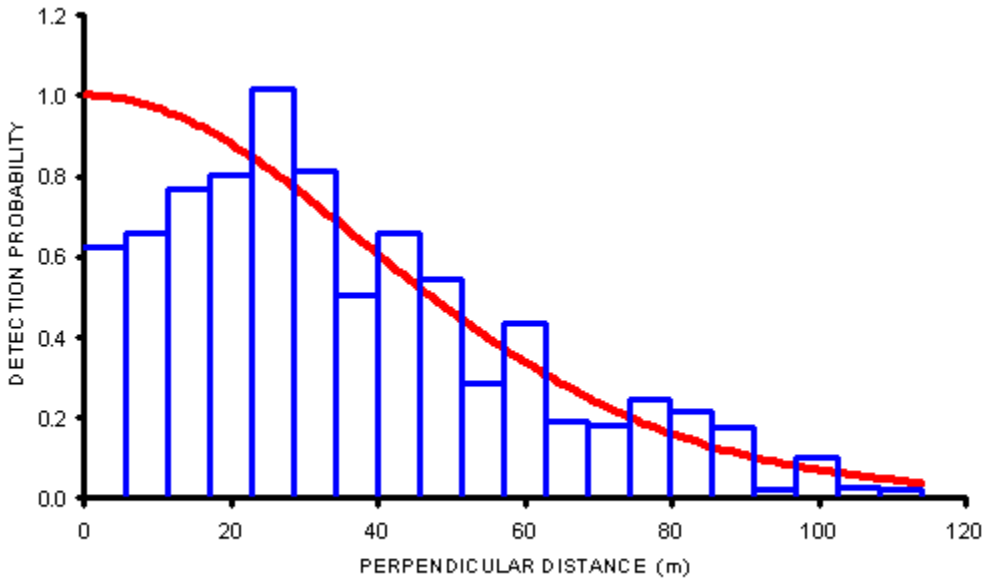

Figure 28. Half-normal key detection function and Northern Cardinal distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 114.0 m.

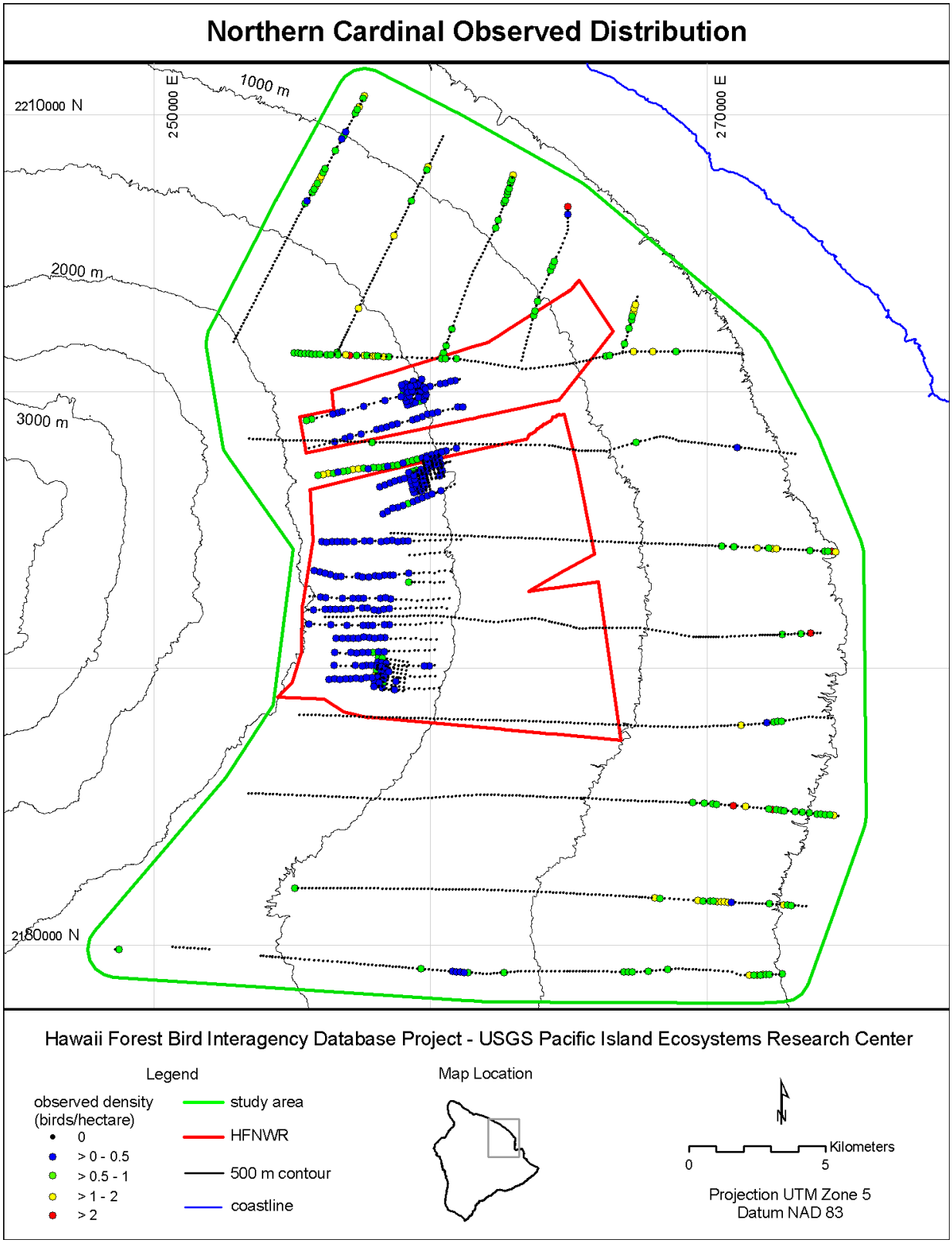

Figure 29. Observed distribution and density of Northern Cardinal in the north Hamakua study area.

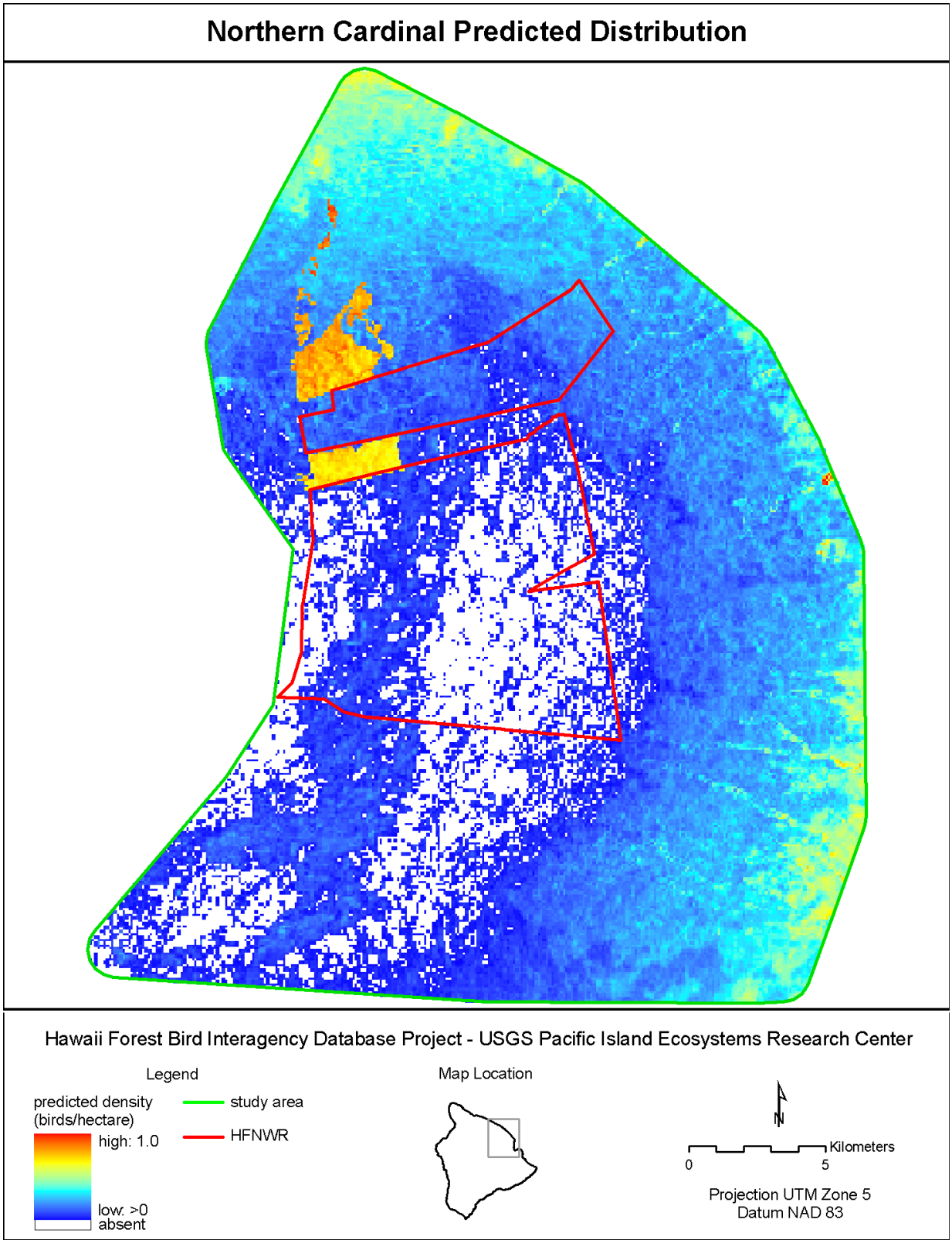

Figure 30. Predicted distribution and density of Northern Cardinal in the north Hamakua study area.

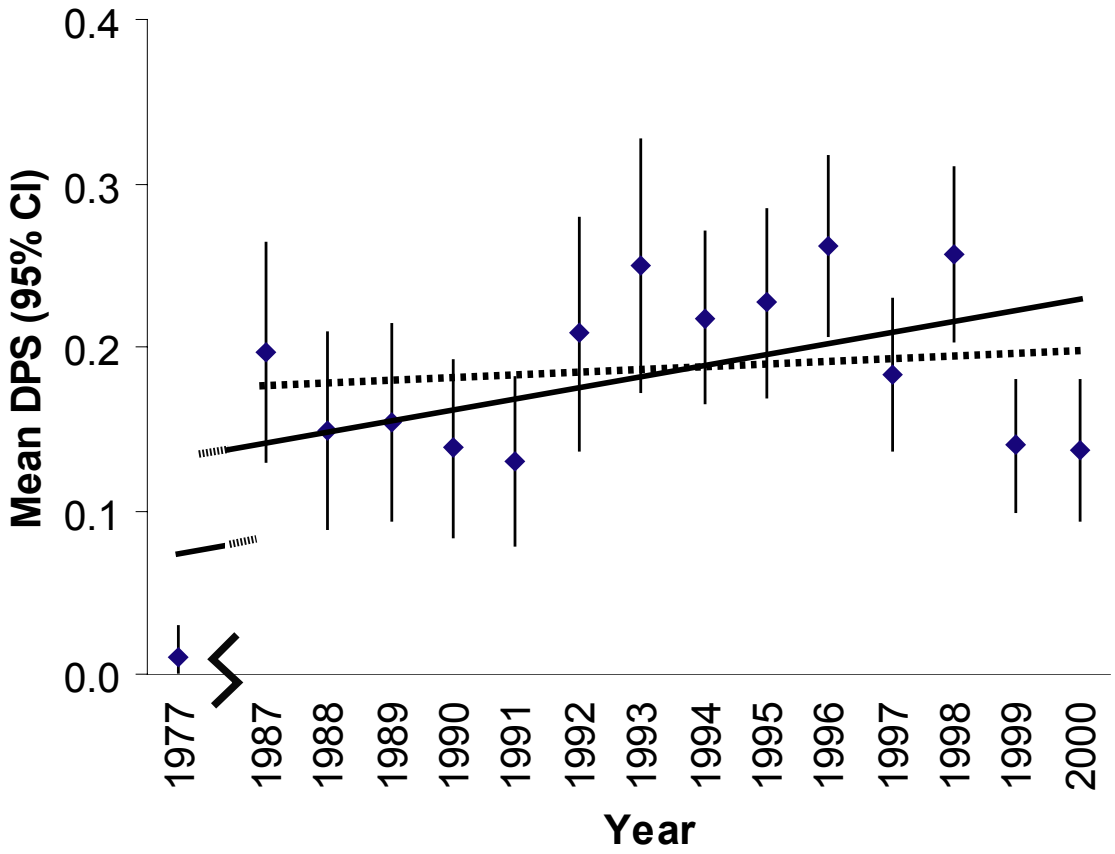

Figure 31. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Northern Cardinal. Regression of log-transformed densities were non-significant for the 14-year survey period (dashed line; slope = 0.004, 95% confidence limit = -0.012 – 0.021, r^2 = 0.03, P = 0.57) and significantly increasing over the 24-year survey period (solid line; slope = 0.043, 95% confidence limit = 0.018 – 0.067, r^2 = 0.53, P = 0.002).

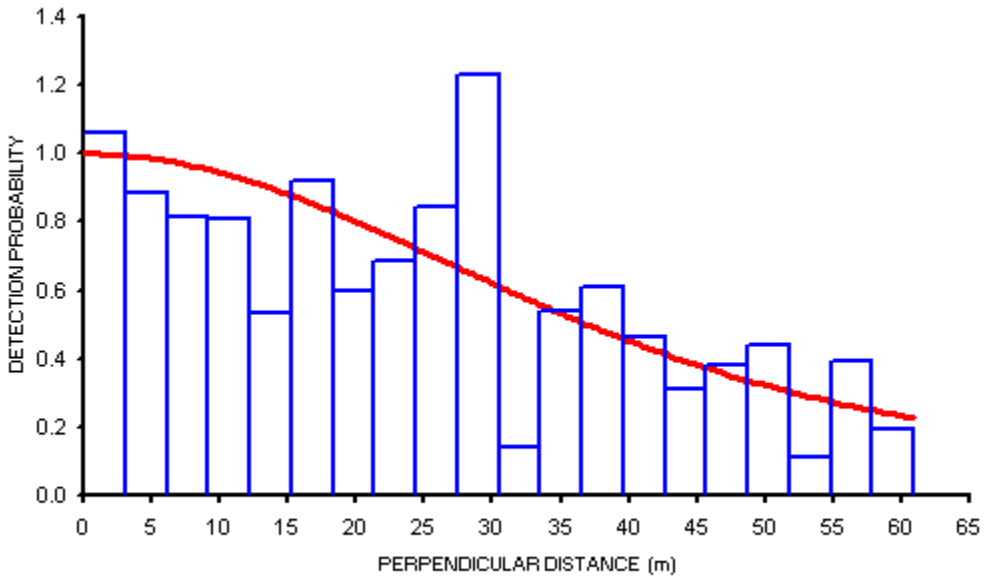

Figure 32. Hazard-rate key detection function and House Finch distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 60.9 m.

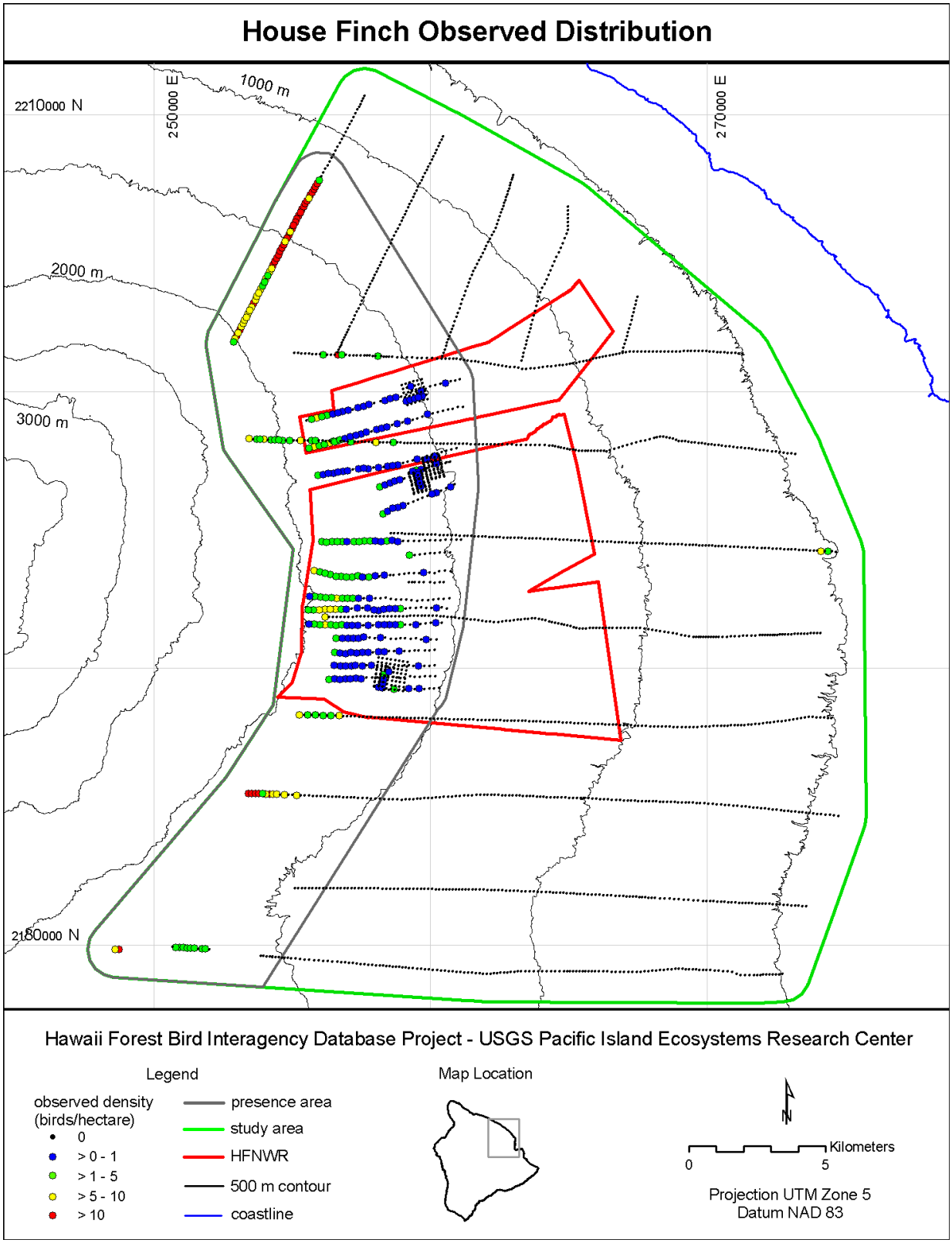

Figure 33. Observed distribution and density of House Finch in the north Hamakua study area.

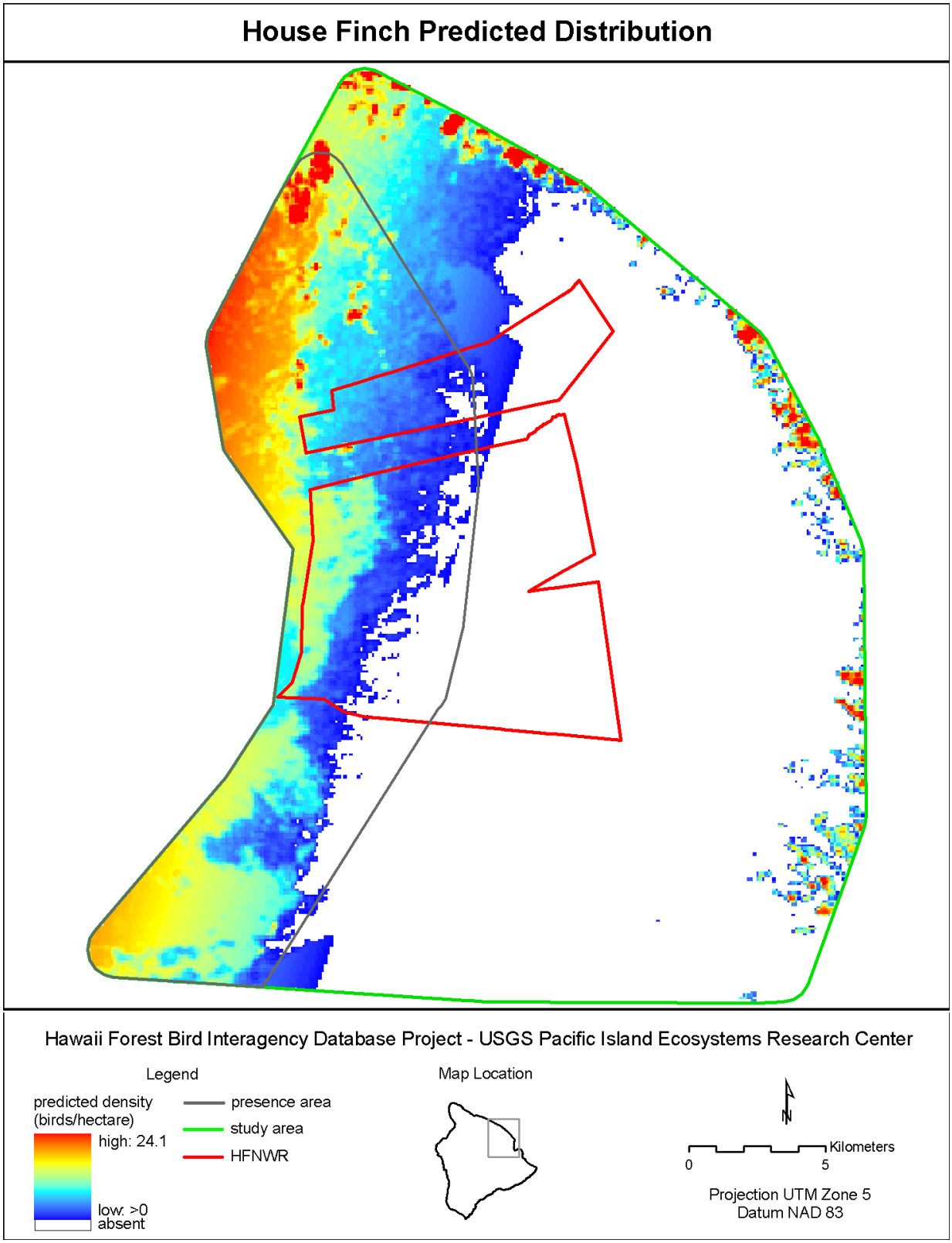

Figure 34. Predicted distribution and density of House Finch in the north Hamakua study area.

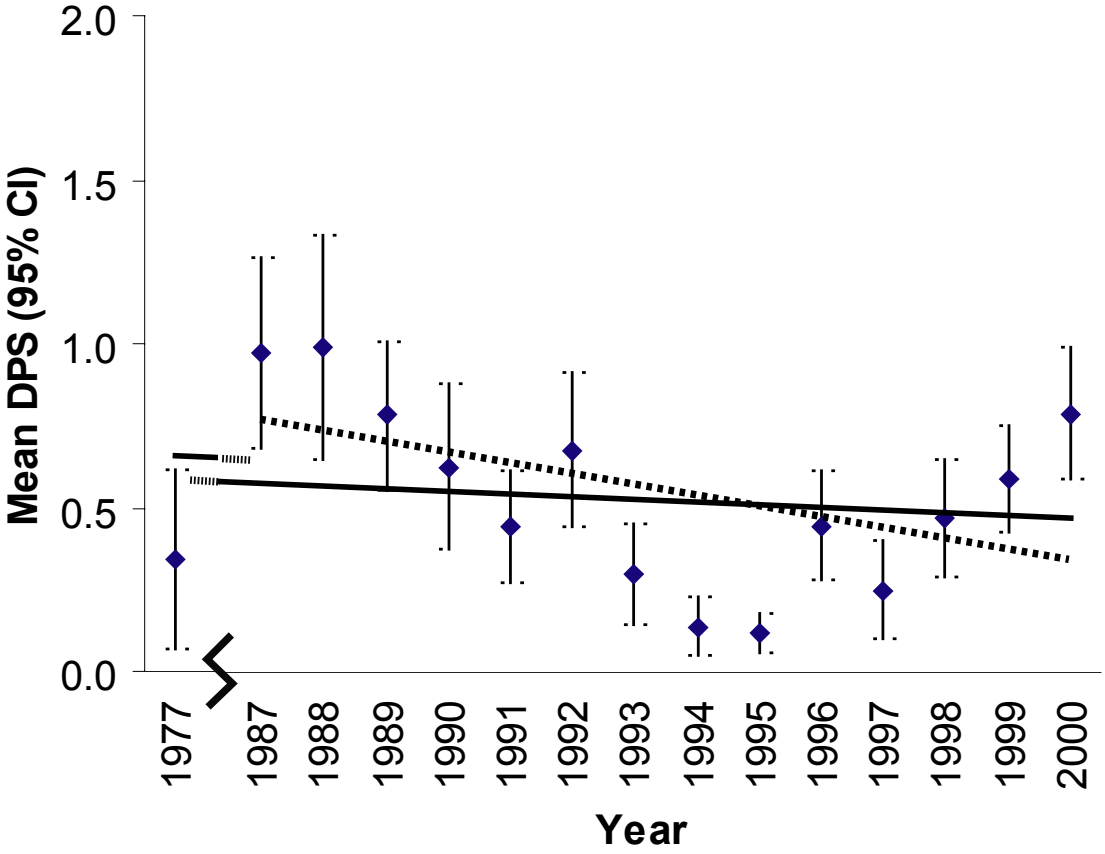

Figure 35. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of House Finch. Regression of log-transformed densities were non-significant for the 14-year (dashed line; slope = -0.024, 95% confidence limit = -0.065 – 0.017, r^2 = 0.12, P = 0.22) and the 24-year survey periods (solid line; slope = -0.008, 95% confidence limit = -0.036 – 0.021, r^2 = 0.02, P = 0.58).

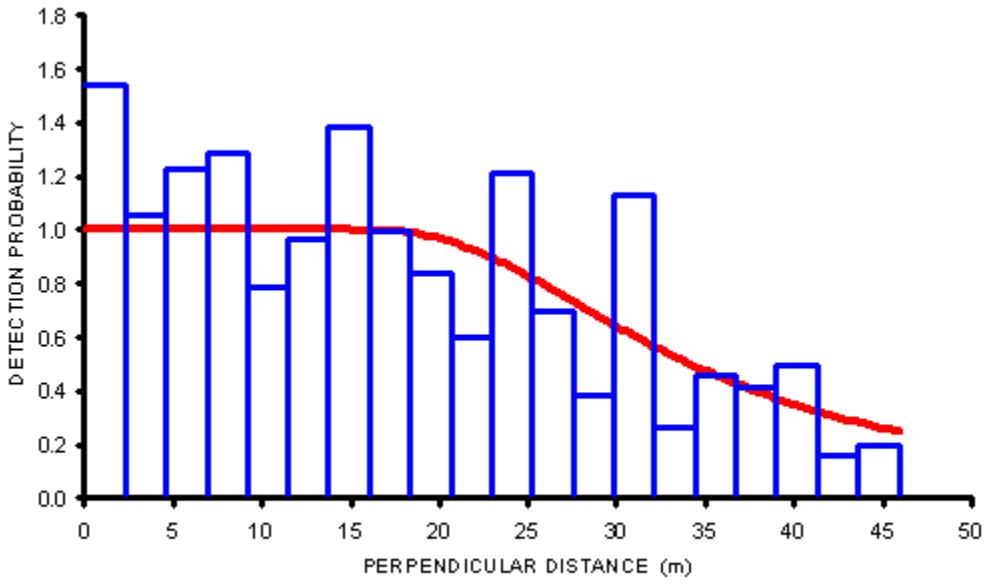

Figure 36. Hazard-rate key detection function and Amakihi distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 45.9 m.

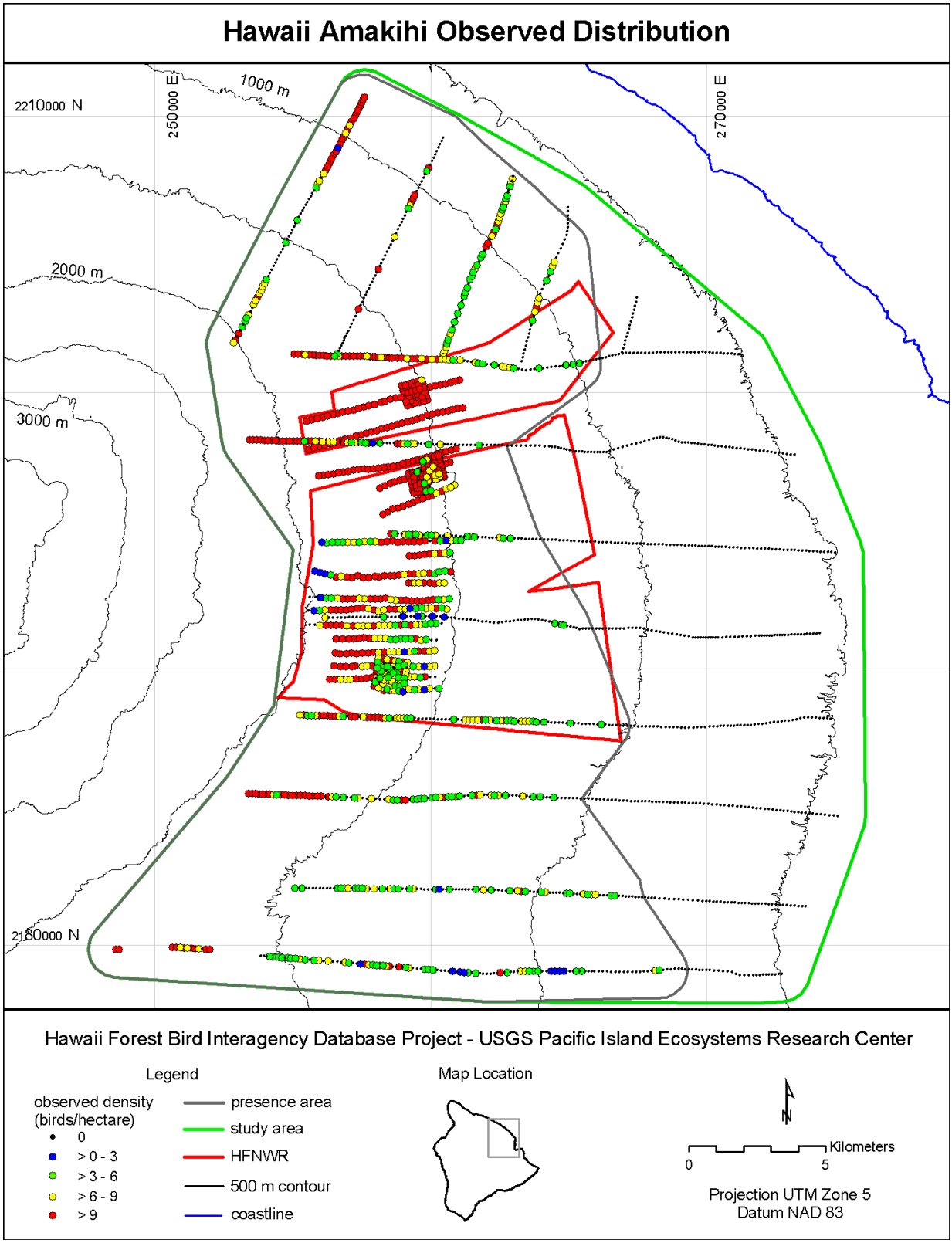

Figure 37. Observed distribution and density of Amakihi in the north Hamakua study area.

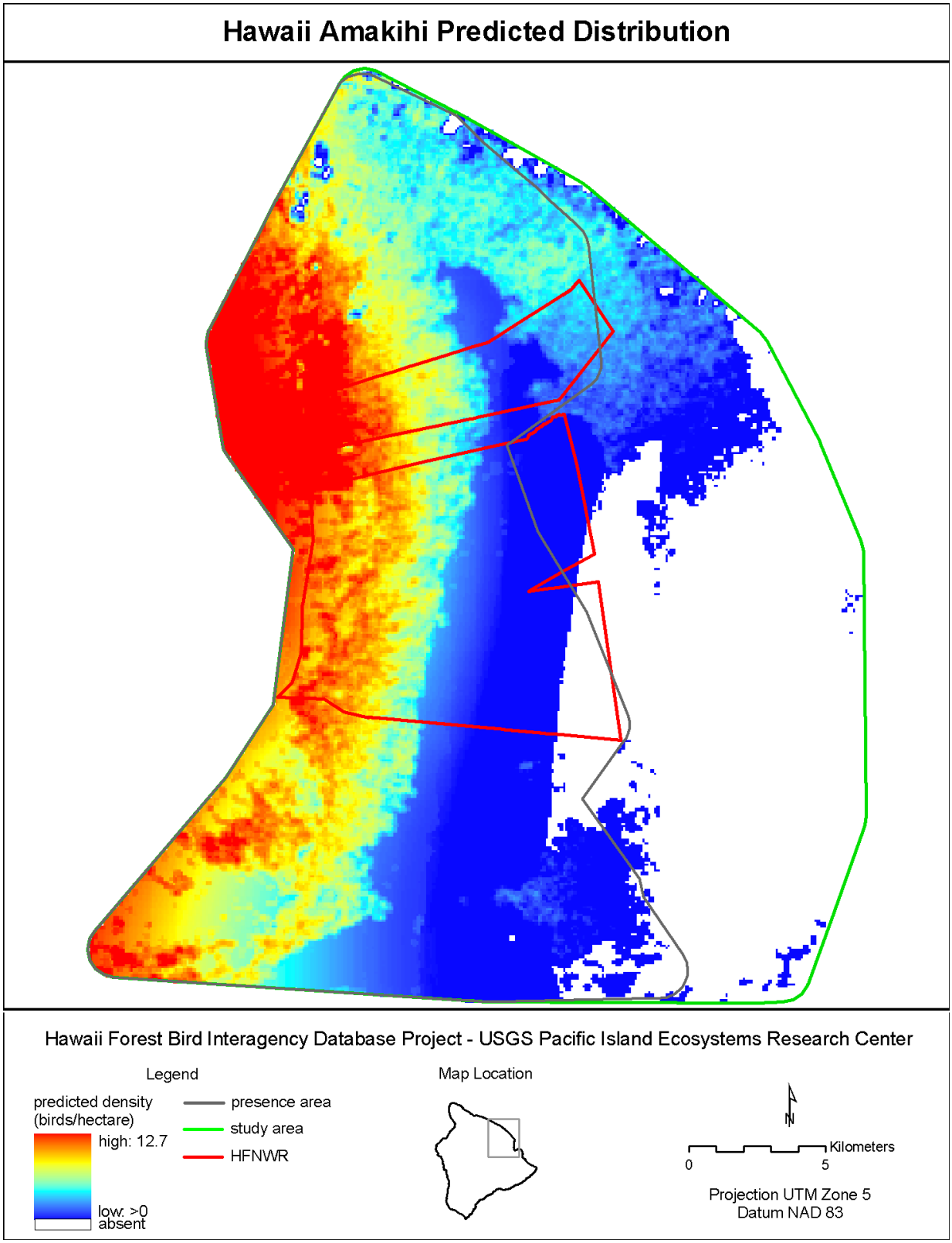

Figure 38. Predicted distribution and density of Amakihi in the north Hamakua study area.

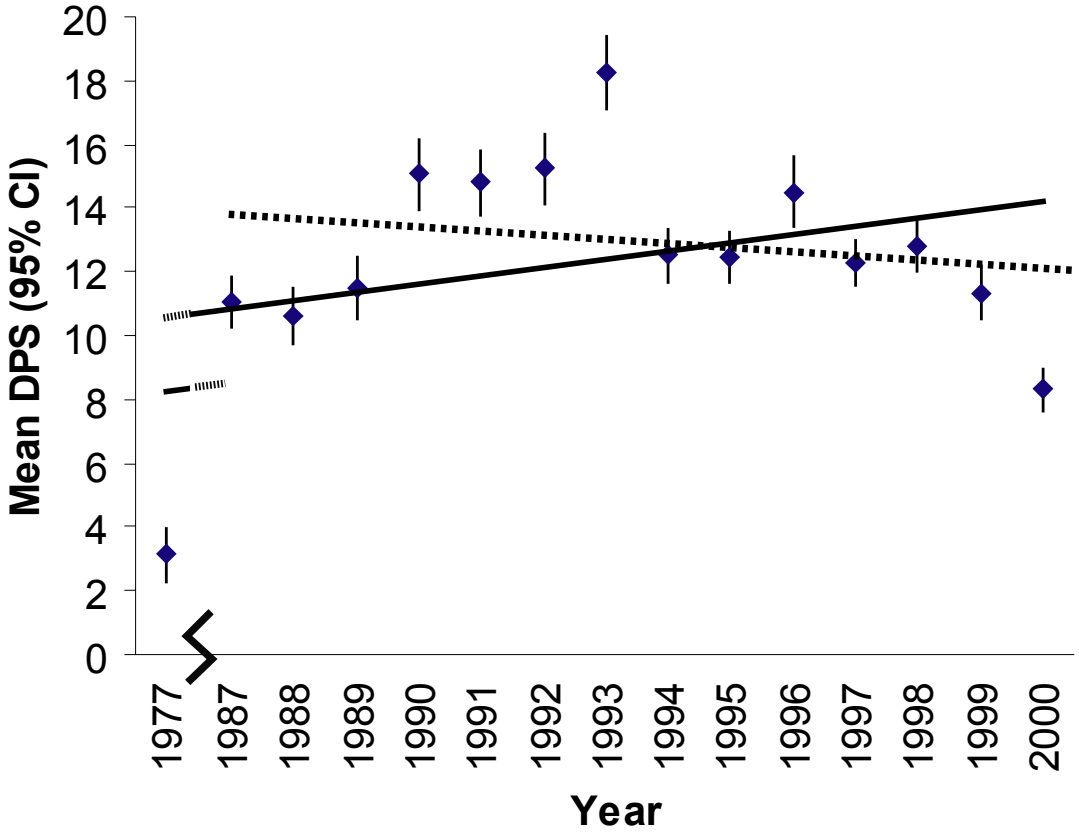

Figure 39. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Amakihi. Regression of log-transformed densities were non-significant for the 14-year survey period (dashed line; slope = -0.004, 95% confidence limit = -0.017 – 0.008, $r^2 = 0.05$, $P = 0.46$) and significantly increasing over the 24-year survey period (solid line; slope = 0.017, 95% confidence limit = 0.003 – 0.032, $r^2 = 0.33$, $P = 0.02$).

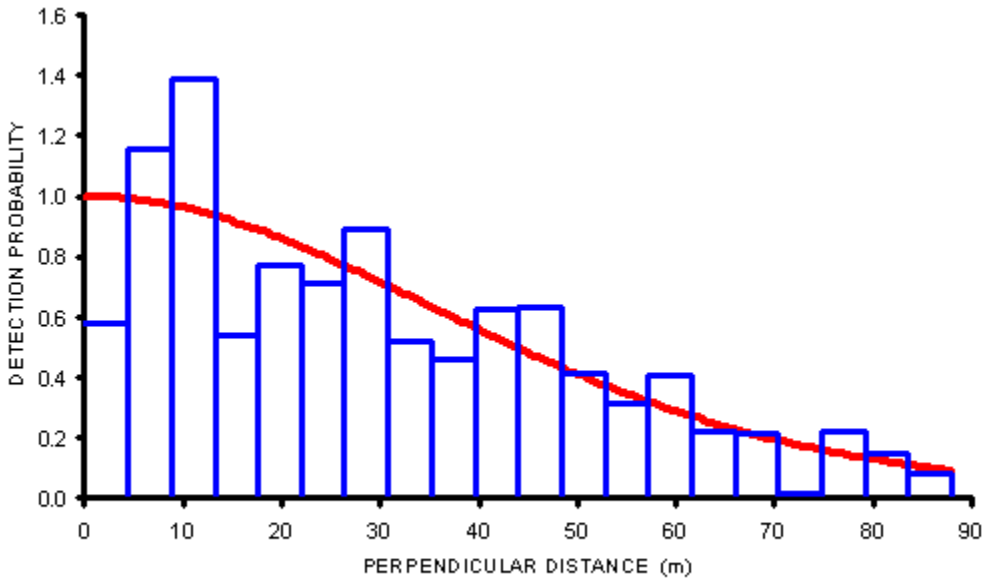

Figure 40. Half-normal key detection function and Akiapolaau distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 88.0 m.

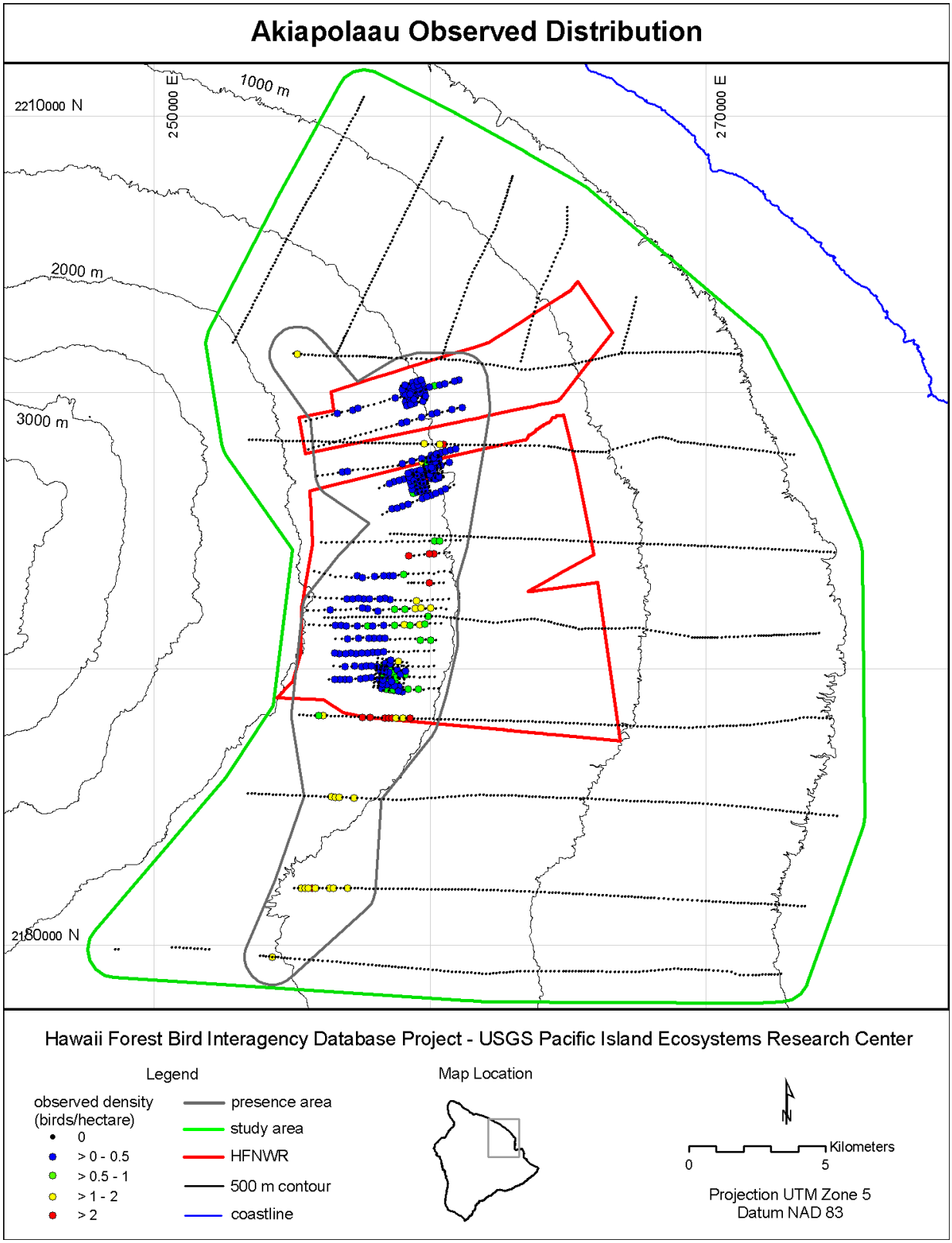

Figure 41. Observed distribution and density of Akiapolaau in the north Hamakua study area.

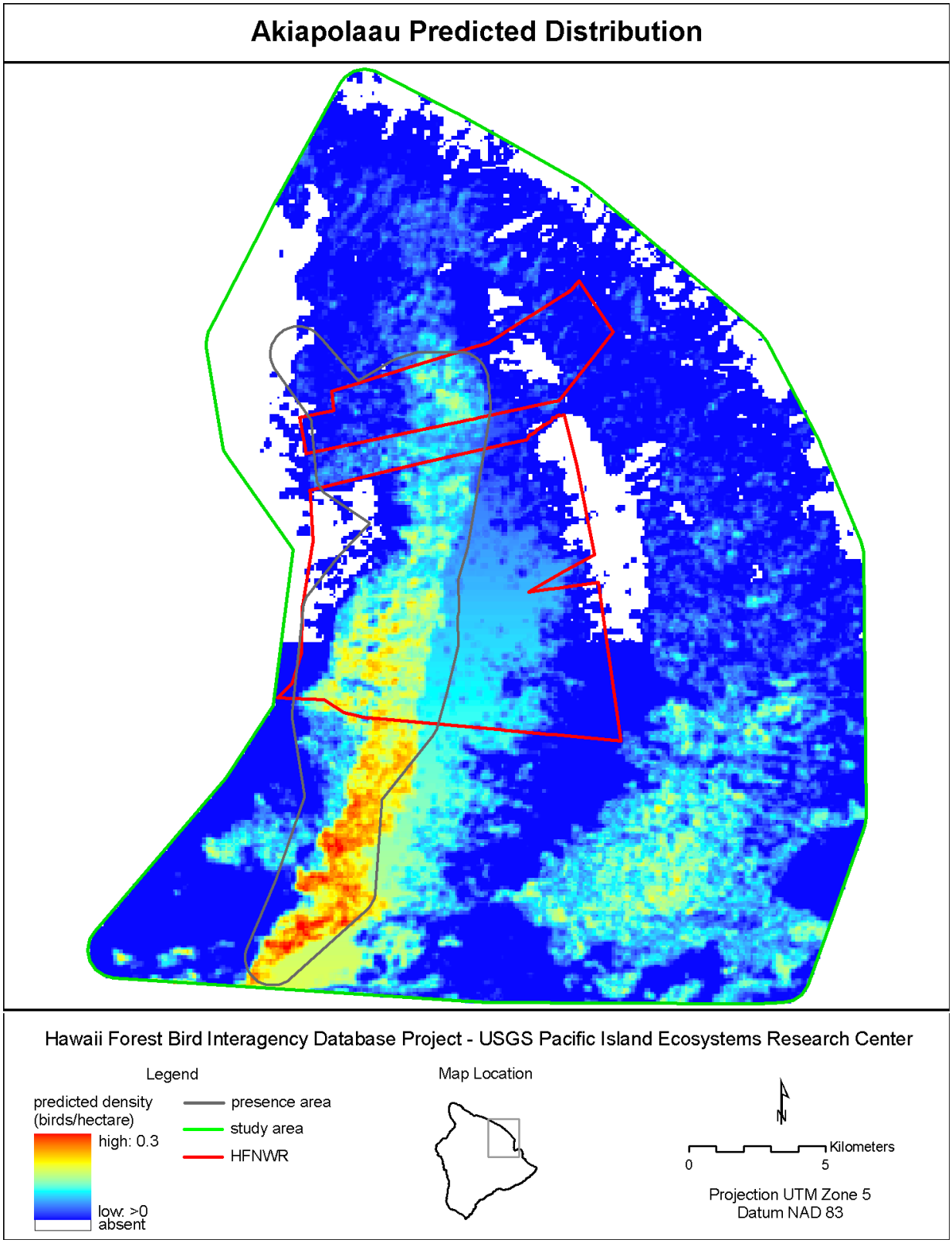

Figure 42. Predicted distribution and density of Akiapolaau in the north Hamakua study area.

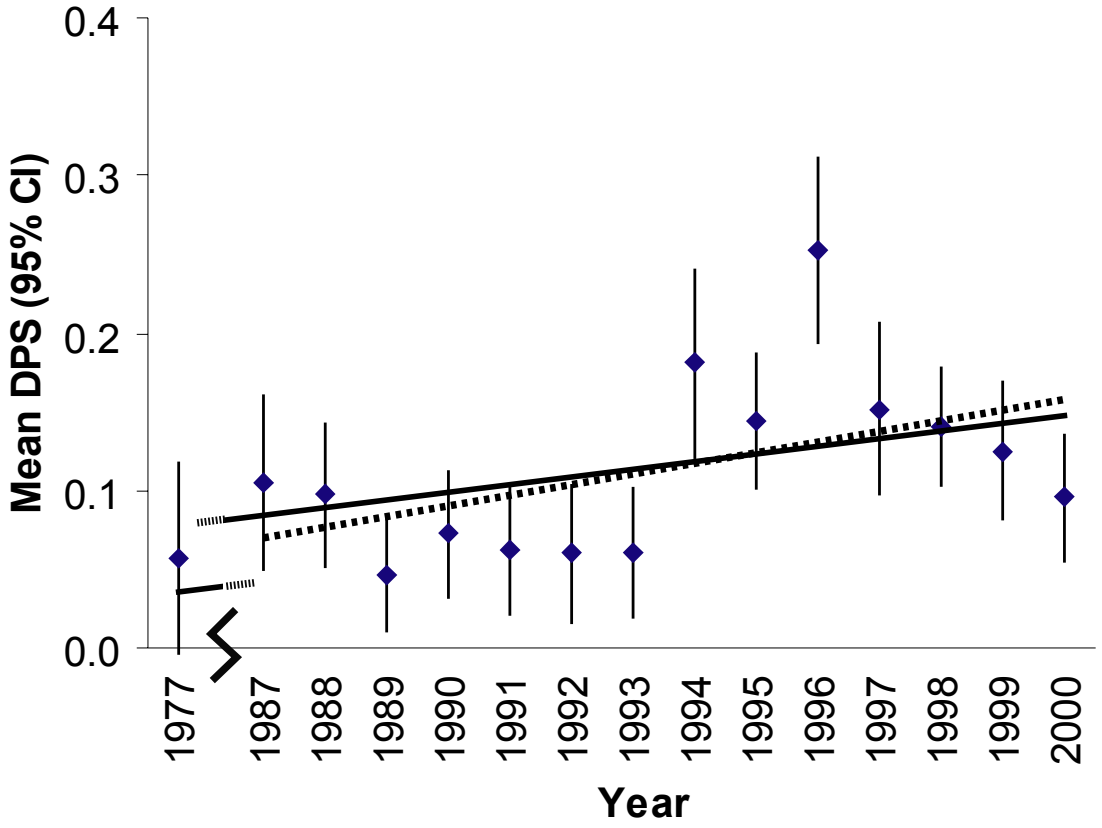

Figure 43. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Akiapolaau. Regression of log-transformed densities were non-significant for the 14-year survey period (dashed line; slope = 0.026, 95% confidence limit = -0.001 – 0.054, r^2 = 0.27, P = 0.06) and significantly increasing over the 24-year survey period (solid line; slope = 0.021, 95% confidence limit = 0.002 – 0.039, r^2 = 0.31, P = 0.03).

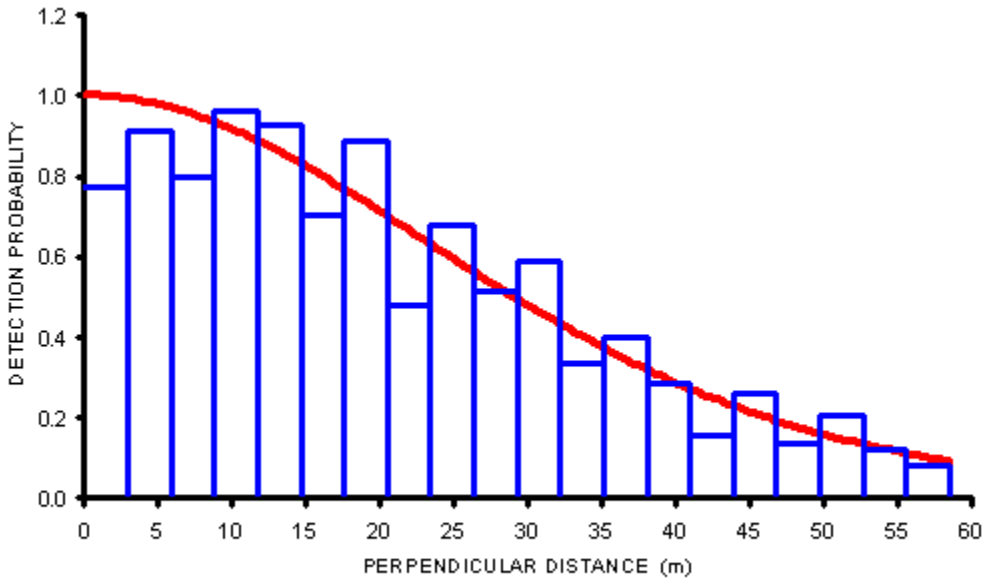

Figure 44. Half-normal key detection function and Creeper distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 58.5 m.

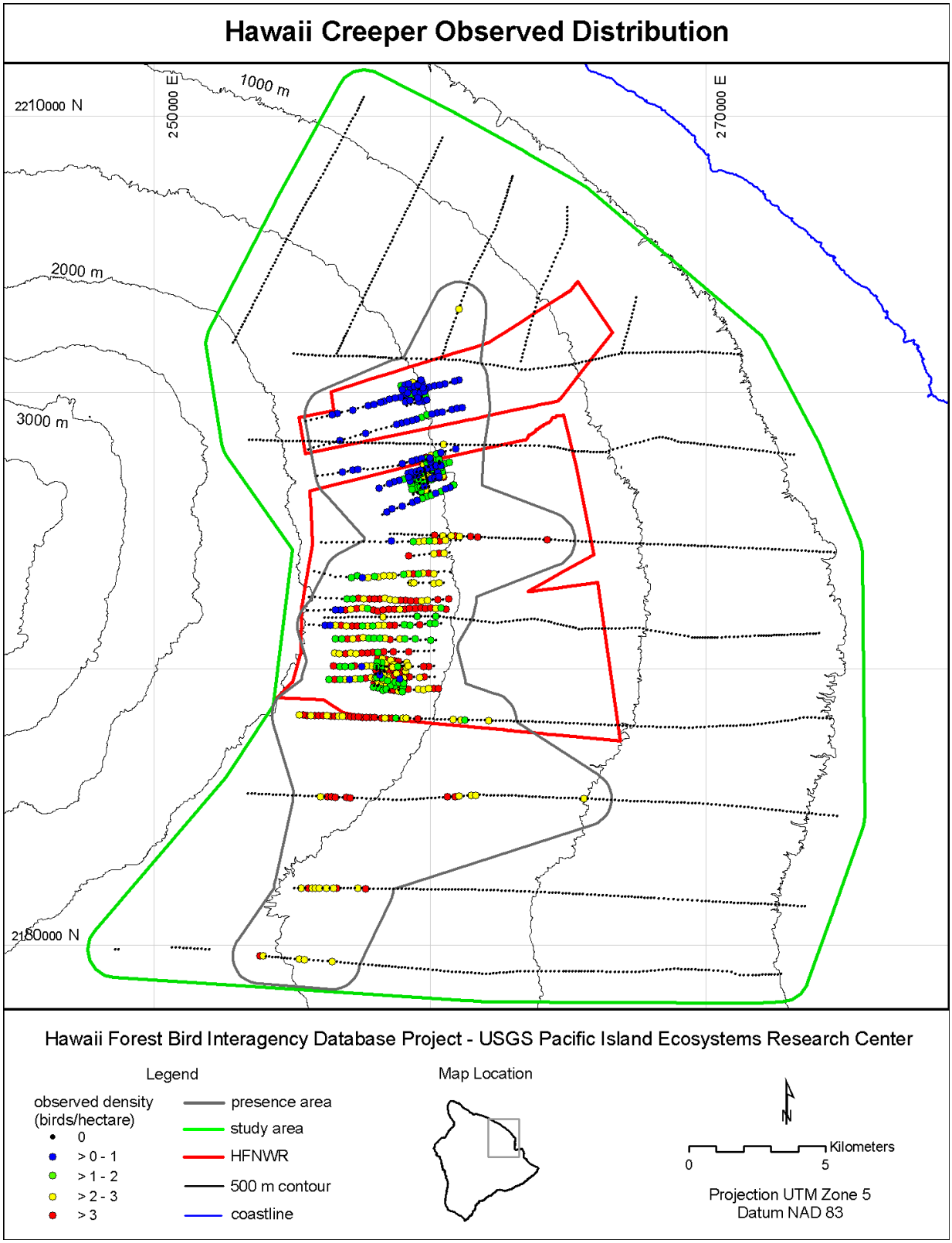

Figure 45. Observed distribution and density of Creeper in the north Hamakua study area.

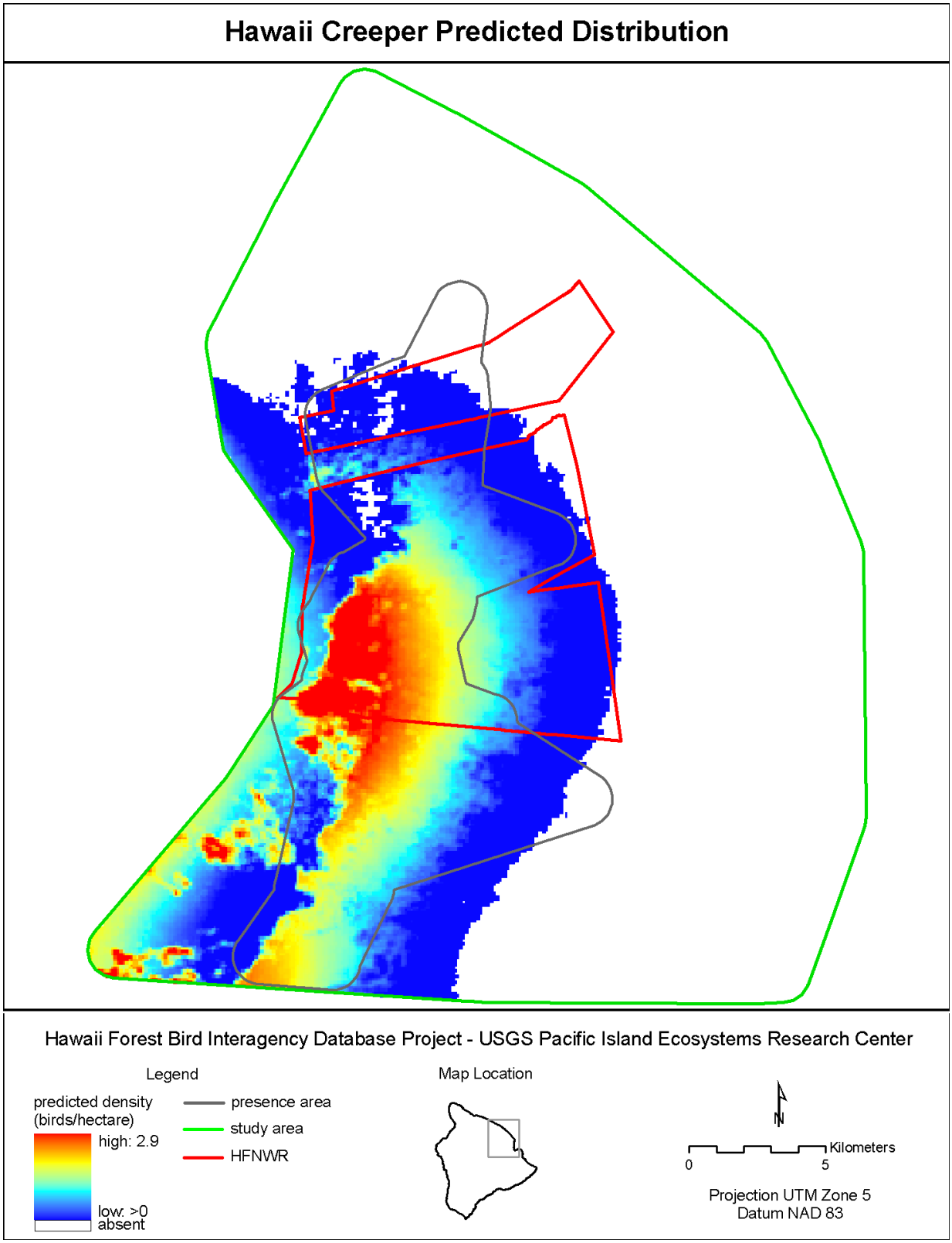

Figure 46. Predicted distribution and density of Creeper in the north Hamakua study area.

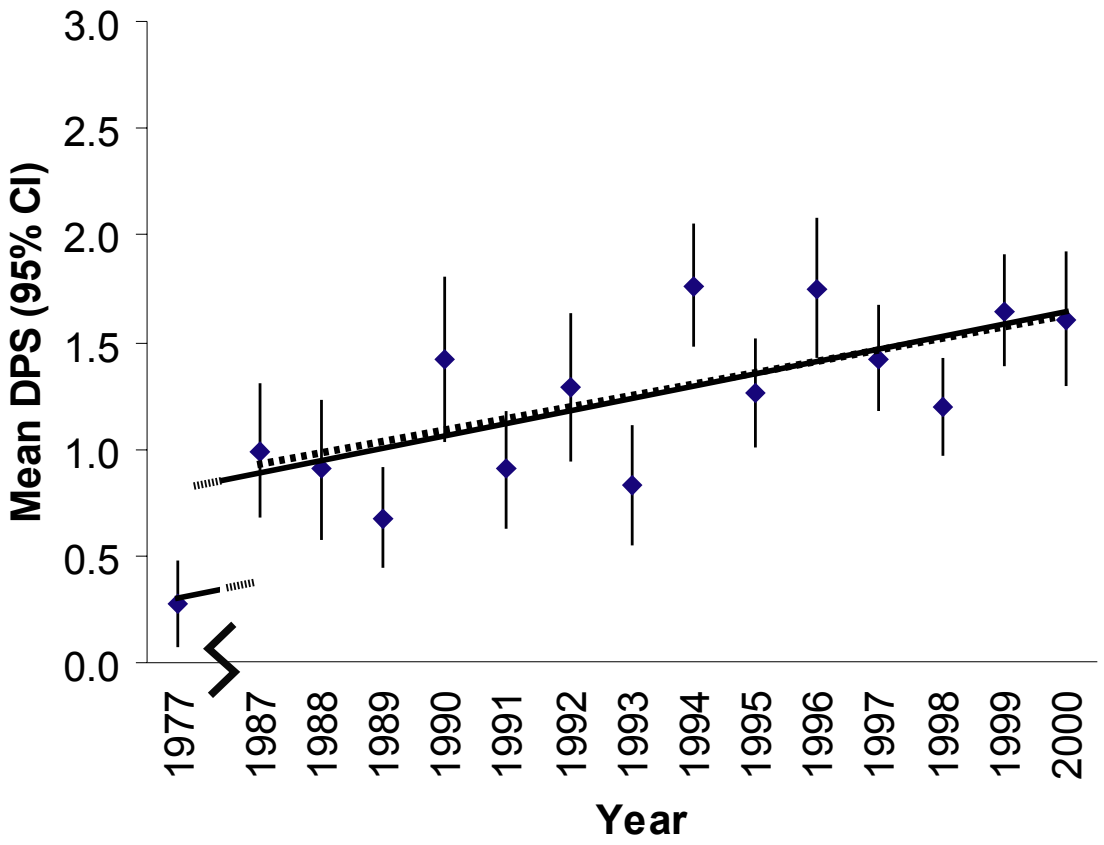

Figure 47. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Creeper. Regression of log-transformed densities were significantly increasing for the 14-year (dashed line; slope = 0.021, 95% confidence limits = 0.006 – 0.036, $r^2 = 0.44$, $P = 0.009$) and the 24-year survey periods (solid line; slope = 0.030, 95% confidence limit = 0.019 – 0.041, $r^2 = 0.73$, $P < 0.001$).

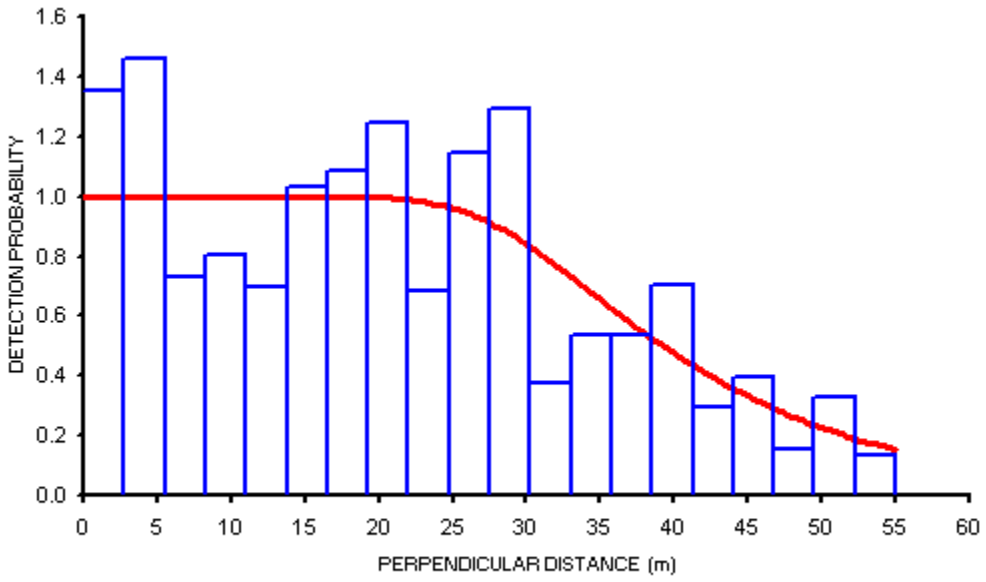

Figure 48. Hazard-rate key detection function and Akepa distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 55.0 m.

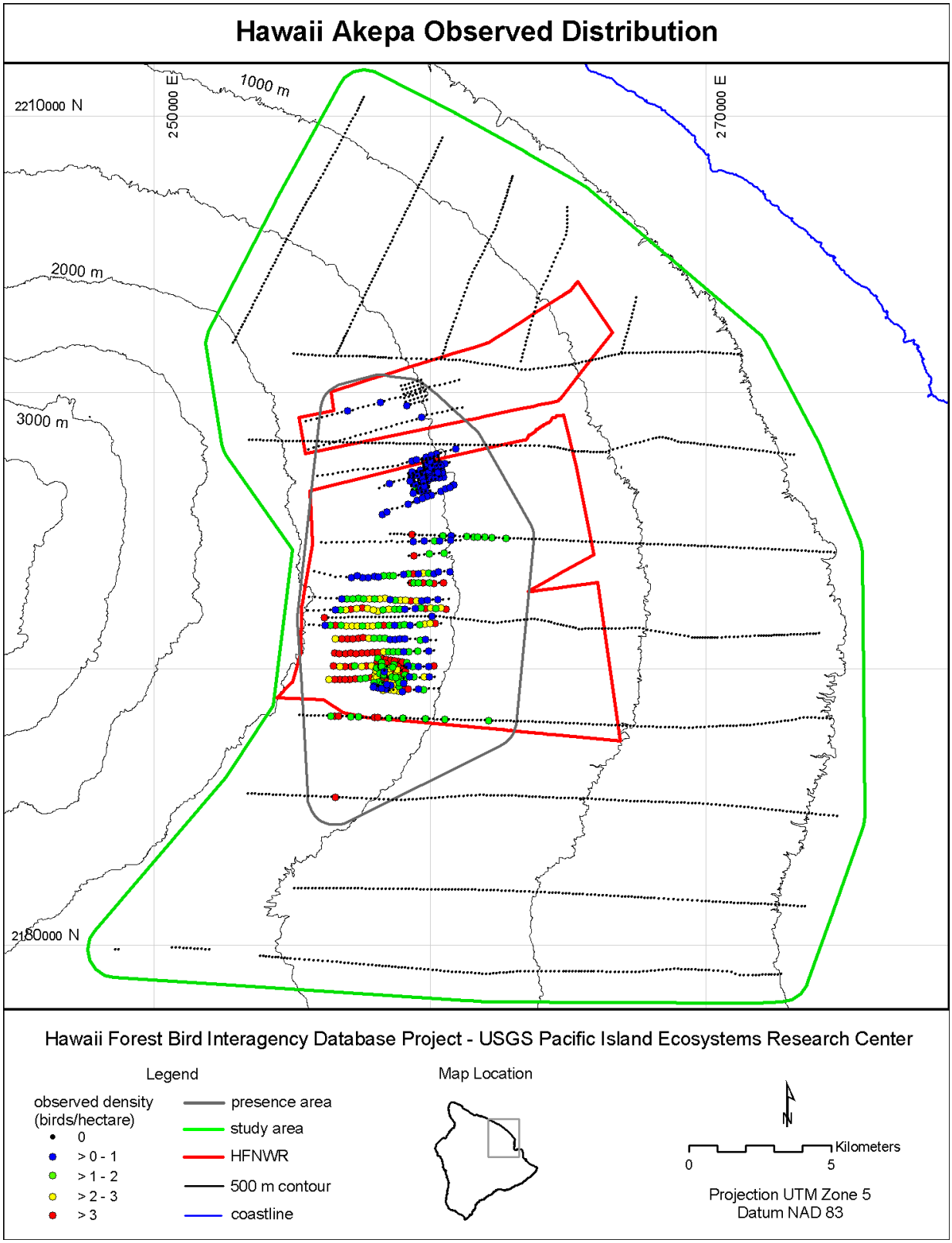

Figure 49. Observed distribution and density of Akepa in the north Hamakua study area.

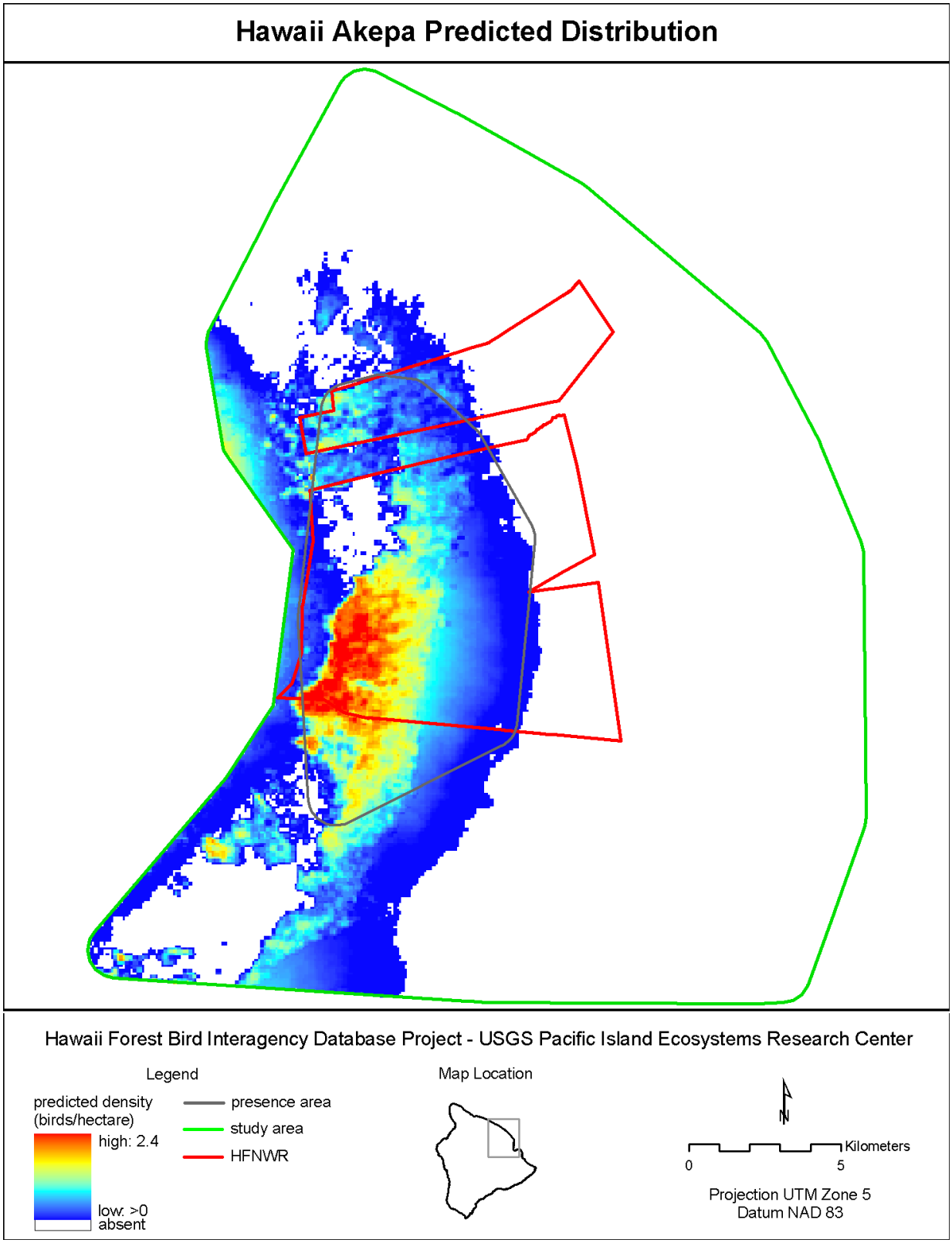

Figure 50. Predicted distribution and density of Akepa in the north Hamakua study area.

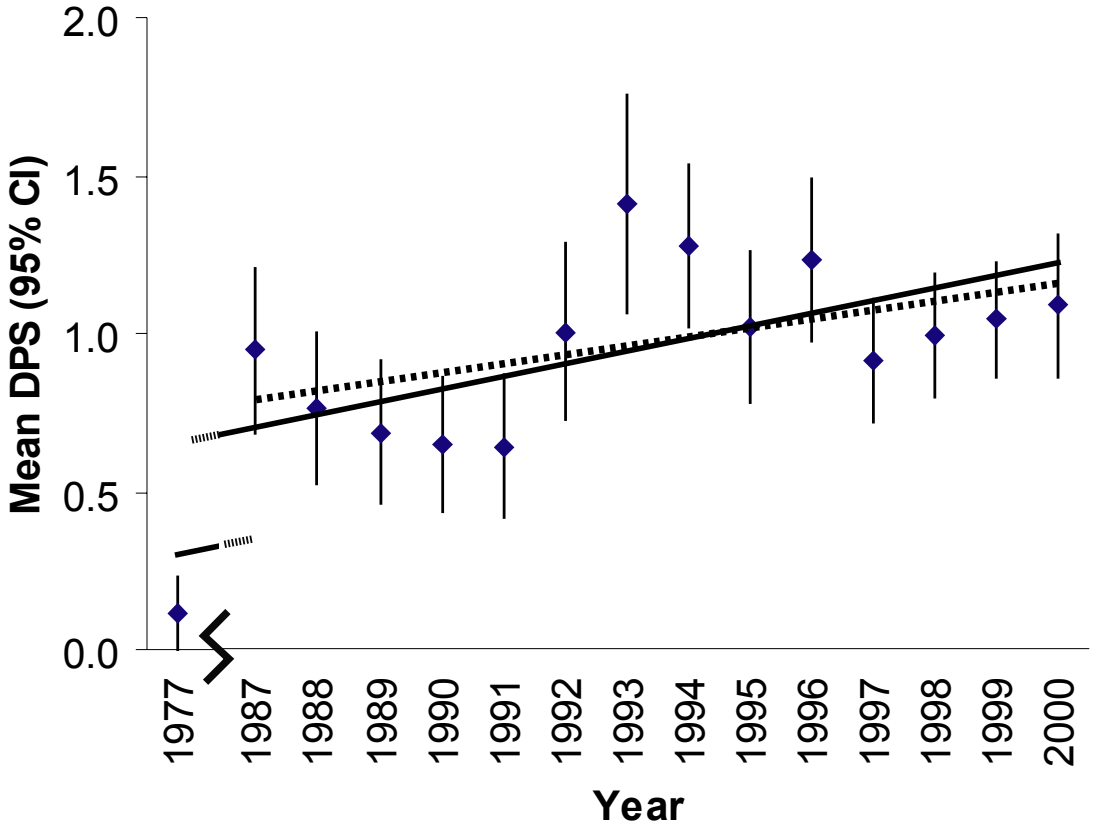

Figure 51. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Akepa. Regression of log-transformed densities were non-significant for the 14-year survey period (dashed line; slope = 0.014, 95% confidence limit = -0.001 – 0.027, $r^2 = 0.27$, $P = 0.06$) and significantly increasing over the 24-year survey period (solid line; slope = 0.035, 95% confidence limit = 0.020 – 0.051, $r^2 = 0.66$, $P < 0.001$).

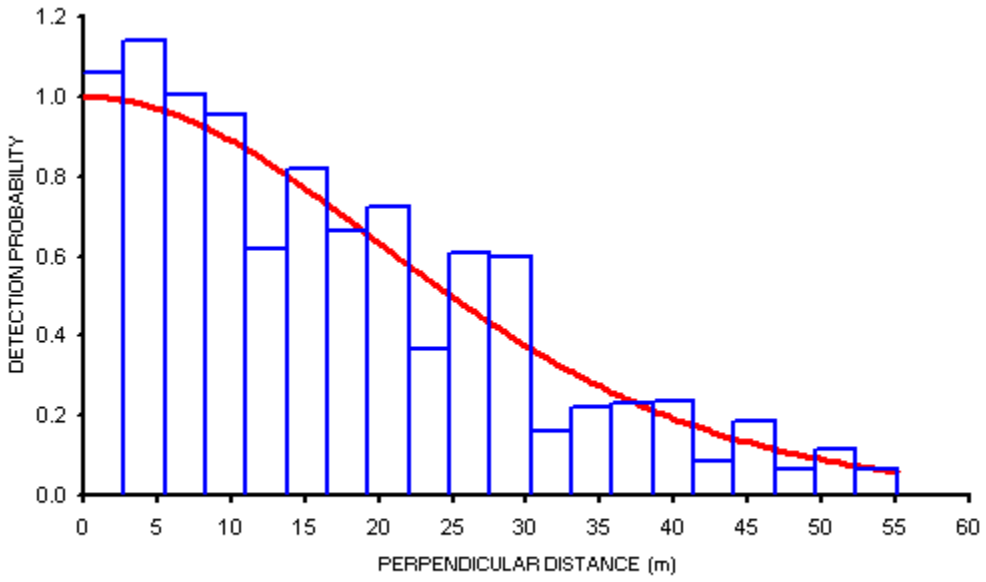

Figure 52. Half-normal key detection function and Iiwi distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 55.1 m.

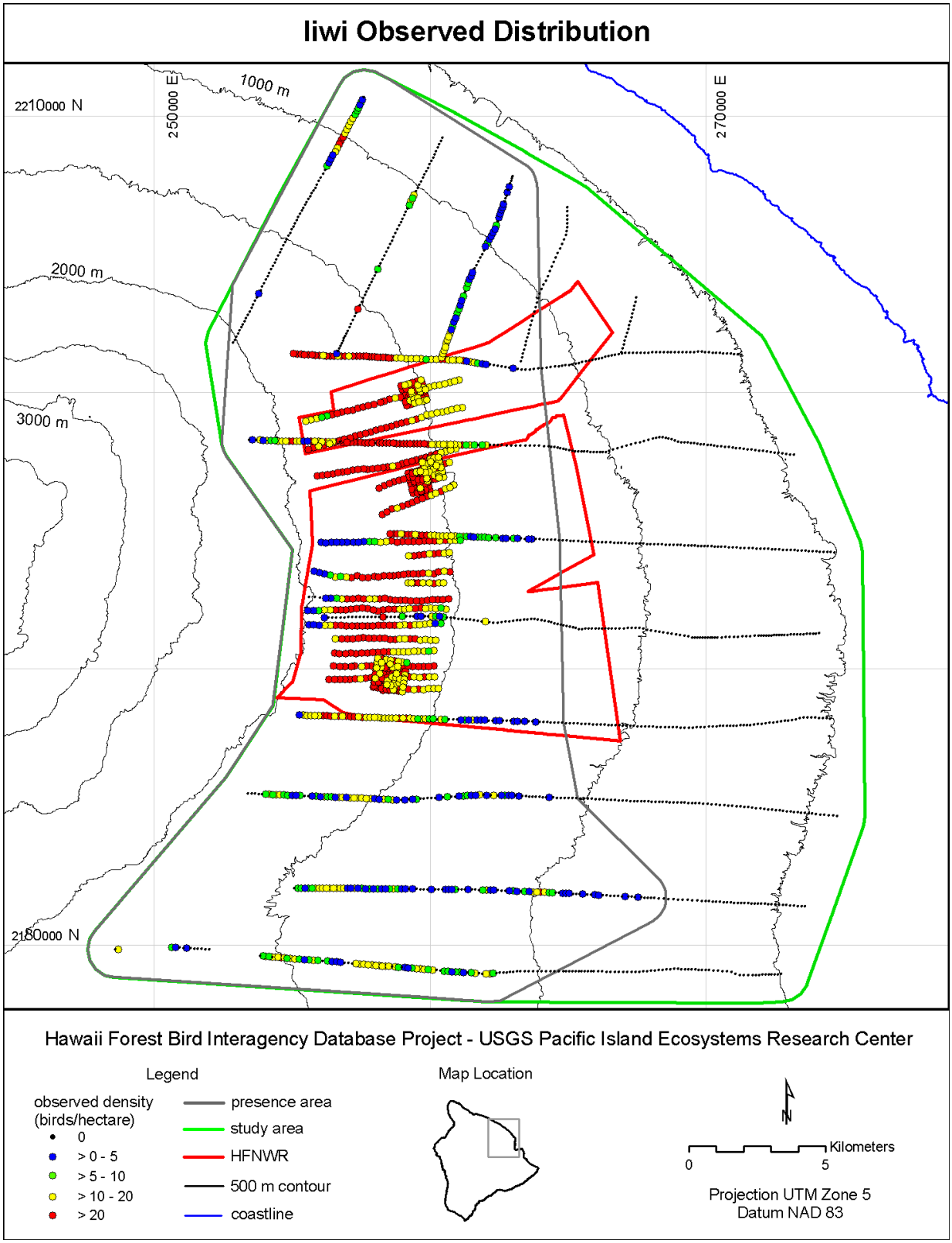

Figure 53. Observed distribution and density of Iiwi in the north Hamakua study area.

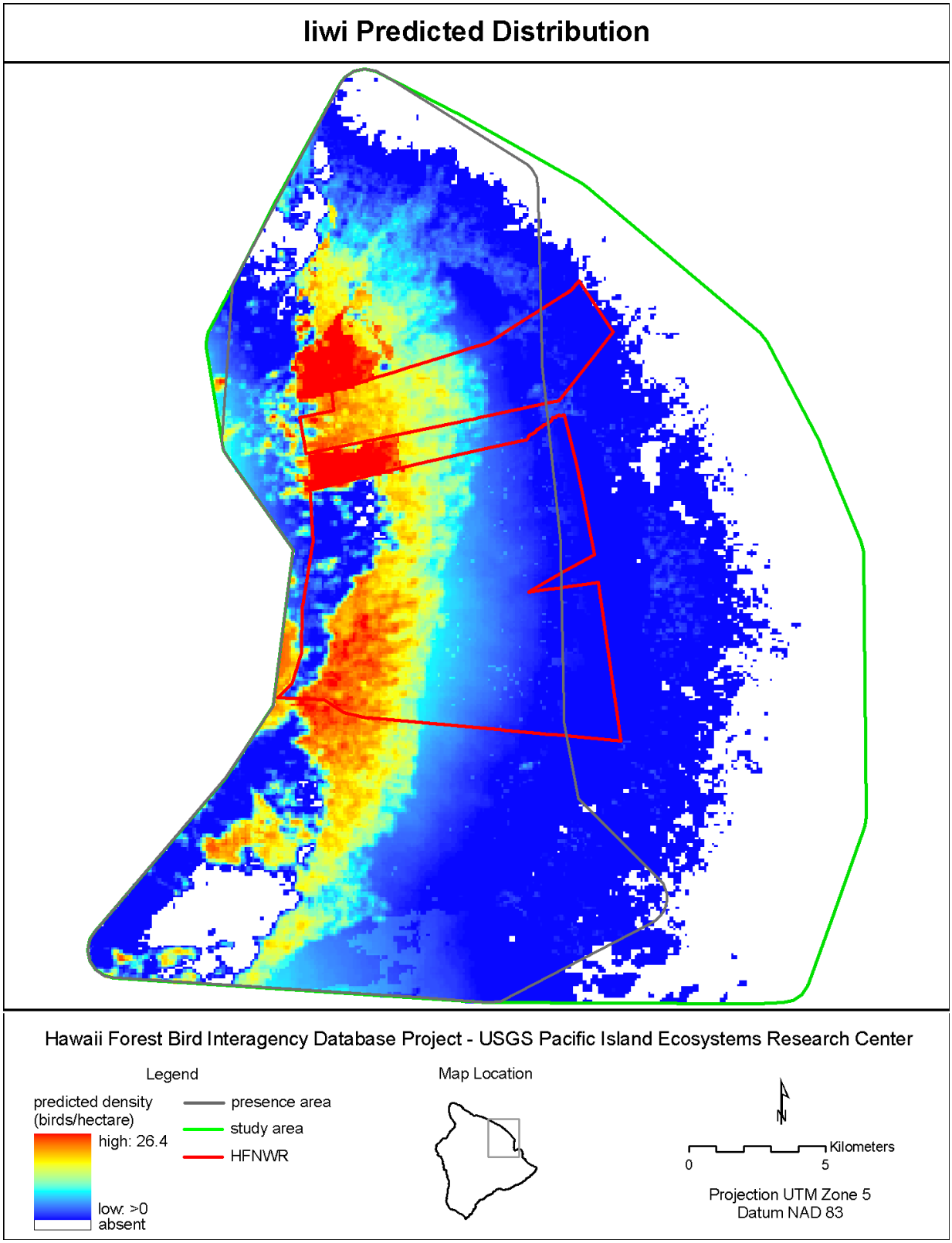

Figure 54. Predicted distribution and density of Iiwi in the north Hamakua study area.

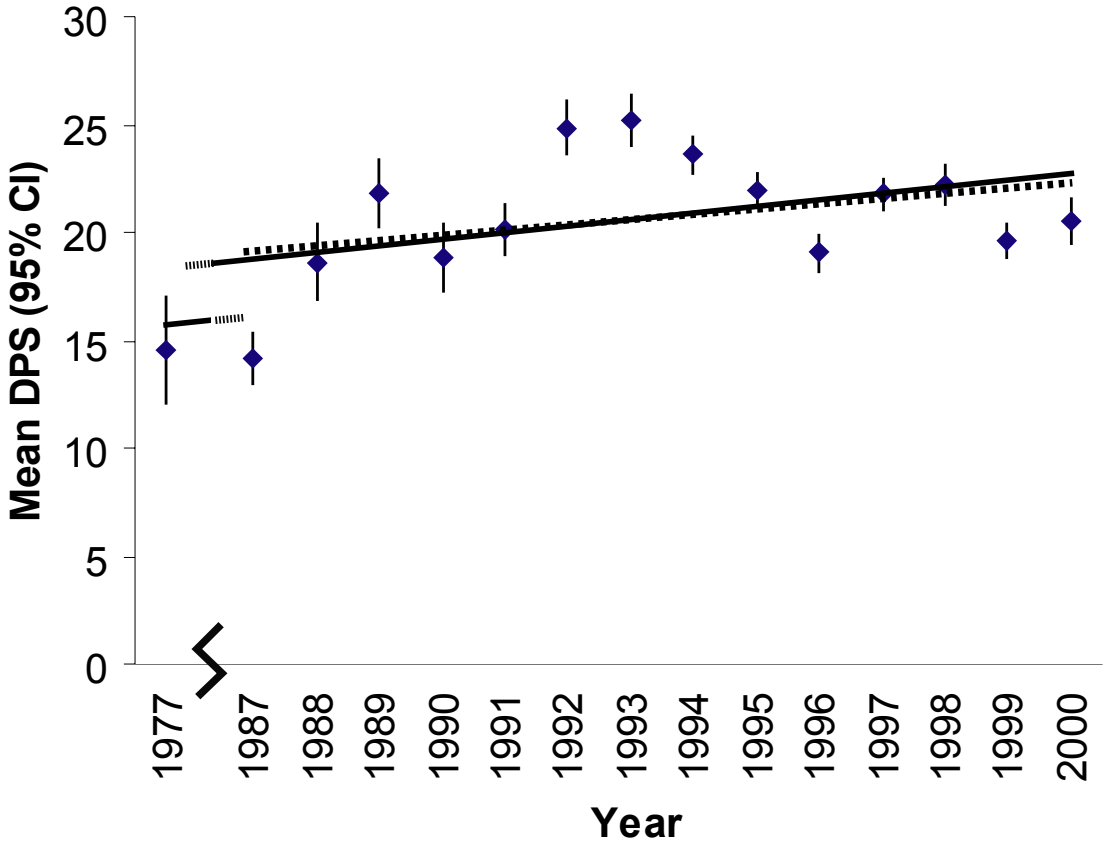

Figure 55. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Iiwi. Regression of log-transformed densities were non-significant for the 14-year survey period (dashed line; slope = 0.006, 95% confidence limit = -0.003 – 0.014, $r^2 = 0.14$, $P = 0.19$) and significantly increasing over the 24-year survey period (solid line; slope = 0.008, 95% confidence limit = 0.002 – 0.013, $r^2 = 0.37$, $P = 0.02$).

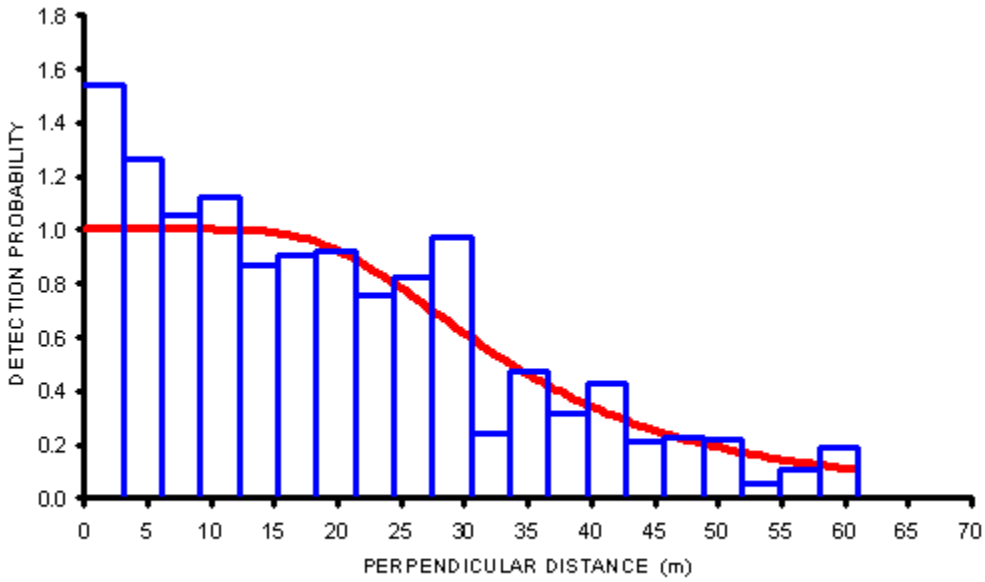

Figure 56. Hazard-rate key detection function and Apapane distance data pooled across all surveys in the north Hamakua study area from 1977 to 2000 for the months of February to July. Data truncated at 61.0 m.

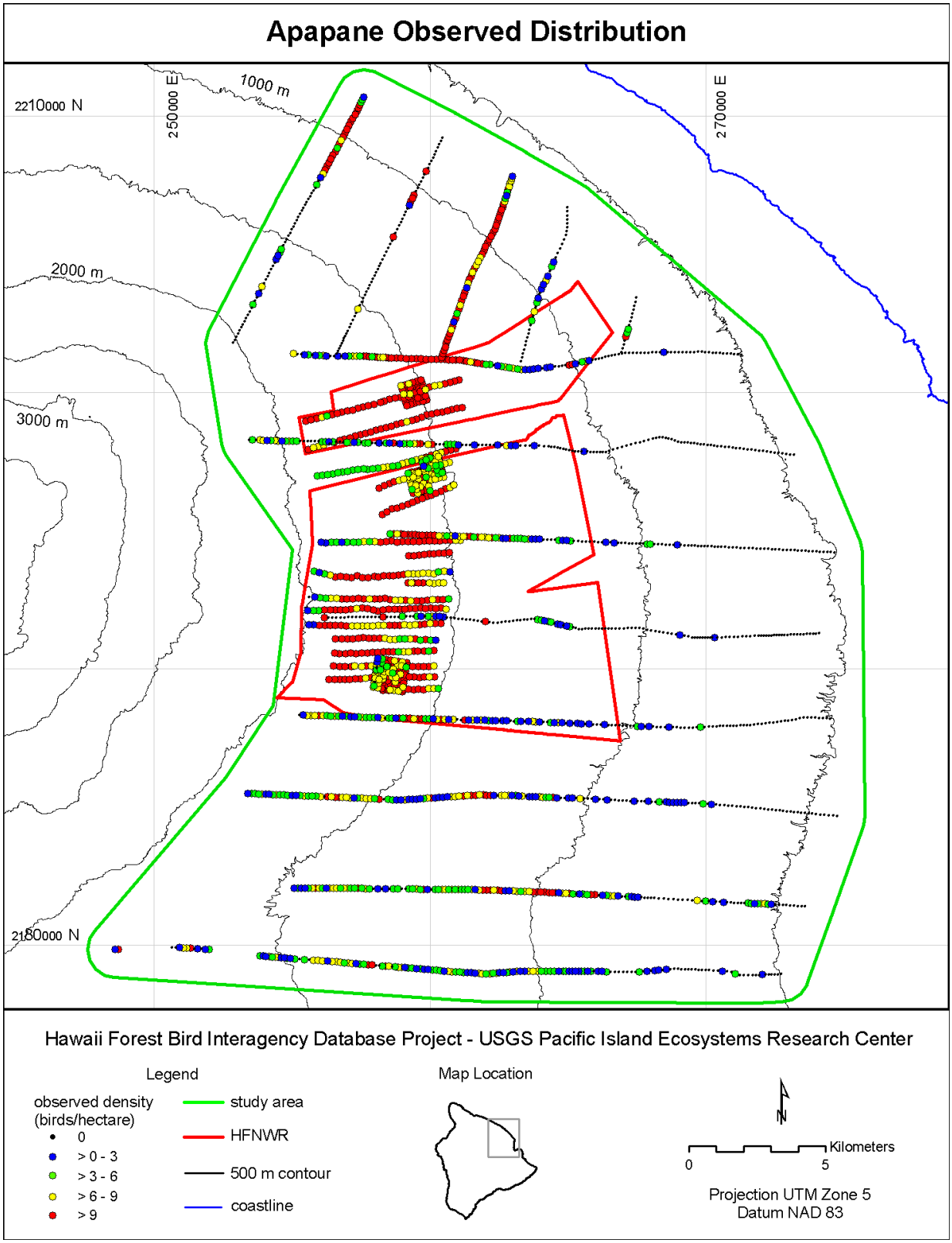

Figure 57. Observed distribution and density of Apapane in the north Hamakua study area.

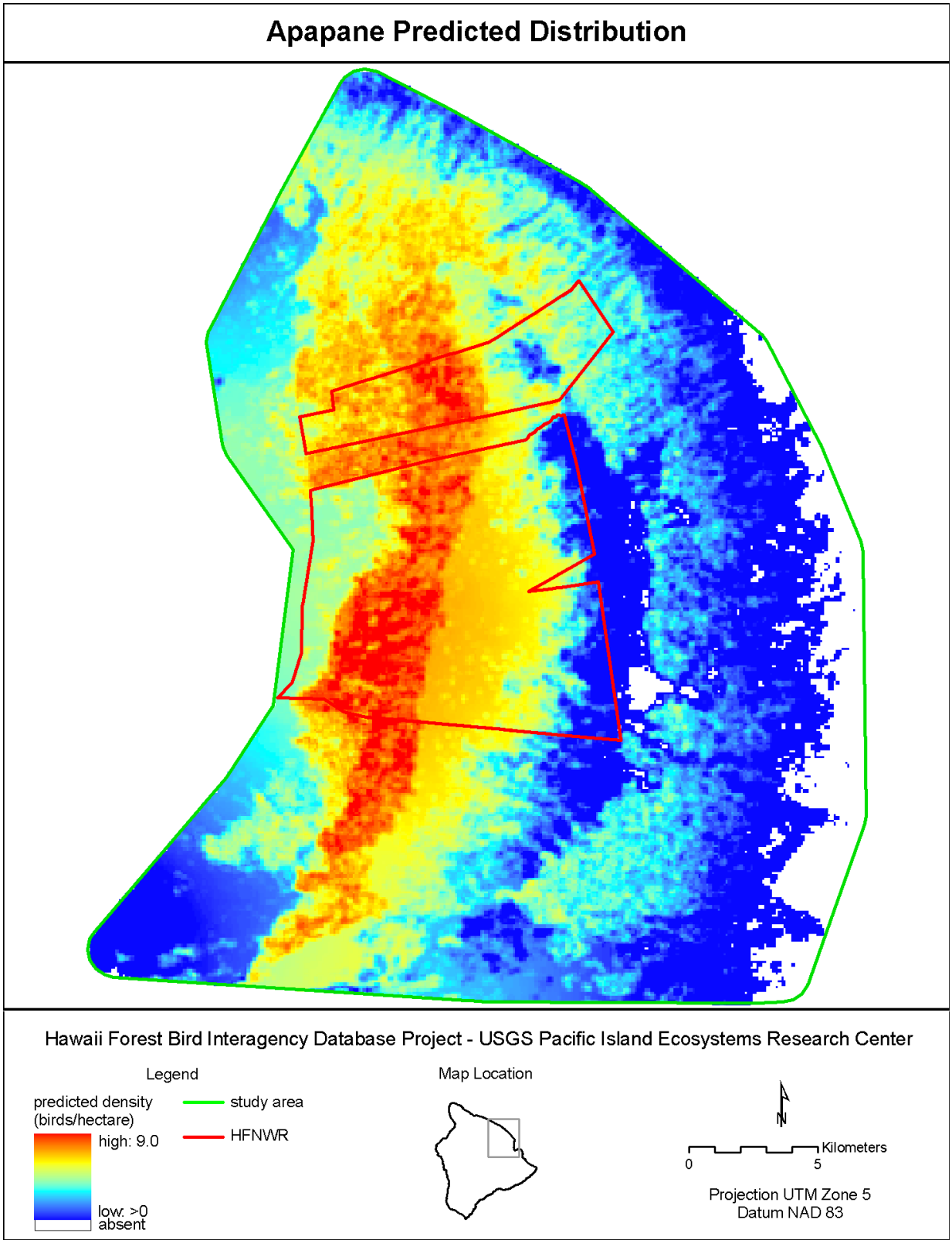

Figure 58. Predicted distribution and density of Apapane in the north Hamakua study area.

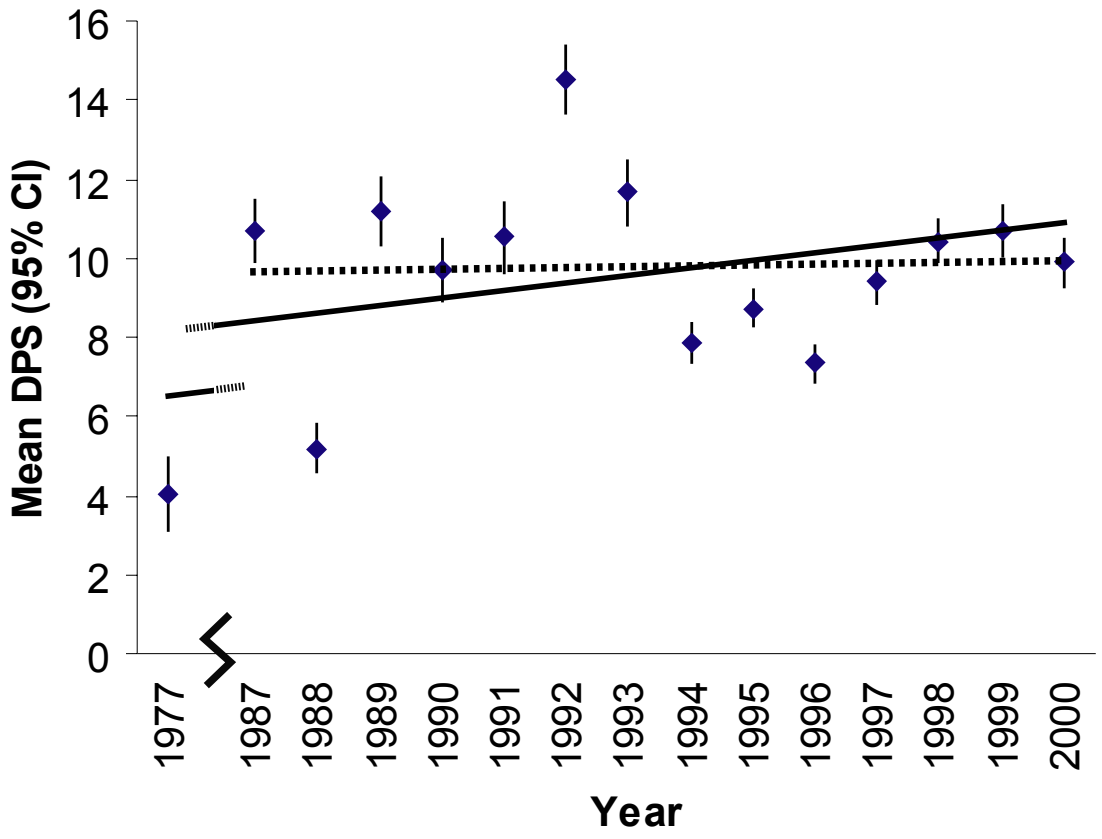

Figure 59. Relationship between untransformed survey year and mean annual density per station (mean DPS ± 95% CI) of Apapane. Regression of log-transformed densities were non-significant for the 14-year survey period (dashed line; slope = 0.002, 95% confidence limit = -0.014 – 0.018, $r^2 = 0.01$, $P = 0.76$) and significantly increasing over the 24-year survey period (solid line; slope = 0.013, 95% confidence limit = 0.001 – 0.025, $r^2 = 0.30$, $P = 0.04$).

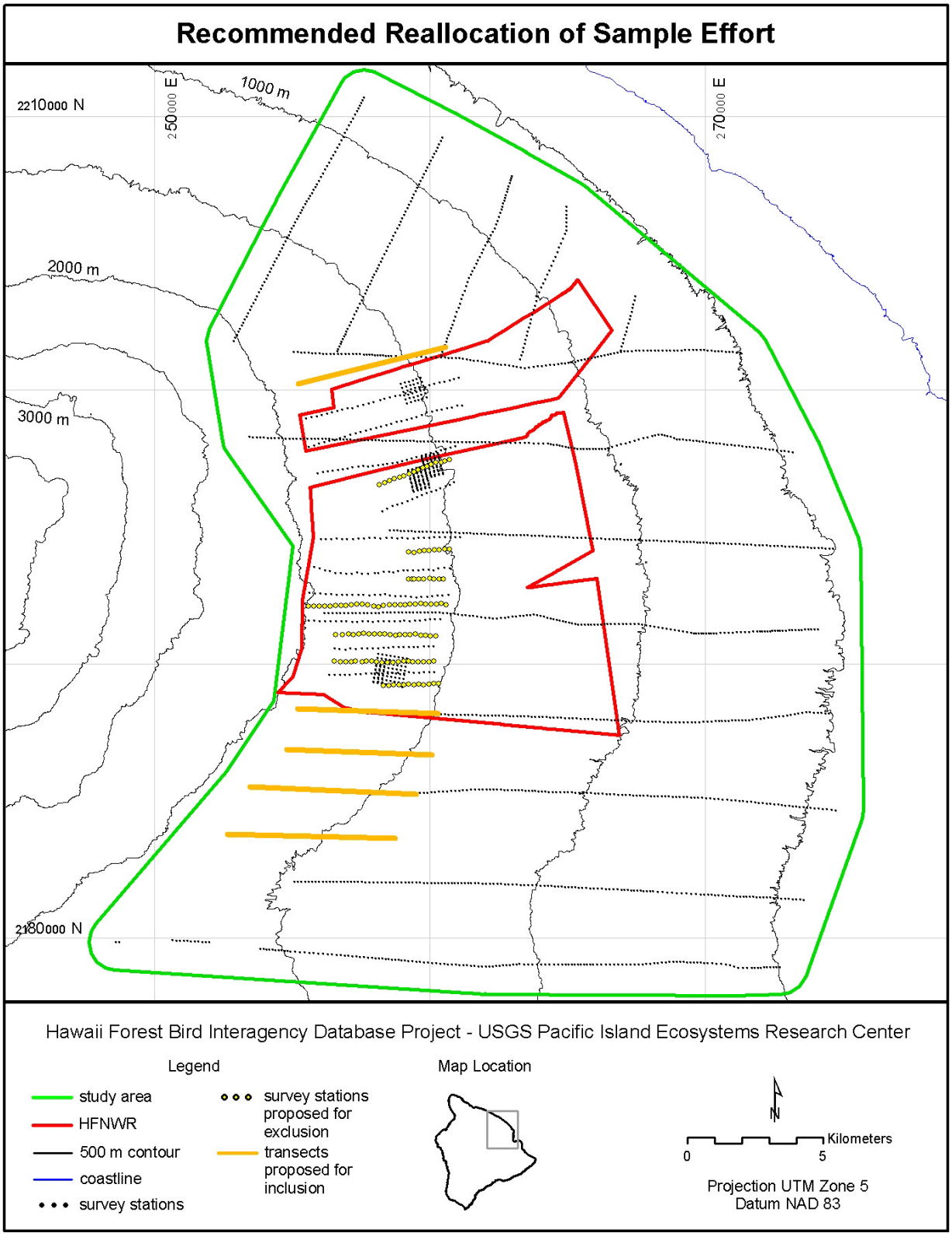

Figure 60. Recommended reallocation of sampling effort within the study area.