CHAPTER 1

UNDERSTANDING THE PROBLEM

1.1 INTRODUCTION

Beginning in 1989, researchers have consistently documented that wind turbines in the Altamont Pass Wind Resource Area (APWRA) kill large numbers of birds—especially raptors (Orloff and Flannery 1992, 1996; Howell 1997; Howell and DiDonato 1991). Early researchers mainly focused on locating fatalities and quantifying bird mortality. Though they hypothesized various causes and mechanisms associated with wind turbine-caused fatalities, this early research was directed mainly at identifying the extent of the problem, not at the underlying causes.

In March 1998, the National Renewable Energy Laboratory (NREL) initiated research to address certain complex questions: What is the full extent of bird mortality in the APWRA? What are the underlying causes of the mortality? What role do bird behaviors play in mortality at wind turbines? Is mortality predictable at wind turbines with certain suites of characteristics? If it is, then can management strategies be developed to reduce mortality?

To help understand the complexity underlying these questions, and some of the terminology associated with them, we present the following framework for addressing and interpreting factors related to bird mortality in the APWRA.

Step 1	Natural behaviors, geographic distributions, and ecological relationships that predispose wildlife to harm due to wind turbines	⇨	**Susceptibility**
Step 2	Placement and operation of wind farm structures and related management activities that pose threats to wildlife	⇨	**Vulnerability**
Step 3	Mortality due to wind farm operations	⇨	**Impacts**
Step 4	Reliably predicting impacts from indicators of susceptibility and vulnerability	⇨	**Solutions**

Within this framework, it is the integration of Steps 1 through 3 that leads to Step 4 and its solutions. An empirical model developed in Step 4 can be broadly applied to predict *impacts* using quantitative measurements of factors that relate to *susceptibility* and *vulnerability*—terms that are drawn from the ecological indicators framework (Rapport et al. 1985; Cairns and McCormick 1992; O'Neill et al. 1994; Rotmans et al. 1994; Schulze et al. 1994; USDA 1994; Battaglin and Goolsby 1995; Wilcox et al. 2003; for examples see Zhang et al. 1998, 2003) and defined below. Step 4, which is the focus of this study, was funded by the California Energy Commission beginning in late fall of 2001 and continuing in the field until May 2003. This research was an extension of work already begun under NREL funding from 1998 into 2001 (Smallwood and Thelander, In review). That effort primarily focused on identifying bird behaviors and attributes of wind turbines, the landscape, and range management practices that associated with fatalities caused by bird collisions with wind turbines. For this report, we have combined the data from both research efforts.

1.1.1 Natural Behaviors and Ecological Relationships: Susceptibility

Natural behaviors and ecological relationships of birds contribute to their inherent susceptibility to wind turbines. Birds die in the APWRA attempting to pass through the rotor plane of operating wind turbines, or when flying into guy wires, or when perching atop electrical distribution poles that service the wind farm, and for other reasons. A bird attempting to fly through the rotor plane is an expression of natural behaviors, but in an artificial context, where the rotor plane has been introduced along with all of the other land uses and structures that typify wind farms. Because each species of bird exhibits unique suites of behaviors, geographic distributions, and ecological relationships, each also possesses unique susceptibilities to wind farms. For example, golden eagles (*Aquila chysaetos*) may spend most of their foraging time in canyons, making them likely to be more susceptible to wind turbines installed in canyons.

Red-tailed hawks (*Buteo jamaicensis*) may be less susceptible to wind turbine placement in canyons, but perhaps more susceptible to wind turbines placed on ridgelines, especially if ridgelines are where they fly most frequently. Burrowing owls (*Athene cunicularia*) might be most susceptible to wind turbines installed where the owls perform their courtship displays, or where their dispersal flights take them into the altitudes of the moving turbine blades. Thus, susceptibility is estimated by measuring and comparing behaviors that could cause individual species to collide with wind turbines as these behaviors continue to be expressed, unaltered, following the installation of wind turbines.

Orloff and Flannery (1996) suggested that some birds inadvertently enter the rotor plane because they simply cannot see moving wind turbine blades. More specifically, they suggested that raptors enter the rotor plane unwittingly when they are fixated on a distant perch or prey item while the blades are in their foreground. Raptors may identify a perch and continuously observe it until they land on it, or they may detect a prey item and continuously observe it until they capture it. If the raptor's target is located behind the moving blades of a wind turbine, then the raptor may not see the blades, or may see them only when it is too late to avoid them.

The relative effects of motion smear (Hodos et al. 2001) versus fixed focus on prey items remains unknown, as does the degree to which these two factors might interact. But the frequent fatalities of non-raptorial birds summarized in this report indicates that fixed focus on prey items or perches are not the only reasons birds attempt to pass through the rotor plane.

Certain flight behaviors might influence a species' susceptibility to wind turbines, such as their long-distance flight behaviors during migration and their use of declivity winds (i.e., strong winds passing over ridge crests as winds are forced upslope). Perching patterns might connote various levels of susceptibility, if, for example, certain birds are prone to perching on wind towers because these towers simulate trees with which the species are familiar. Certain mating behaviors might distract individuals regardless of whether wind turbines are operating nearby. Nocturnal predators may or may not be more susceptible than diurnal predators, due to differences in sensory perception relied upon by animals during the night versus during the day. Last, some bird species that occur in relatively large numbers in the study area may only fly at heights well above the rotor blades, thus indicating low susceptibility to the wind turbines presently in use. Future upgrades involving larger and taller wind turbines might alter the susceptibility of these bird species. For these and other potential interspecific differences in susceptibility associated with flight behaviors, future changes in wind turbine design, operation, and placement might yield different mortalities among bird species in the APWRA.

The preferred approach to estimating susceptibility is to implement a *before-after control impact* (BACI) design with replication of impact and control treatments (Anderson et al. 1999). However, we could not implement such a design, because we were assigned wind turbines that were put into operation prior to the initiation of our study. Uninformed about bird behaviors in the APWRA prior to wind turbine operations, we made what inferences we could about susceptibility of bird species to the placement and operation of wind turbines (see Chapter 8).

1.1.2 Exposure to Wind Farm Operations: Vulnerability

The placement and operation of wind turbines can make birds vulnerable to wind turbine collisions when and where birds are already susceptible to wind turbines due to the birds' relative abundance, behaviors, and ecological relationships (e.g., predator-prey interactions). *Vulnerability* is a relative term that requires the measurement of susceptibility and impact across ranges of environmental conditions within a study area.

Quantifying vulnerability requires the comparisons of bird activity near wind turbines and bird deaths to the availability of wind turbines within the environmental elements of interest, such as types of physical relief, seasons, and proximity to particular prey species, as examples. Measures of vulnerability can be based on relative abundance near wind turbines and/or on the relative mortality of bird species at wind turbines with particular attributes. In either case, use-and-availability analysis using chi-square test statistics is an effective means of testing whether particular levels of vulnerability are significant.

As an example of applying use-and-availability analysis, relative abundance can be measured as the proportion of the sampling periods that each bird species is observed flying over landscape element *i*, and this proportion of flight time is related to the proportion of landscape element *i* occurring within the study area. Bird mortality can be measured as the proportion of the sample of individuals killed at wind turbines of a particular type or environmental setting relative to the proportion of those types or settings in which all of the wind turbines in the study area occur. Vulnerability due to placement of wind turbines on certain landscape elements (as an example of any environmental element that one wishes to measure) can be expressed by the following model:

$$\frac{\chi^2 \ Observed}{\chi^2 \ Expected} = \frac{n_i}{N\, p_i},$$

where, in the case of measuring use of the areas near wind turbines, n = flight time of a particular species nearby wind turbines on landscape element i, N = total flight time of the species on the sampled landscape; and where, in the case of measuring mortality, n_i = number of individuals of the species killed at wind turbines on landscape element i, and N = total number of the species killed within the landscape area being sampled; and in both cases, p_i = proportion of the sampled landscape composed of landscape element i. In summary, part of our study attempts to identify the vulnerability of bird species to strikes with wind turbines based on our weighted measurements of susceptibility and impacts.

1.1.3 Measuring Effects on Birds: Impacts

Bird mortality studies conducted at wind resource areas have produced a variety of mortality estimates. Howell and DiDonato (1991) sampled wind turbines in the APWRA during 1988–1989 and reported 0.05 deaths per wind turbine per year (n = 17 fatalities). Orloff and Flannery (1996) conservatively estimated that 39 golden eagles were killed during a one-year period in the APWRA. They also estimated raptor mortality to range from 0.02–0.05 deaths/turbine/year. During a one-year period, Howell (1997) confirmed 72 wind turbine-caused fatalities during an 18-month period at two wind resource areas: the APWRA and the Montezuma Hills WRA. Bird fatalities consisted of 44 raptors and 28 non-raptors, with a mean raptor mortality of 0.03 deaths/turbine/year.

There are two fundamental perspectives from which one can interpret the effects of wind turbine operations on birds: legal and biological. From a legal perspective, individual fatalities can be considered significant effects and subject to civil or criminal penalties. Federal laws that specifically protect raptors include the Migratory Bird Treaty Act (MBTA), the Bald and Golden Eagle Protection Act, and the Endangered Species Act. Raptors are also protected under California Fish and Game Code 3503.5, which makes it illegal to take, possess, or destroy any bird in the Order Falconiformes or Strigiformes.

The MBTA prohibits killing any bird species designated as fully protected. The U.S. Fish and Wildlife Service (USFWS) considers any injury or fatality of any raptor from a collision with a wind turbine or ancillary facilities in the APWRA to be a "take," and therefore a violation of the MBTA (S. Pearson, USFWS, pers. comm.). Bird fatalities attributable to wind turbine operations are significant effects, from a legal perspective, because they violate the MBTA. The MBTA constitutes a decision that any additional human-caused losses of individuals of raptor species covered by the MBTA are legally significant.

Comparing the wind turbine-caused mortality to both the natural mortality and the recruitment rate of each affected species would effectively measure the biological importance of wind turbine-caused fatalities. Doing so would yield estimates of the degree to which wind turbines adversely affect a species' population size, stability, and distribution. However, to do so would require extensive information about the distribution and demographic structure of populations occurring at and around the APWRA. Simply counting living birds in the APWRA would be inadequate for this purpose, because for numerous species their numbers would change dramatically throughout the year due to migrations. The numerical estimates made in the APWRA would be, in multiple cases, contaminated by individuals that live most or part of their lives elsewhere.

The APWRA may directly affect many bird species that occur over a broad geographic area. Thus, the geographic scale required for estimating impacts to bird species would be much larger than the APWRA itself. The scope of the present study would not allow inferences of population-level or regional impact assessments to be made, but it is important to consider that these impacts are possible, and they are worthy of additional research.

Among the species of raptors killed in the APWRA, golden eagles and burrowing owls are probably the species of greatest concern, because they are California Species of Special Concern. No detailed studies have addressed impacts to burrowing owls, but a recent study of golden eagle mortality factors and population regulation over a broad geographic region specifically included the APWRA within its overall study area (Hunt 1994, 2002; Hunt and Culp 1997).

In recent years, numerous golden eagle deaths in the area have been attributed to wind turbines. Hunt (1994) and Hunt and Culp (1997) concluded that the additional effect of wind turbine-caused mortality might be contributing to a long-term decline in the local golden eagle population, but Hunt (2002) later concluded the local population might be stable. However, Hunt's study was too brief to reliably estimate multi-generational trends in golden eagle numerical abundance and demography (see Smallwood and Schonewald 1998; Hunt 2002). Hunt suggested that continuous monitoring would be needed and that recruitment was critical if the population was to maintain stability. Also, a high mortality of golden eagles might not change the number of individuals in the population so long as recruitment keeps pace with mortality, but a high rate of ill-fated recruitment might very well deplete golden eagle numbers in source areas (Smallwood 2002; Hunt 1998; Hunt 2002).

Until more rigorous research efforts are conducted in the APWRA for each bird species affected there, the full environmental impact of the APWRA will remain unknown. We will not know how the localized killing of individual birds affects their regional populations. In lieu of more rigorous research on population-level impacts, effective management practices are needed that will demonstrably reduce the vulnerability of bird species in the APWRA.

1.1.4 Relating Impacts to Causal Variables: Predictions and Solutions

Holding aside effects of season, weather, and wind turbine design and operation, if individuals of one bird species were randomly killed at wind turbines among measured environmental elements in the APWRA, then the probability of an individual being killed by a wind turbine occurring on a particular environmental element would equal the proportion of the wind turbines associated with that environmental element multiplied by the total number of that species killed in the study area. For example, if 20% of the wind turbines in a study area occurred on southeast-facing slopes, then a random distribution of 100 red-tailed hawk fatalities at wind turbines should have included about 20 birds killed by wind turbines on southeast-facing slopes. This product of total number killed (N) and the incidence of wind turbines on the ith landscape element is an expected kill rate at the ith landscape element. The number of fatalities at the ith landscape element can then be compared to the expected number of fatalities. For example, had 40 red-tailed hawks been killed by wind turbines on southeast-facing slopes, this observed frequency was twice the frequency expected of a random or uniform distribution of fatalities.

When the observed and expected frequencies of fatalities are equal, then the observed frequency must be attributed statistically to the number of wind turbines. However, when the converse is true, an association exists between that environmental element and mortality. If the relationship is less than one, then there may be an avoidance of one environmental element and the possible selection of another. By identifying environmental elements where mortality exceeded expectations due to wind turbine numbers alone (i.e., observed ÷ expected >1), we are able to identify which environmental factors might have a causal relationship. It is through the application of this approach that we assess vulnerability.

At selected wind turbines in the APWRA, we compiled data separately for bird behaviors, wind turbine and tower characteristics, fatality searches, fatality search results, maps of rodent burrow systems, and various other physical and biological factors. This report summarizes the resulting integration of these data. In turn, this data integration process provided the opportunity to develop predictive models for bird mortality at wind turbines based on wind turbine location on the landscape, wind turbine location relative to other wind turbines, wind turbine design and operation, the distribution of raptor prey species near wind turbines, and other potential predictor variables.

1.2 OBJECTIVES

The primary objectives of this research were to: (1) quantify bird use, including characterizing and quantifying perching and flying behaviors exhibited by individual birds around wind turbines, (2) evaluate the flying behaviors and the environmental and topographic conditions associated with flight behaviors, (3) identify possible relationships between bird mortality and bird behaviors, wind tower design and operations, landscape attributes, and prey availability, and (4) develop predictive, empirical models that identify areas or conditions that are associated with high vulnerability. Such models can be used to identify locations and conditions of high versus low vulnerability in the APWRA, or to reliably identify those wind turbines and landscape attributes that pose ongoing threats to birds.

We began the project by quantifying bird use and bird fatalities associated with that use. Only about 28% of the APWRA's total wind turbine population was included in the project initially, due to limitations placed on access to turbines. We quantified bird flight and perching behaviors at the various wind turbine types, and examined whether the frequencies of these behaviors at wind turbines were related to environmental factors such as weather, topography, habitat features, prey availability, and others.

As our study progressed, unexpected patterns prompted us to add certain focused subtasks and activities to complement the basic goals of the project. Such patterns included ground squirrel distribution and abundance not relating to raptor mortality; pocket gophers clustering near wind towers on steep ridgelines; and raptors generally avoiding perching upon wind towers while turbines operated. We added research on rodent distribution in relation to tower locations, bird use, and fatality locations. We also examined topographic and landscape features and related these to bird use and bird fatalities.

In general, the topics we examined fell into three broad categories: (1) bird flight behaviors; (2) wind turbine/tower design, placement, and operations; and, (3) raptor prey availability and distribution in relation to individual wind turbines and turbine strings. Wherever applicable, the methods used in our project adhere to guidelines developed and recommended for such studies by the Avian Subcommittee of the National Wind Coordinating Committee (Anderson et al. 1999).

1.3 STUDY AREA

The Altamont Pass Wind Resource Area is located in central California about 90 km east of San Francisco in eastern Alameda and southeastern Contra Costa counties (Figure 1-1). In the APWRA (which is the largest wind energy facility in the world), permits to install some 8,200 wind turbines were approved by the regulating authority, but about 5,400 were in place during our study (Alameda County 1998). The output capacity of the installed wind turbines is reported to be 580 megawatts (MW). The actual output may be 35%–40% of the rated capacity, depending on the hardware specifications (R. Thresher, NREL, pers. comm.). The turbines are distributed over approximately 150 km^2 (50,000 acres). Photos 1-1 through 1-8 depict aspects of the wind farm and various types of wind turbines.

Energy generation in the APWRA reached significant levels during the mid-1980s, when most of the wind turbines now at the site were installed. Wind turbines are generally grouped under common ownership. At least 13 different companies manage the energy that is produced in the APWRA, each using different tower/turbine configurations. Table 1-1 summarizes the wind turbine attributes of the wind turbines included in our sample in the APWRA.

The Altamont Pass region exhibits a complex topographic relief. Hilltop elevations range from 230 to 470 m (755 to 1,542 ft.) above sea level. Valley elevations range from about 78 to 188 m (256 to 617 ft.) above sea level. Livestock grazing constitutes the primary land use in the area.

Steady winds from the southwest blow across Altamont Pass during about April to October. Differential air temperatures form as the warmer Central Valley east of Altamont Pass draws in cooler, marine air from San Francisco Bay to the west. Winds are more erratic at other times of the year. They can originate from any direction. Wind speeds average 25–45 kilometers per hour (km/hr) between April and September, during which time the APWRA produces 70%–80% of its power. During the summer months, wind speeds are sufficient to operate the wind turbines beginning about mid-afternoon and increasing during the evening hours (Taylor 1998, pers. comm.). During winter, wind speeds average 15–25 km/hr. Dense fog can occur in the Altamont Pass during summer and winter. Winter fog conditions, known locally as “tule fog,” often linger for many consecutive days.

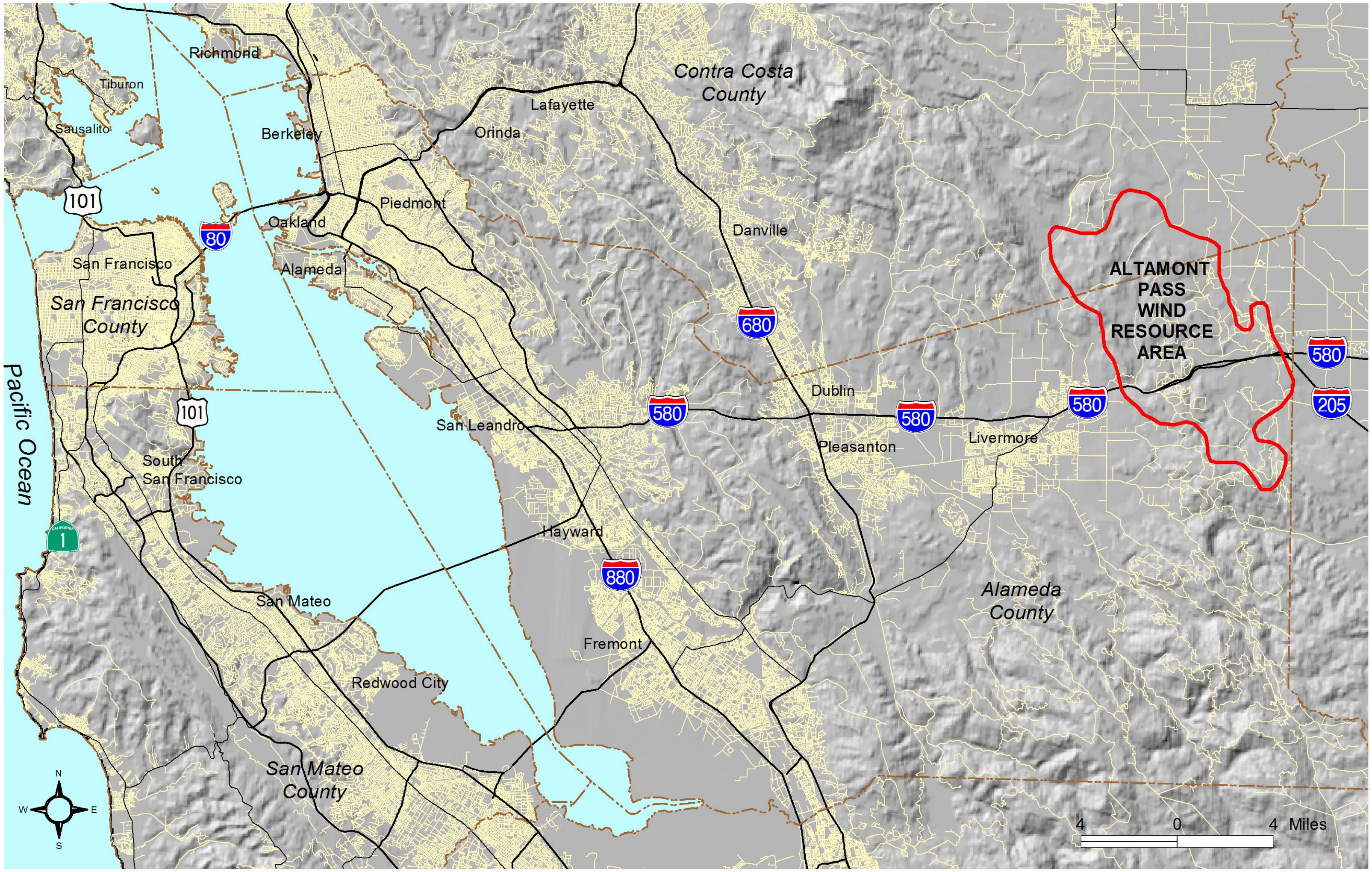

Figure 1-1. Location of the Altamont Pass Wind Resource Area (APWRA) in west-central California

Photo 1-1. Bonus 150-kW wind turbines mounted on tubular towers, plus Flowind 150-kW vertical axis wind turbines to the right

Photo 1-2. In the foreground are two Bonus wind turbines mounted on grey tubular towers. Downhill are five Danwin 110-kW wind turbines mounted on white tubular towers.

Photo 1-3. A string of Flowind 150-kW vertical axis turbines

Photo 1-4. Micon 65-kW wind turbines near Mountain House

Photo 1-5. KVS-33 turbines painted with stripes (experimentally) to increase their visibility to birds

Photo 1-6. An Enertech 40-kW wind turbine with two turkey vultures flying nearby

Photo 1-7. Example of a wind wall. KCS-56 turbines are mounted on two different tower heights to catch a larger height domain of the wind.

Photo 1-8. Windmatic 65-kW turbine adjacent to Old Altamont Pass Road

Table 1-1. Wind turbine models and associated attributes in the APWRA. Information provided by Altamont Infrastructure Company, Altamont Power Co., EnXco, SeaWest, and WindWorks.

Wind turbine manufacturer	Size (kW)	Tower type	Rotor diameter (m)	Tip Speed (kph)	Rated wind speed (kph)	Tower Height (m)	Percent time in operation	No.of blades
Bonus	120	Tubular	19.5	146.42	64.4	24.6	unknown	3
Bonus	150	Tubular	23.4	173.77	64.4	25.2	unknown	3
Danwind	110	Tubular	19.2	193.08	48.3	24.0	50 %	3
Enertech	40	Lattice	13.5	148.03	48.3	18.5	unknown	3
Flowind	150	Vertical axis	17.2	193.08	61.1	29.5	32 %	2
Flowind	250	Vertical axis	19.1	194.69	61.1	32.3	32 %	2
Howden	330	Tubular	31.4	239.74	43.4	24.6	unknown	3
Kenetech KCS-56	100	Horizontal lattice	17.8	246.18	46.7	14.0	39 %	3
Kenetech KCS-56	100	Horizontal lattice	17.8	246.18	46.7	18.5	39 %	3
Kenetech KCS-56	100	Horizontal lattice	17.8	246.18	46.7	24.6	39 %	3
Kenetech KCS-56	100	Lattice	17.8	246.18	46.7	43.1	39 %	3
Kenetech KVS-33 [a]	400	Lattice	33.2	180.21	43.0	24.6	69 %	3
Kenetech KVS-33 [a]	400	Lattice	33.2	180.21	43.0	36.9	69 %	3
Kenetech KVS-33 [a]	400	Tubular	33.2	180.21	43.0	24.6	69 %	3
Kenetech KVS-33 [a]	400	Tubular	33.2	180.21	43.0	36.9	69 %	3
Micon	65	Tubular	16.0	149.64	54.7	24.6	unknown	3
Nordtank	65	Tubular	16.0	143.20	54.7	24.6	unknown	3
Polenko	100	Tubular	18.2	149.64	49.9	24.6	unknown	3
Vestas	100	Lattice	17.2	167.34	67.6	unknown	unknown	3
W.E.G.	250	Tubular	25.2	212.39	48.3	24.6	52 %	3
Windmaster	200	Tubular	22.2	205.95	53.1	23.1	unknown	3
Windmaster	75	Tubular	22.2	205.95	32.2	23.1	unknown	3
Windmaster	250	Tubular	23.4	217.22	51.5	23.1	unknown	3
Windmaster	300	Tubular	25.2	234.91	54.7	23.1	unknown	3
Windmatic	65	Lattice	14.8	136.77	56.3	18.5	unknown	3

[a] The KVS-33 is a variable-speed wind turbine. The rotor speed at rated power (wind speed 26.7 mph) is 50 rotations per minute (rpm) and tip speed is 193.3 mph. The rotor speed at cut-in wind speed is 14 rpm and tip speed is 47.2 mph. The rotor speed in Altamont average winds (16 mph) is 29 rpm and tip speed is 112.1 mph (180.21 kph).

The vegetation is predominately nonnative annual grassland consisting of soft chess (*Bromus hordeaceus*), rip-gut brome (*Bromus diandrus*), foxtail barley (*Hordeum murinum ssp. leporinum*), Italian rye grass (*Lolium multiflorum*), and wild oats (*Avena fatua*). Common forbs include black mustard (*Brassica nigra*), fiddle-neck (*Amsinckia menziesii ssp. intermedia*), chick lupine (*Lupinus microcarpus var. densiflorus*), bush lupine (*Lupinus albifrons*), and wally baskets (*Triteleia laxa*). Grasses and forbs grow during the rainy months of January, February, and March; then die or go dormant by the beginning of June. The APWRA includes the following physiographic elements that harbor characteristic groups of species: annual grassland, alkali meadow, emergent marsh, riparian woodland and scrub, creeks and drainages, stock ponds, cultivated land, and rock outcrops.

At least 18 special-status wildlife species occur in the area, including: San Joaquin kit fox (*Vulpes macrotis mutica*), California red-legged frog (*Rana aurora draytonii*), San Joaquin pocket mouse (*Perognathus inornatus inornatus*), American badger (*Taxidea taxus*), Swainson's hawk (*Buteo swainsoni*), peregrine falcon (*Falco peregrinus anatum*), California tiger salamander (*Ambystoma californiense*), two species of fairy shrimp, and others. In addition, the area supports as many as 15 special-status plant species (Alameda County 1998).

Figures 1-2 through 1-7 help characterize the APWRA by illustrating the distribution of wind turbines classified by tower type (Figure 1-2), whether part of a wind wall (Figure 1-3), whether in or outside a "canyon" (Figure 1-4), the type of physical feature of the landscape the turbine was installed upon (Figure 1-5), the elevation at the turbine tower's base (Figure 1-6), and the level of intensity of rodent control practiced by the ranch owner, County of Alameda, and the turbine operators (Figure 1-7). Many other factors of the study area were also characterized numerically or categorically, and are described in the chapters that follow.

Within the APWRA study area, we performed focused studies involving smaller areas or select groups of wind turbines. One such study included observations of bird activities and behavior. This study involved about 1,500 wind turbines. Another focused study was of rodent species distributions around select strings or rows of wind turbines. Therefore, some of the chapters that follow require a somewhat different study area description from the one presented here.

The ecological relationships that have developed over time in the APWRA are in many ways analogous to those of an artificial undersea reef. Artificial reefs create lateral and vertical substrates where none existed before, and they attract a variety and abundance of organisms that would not be found there naturally. Similarly, the Altamont Hills once were covered largely by short-stature, annual grasses. Now those same grasslands provide an artificial substrate attractive to a variety of native terrestrial wildlife species, as well as non-native species whose numbers and distributions are artificial.

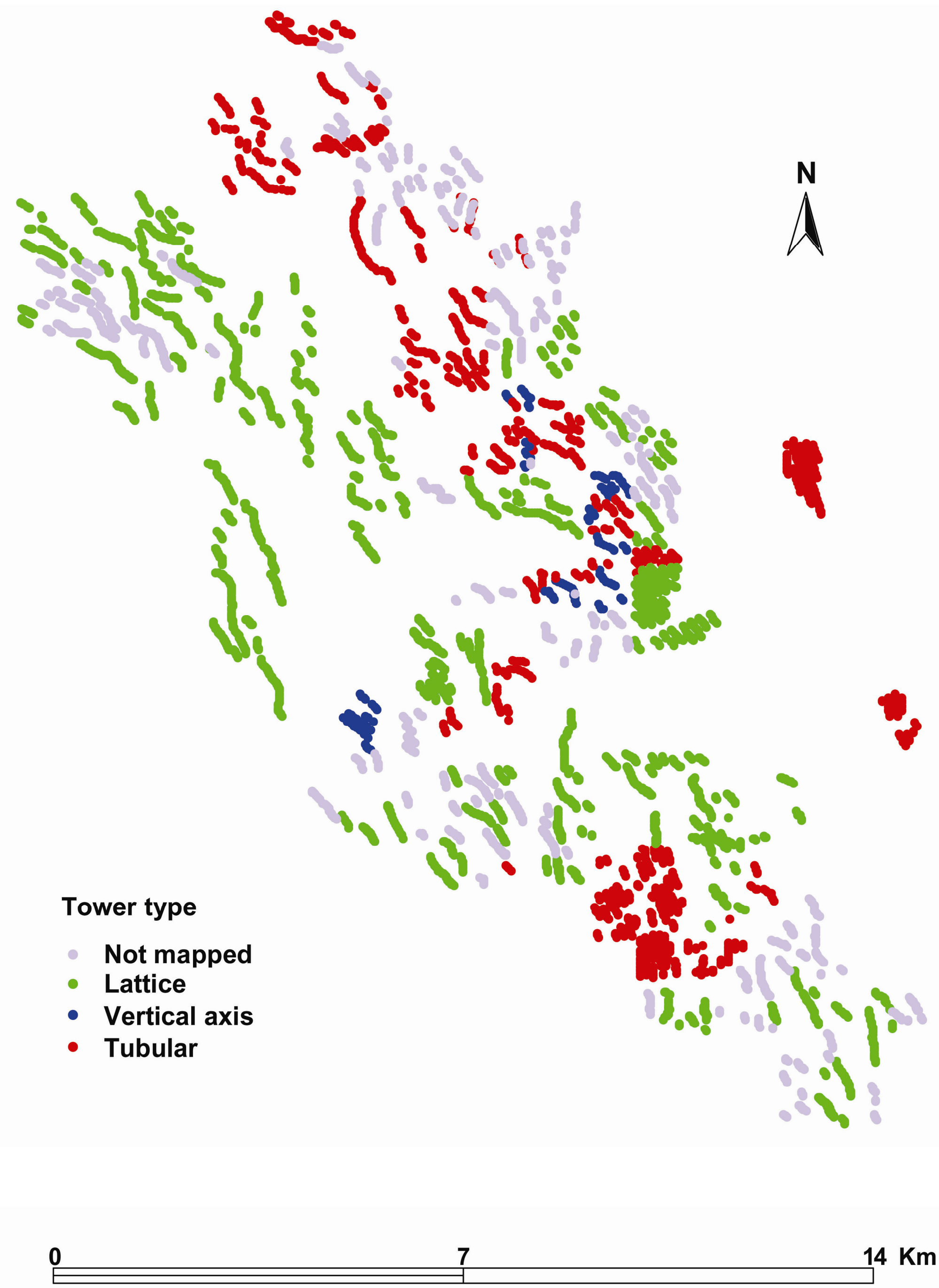

Figure 1-2. Distribution of wind tower types in the APWRA

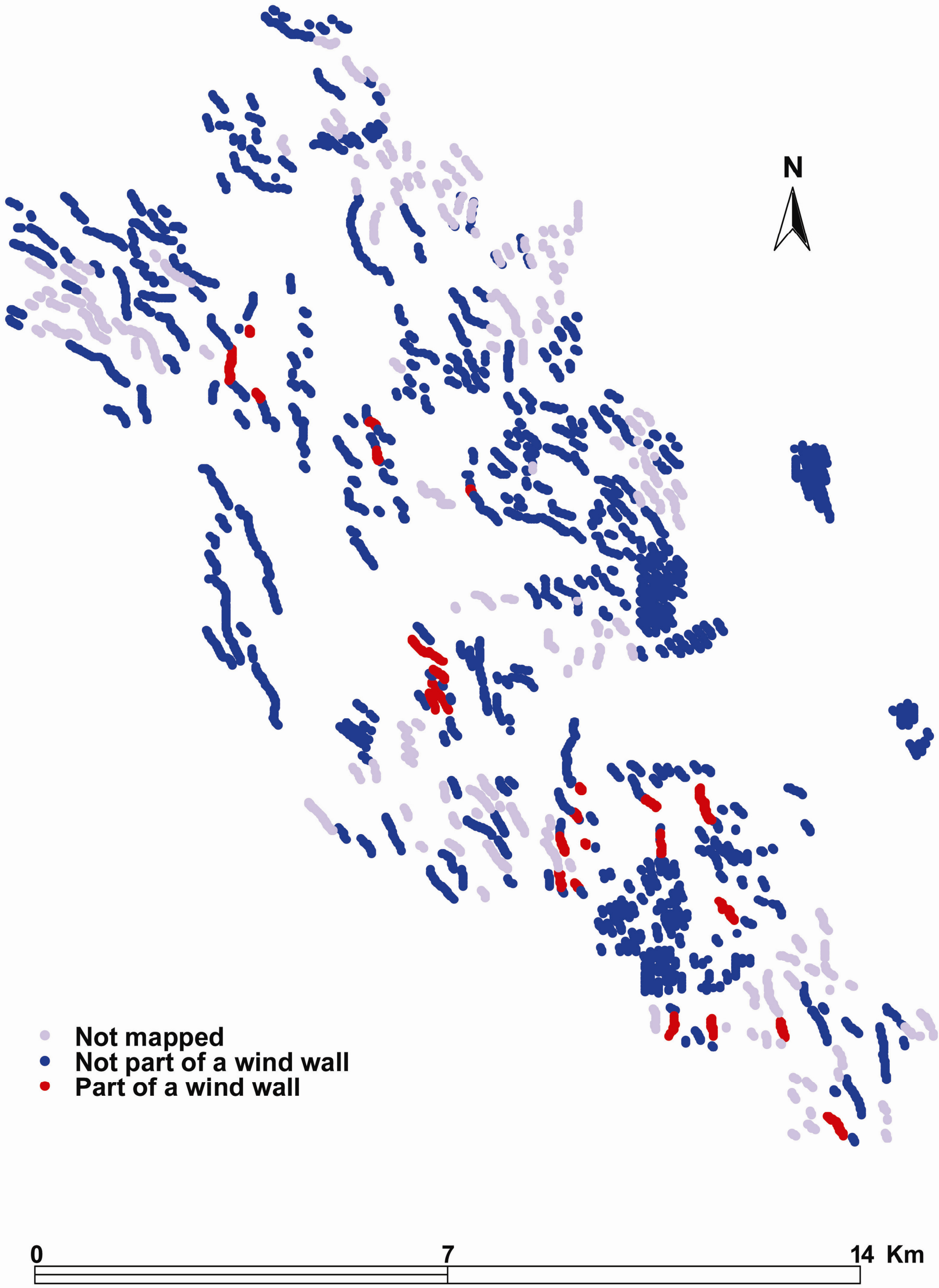

Figure 1-3. Distribution of wind walls in the APWRA. Wind walls are combinations of wind turbines on shorter and taller towers that are installed close to one another to capture a greater height domain of wind.

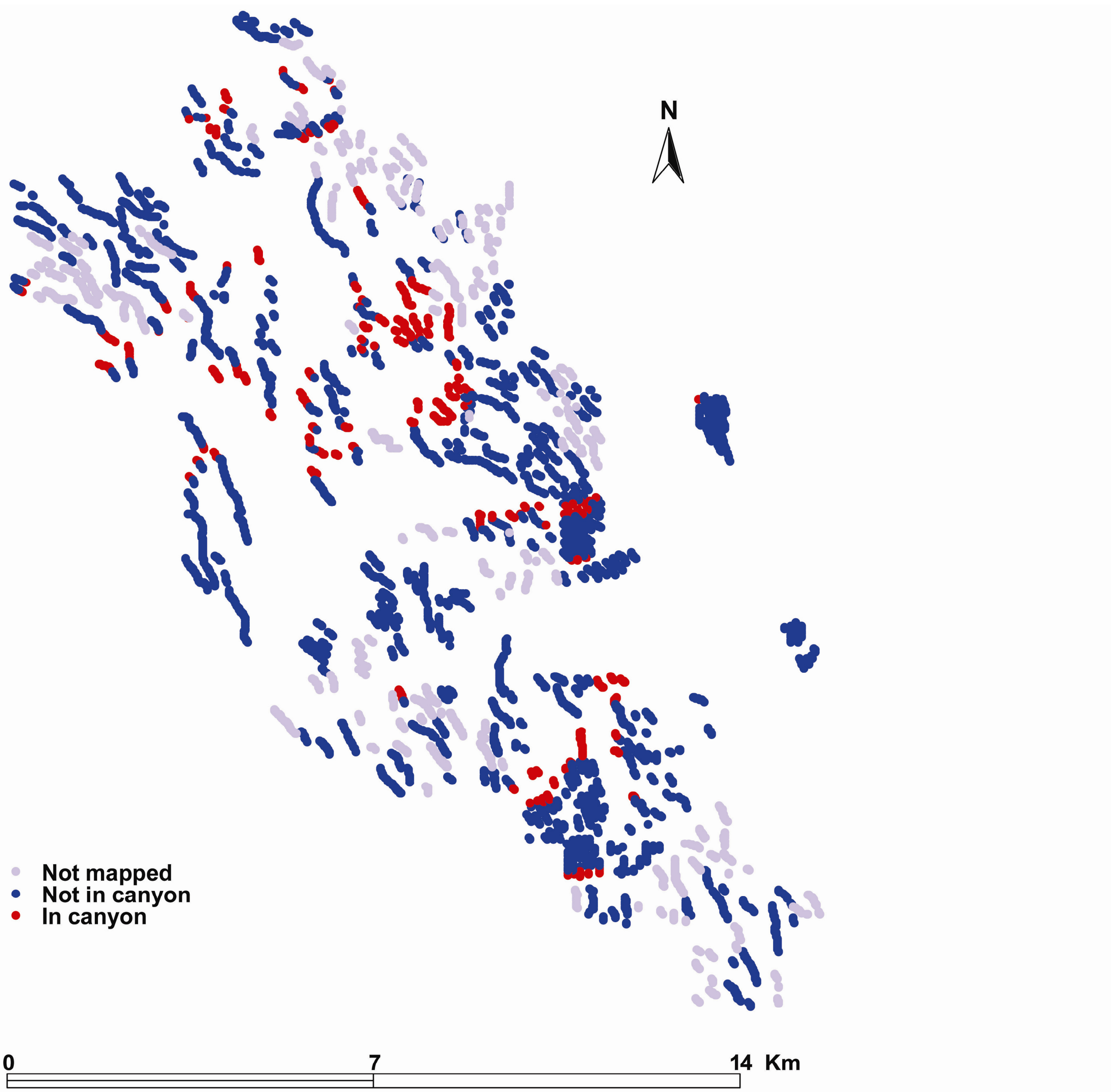

Figure 1-4. Distribution of wind turbines inside and outside of "canyons" in the APWRA

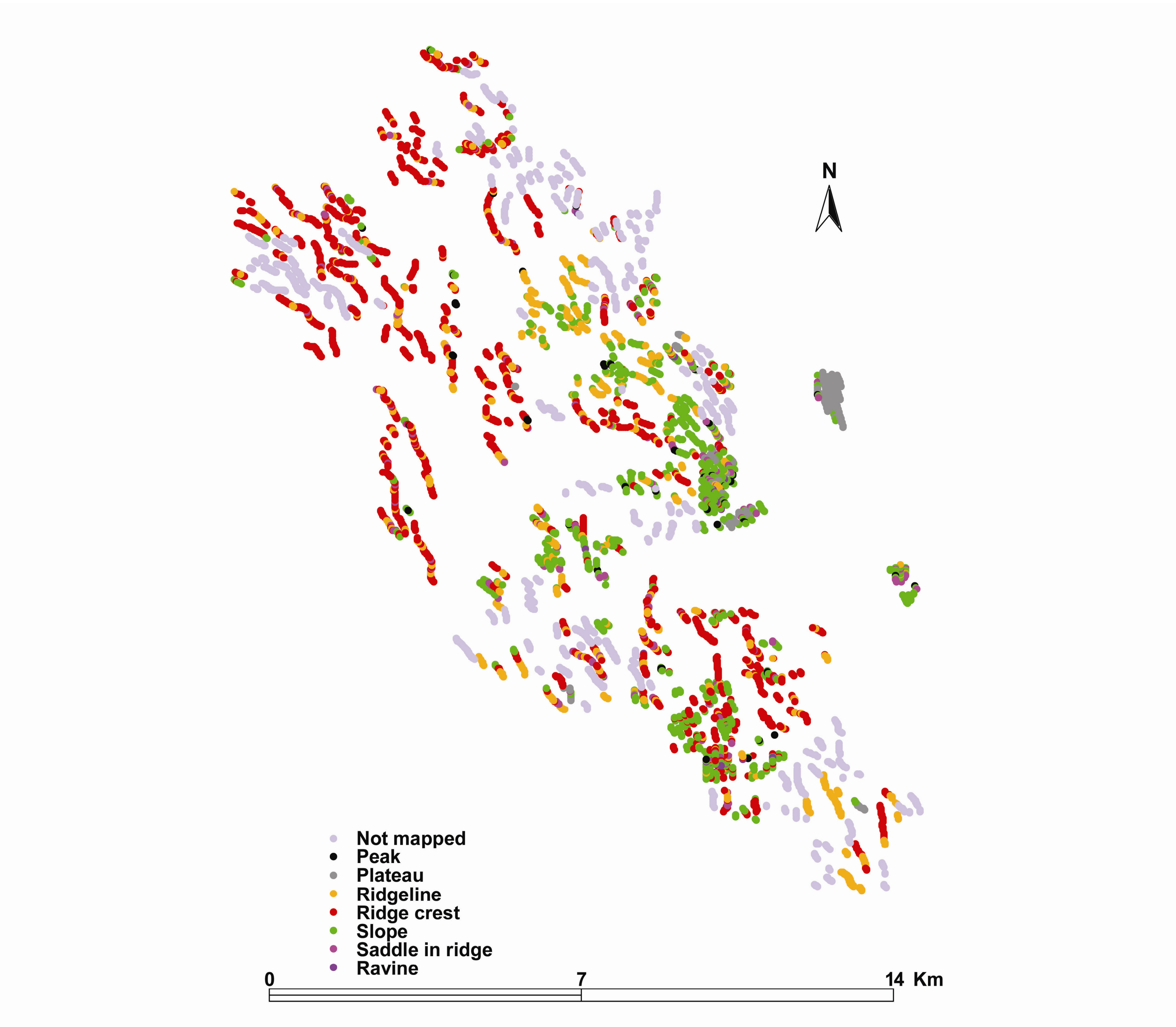

Figure 1-5. Distribution of wind turbines on various types of topographic features in the APWRA

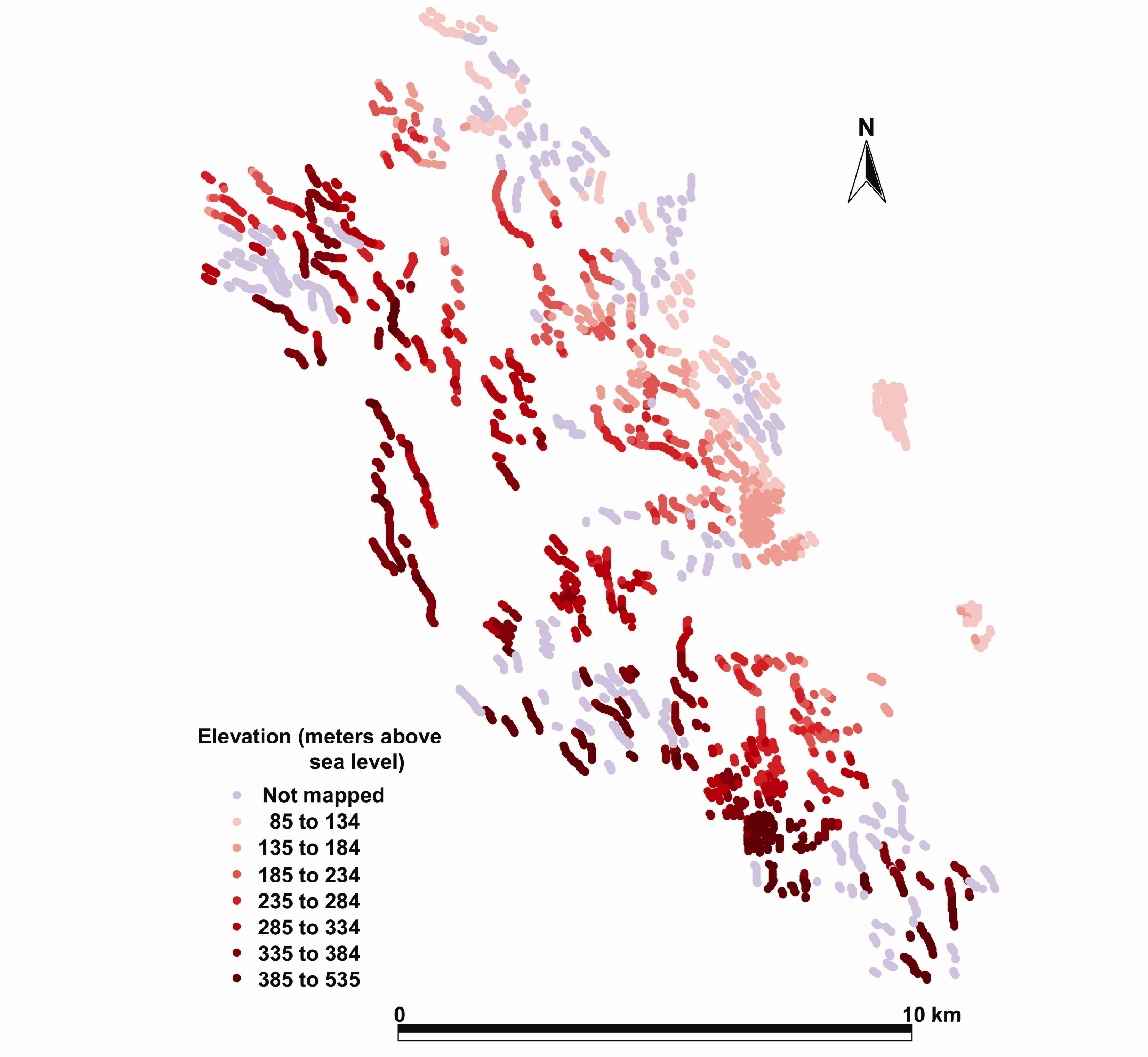

Figure 1-6. Distribution of wind turbines by elevation in the APWRA

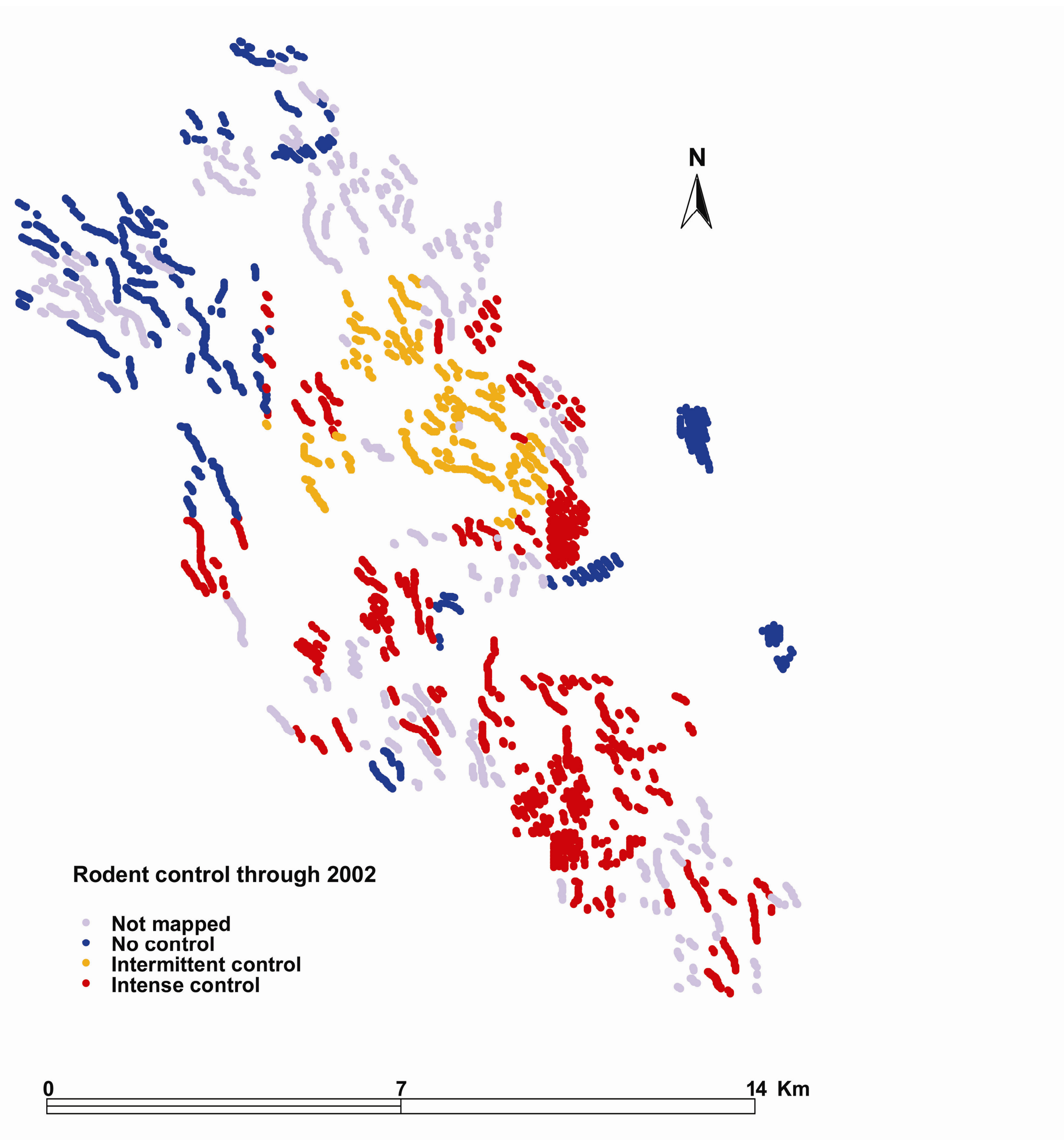

Figure 1-7. Distribution of wind turbines among levels of rodent control implemented in the APWRA during 1997–2002

Rodents and lagomorphs burrow under the wind tower pads where none existed before the APWRA was created. Rodents burrow into artificial berms created by access roads and into cut slopes. Lizards find shade and shelter under lattice towers. Cattle find shade and perhaps some other comfort near tubular towers. Where cattle spend their time, there will be more cattle pats and a greater foundation of a food web. Birds use the turbine towers as perching sites from which to loaf or hunt, and raptors hunt for prey that are attracted to the artificial substrate of the wind towers.

To uncover and understand the patterns of bird mortality at a wind farm one must first interpret the influences on wildlife ecology that are caused by wind turbines. They are artificial structures installed in an otherwise natural setting that can have a profound influence on how arrays of inter-related landscape components function. Pursuing just such an understanding became the basis for designing and conducting the research project described in this report.