National Park Service's Intermountain Region Noxious Weed Inventory and Mapping Progam

Petrified Forest National Park Invasive Plant Survey and Mapping: 2002–2005

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U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph showing a sand dune where the invasive plant *Salsola* sp. (Russian thistle) has replaced native plants, Petrified Forest National Park, Arizona. (U.S. Geological Survey photograph.)

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Petrified Forest National Park Invasive Plant Species Survey and Mapping: 2002–2005

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Abstract

We conducted a survey for invasive nonnative plant species at Petrified Forest National Park from 2002 through 2005. The survey employed a unique sampling design consisting of a grid of consecutive one-hectare cells as the sampling units. Our use of predetermined sampling units allowed all observations to be referenced to a fixed area with geographic coordinates that easily transferred to a geographic information system. Our field team surveyed 2,730 sampling units in three select areas for at least 1 year and 879 sampling units for 4 years. During this period we identified 40 different invasive plant species; more than half the invasive plants (22 species) were annual forbs and grasses. Four invasive plant species occurred in 25 percent or more of all sampling units observed in one or more years: *Bromus tectorum*, *Erodium cicutarium*, *Salsola tragus*, and *Sisymbrium altissimum*. *Salsola tragus* was the most abundant species in all years and occurred in more than 55 percent of all sampling units surveyed each year.

Introduction

Throughout the Southwest, invasive nonnative plant species (invasive plants) are of concern to land managers because of their ability to compete with native species, alter ecological processes, and change hydrologic regimes (Vitousek, 1990). Natural resource management requires planning for invasive plant management; identification of the invasive plants present and determination of their distribution and abundance is a needed first step. The National Park Service's Intermountain Region Noxious Weed Inventory and Mapping Program provided funding for a survey of invasive plants at Petrified Forest National Park from 2002 to 2005 to help the Park manage their natural resources.

One objective of the inventory was to inform the Park resource management staff of the status of invasive plants in select areas of the Park, including which invasive plants were present, where they were distributed, and an estimate of their abundance. A second objective was to incorporate the inventory results into ongoing Park-wide invasive treatment management planning. Park management was interested in using the invasive plant inventory and resulting maps as part of their ongoing Wilderness Management Planning and General Management Plan Revision. The Park had issues with trespass grazing, especially around Puerco River and Rainbow Forest, and wanted to use inventory data to develop immediate management actions, including selecting priority areas for treatment. Also, resource management had concerns about ongoing rehabilitation and repair projects which could result in the transport of invasive plant propagules to other park areas without active weed management. The third objective of the study was to develop a systematic survey and reporting technique that allowed for continued monitoring of invasive plant occurrence and the outcome of control actions within the Park.

Petrified Forest National Park (NP) resource management identified areas of invasive plant management concern in the Park in early 2002. The U.S. Geological Survey Southwest Biological Science Center team surveyed these targeted areas in 2002, 2003, 2004, and 2005. Initially the study period was to be for 3 years; however, we conducted a 4th year of partial survey in 2005 to document invasive plant response to the heavy precipitation of the winter of 2004–05.

This report describes the survey methodology and findings; it also includes an Access database with field data and a shapefile of the sampling grid used to conduct the survey. Metadata accompany both.

Petrified Forest National Park

Geography

The Petrified Forest National Park (NP) is located in the Lower Puerco River watershed in Navajo and Apache Counties, northeastern Arizona (fig. 1). At the time of the survey, its surface area was more than 147 square miles (approximately 38,000 ha). Areas bordering the Park include state lands, (mostly used for cattle grazing), private cattle ranches, and the Navajo Nation. The nearest town is Holbrook, Arizona, 22 mi (35 km) to the west.

The Park's average elevation is 5,500 ft (1,680 m) and elevations range between 5,340 ft in the Puerco River corridor to 6,230 ft at Pilot Rock (1,620 to 1,890 m). Gently rolling hills in the south and steeply eroded badlands in the north characterize the terrain. The Park is divided by the Puerco River into a northern section (added in 1932), protecting the natural resources of the Painted Desert region, and a southern section, set aside in 1906, to protect the petrified wood accumulations of Rainbow Forest, Crystal Forest, and other major outcrops in the area.

Interstate 40 (I-40) bisects the Park in the east-west direction in the northern section. The north-south Park Road connects I-40 with Highway 180 south of the Park. Former Route 66 in the northern section and old Highway 180 in the southern section also cross the Park. Both are in deteriorating condition and are closed to the public. There are also a number of dirt roads of different ages and origins. Many of these are closed to public traffic and serve park-maintenance needs.

Climate

Two weather stations exist at the Park, one in the south at Rainbow Forest (table 1) and one in the north at the Painted Desert Station (table 2). They provide a view of the climate of Petrified Forest NP from 1973 until present (see Western Regional Climate Center http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?az6190 and http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?az6468).

Precipitation

Two distinct precipitation periods provide moisture to the Park, one during the winter months and the other during the summer months. Petrified Forest NP experiences drier months in the spring (April, May, and June). The total annual rainfall in the Park is approximately 10.6 in. per year in the north and 9.5 in. the south.

The Mogollon Rim, which stretches across the central part of Arizona, influences winter storms reaching the Park. Petrified Forest NP is located on the rain shadow side of this mountainous region. During the winter, precipitation originates from low-pressure systems that travel eastward from Southern California and deposit snow and rain as they encounter the Mogollon Rim. Often only a little ground accumulation of snow and rain actually reaches the Park. When precipitation does occur from winter storms, it is often characterized by gentle showers followed by strong winds.

Summer storms originate from monsoon-like weather arising in the Gulf of Mexico. These storms are more frequent than winter storms and often consist of heavy isolated rain with excessive runoff resulting in much soil erosion.

During the years the survey was conducted, annual rainfall varied between 5.24 in. and 11.23 in. in the south and between 7.3 in. and 10.58 in. in the north. The driest year was 2003 and the wettest 2004 in both the north and south. However, the seasonality of rainfall was variable. The winter rainfall in 2002 was extremely low (<1.25 in. at both stations) and high in the spring of 2005 (4.29 in. Rainbow Forest and 6.04 in. at Painted Desert Station). Summer precipitation was low in the summer of 2003, particularly for the southern station (1.77 in.).

Temperature

Winter is a variable season at the Park, ranging from warm winter temperatures in the sixties Fahrenheit (F) to extreme subzero temperatures. Mid-summer daily temperatures occasionally exceed 100° F, but low humidity and clear skies generally tend to keep summer nights cool. On average, the maximum temperature for July, the warmest month, is 92° F and the minimum temperature, for July also, is 60° F.

Winds

High winds are a feature of the Painted Desert Basin and derive from slope winds on the east side of the San Francisco Peaks to the west (Smiley and others, 1984). During the spring, wind speeds of about 20 knots (about 23 mph) are common (Smiley and others, 1984).

Survey Area

Three areas of Petrified Forest National Park were surveyed (fig. 2): the northern Headquarters (HQ) adjacent to Interstate 40 and the Park's north entrance; the Puerco River bottomlands in the middle section of the Park (Puerco); and a third section at the southern Park entrance (Rainbow). We selected these three areas in consultation with Park natural resources staff. These areas included developed features, such as transportation and utility corridors, visitor centers, and Park offices and housing. They also included large areas of undisturbed natural areas, such as riparian corridors, grasslands, sand sage flats, sand dunes, and naturally barren and sparse vegetation. The natural areas were believed to be at highest risk for invasive because of their proximity to the developed features, which promote invasive propagule introduction and spread.

Methods

Sampling Design

We developed a spatial grid of sampling units in a geographic information system (GIS) for the areas of the Park to survey (fig. 3). The initial grid consisted of 2,889 one-ha (100 m^2) sampling units distributed such that the northern area, HQ, had 1,459 sampling units; the Puerco sampling area had 336 units; and the southern area, Rainbow, had 1,094 units.

The spatial grid was a regular lattice of cells, each representing a one-hectare square sampling unit, with the center of each hectare occurring 100 m from adjacent sampling units (fig. 3). We selected the center-point coordinates for each sampling unit to occur at even intervals. For example, if the center coordinates of the first sampling unit were 607700 UTM easting and 3878400 UTM northing, then the coordinates of the sampling unit directly to the east were UTM 607800 easting and UTM 3878400 northing. We first created a grid for the entire Park and then divided it into three sampling areas. Once the three subsets were established, we numbered each unit, starting with “1” at the grid cell representing the northernmost and westernmost sampling unit, continuing to the grid cell representing the last sampling unit numbered 2,889. The grid was created using Universal Transverse Mercator (UTM) projection, zone 12, North American Datum of 1927.

Field Survey Methods

We developed a list of potential invasive plants at the Park by listing all State and Federal noxious invasive plants known to occur in northern Arizona or in adjacent areas of Utah, Colorado, and New Mexico. Park staff reviewed this list and added invasive plants known to be of management concern, resulting in an initial list of 37 potential invasive plants.

The field team used a Trimble® Geoexplorer 3 Global Positioning Satellite unit programmed with GPS Pathfinder Office 2.90 (GPS) for navigation and to support direct data entry into the GPS. The central geographic coordinates of each sampling unit were entered into the GPS as waypoints that the field team could use to navigate to and within each unit. The GPS was programmed with a drop-down menu listing the 37 possible invasive plants. We added new invasive plants to the drop-down-menu when they were first observed. The drop-down menu also provided six cover categories: (1) none (no invasive plants present), (2) >0–1 percent cover of invasive plants, (3) >1–5 percent, (4) >5–25 percent, (5) >25–50 percent, and (6) >50–75 percent.

Sampling was conducted on the one-hectare sampling units from late in the summer monsoon season into the late fall during each sampling year except 2005. The 2002 season survey was conducted from the first week of September until the first week of December; the 2003 survey was conducted from the second week in August to the first week in December; the 2004 survey was conducted from the second week in September until the second week in November. In the final year, 2005, the survey was conducted in late May and early June and was targeted that year toward areas with known infestations.

During the first sampling season, informal transects were walked in each of the four cardinal directions from the center of a sampling unit in order to make observations on the occurrence and abundance of the invasive plants (fig. 4). The field observer navigated to the center of a unit using the unit’s GPS waypoint and an entry line oriented to a cardinal direction. As the observer entered the unit and navigated to the centerpoint, he/she scanned along that transect for the invasive plants. At the centerpoint, geographic coordinates were obtained and downloaded into the GPS to verify that observer’s actual location was the same as the waypoint. At the centerpoint, the observer did a broad visual sweep, particularly for potential “hot spots” of invasive plants. After flagging the centerpoint, the observer then navigated 50 m towards the sampling unit edge at right angles to the entry line, scanning for invasive plants along the way. The field observer took a more arcing path on the return back to the centerpoint. If spotted a “hot spot” of invasive plants was spotted near this transect, the field observer moved to that area to make an evaluation. This transect observation line was repeated in the opposite cardinal direction. The field observer then navigated in the direction of the final cardinal direction, the exit transit, to the edge of the next sampling unit while finishing the sweeping visual scan. At the edge of the just-finished sampling unit, all invasive plants observed in the sampling unit and estimates of their cover were entered into the GPS using the drop-down menus. Anthropogenic effects, such as transportation and utility corridors and facilities, grazed areas (southern boundary and Puerco River), and construction sites, were recorded in a field notebook. Field samples of unknown invasive plants were collected for later identification.

From the first year's experience, we made some modifications in 2003 to the search strategy for each unit. The landscape in the Petrified Forest NP often lends itself to easy visual inspection because of its relatively flat nature and open vegetation structure. Repeat field observers also developed a better search image for invasive plants based on their work in 2002. The transect lines perpendicular to the entry/exit transect line were eliminated when the unit could be readily visually scanned from one transect line. This had the effect of halving the amount of walking in these sampling units and allowed the field team the opportunity to increase significantly the number of sampling units visited each day.

Data Management and Analysis

All field observations were downloaded daily from the GPS/datalogger and imported into an Access database developed for this project. The Access database structure was based on recommendations of the Intermountain Region (IMR) Weed Mapping Committee and the North American Weed Management Association (NAWMA; North American Weed Management Association, 2002). With a few exceptions, all elements required by the IMR Weed Mapping Committee and NAWMA standards were included. Those that were omitted were instead included in the metadata for the database. Some fields in the database were not required by the standards but were added for better documentation.

Results

Sampling Design

The sampling grid contained 2,889 sampling units for the three study areas, although not all units were visited. During the first year of sampling (2002), we eliminated 159 sampling units, mainly on the edges of the original study area. These units were in highly dissected and steep terrain that was dangerous to access. We did not observe all of the remaining 2,730 sampling units in each of the subsequent years. In 2002, 2,467 units were sampled; in 2003, 1,810; in 2004, 2,624; and in 2005, 983. Cumulatively, 879 sampling units were measured all four years, 904 for three years, 707 for two years, and 240 for one (fig. 5).

The field observers recorded 11,837 observations during the course of the study, including observations of weed-free sampling units. Each observation consisted of the record of an invasive plant species presence and its cover estimate in a sampling unit during one yearly visit.

The sampling grid (PEFO_InvasivesSamplingGrid) and the observation database (PEFO_InvasivesDatabase) are available with this report in shapefile and Access format, respectively. Metadata accompany both.

Field Results

A total of 40 invasive plants were observed (table 3). In each of 2003, 2004, and 2005, additional species were added to the list as they were discovered in the field. The original listing of 37 species was also corrected, as some species originally on the list were identified as native, albeit weedy. The final listing comprises nonnative plant species only. The invasive plants found included 4 trees, 2 shrubs and subshrubs, 6 grasses, and 27 forbs. More than half of the invasive plants were annual (22 species), 13 were perennial, and 5 were biennial.

Twenty-eight of the species observed occurred in 1 percent or less of the sampling cells yearly and another 7 occurred in 10 percent or less of the sampling cells yearly. Four invasive plants occurred in 25 percent or more of all sampling units observed in one or more years: *Bromus tectorum, Erodium* *cicutarium, Salsola tragus,* and *Sisymbrium altissimum*. *Salsola tragus* was the most abundant species in all years and occurred in over 55 percent of all units surveyed each year. *Bromus tectorum, Erodium cicutarium*, and *Sisymbrium altissimum* varied in frequency depending upon the year, with *Sisymbrium altissimum* being observed with highest frequency in the 2005 survey. These trends were seen both in all sampling units (table 4) and in the subset of 879 sampling units measured all years (table 5).

Each survey year a number of sample units had no invasive plants (fig. 6). A total of 119 sampling units, or 4.4 percent of the study area, were sampled either 3 or 4 years and had no invasive plants, and 286 sampling units, or 10.5 percent of the study area, were sampled 1 or 2 years and had no invasive plants. When the sampling units measured all 4 years are considered, the number of units with no weeds varied from year to year, with 2003 and 2005 being years with the least number of weed-free sampling units and 2002 being the year with the highest number of weed-free sampling units.

Infestation cover was estimated within each sampling unit in which an invasive plant was found. Twenty-nine invasive plants consistently had low cover (<1 percent), regardless of year. Three invasive plants had infestations greater than 25 percent in one or more sampling units (table 6): *Elaeagnus angustifolia, Tamarix chinensis,* and *Salsola tragus.*

The highest cover of invasive plants, regardless of species, for each sampling unit is shown in figure 7. Visual observation shows a distinct pattern of highest cover along road corridors and along the Puerco River. A similar pattern was observed for invasive-plant richness; that is, the number of different kinds of invasive plants found among all observation years in each sampling unit was highest along primary and secondary road corridors, the Puerco River, and the southern park border (fig. 8).

Maps of the distribution of each invasive plant, indicated by highest cover observed at each sampling unit between 2002 and 2005 are presented in appendix 1 (1.1 through 1.40).

Discussion

Invasive Plants of Concern

Not all invasive plants are equal in their known or predicted impacts or in the legal mandates for their management. The invasive plants found at Petrified Forest National Park can be categorized by three parameters—their legal designation, probable impact, and extent (table 7).

The Arizona Department of Agriculture designates which plant species are noxious in the state (http://www.azda.gov/PSD/quarantine5.htm). Three designations exist: prohibited (prohibited from entry into the state), regulated (if found within the state may be controlled or quarantined to prevent further infestation or contamination), or restricted (if found within the state shall be quarantined to prevent further infestation or contamination).

Three independent review panels have developed invasive-plant impact rankings. These panels consist of the The Arizona Wildlands Invasive Plant (AZ-WIP) working group (Warner and others, 2003), the California Invasive Plant Council (Cal-IPC) (California Invasive Plant Council 2006), and NatureServe (Morse and others, 2004).

Table 7 shows the extent of infestation for invasive plant species as determined in the survey. The extent of infestation is indicated by the highest number of sampling units in which the plant occurred during the study period.

Twelve invasive plants found at Petrified Forest NP are prohibited, regulated, or prohibited and restricted in Arizona (table 7): *Acroptilon repens, Aegilops cylindrica, Alhagi maurorum, Cardaria draba, Carduus acanthoides, Centaurea diffusa, Centaurea solstitialis, Cirsium arvense, Convolvulus* *arvensis, Halogeton glomeratus, Linaria dalmatica,* and *Tribulus terrestr*is. Infestations of these 12 invasive plants are localized in 1–6 sampling units, except for *Tribulus terrestris* (70 sampling units) and *Centaurea solstitialis* (14 sampling units).

At Petrified Forest NP, eight invasive plants are ranked as having potentially high impact by one or more of the impact rankings (table 7): *Acroptilon repens, Bromus rubens, Bromus tectorum, Centaurea solstitialis, Elaeagnus angustifolia, Halogetonglomertus, Polypogon monspeliensis,* and *Tamarix chinensis*. Three of these (*Bromus tectorum*, *Elaeagnus angustifolia*, and *Tamarix chinensis*) occurred in 50 or more sampling units at their highest occurrence. Three of the eight (*Acroptilon repens, Centaurea solstitialis,* and *Halogeton glomeratus*) are considered prohibited and restricted in Arizona

An additional five invasive plants occurred in 50 or more sampling units at their highest occurrence but did not have legal designation or high impact ranking. Notable among these were *Sisymbrium altissimum,* with 307 units in 2005, and *Salsola tragus,* with 1,738 sampling units in 2004 (table 7). *Sisymbrium altissimum* had high occurrence after heavy spring rains in 2005. *Salsola tragus* (appendix 1.31) was ubiquitous. The AZ-WIP gave it a medium impact rating; however, the extent of its distribution within the park and observations of it replacing native vegetation on dunes suggest that its impacts on native vegetation in the Park should be investigated (fig. 9). The other invasive plants occurring in more than 50 sampling units are *Erodium cicutarium, Kochia scoparia,* and *Lactuca serriola.*

Areas of Concern

Given that nonnative invasive plants are often reliant on anthropogenic influences to aid their spread, many of the distribution patterns observed within Petrified Forest National Park are as expected. Major transportation corridors bisecting the Park, such as Interstate 40, U.S. Highway 180, the main park road, and the busy Santa Fe Railroad line along the Puerco River, show high invasive plant cover and richness and serve as a constant source of propagules into other Park habitats. Secondary corridors (such as abandoned utility corridors, roads, and tourist facilities) and natural weather phenomena such as prevailing wind patterns could further the advance of invasive plants, either by providing suitable, though highly localized, habitats or by aiding the dispersal of these invaders along and away from Park roads and utility corridors.

The sampling units with the highest diversity of invasive plants are especially clustered around areas with intensive stop-and-go auto traffic: the Park's north entrance interchange along Interstate 40; the northern HQ and visitor's center (includes the residential and office complex and the sewage treatment facility); the sewage treatment complex near the Puerco River; the Puerco River itself; the Rainbow visitors' center in the Rainbow unit; and the southern entrance station.

The greatest concentrations and abundances of nonnative invasive plants are along the length of the interstate highway, especially around the exit and entrance ramps that lead to the northern entrance; the northern and southern visitors' centers; Jim Camp and Cottonwood Washes in the southern unit; and the Puerco River corridor. The influx of species into the area along the freeway is aided by vehicles and, for some species, probably by the local wind that fast-moving vehicles generate. Runoff from the asphalt and barren ground along the roadsides and within the center dividers can provide much more moisture to roadside plants and propagules than to those further from the road. Other high concentrations of infestation also occur in the swales created within the depressions of the center dividers. Construction along the onramps and offramps and the new parking area near the northern entrance constructed during the study provided disturbed substrate that favors quickly germinating opportunists. Another potential introduction point is the construction and landscaping in and around both the north and south visitors' centers.

The northern headquarters and visitor's center provide a variety of suitable substrates and habitats that can promote germination and maintenance for a wide variety and great abundance of invasive plants. Vectors in the form of heavy visitor traffic presumably aid in the dispersal of invasive plants from the freeway into the Park. Other concentrations are usually found along the main asphalt road that runs the length of the Park. (This corridor was mowed before the start of the 2004 survey, and the reduced numbers of nonnative plants detected are reflected in the data). The phenomenon of increased invasive plants associated with rain runoff from asphalt is repeated in the small parking lots at each of the overlooks along the drive. The southern visitors' center at Rainbow Forest provides a smaller version of the same issues found at the northern center.

The Puerco River is unique in that it provides both an artificial corridor (railroad line) and natural corridor to nonnative invasive plant dispersal. Not surprisingly, riparian and phreatophytic nonnatives (*Tamarix* spp. and *Elaeagnus*) thrive in this setting and in the smaller scaled ephemeral drainages such as Jim Camp and Cottonwood Washes in the southern unit. *Salsola tragus* and *Bromus tectorum* reach some of their highest cover values among the dunes across the floodplains of the Puerco River. Exacerbating conditions along the Puerco River are the effects of intensive cattle grazing. The fencing for this section of the Park is all but destroyed; hence this section is vulnerable to trespass grazing.

Three more trouble areas are the sewage treatment ponds found in each of the survey units. The open water does not seem to be an influence where the plastic embankment covers are in place. However, the drying ponds are full of mud, and this habitat, along with adjacent construction disturbance and repeated visits by Park maintenance vehicles, provides islands of habitat for abundant invasive plant growth.

Seasonality and Observations

The timing of rainfall during each survey year was highly correlated with the abundance and types of invasive plants observed. In the initial year, 2002, winter rainfall was lower than normal and the summer monsoons did not strongly initiate until late August. In the early part of the summer, before the summer monsoons, invasive plants were not obvious, so initiation of the survey was postponed until late summer. Invasive species strongly responded to the late summer rainfall and that year had the highest percentage of sampling units with invasive plants (37.8 percent). In subsequent years, except for 2005, we initiated surveys later in the summer so that the survey times were similar to this first year of the survey and so that we captured the response of invasive species to the summer rainfall.

Total rainfall in 2003 was less than in 2002. However, the distribution of the rainfall throughout the season made an apparent difference in the nonnative plant species observed that year. In 2003, winter rainfall was greater, and although the monsoons had overall lower total precipitation, they initiated earlier than in 2002. This may have accounted for the increased observation of such species as *Bromus tectorum* and *Kochia scoparia* in 2003.

In 2004 overall precipitation was significantly greater than in 2003, particularly during the monsoon season. However, any increase in invasive plant germination and growth that would have resulted may have been undercut by the mowing of roadsides in areas that hosted such invasive plant growth. Furthermore, construction and cutting in and around the northern headquarters may have eliminated most of the plants that would otherwise have been observed. There was also a similar decrease along the freeway corridor. The surveyors noticed evidence of what may have been mowing along the berms and medians.

The 2005 survey was conducted specifically to document the extensive invasive plant infestations noted after abundant spring rains that year. Although the area sampled in 2005 was biased toward those areas with high infestations, three species appeared to be particularly responsive to the early rainfall: *Bromus tectorum, Erodium cicutarium,* and *Sisymbrium altissimum.* Although we only recorded observations in the early part of the summer in 2005, informal observations in the early summer of previous years indicated that high presence of invasive plants in the spring depended upon abundant winter and spring rainfall. For example, the senescent stalks of *Sisymbrium altissimum* will usually remain standing through summer. However, senescent stalks were not noticed in the previous surveys, indicating that any spring germination and establishment of this invasive plant was minimal then and that the prolific 2005 bloom was correlated with the high total rainfall in the late winter and spring of 2005.

Our survey results and informal observations made apparent that the timing and amount of precipitation was a primary driver of the seasonal germination and establishment phenology of the annual and nonwoody perennial forbs and grasses at Petrified Forest NP. Germination and growth of annual species was highly correlated with yearly precipitation patterns, and the size of plants later in the season was influenced by the magnitude of summer rainfall. The relationship between seasonal rainfall variability and plant growth makes cover a poor estimator of the actual number of plants present, because years with more abundant rainfall resulted in larger and more easily detected plants but not necessarily more plants in a given sampling unit. Regardless of the rainfall in a given year, these more ephemeral species are present in the soil seedbank and are capable of responding opportunistically when rainfall conditions are suitable. This was particularly apparent in the spring of 2005, when *Sisymbrium altissimum* was prolific but had been only minimally present above ground in previous years.

Sampling Design

This survey employed a novel sampling design through the use of a sampling grid standardized to geographic coordinates. The grid provided a framework for field work, allowed direct geographic comparisons of infestation observations among the sampling years, and was a convenient structure for data curation and graphic display. Alternative methods of mapping include the use of fixed points to describe infestations of variable size or of delineated polygons of infestations. The method used in this survey avoided the subjectivity of determining an infestation boundary, as often occurs with delineated polygons. In contrast with fixed-point documentation, the sampling-grid method provides surfacewide documentation of infestations and documents absence of infestation. It provides a more rigorous way to capture variations in infestation cover over time.

Detection

With any invasive plant survey, particularly one that is covering an extensive area, the probability of missed detection is a concern. Several environmental factors influenced detection of invasive plants within a sampling unit. The timing and magnitude of rainfall, as noted above, influenced a plant’s size, with drier summers resulting in smaller, less obvious plants. Seasonality of rainfall influenced the probability of germination for any one sampling year. We attempted to maximize detection for any one year by surveying later in the season to capture the peak of invasive plant growth response to summer rains. However, we only surveyed early in the season in a year with heavy spring rain and cannot discount the presence of spring-established invasive plants until a survey is conducted in the spring of a drier year.

Human factors were also an influence in detection. Most of the survey was conducted by one surveyor who followed a consistent protocol. However, several other surveyors contributed. The use of a standardized protocol for making observations in a sampling unit was adopted to minimize human variation in invasive plant detection. The Park management activities also influenced the field team's observations. Roadside mowing reduced the probability of detection, and active management of saltcedar reduced the actual number of invasive plants to detect.

We believe the use of the continuous sampling units provides an additional check against missed invasive plants. The detection of an invasive plant species in one sampling unit implies a higher probability of the invasive plant species occurring in adjacent sampling units. This 'neighborhood' feature of the sampling units can be useful in planning invasive plant management.

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Figures

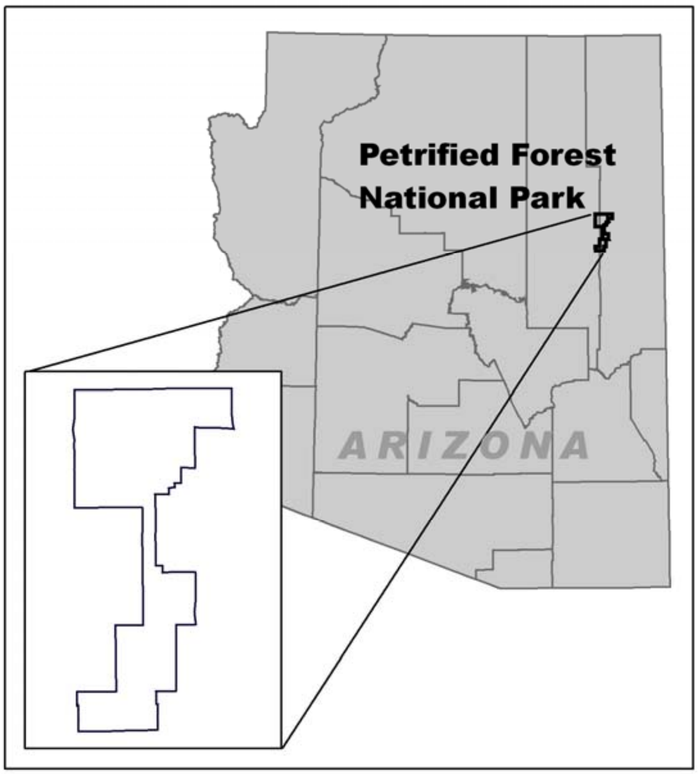


Figure 1. Location of Petrified Forest National Park in Arizona.

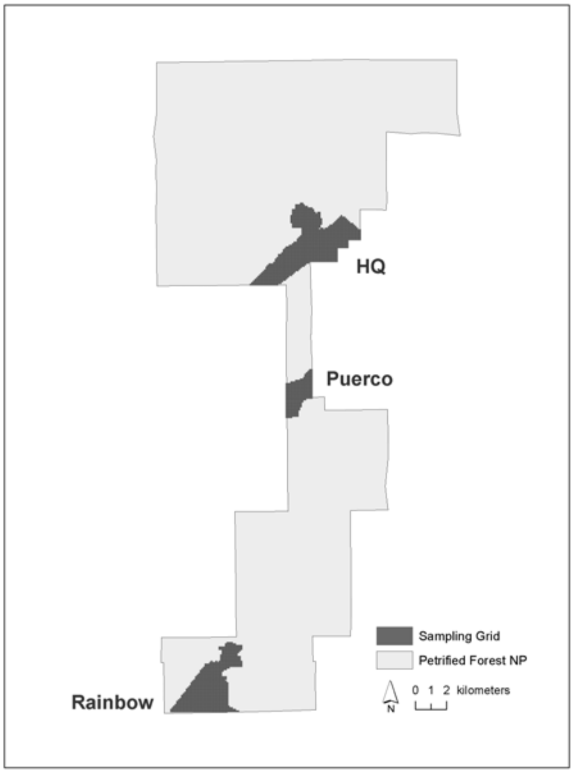


Figure 2. Locations of three invasive plant survey areas (sampling grids) at Petrified Forest National Park: Headquarters (HQ), Puerco, and Rainbow.

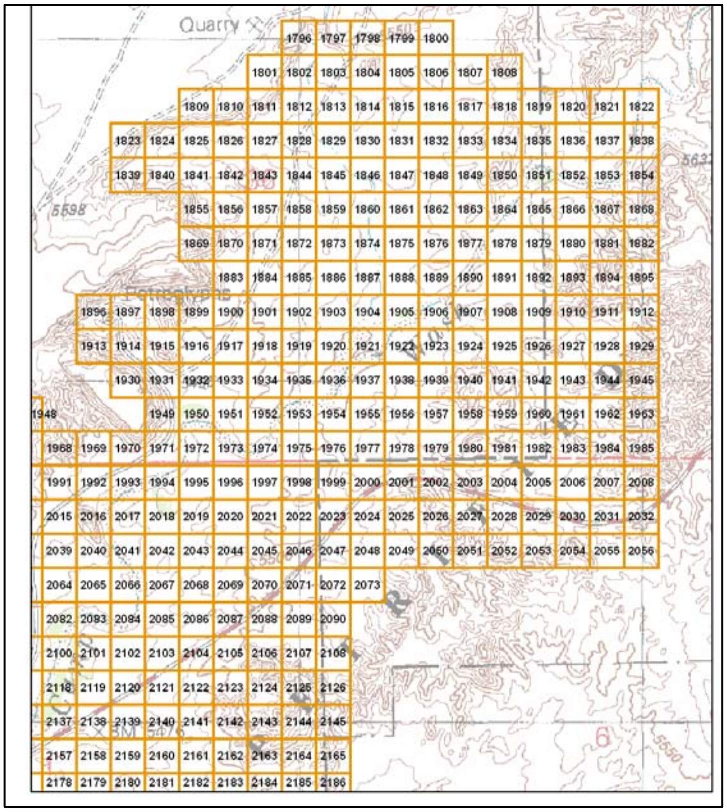


Figure 3. An example of the sampling grid for the eastern part of the Rainbow study area. Each one-hectare sampling unit is represented by a grid cell in a GIS. The centerpoint of each sampling unit is referenced so that it is 100 m from the centerpoint of each of its four neighboring sampling units.

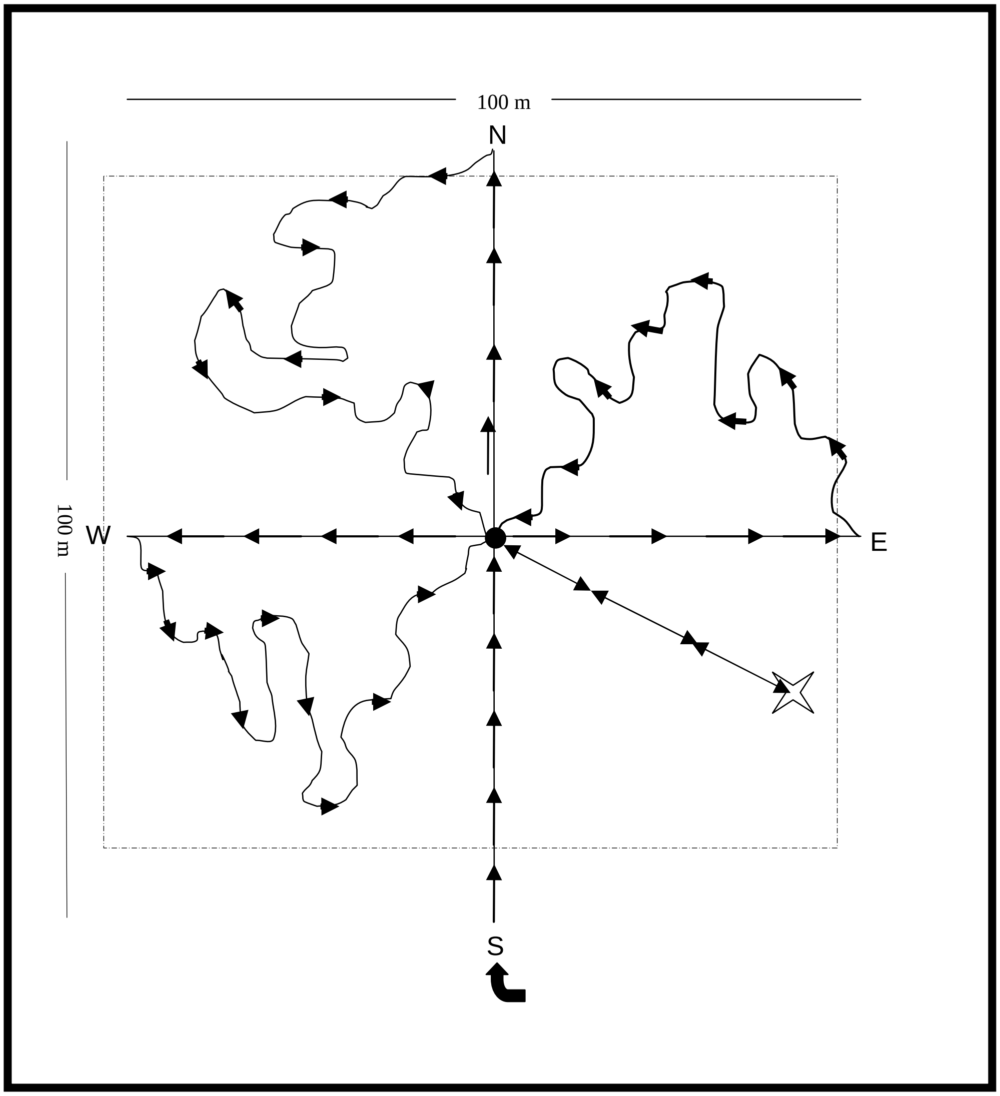


Figure 4. Diagram illustrating the informal transects within each 100-m^2 (1 ha) sampling unit used for sampling in 2002. The landscape on these sites was open, which facilitated the observer's ability to visually sweep the unit. When necessary, the observer moved away from the informal transect to verify invasive plant occurrences, such as illustrated by the star in the lower right quadrant. In 2003, the transect lines running from the centerpoint west and east were eliminated if the unit could be readily scanned from the north-south transect.

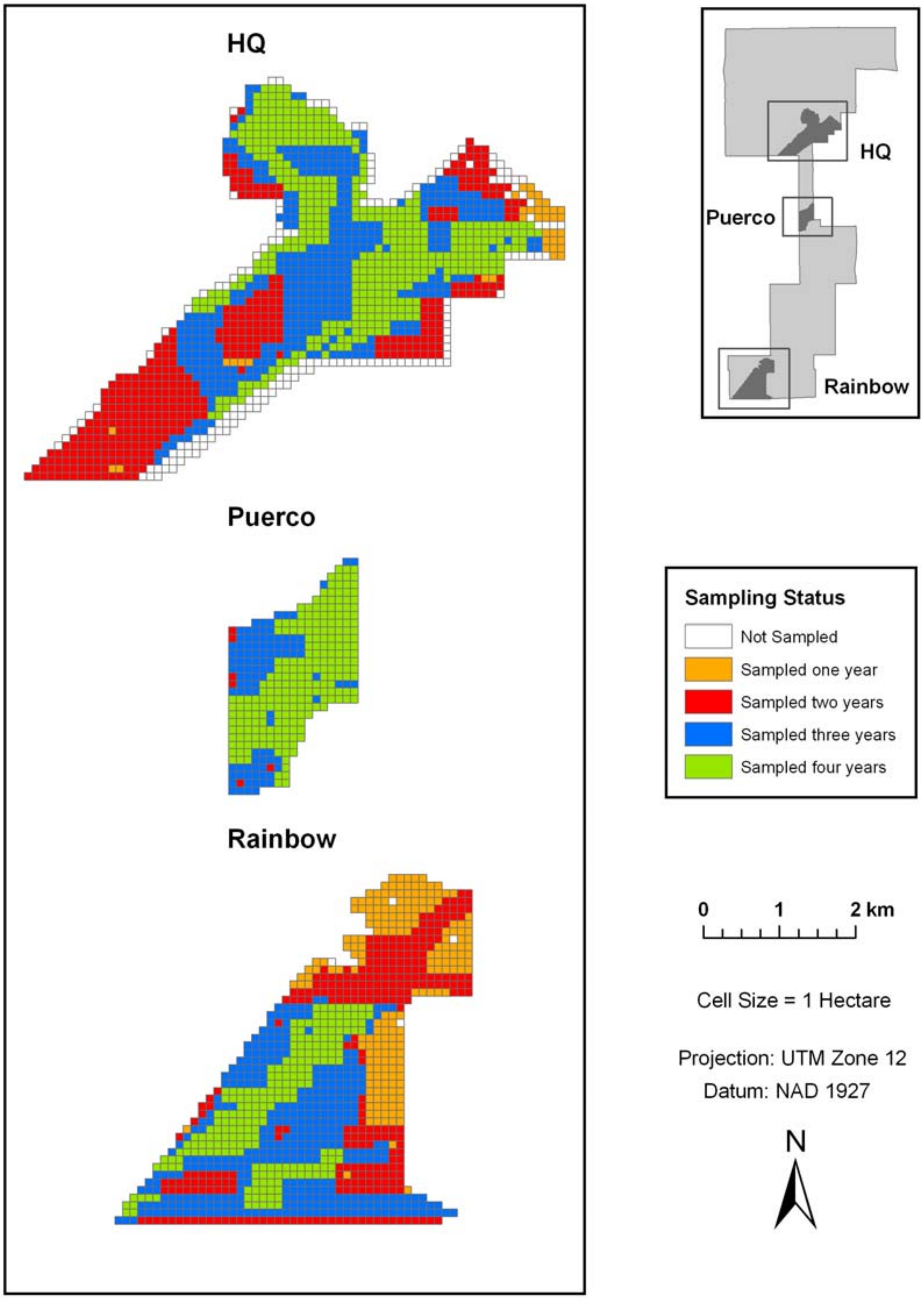


Figure 5. Number of years in which each sampling unit in each of the three sampling areas of Petrified Forest National Park was observed from 2002 to 2005.

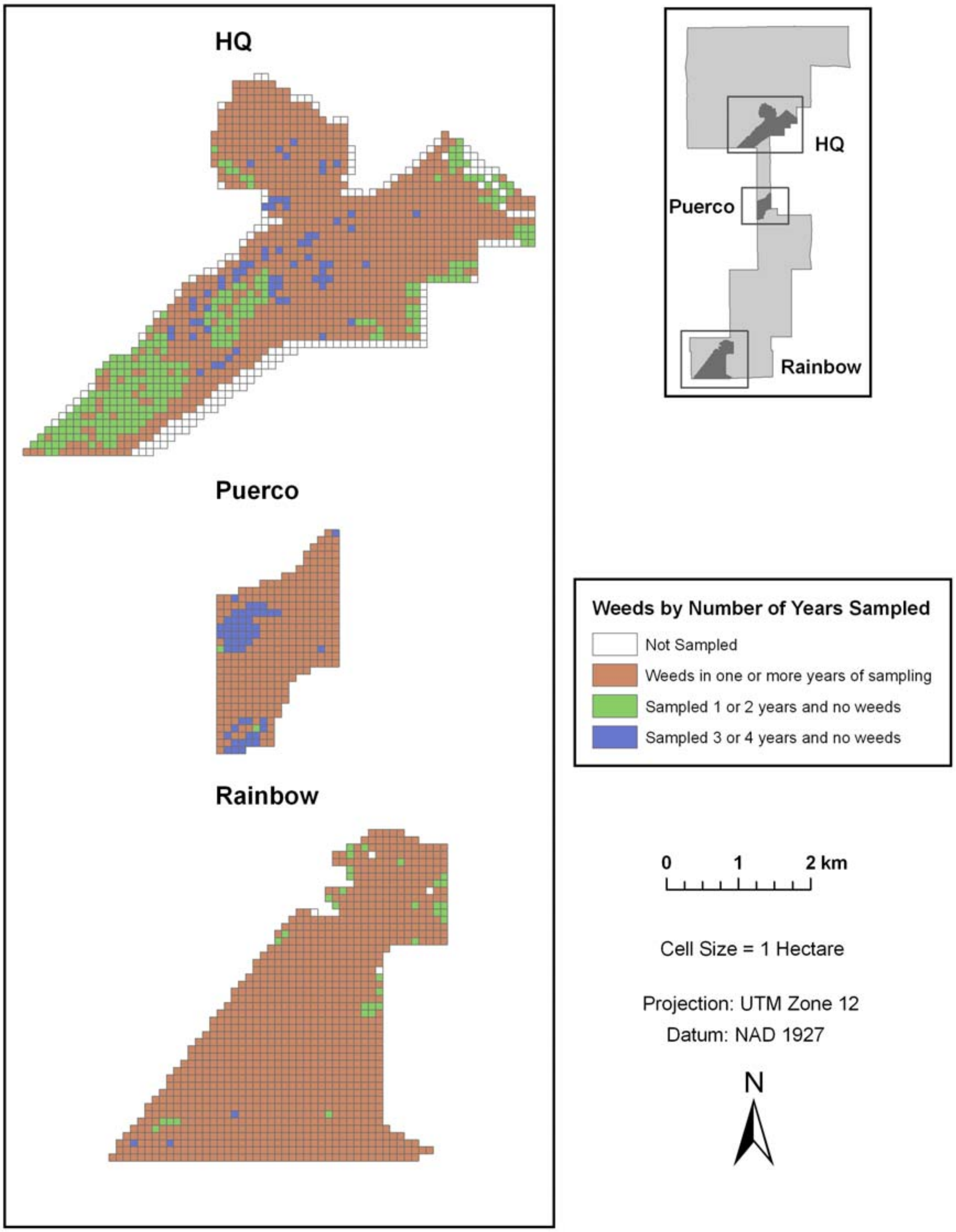


Figure 6. Sampling units free of invasive plants compared to sampling units with invasive plants (weeds) in one or more years of sampling from 2002 to 2005, Petrified Forest National Park.

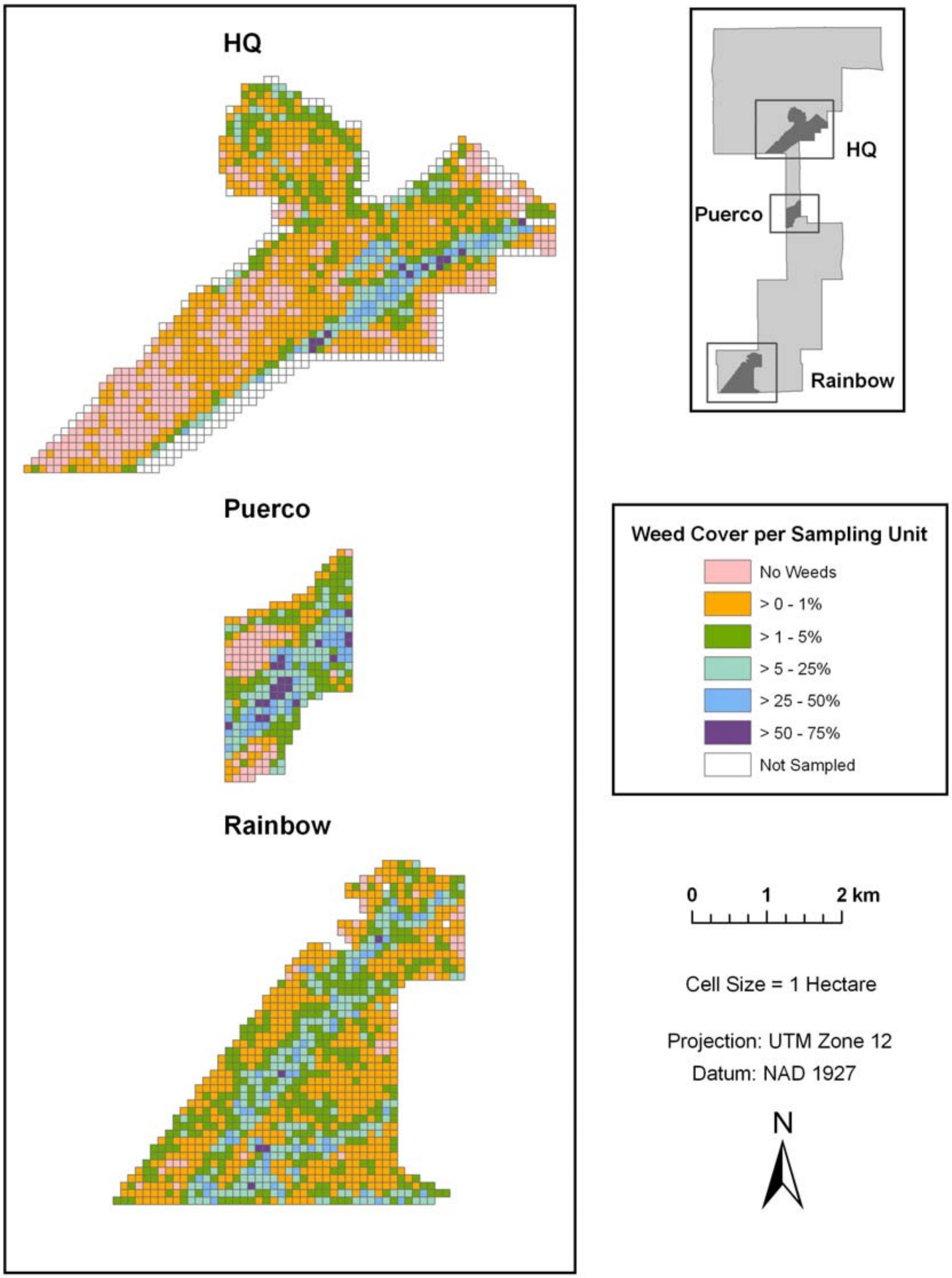


Figure 7. Highest cover category (for any invasive plant observed) in sampling units at Petrified Forest National Park in the 2002–2005 study period.

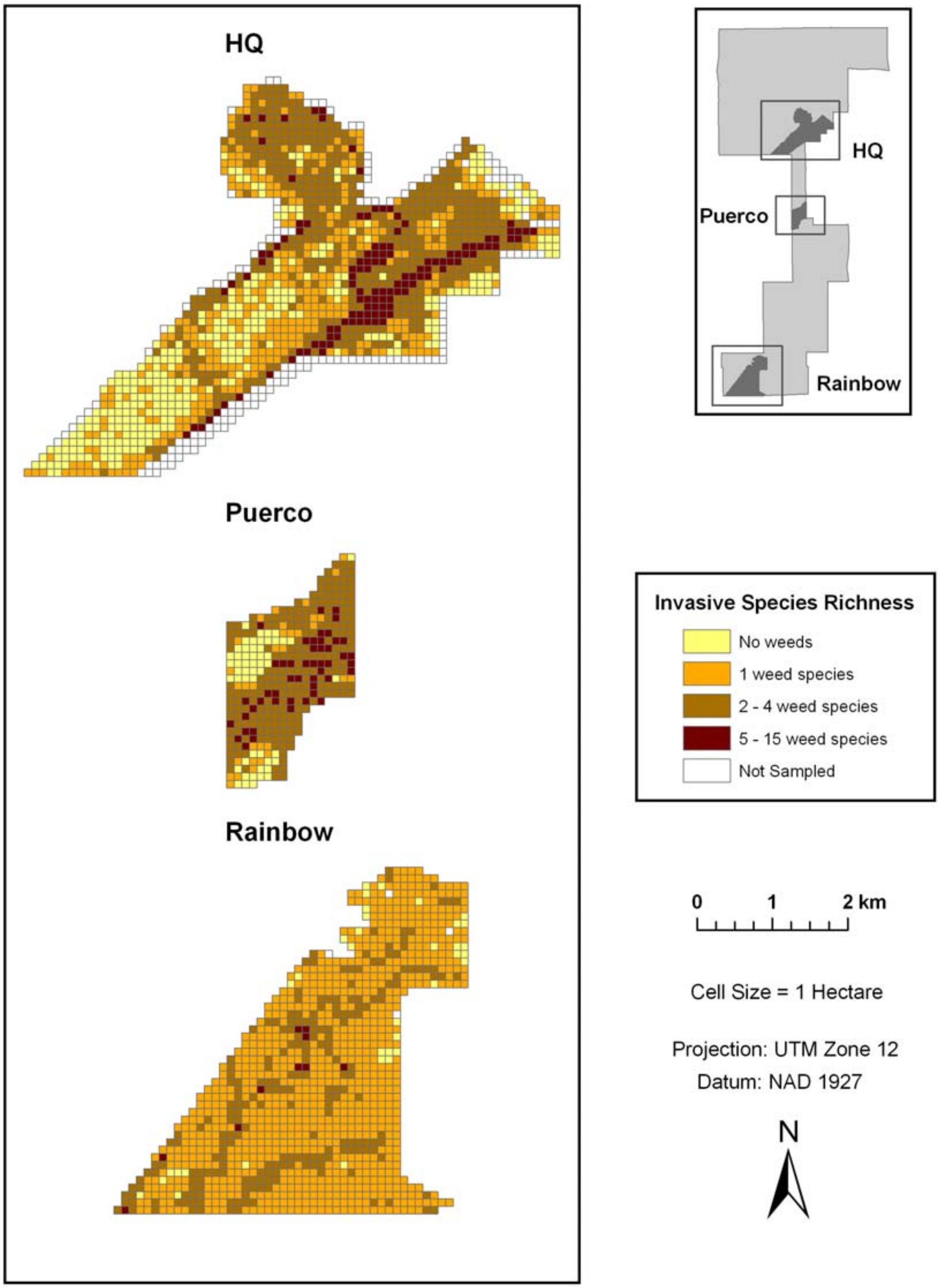


Figure 8. Total invasive-plant species richness observed in sampling units at Petrified Forest National Park in the 2002–2005 study period.

Figure 9. Example of *Salsola tragus* infestation on a sand dune at Petrified Forest National Park. The *Salsola* (Russian thistle) dominates the native vegetation and appears as both brown dead annual plants from previous years and green current year's growth.

Tables

Table 1. Rainbow Forest station monthly total precipitation (inches). [1]

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2002	0.24	0.02	0.18	0.71	0.00	0.00	2.21	0.64	2.04	0.39	0.77	1.23	8.43
2003	0.20	1.63	0.47	0.21	0.01	0.26	0.10	1.35	0.32	0.53	0.36	0.00	5.24
2004	0.34	0.38	0.42	1.60	0.00	0.26	2.34	2.25	1.21	1.11	0.69	0.63	11.23
2005	0.89	2.51	0.89	0	0	0.5	0.38	1.8	0.28	0.19	0.04	0.01	6.15

[1] Petrified Forest National Park, Arizona (Petrified Forest NP http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?azpetr, accessed 01/03/07)

Table 2. Painted Desert station monthly total precipitation (inches). [1]

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2002	0.30	0.00	0.31	0.61	0.00	0.00	1.14	0.84	3.14	0.22	0.47	1.80	8.83
2003	0.03	1.31	0.51	0.29	0.00	0.22	0.48	2.78	0.67	0.45	0.56	0.00	7.30
2004	0.29	0.15	0.25	0.76	0.00	0.15	0.30	1.26	2.44	3.67	0.00	0.00	9.27
2005	1.17	2.82	1.23	.82	0.15	0.73	0.37	2.44	0.28	0.43	0.09	0.05	10.58

[1] Petrified Forest N P, Arizona (Painted Desert NP http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?azpain, accessed 01/03/07)

Table 3. Invasive plants observed in Petrified Forest National Park during survey, 2002–2005. [1]

Lifeform/duration	Scientific name	Common name
Tree/perennial	*Ailanthus altissima*	tree-of-heaven
	Elaeagnus angustifolia	Russian olive
	Tamarix chinensis [2]	tamarisk, saltcedar
	Ulmus pumila	Siberian elm
Shrub/perennial	*Alhagi maurorum*	Camelthorn
Subshrub/perennial	*Marrubium vulgare*	horehound
Vine/perennial	*Convolvulus arvensis*	field bindweed
Grass/perennial	*Cynodon dactylon*	Bermudagrass
Grass/annual	*Aegilops cylindrica*	jointed goatgrass
	Bromus rigidus [3]	ripgut brome
	Bromus rubens [4]	red brome
	Bromus tectorum	western cheatgrass
	Polypogon monspeliensis	rabbitsfoot grass
Forb/perennial	*Acroptilon repens*	Russian knapweed
	Cardaria draba	whitetop
	Cirsium arvense	Canada thistle
	Linaria dalmatica	Dalmatian toadflax
	Rumex crispus	curly dock
Forb/biennial	*Carduus acanthoides*	spiny plumeless thistle
	Cichorium intybus	Chicory
	Cirsium vulgare	bull thistle
	Verbascum blattaria	moth mullein
	Verbascum thapsus	common mullein
Forb/annual	*Bassia hyssopifolia*	fivehorn smotherweed
	Brassica juncea	India mustard
	Centaurea diffusa	diffuse knapweed
	Centaurea solstitialis	yellow starthistle
	Chorispora tenella	blue mustard
	Erodium cicutarium	redstem stork's bill
	Halogeton glomeratus	halogeton
	Lactuca serriola	prickly lettuce
	Kochia scoparia	kochia/burning bush
	Melilotus alba [4]	white sweetclover
	Melilotus officinalis	yellow sweetclover

Lifeform/duration	Scientific name	Common name
	Salsola tragus[5]	prickly Russian thistle
	Sonchus oleraceus	common sowthistle
	Sonchus asper	spiny sowthistle
	Sisymbrium altissimum	tumble mustard
	Tragopogon dubius[6]	yellow salsify
	Tribulus terrestris	puncturevine

[1] The Integrated Taxonomic Information System (ITIS) on-line taxonomic database (http://www.itis.gov/, accessed 5/14/09) was used as the taxonomic authority for current nomenclature.

[2] The specific epitaph '*chinensis*' was not determined in the field but was assigned after the survey using Hansen and Thomas (2006) as the source.

[3] USDA PLANTS (http://plants.usda.gov/, accessed 5/14/09) taxonomic database recognizes *Bromus rigidus* as a synonym for *Bromus diandrus* ssp. *rigidus*.

[4] USDA PLANTS (assessed 5/14/09) recognizes *Melilotus alba* as a synonym for *Melilotus officinalis*. It does not recognize two species as does ITIS.

[5] The specific epitaph '*tragus*' was not determined in the field but was assigned after the survey using Hansen and Thomas (2006) as the source.

[6] The specific epitaph '*dubius*' was not determined in the field but was assigned after the survey using Hansen and Thomas (2006) as the source.

Table 4. Number of sampling units in which each invasive plant species occurred and frequency of occurrence among all sampling units for each year of the survey, 2002–2005. [1]

[Blank spaces mean the species was observed in no sampling units that year.]

	2002		2003		2004		2005	
Scientific Name	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Acroptilon repens	1	<0.1%	1	<0.1%	6	0.2%	1	0.1%
Aegilops cylindrica							1	0.1%
Ailanthus altissima	3	0.1%	4	0.2%	1	<0.1%	1	0.1%
Alhagi maurorum	4	0.2%	1	0.1%	3	0.1%	2	0.2%
Bassia hyssopifolia					5	0.2%		
Brassica juncea							17	1.7%
Bromus rigidus							9	0.9%
Bromus rubens			9	0.5%			45	4.6%
Bromus tectorum	5	0.2%	686	38.5%	447	17.0%	588	59.8%
Cardaria draba			3	0.2%	1	<0.1%		
Carduus acanthoides	1	<0.1%	1	0.1%				
Centaurea diffusa			2	0.1%				
Centaurea solstitialis	14	0.6%	7	0.4%				
Chorispora tenella	5	0.2%	4	0.2%				
Cichorium intybus			1	0.1%				
Cirsium arvense			1	0.1%				
Cirsium vulgare	1	<0.1%	1	0.1%	2	0.1%		
Convolvulus arvensis	6	0.2%	7	0.4%	3	0.1%	3	0.3%
Cynodon dactylon			6	0.3%	25	1.0%	1	0.1%
Elaeagnus angustifolia	49	2.0%	64	3.6%	66	2.5%	46	4.7%
Erodium cicutarium	238	9.6%	133	7.5%	196	7.5%	250	25.4%
Halogeton glomeratus	8	0.3%	5	0.3%				
Kochia scoparia	54	2.2%	101	5.7%	42	1.6%	62	6.3%
Lactuca serriola			26	1.5%			61	6.2%
Linaria dalmatica			2	0.1%				
Marrubium vulgare	5	0.2%	3	0.2%	2	0.1%	1	0.1%
Melilotus alba	36	1.5%	14	0.8%	3	0.1%	5	0.5%
Melilotus officinalis	2	0.1%	8	0.4%	2	0.1%	1	0.1%
Polypogon monspeliensis			1	0.1%			7	0.7%
Rumex crispus			4	0.2%	1	<0.1%	1	0.1%
Salsola tragus	1437	58.2%	1393	78.1%	1738	66.2%	552	56.2%
Sisymbrium altissimum			3	0.2%	5	0.2%	307	31.2%
Sonchus asper							1	0.1%
Sonchus oleraceus	14	0.6%	2	0.1%				
Tamarix chinensis	253	10.3%	261	14.6%	234	8.9%	176	17.9%
Tragopogon dubius	3	0.1%			1	<0.1%	26	2.6%
Tribulus terrestris	70	2.8%	28	1.6%	8	0.3%		
Ulmus pumila	4	0.2%	4	0.2%	3	0.1%	1	0.1%
Verbascum blattaria	3	0.1%	1	0.1%	1	<0.1%	2	0.2%
Verbascum thapsus	1	<0.1%	1	0.1%				
No Weeds	932	37.8%	246	13.8%	659	25.1%	35	3.6%
With Weeds	1535	62.2%	1564	87.7%	1965	74.9%	948	96.4%

	2002 2003 2004				2005	
Scientific Name	**#**	**%**	**# %**	**# %**	**#**	**%**
Units Sampled	2467		1784	2624	983	

[1] The number of sampling units visited each year varied.

Table 5. Number of sampling units in which each invasive plant species occurred and frequency of occurrence in the 879 units sampled every year from 2002 through 2005.

[Blank spaces mean the species was observed in no sampling units that year.]

	2002		2003		2004		2005	
Scientific Name	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Acroptilon repens	1	0.1%		0.0%	5	0.6%	1	0.1%
Aegilops cylindrica							1	0.1%
Ailanthus altissima	3	0.3%	3	0.3%	1	0.1%	1	0.1%
Alhagi maurorum	3	0.3%		0.0%		0.0%	1	0.1%
Bassia hyssopifolia					2	0.2%		
Brassica juncea							17	1.9%
Bromus rigidus							9	1.0%
Bromus rubens		0.0%	1	0.1%		0.0%	36	4.1%
Bromus tectorum	4	0.5%	513	58.4%	300	34.1%	530	60.3%
Carduus acanthoides	1	0.1%	1	0.1%	3	0.3%	1	0.1%
Centaurea diffusa			2	0.2%				
Centaurea solstitialis	8	0.9%	5	0.6%				
Chorispora tenella	5	0.6%	3	0.3%				
Cichorium intybus			1	0.1%				
Cirsium arvense			1	0.1%				
Cirsium vulgare			1	0.1%	2	0.2%		
Convolvulus arvensis	6	0.7%	6	0.7%	2	0.2%	3	0.3%
Cynodon dactylon			2	0.2%	14	1.6%		
Elaeagnus angustifolia	47	5.3%	60	6.8%	65	7.4%	45	5.1%
Erodium cicutarium	188	21.4%	119	13.5%	143	16.3%	226	25.7%
Halogeton glomeratus	6	0.7%	4	0.5%				
Kochi scoparia	38	4.3%	80	9.1%	36	4.1%	54	6.1%
Lactuca serriola			26	3.0%			59	6.7%
Linaria dalmatica			2	0.2%				
Marrubium vulgare	4	0.5%	2	0.2%	2	0.2%	1	0.1%
Melilotus alba	28	3.2%	9	1.0%	3	0.3%	5	0.6%
Melilotus officinalis	1	0.1%	7	0.8%			1	0.1%
Polypogon monspeliensis	1	0.1%					7	0.8%
Rumex crispus			4	0.5%	1	0.1%	1	0.1%
Salsola tragus.	692	78.7%	783	89.1%	694	79.0%	487	55.4%
Sisymbrium altissimum			2	0.2%	4	0.5%	258	29.4%
Sonchus asper							1	0.1%
Sonchus oleraceus	13	1.5%	1	0.1%				
Tamarix chinensis	196	22.3%	219	24.9%	189	21.5%	167	19.0%
Tragopogon dubius	3	0.3%			1	0.1%	25	2.8%
Tribulus terrestris	55	6.3%	25	2.8%	6	0.7%		
Ulmus pumila	3	0.3%	3	0.3%	3	0.3%	1	0.1%
Verbascum blattaria	3	0.3%	1	0.1%			2	0.2%
Verbascum thapsus	1	0.1%	1	0.1%				
No Weeds	123	14.0%	27	3.1%	81	9.2%	32	3.6%
Units Sampled	879		879		879		879	

Table 6. Highest cover class observed in sampling units at Petrified Forest National Park for each invasive plant, 2002–2005.

Low cover		Moderate cover	High cover
<1%	**1 to <5%**	**5 to <25%**	**25% or more**
Aegilops cylindrica	*Acroptilon repens*	*Kochia scoparia*	*Elaeagnus angustifolia*
Bassia hyssopifolia	*Ailanthus altissima*	*Bromus tectorum*	*Salsola tragus*
Cardaria draba	*Alhagi maurorum*	*Cynodon dactylon*	*Tamarix chinensis*
Carduus acanthoides	*Brassica juncea*	*Erodium cicutarium*	
Centaurea diffusa	*Bromus rubens*	*Halogeton glomeratus*	
Chorispora tenella	*Bromus rigidus*	*Sisymbrium altissimum*	
Cichorium intybus	*Centaurea solstitialis*	*Tribulus terrestris*	
Cirsium arvense	*Convolvulus arvensis*		
Cirsium vulgare	*Lactuca serriola*		
Marrubium vulgare	*Linaria dalmatica*		
Melilotus officinalis	*Melilotus alba*		
Polypogon monspeliensis	*Sonchus oleraceus*		
Rumex crispus	*Ulmus pumila*		
Sonchus asper			
Tragopogon dubius			
Verbascum blattaria			
Verbascum thapsus			

Table 7. Highest yearly occurrence (number of sampling units) of each plant, 'invasiveness' ratings, and legal designation in Arizona for invasive plants at Petrified Forest National Park

[Blank spaces mean the species was either evaluated and did not receive an impact ranking or was not evaluated.]

Highest # Sampling Units	Year Highest	Scientific name	Impact Ratings			
			AZ-WIPWG[1]	Cal-IPC[2]	Nature Serve[3]	AZ Noxious[4]
6	2004	*Acroptilon repens*	high	moderate	high/medium	prohibited and restricted
1	2005	*Aegilops cylindrica*	low, red flag			prohibited and restricted
4	2003	*Ailanthus altissima*	medium	moderate		
4	2002	*Alhagi maurorum*	medium	moderate	medium/low	prohibited and restricted
5	2004	*Bassia hyssopifolia*		limited	low/insignificant	
17	2005	*Brassica juncea*				
9	2005	*Bromus rigidus*	medium	moderate		
45	2005	*Bromus rubens*	high	high		
686	2003	*Bromus tectorum*	high	high	high	
3	2003	*Cardaria draba*	medium	moderate		prohibited and restricted
1	2002/03	*Carduus acanthoides*		limited		prohibited
2	2003	*Centaurea diffusa*	medium	moderate		prohibited and restricted
14	2002	*Centaurea solstitialis*	high	high	medium/low	prohibited and restricted
5	2002	*Chorispora tenella*		evaluated, not listed	insignificant	
1	2003	*Cirsium arvense*	medium, red flag	moderate		prohibited
1	2003	*Cichorium intybus*				
2	2004	*Cirsium vulgare*	low	moderate		
7	2005	*Convolvulus arvensis*	medium	evaluated, not listed	medium/low	prohibited, regulated
25	2004	*Cynodon dactylon*	medium	moderate	medium/low	
66	2004	*Elaeagnus angustifolia*	high	moderate	high	
250	2005	*Erodium cicutarium*	medium	limited	medium/low	
8	2002	*Halogeton glomeratus*		moderate	high/medium	prohibited and restricted
101	2003	*Kochia scoparia*		limited		
61	2003	*Lactuca serriola*		evaluated, not listed	low/insignificant	
2	2003	*Linaria dalmatica*	medium, red flag	moderate		prohibited and restricted
3	2003	*Marrubium vulgare*		limited	medium/low	
36	2002	*Melilotus alba*	medium, red flag			
8	2003	*Melilotus officinalis*	medium, red flag	evaluated, not listed	medium/low	

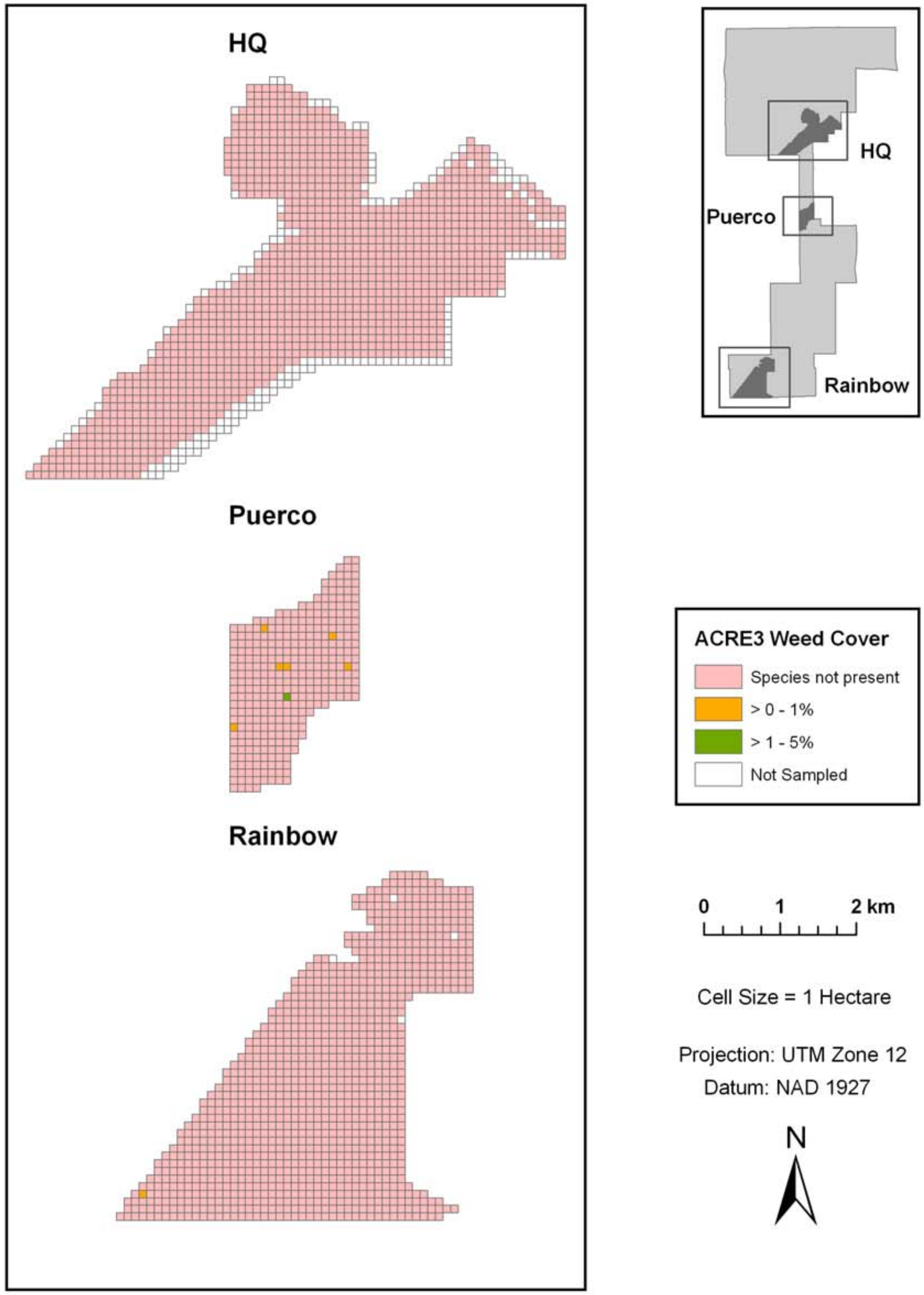
Highest # Sampling Units	Year Highest	Scientific name	Impact Ratings			
			AZ-WIPWG[1]	Cal-IPC[2]	NatureServe[3]	AZ Noxious[4]
7	2005	*Polypogon monspeliensis*		limited	high/low	
4	2003	*Rumex crispus*		limited		
1738	2004	*Salsola tragus*	medium	limited		
307	2005	*Sisymbrium altissimum*				
1	2005	*Sonchus asper*	medium	evaluated, not listed		
14	2002	*Sonchus oleraceus*	medium			
261	2003	*Tamarix chinensis*	high, red flag			
26	2005	*Tragopogon dubius*		evaluated, not listed		
70	2002	*Tribulus terrestris*	evaluated, not listed			prohibited, regulated
4	2003	*Ulmus pumila*	medium		medium/low	
3	2002	*Verbascum blattaria*				
1	2003	*Verbascum thapsus*	evaluated, not listed	limited	medium/low	

[1] Arizona Wildlands Invasive Plant Working Group (Arizona Wildlands Invasive Plant Working Group 2005)
[2] California Invasive Plant Council (California Invasive Plant Council 2006)
[3] NatureServe (Morse and others 2004)
[4] Arizona Prohibited, Regulated and Restricted Noxious Weeds, Arizona Department of Agriculture *http://www.azda.gov/PSD/quarantine5.htm*. Date last accessed August 20, 2009.

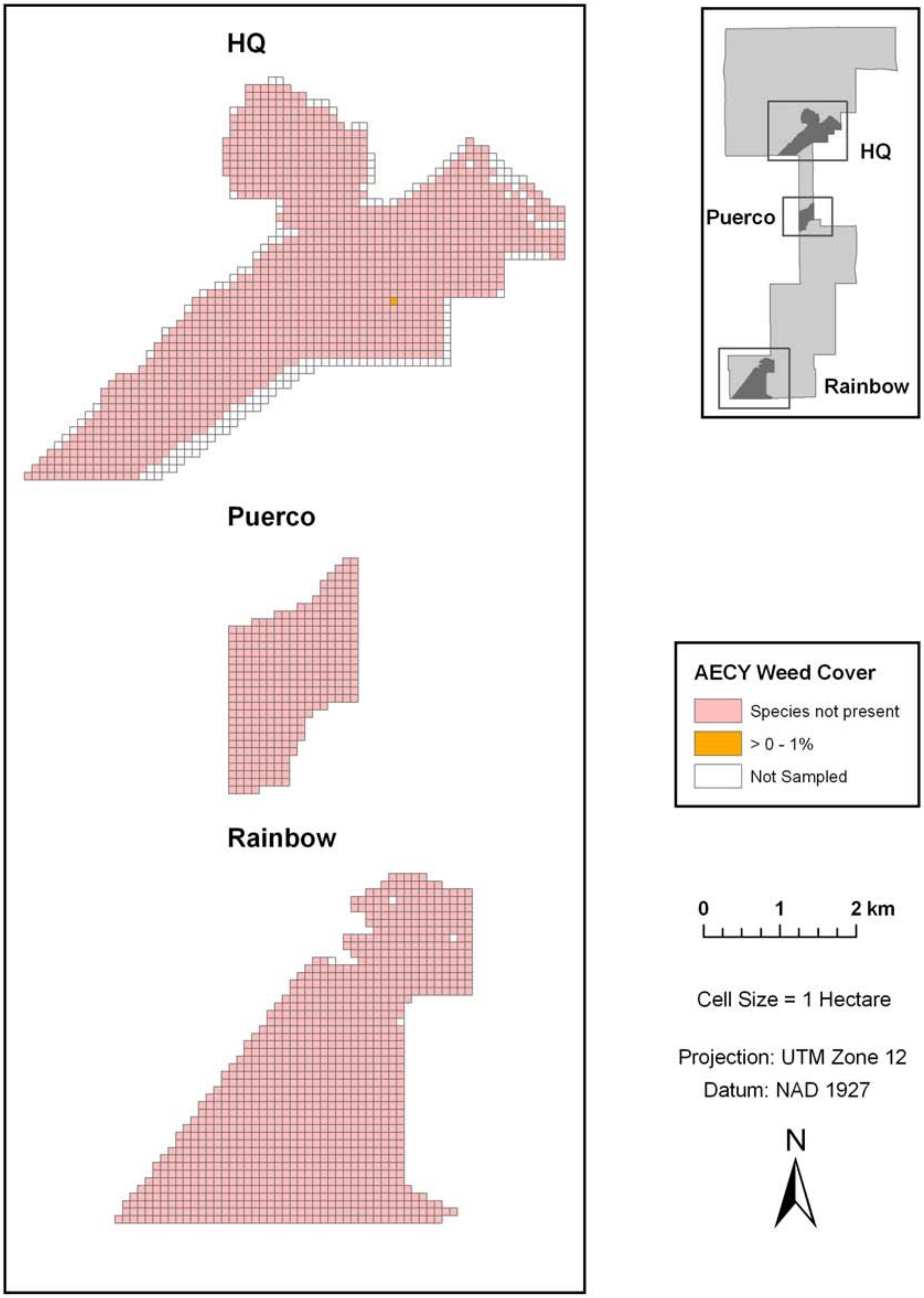
Appendix 1

The following maps show, for each invasive plant species observed at Petrified Forest National Park during the study from 2002 to 2005, the highest cover class for that plant in each sampling unit during the 4-year period.

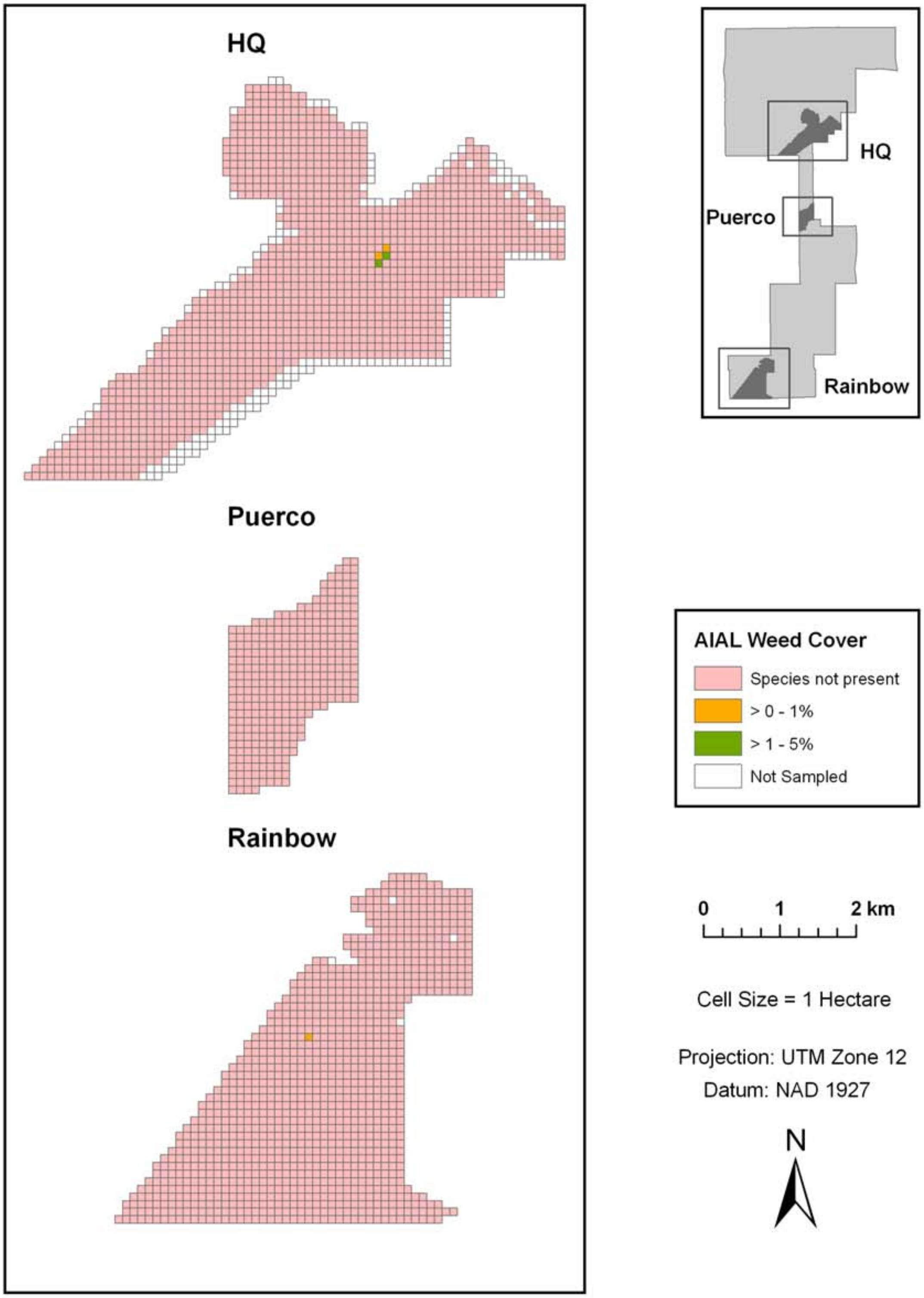
Appendix 1.1 *Acroptilon repens*: Highest cover class and distribution



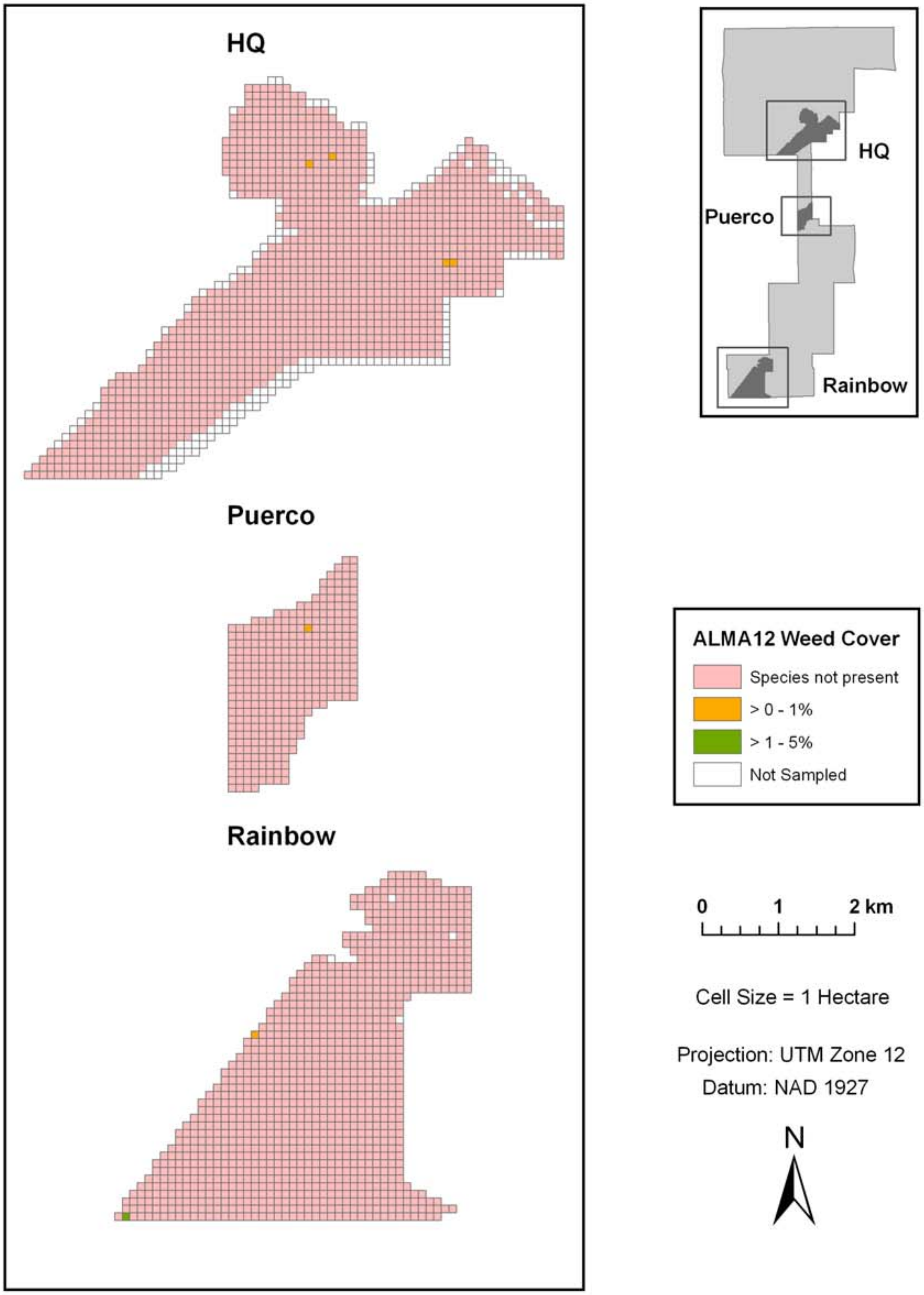
Appendix 1.2 *Aegilops cylindrica*: Highest cover class and distribution



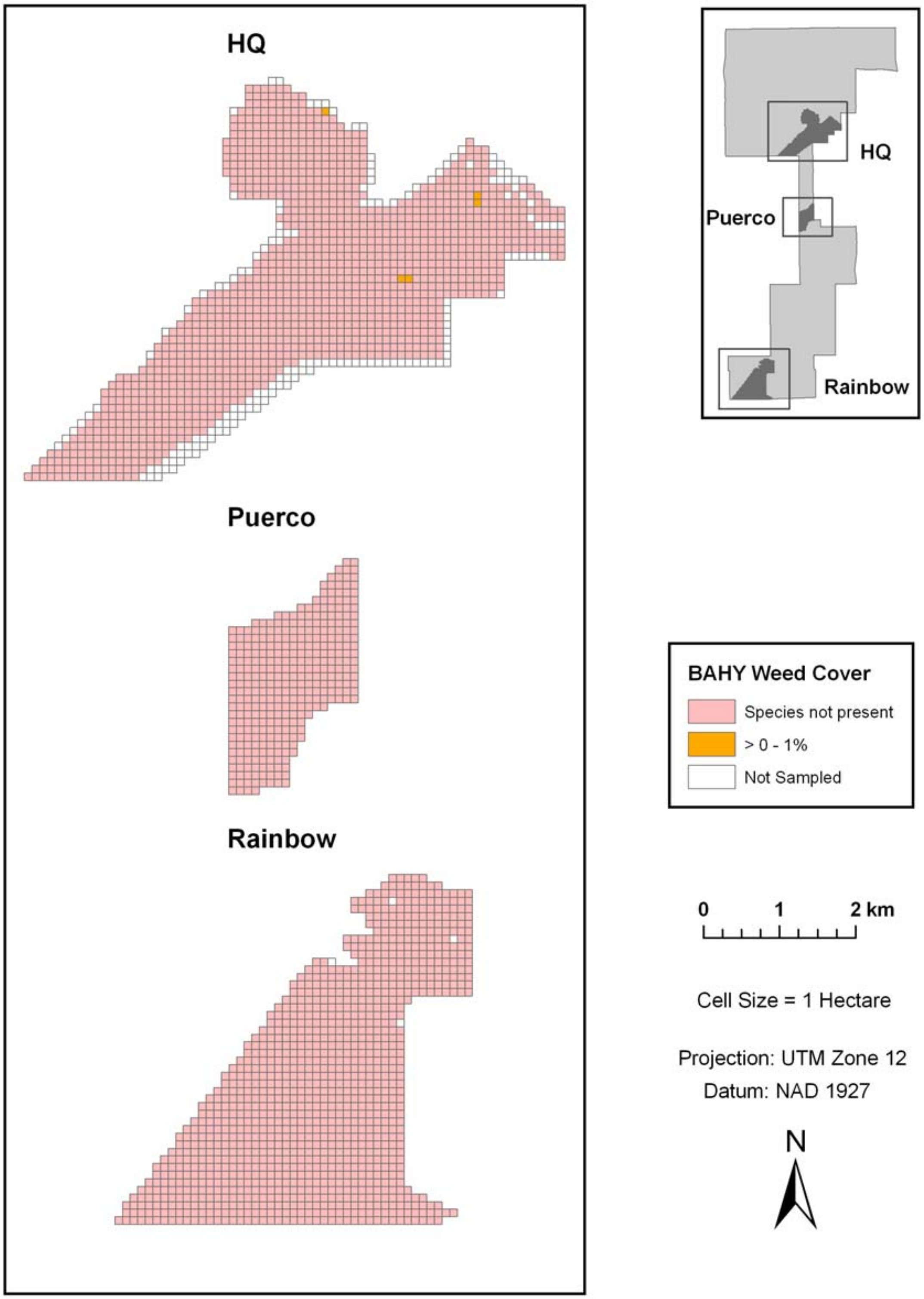
Appendix 1.3 *Ailanthus altissima*: Highest cover class and distribution



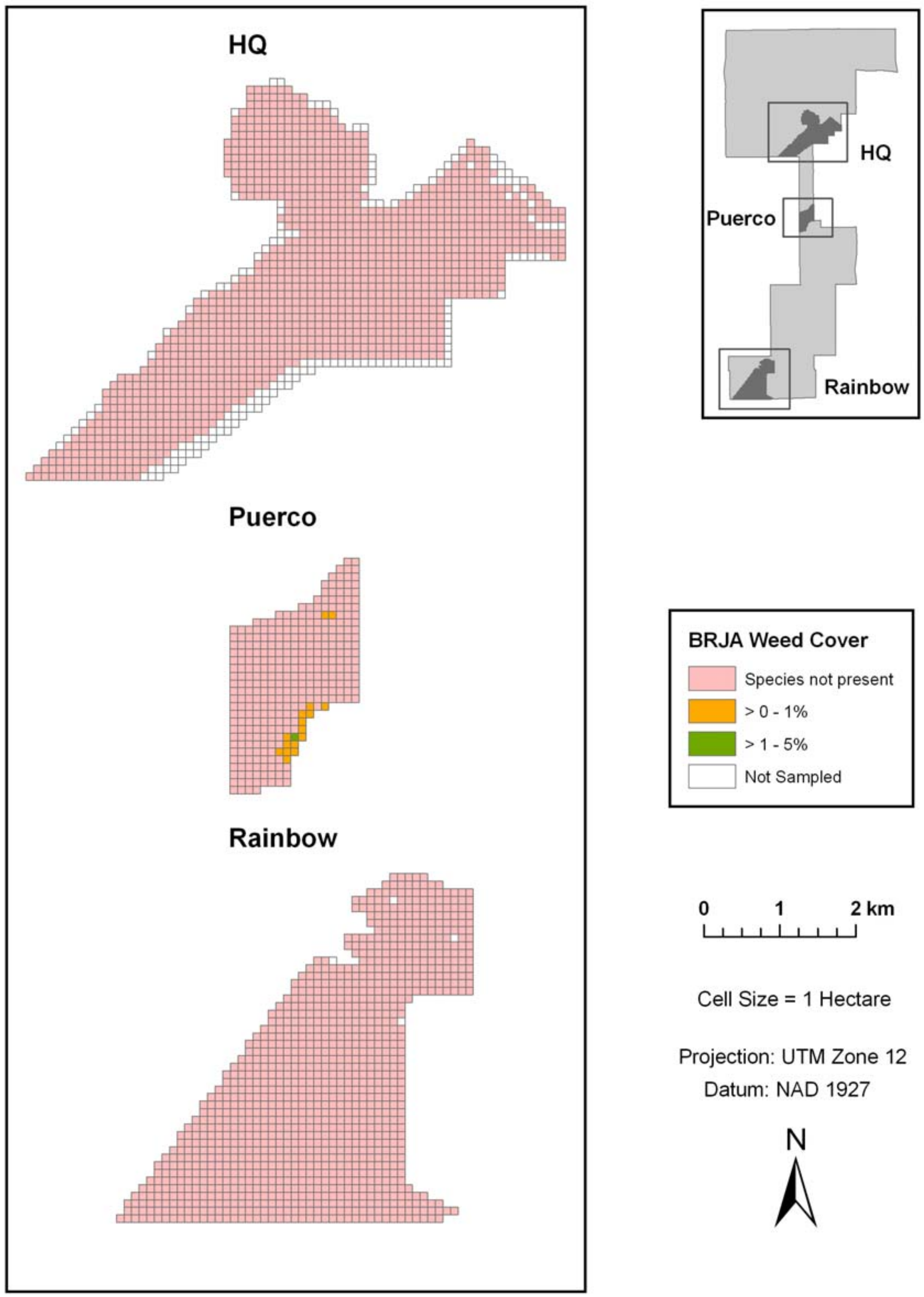
Appendix 1.4 *Alhagi maurorum*: Highest cover class and distribution



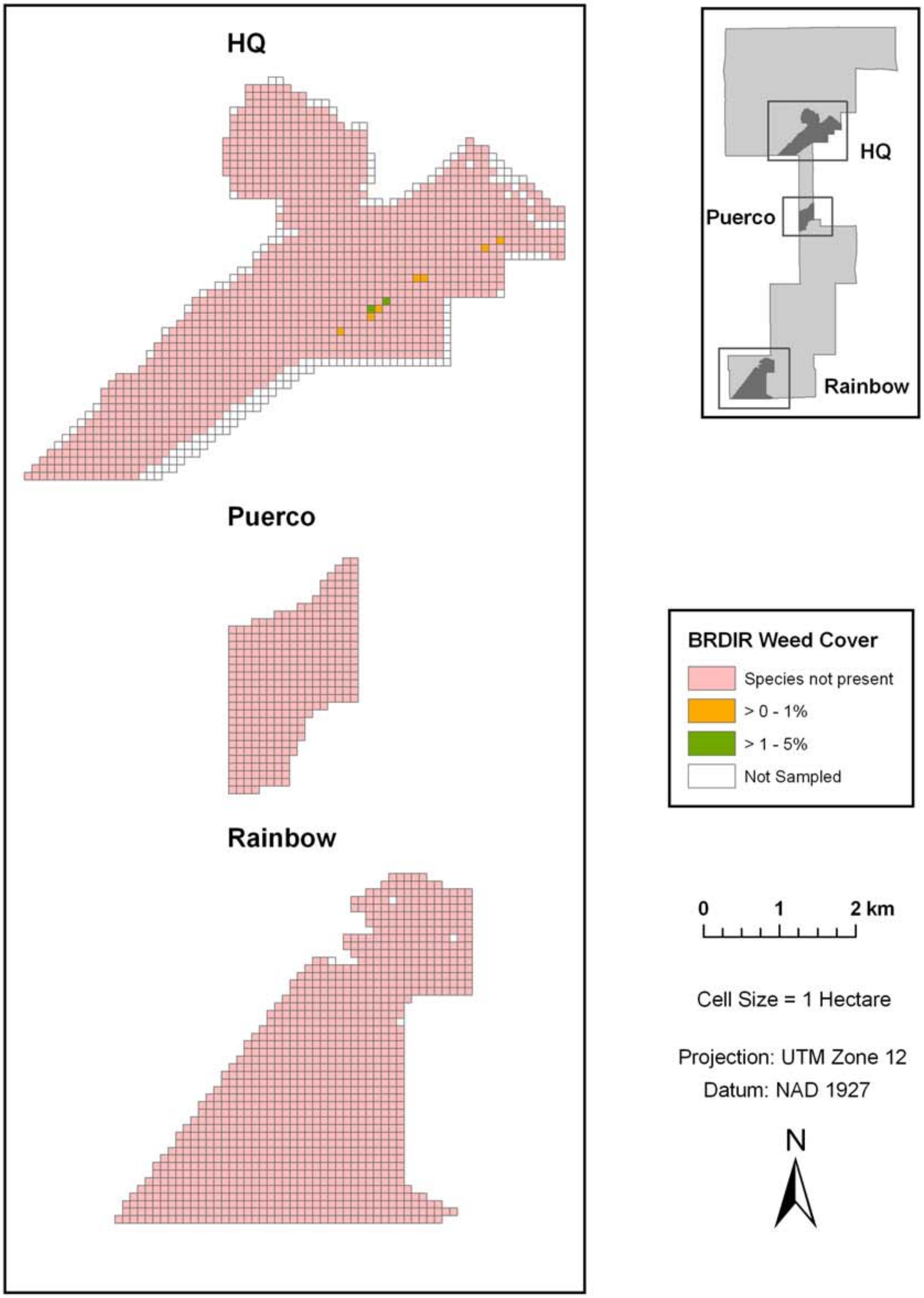
Appendix 1.5 *Bassia hyssopifolia:* Highest cover class and distribution



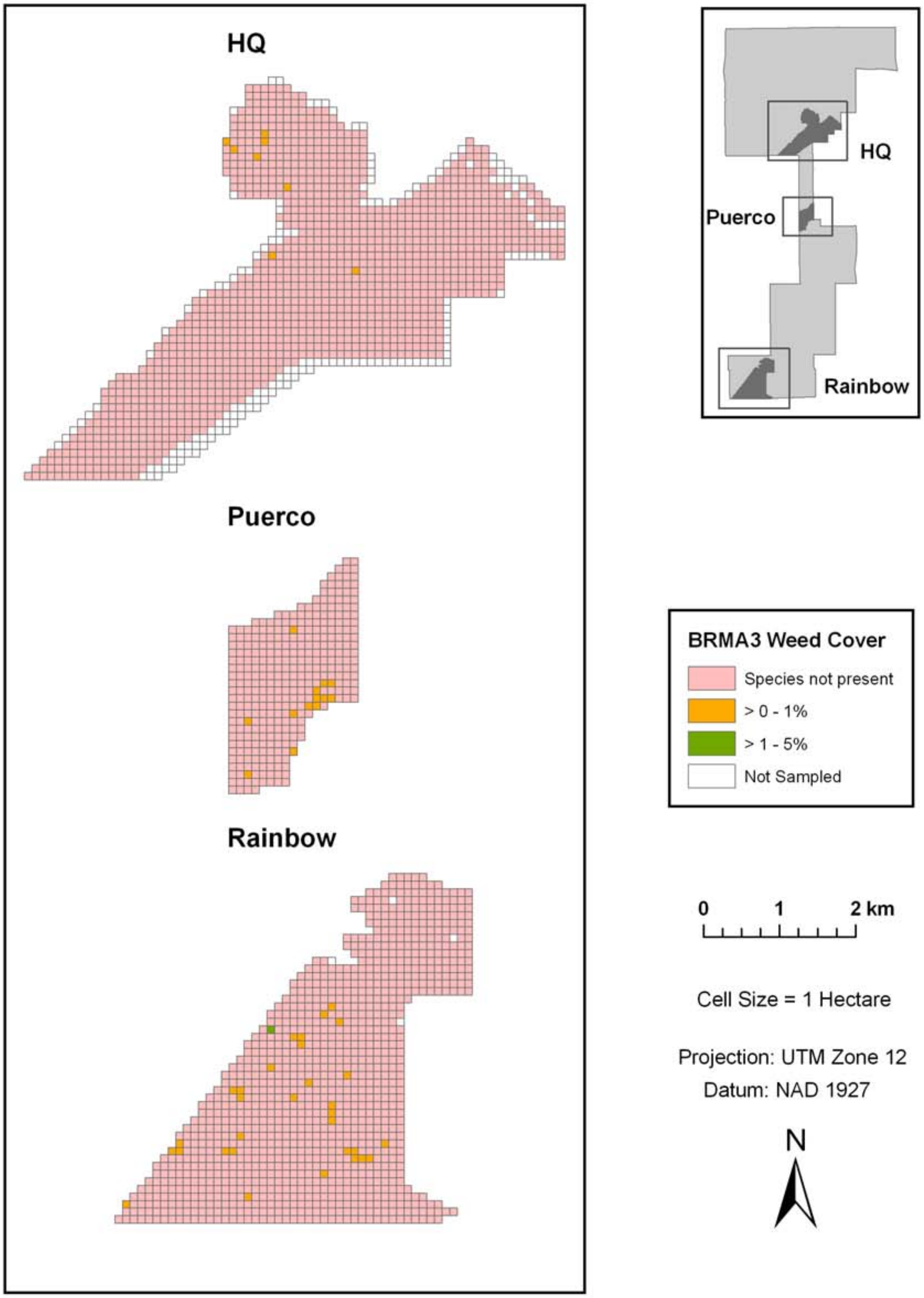
Appendix 1.6 *Brassia juncea*: Highest cover class and distribution



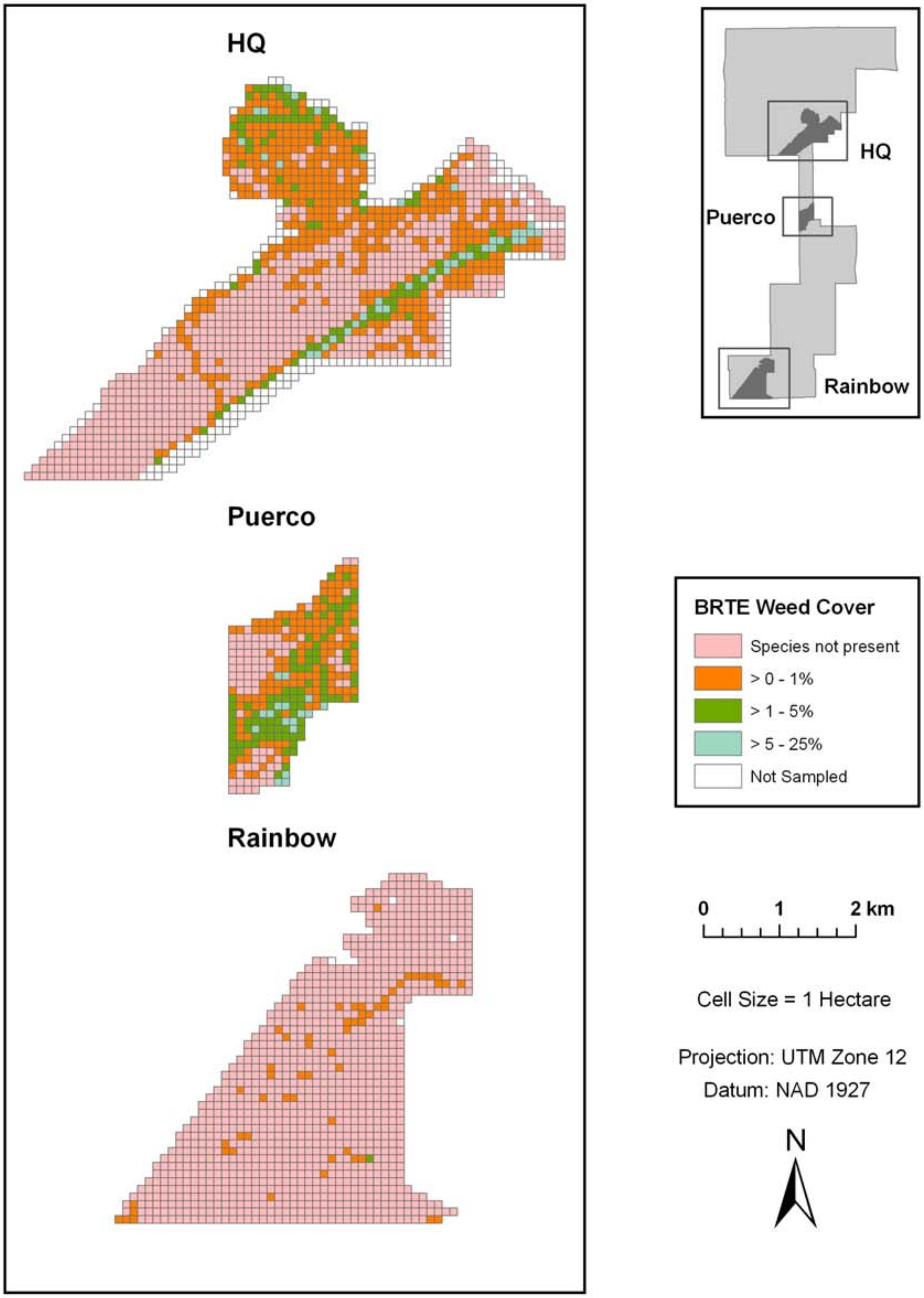
Appendix 1.7 *Bromus rigidus*: Highest cover class and distribution



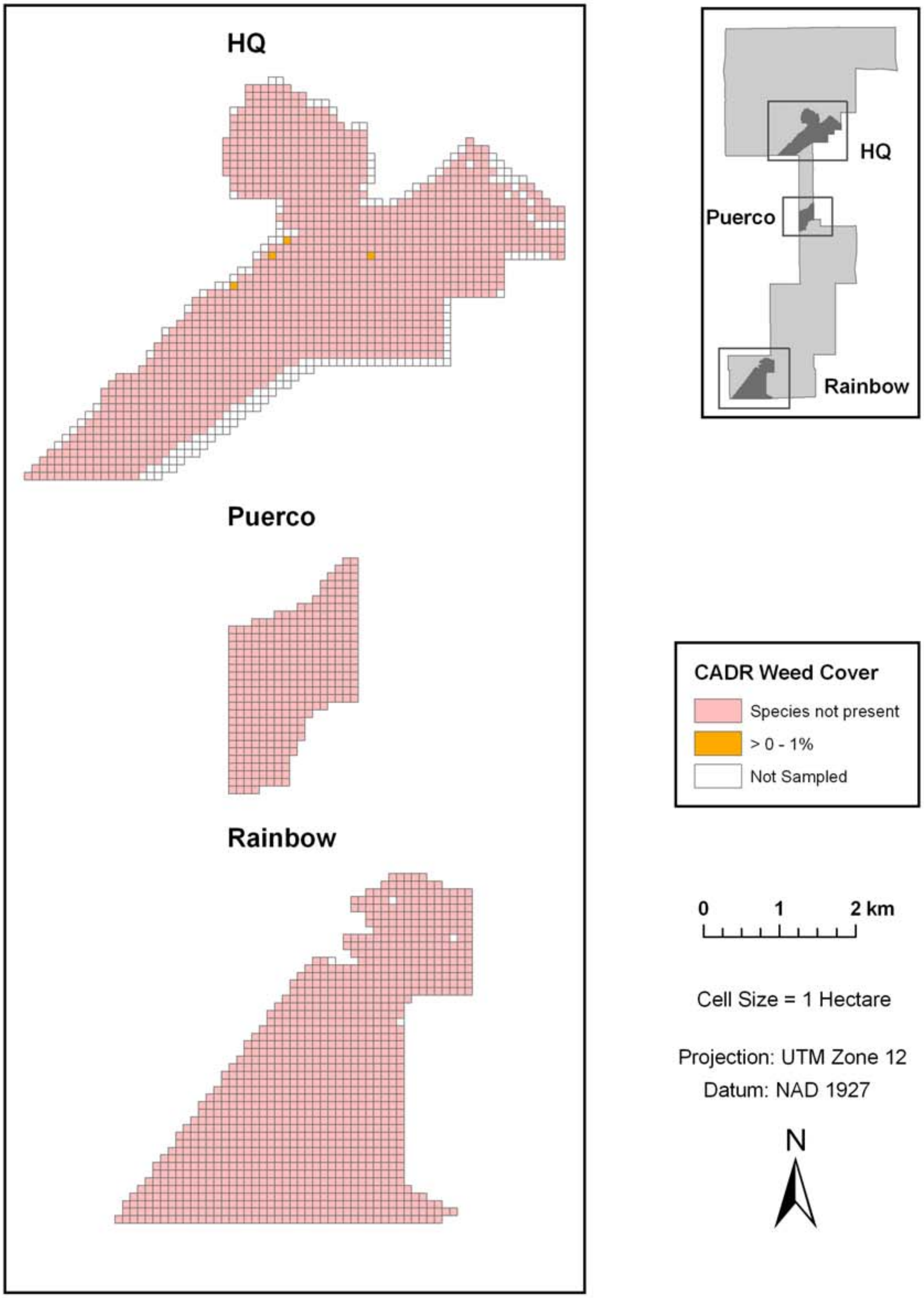
Appendix 1.8 *Bromus rubens*: Highest cover class and distribution



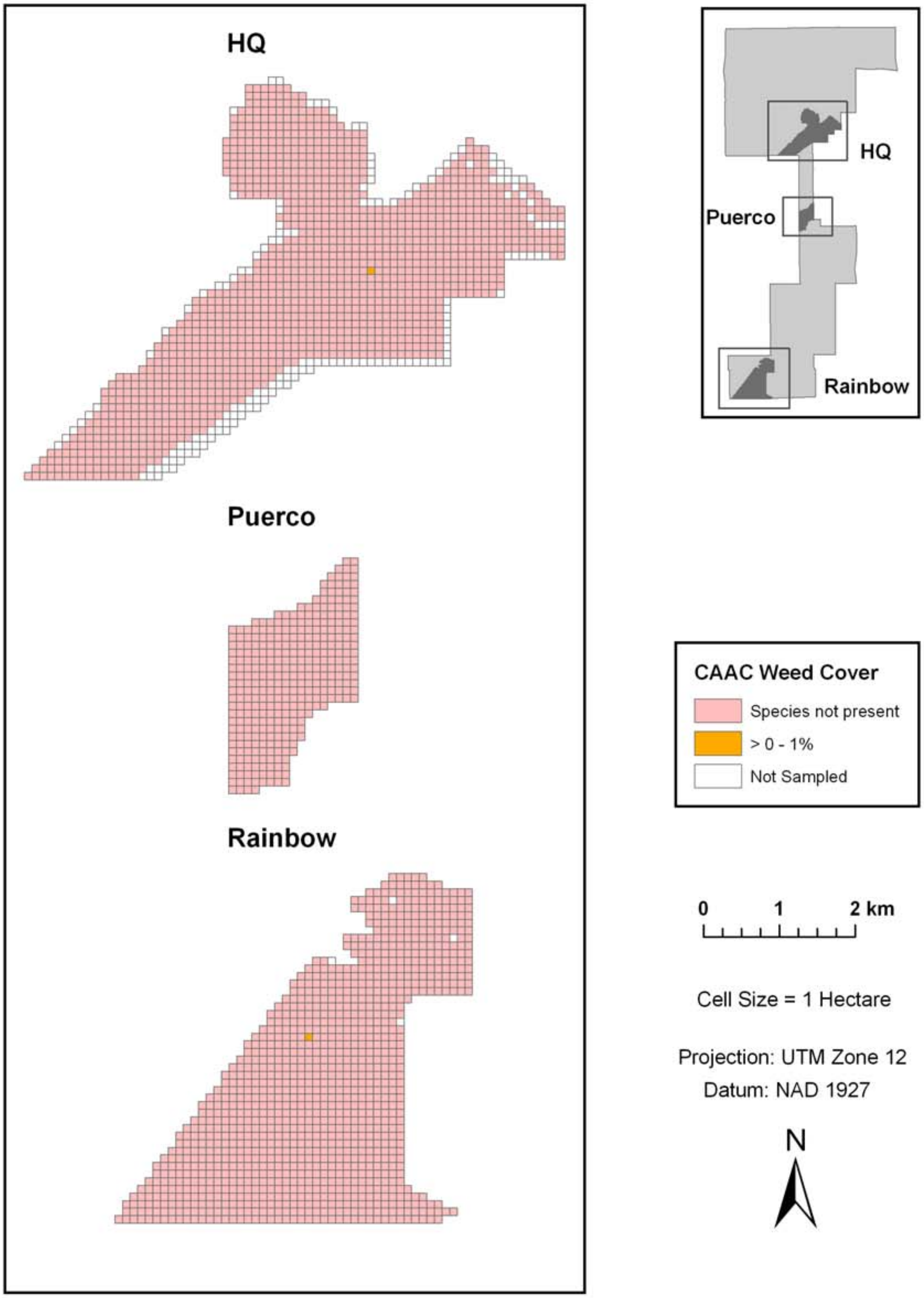
Appendix 1.9 *Bromus tectorum*: Highest cover class and distribution



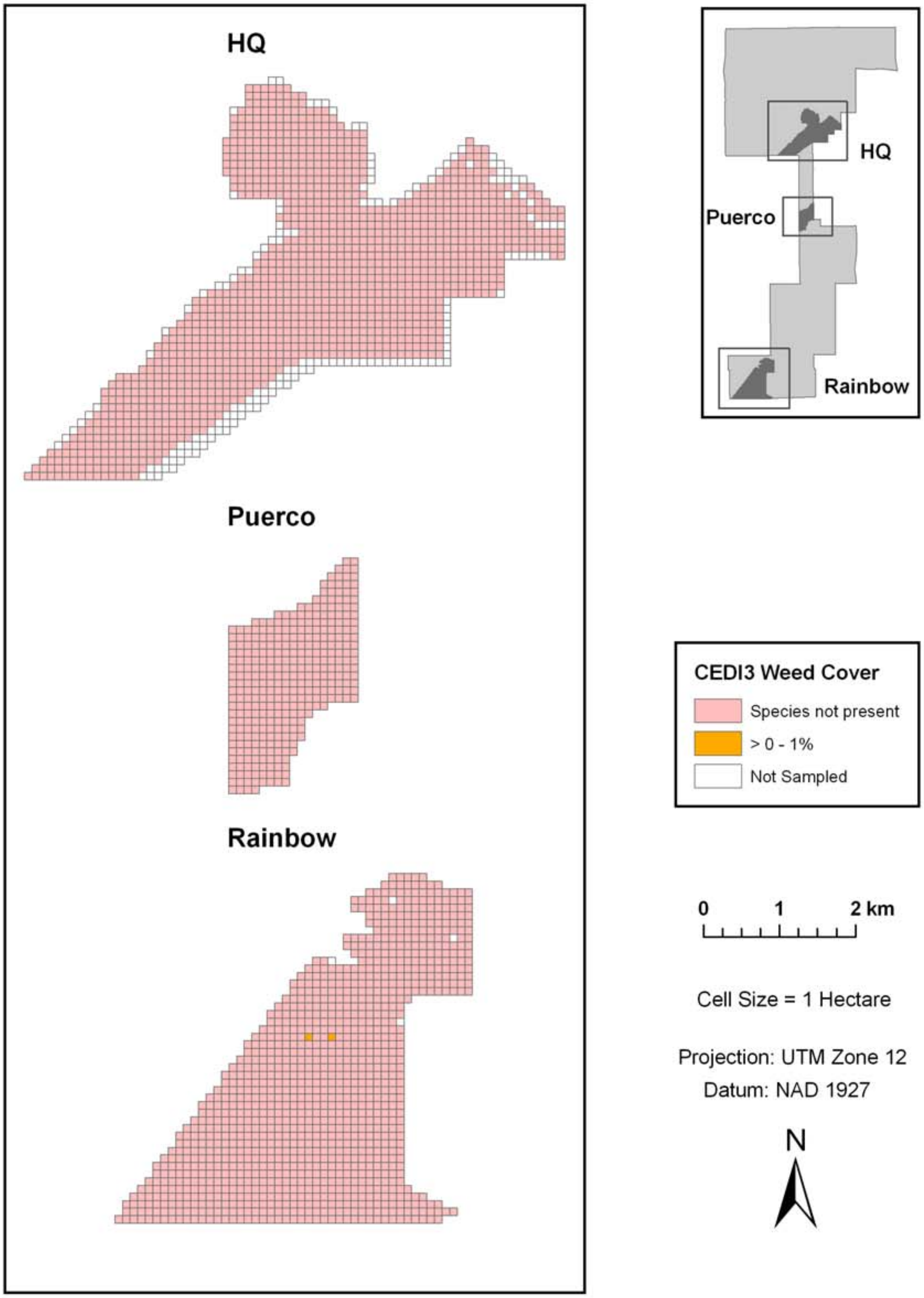
Appendix 1.10 *Cardaria draba*: Highest cover class and distribution



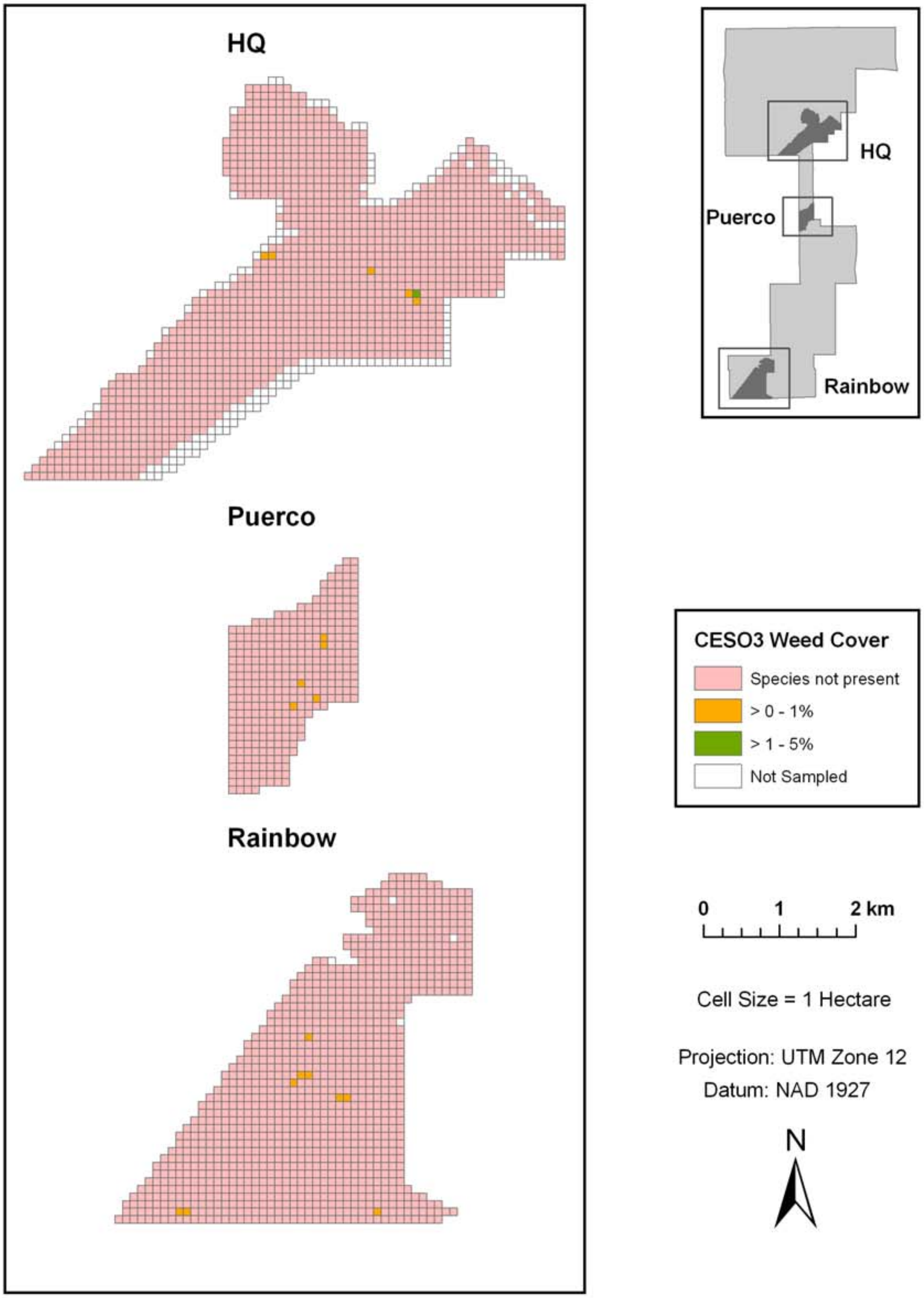
Appendix 1.11 *Carduus acanthoides*: Highest cover class and distribution



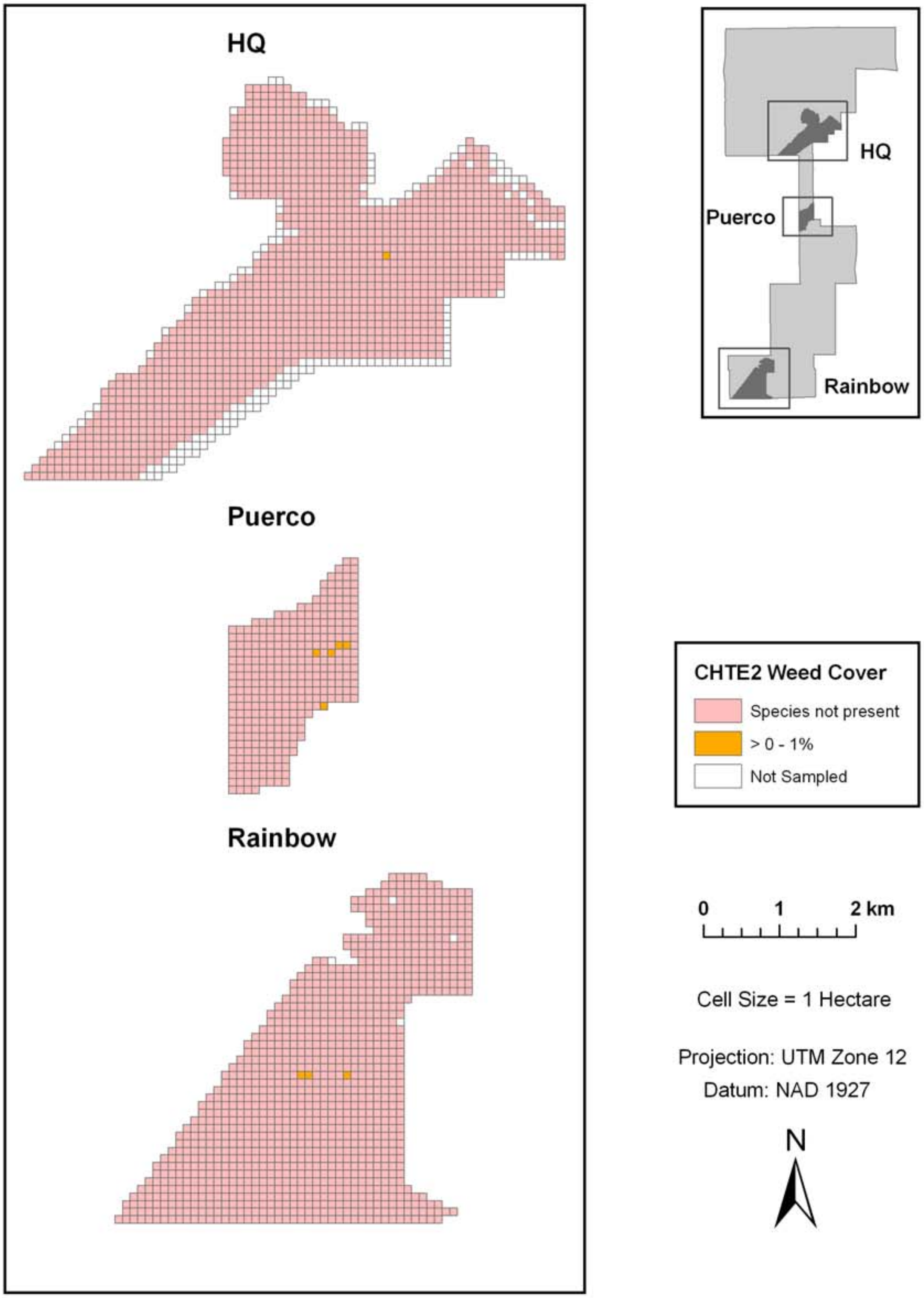
Appendix 1.12 *Centaurea diffusa*: Highest cover class and distribution



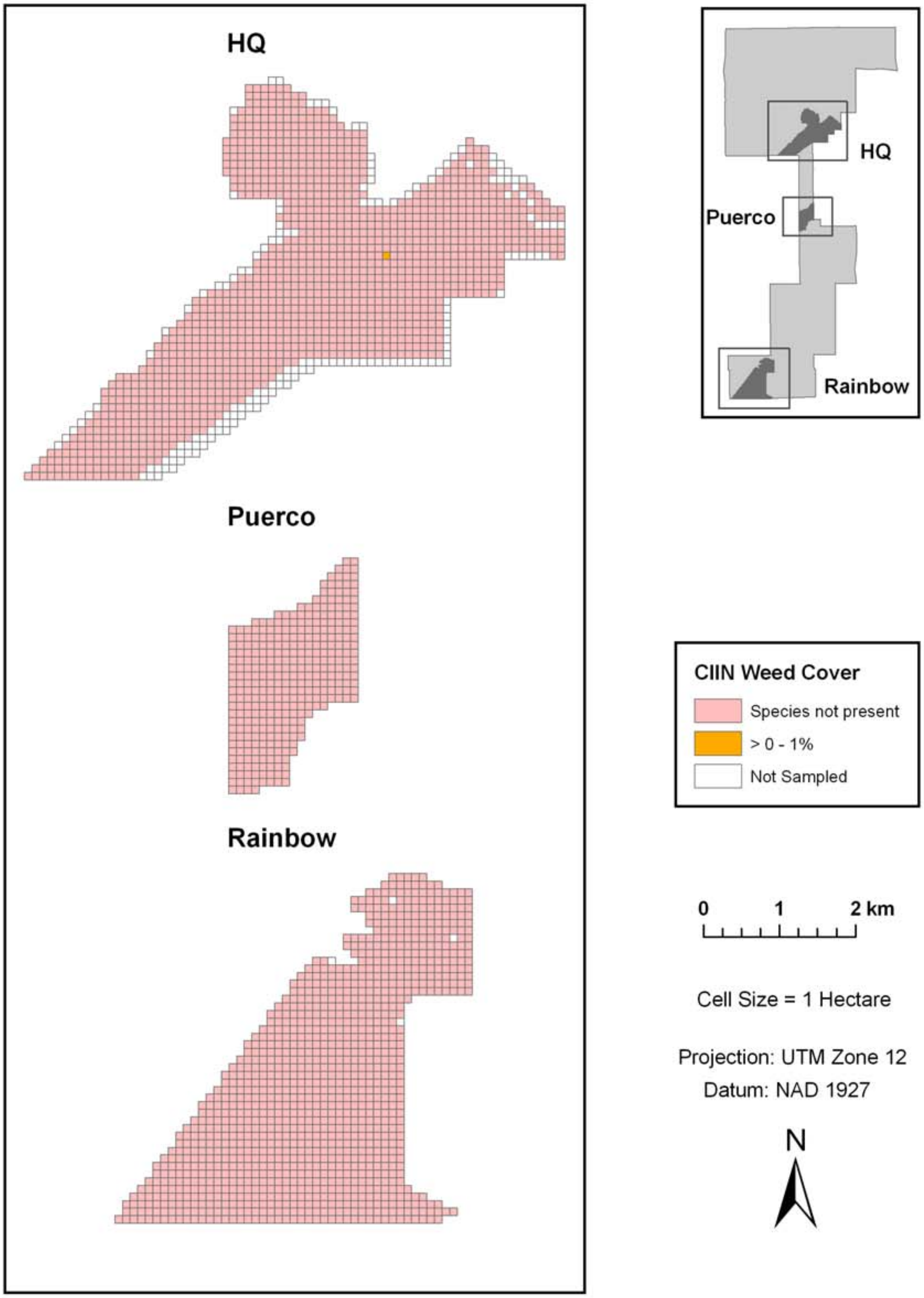
Appendix 1.13 *Centaurea solstitialis*: Highest cover class and distribution



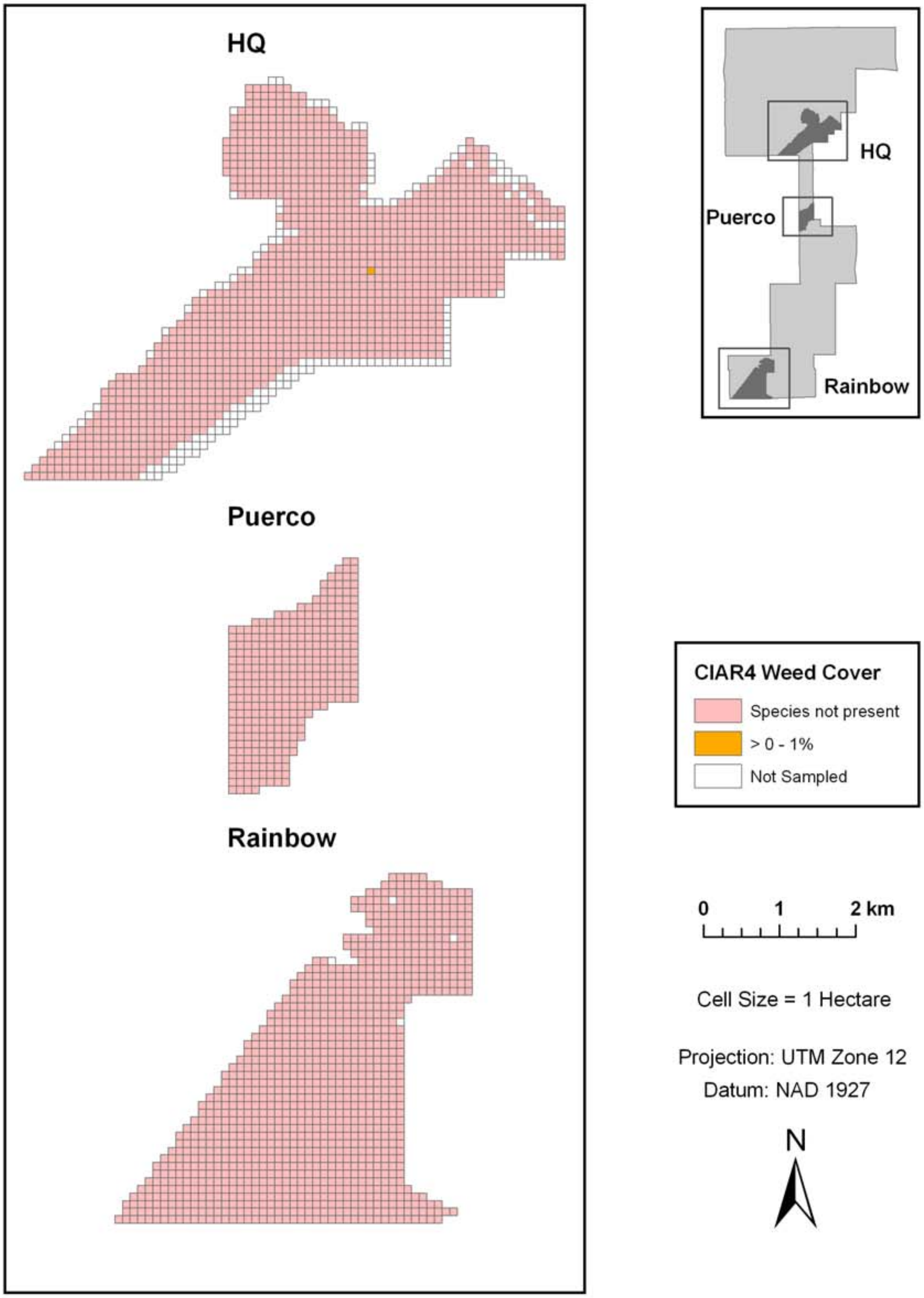
Appendix 1.14 *Chorispora tenella*: Highest cover class and distribution



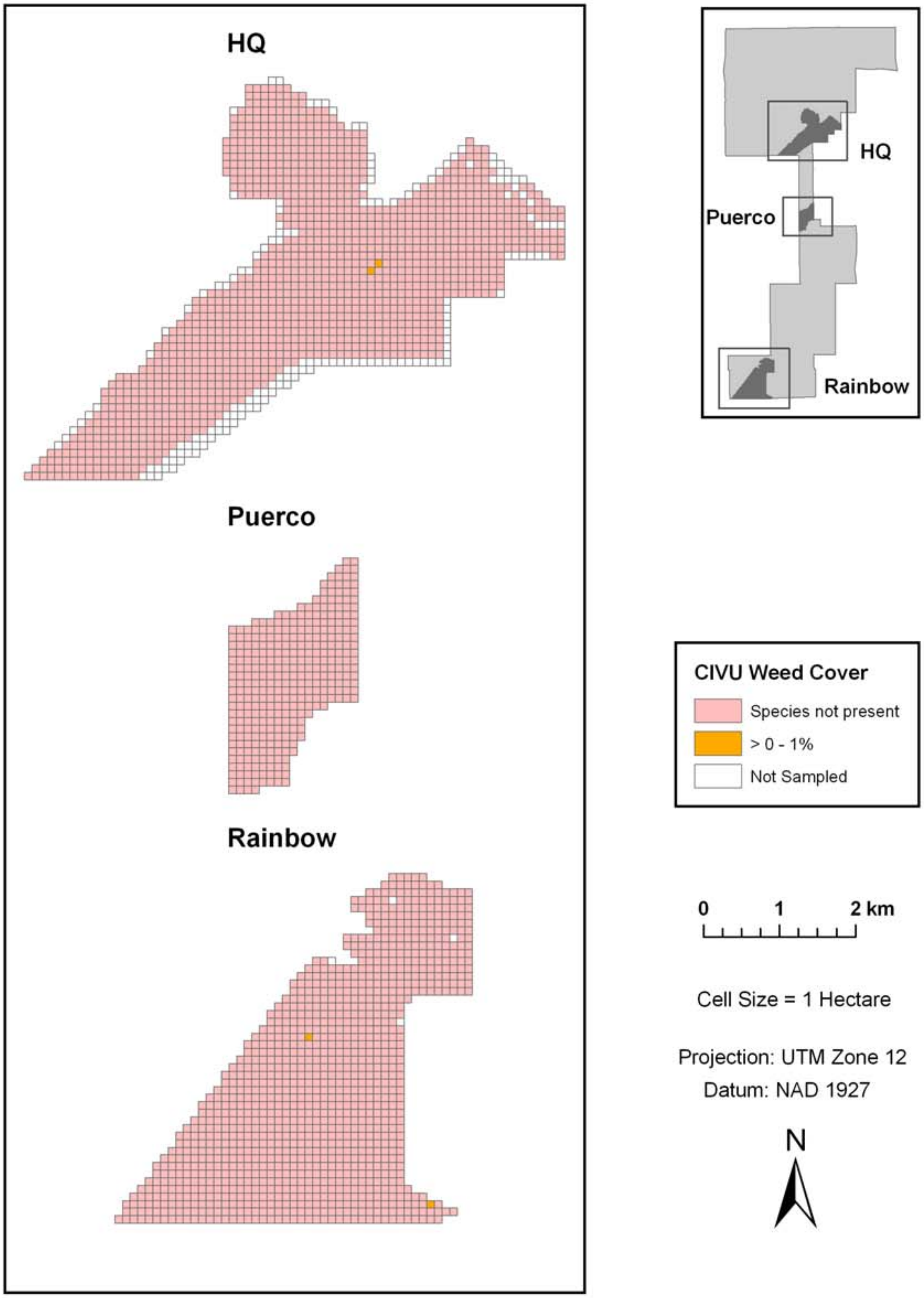
Appendix 1.15 *Cichorium intybus*: Highest cover class and distribution



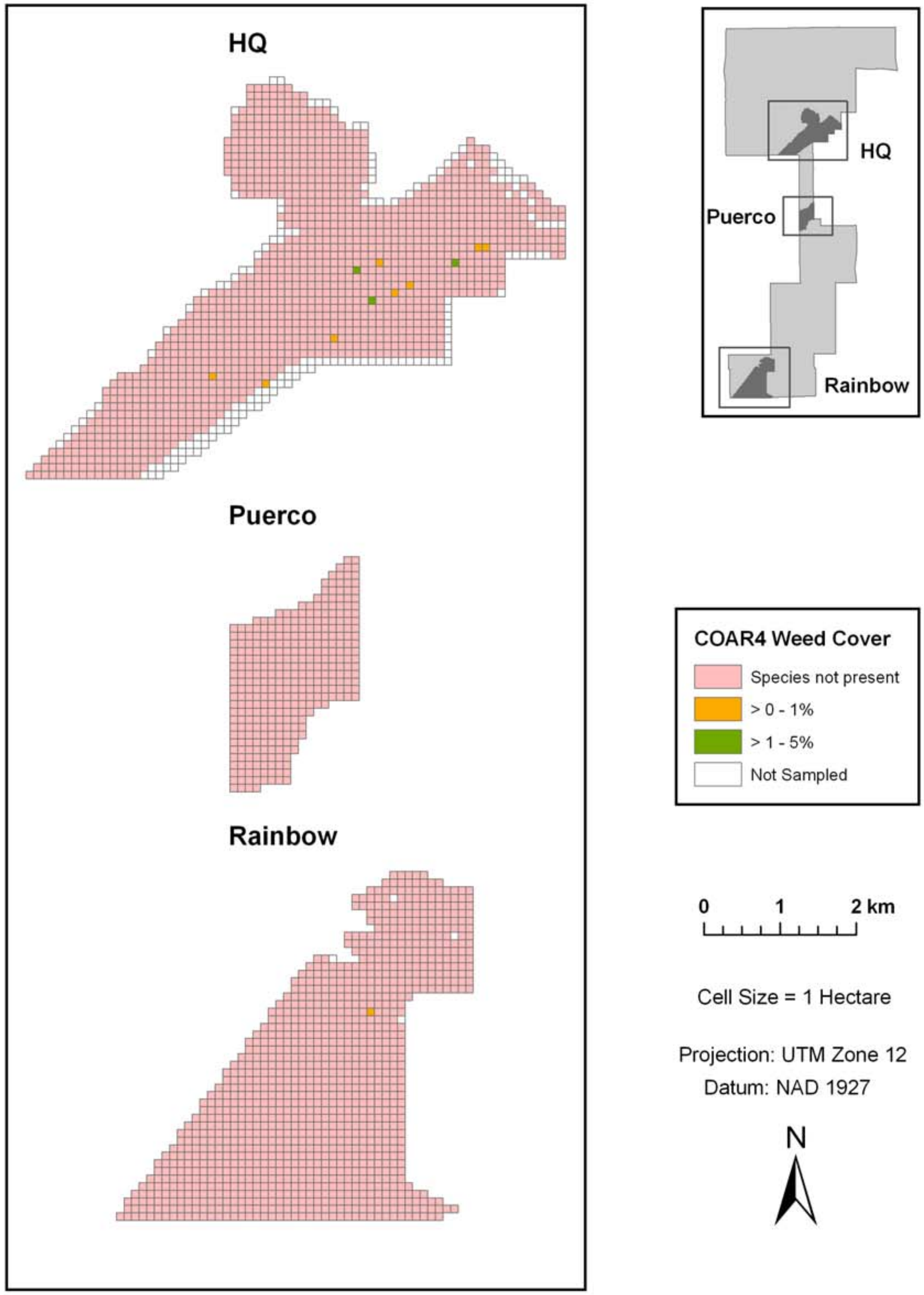
Appendix 1.16 *Cirsium arvense*: Highest cover class and distribution



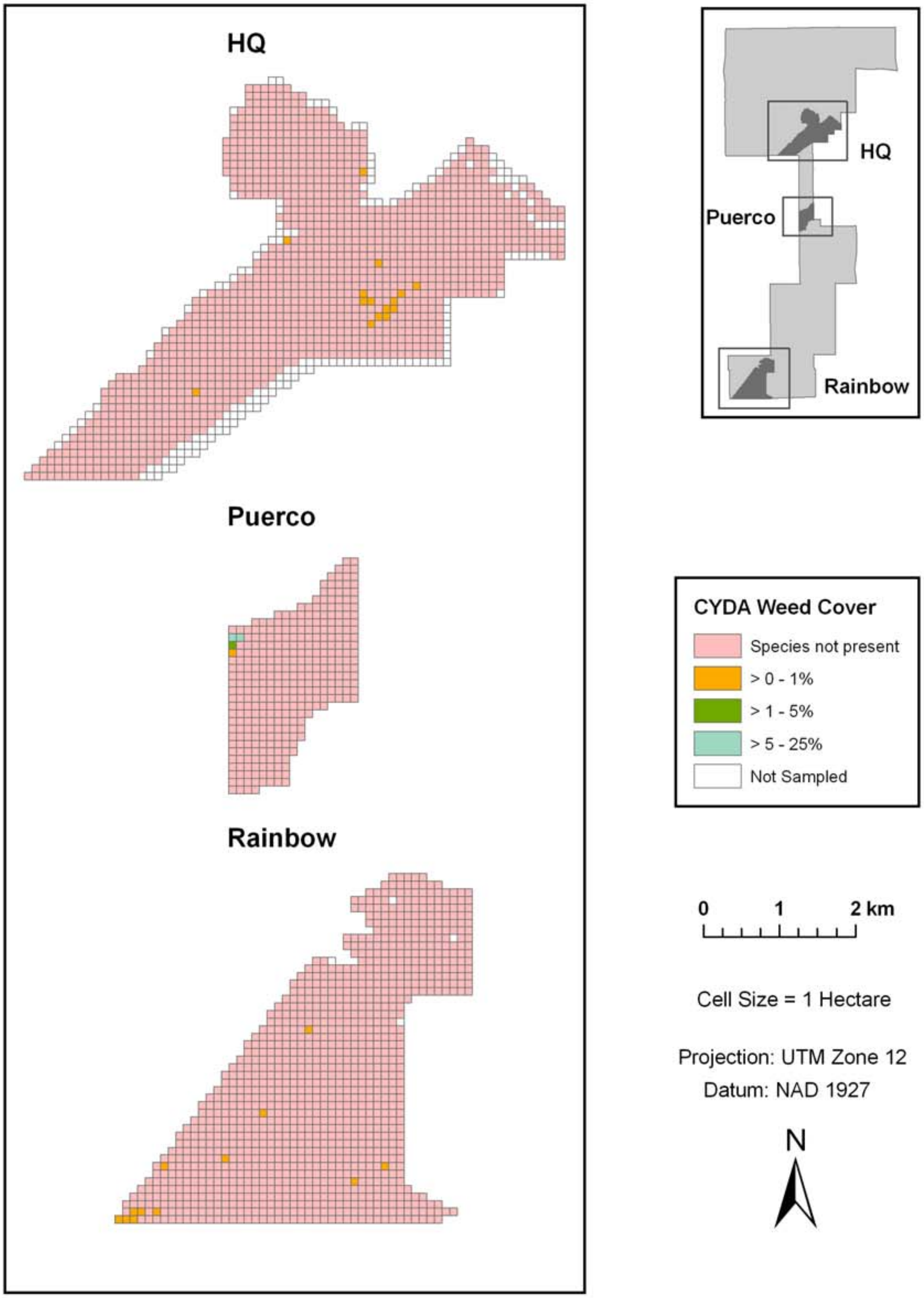
Appendix 1.17 *Cirsium vulgare*: Highest cover class and distribution



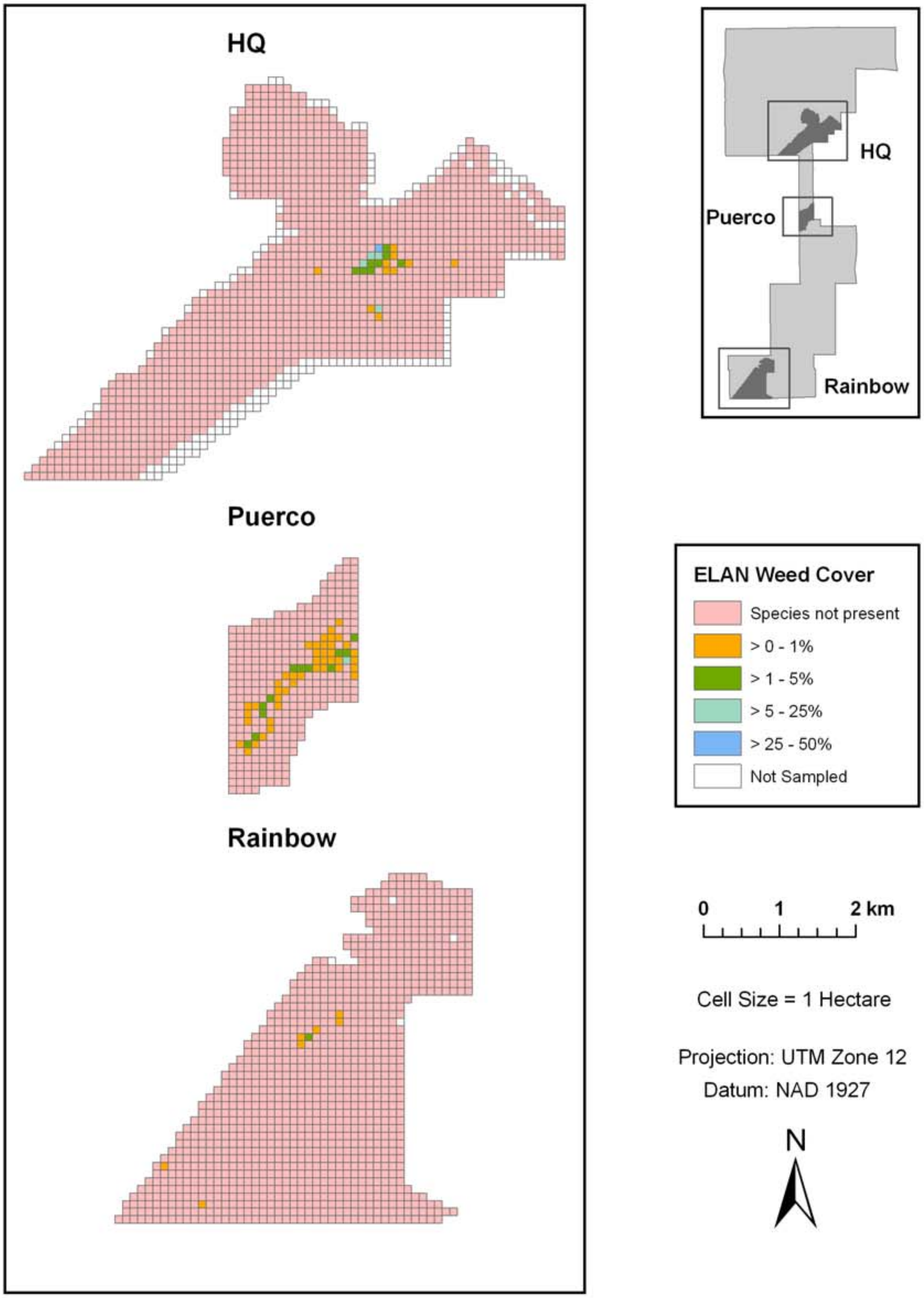
Appendix 1.18 *Convolvulus arvensis*: Highest cover class and distribution



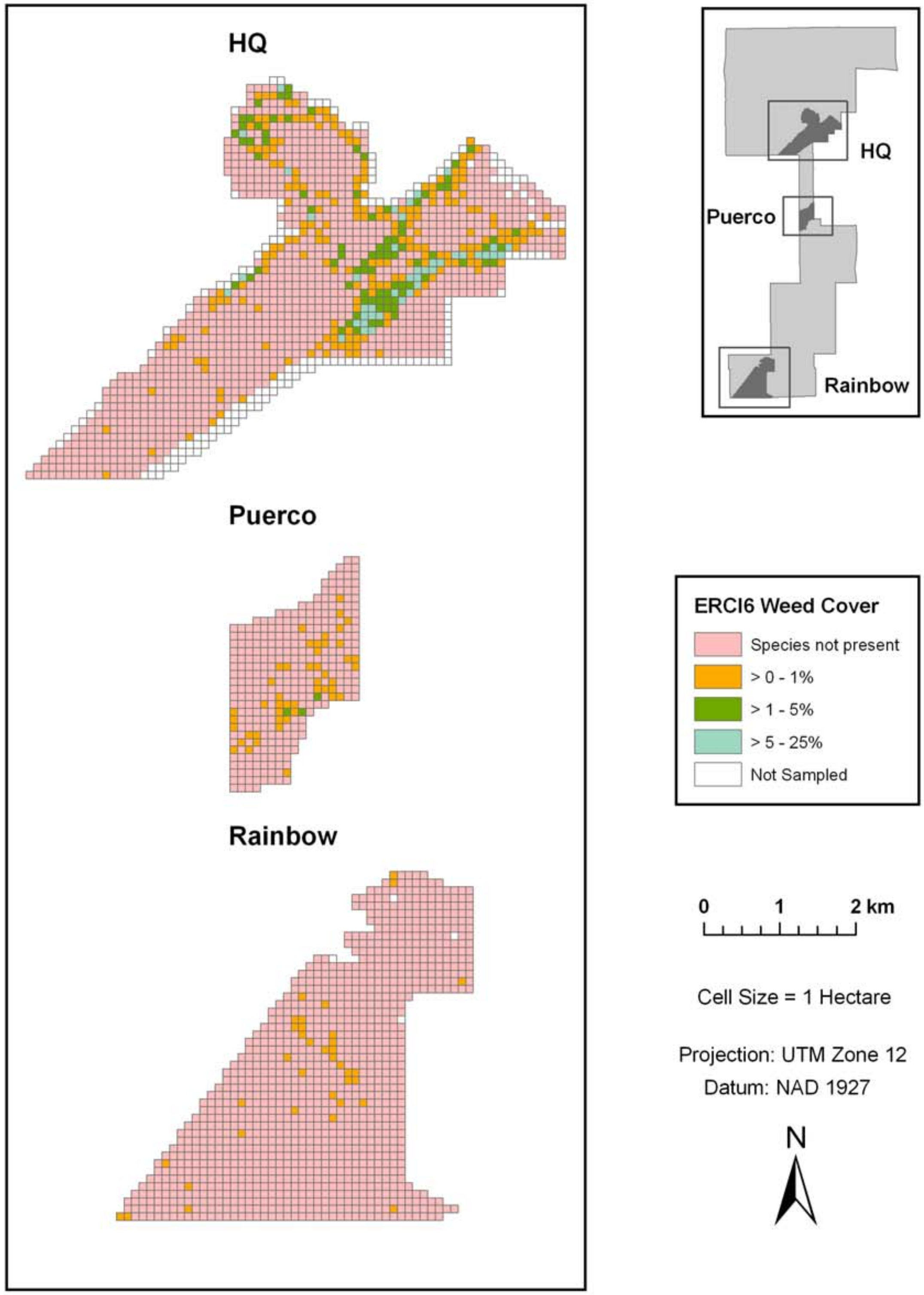
Appendix 1.19 *Cynodon dactylon*: Highest cover class and distribution



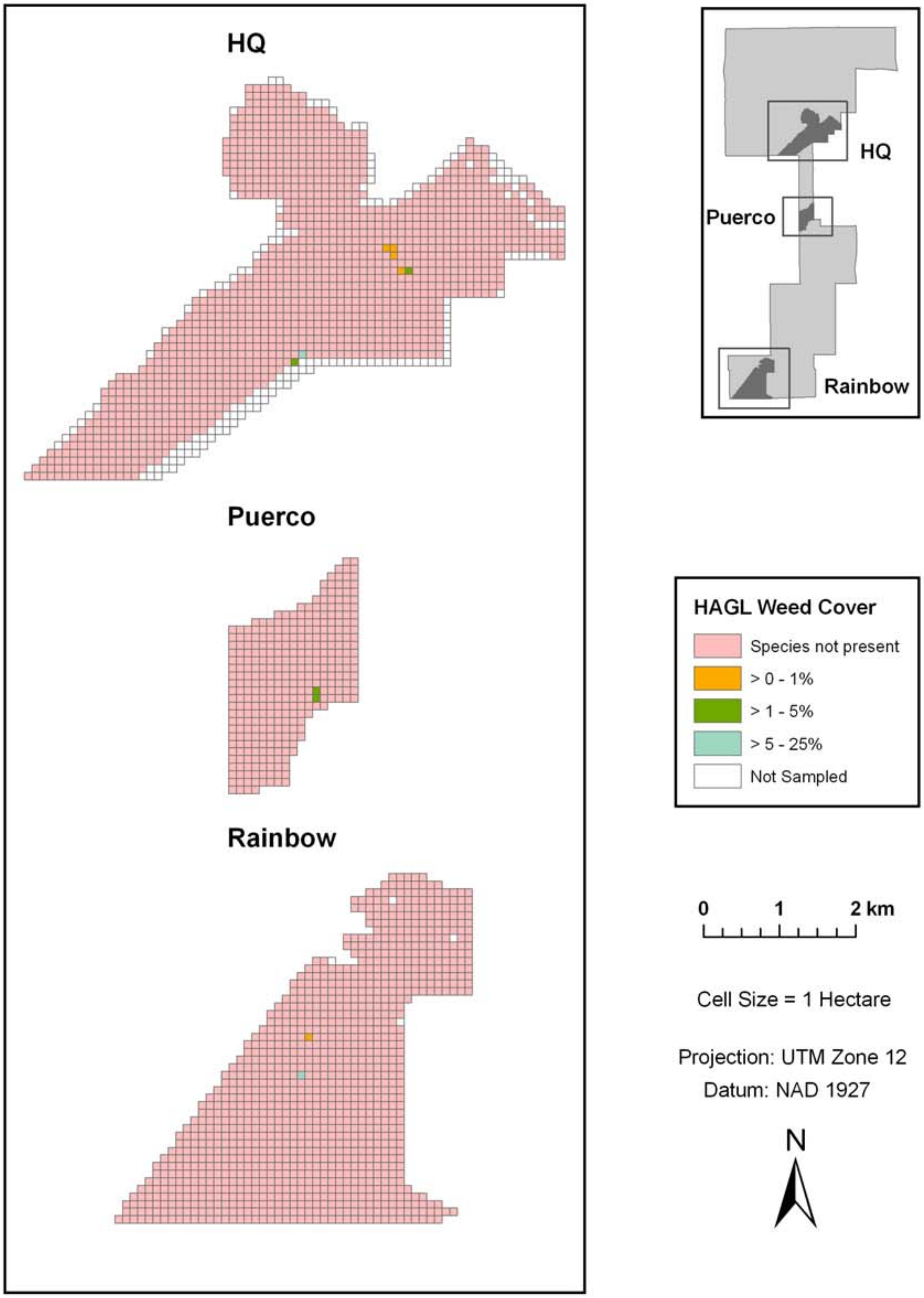
Appendix 1.20 *Elaeagnus angustifolia*: Highest cover class and distribution



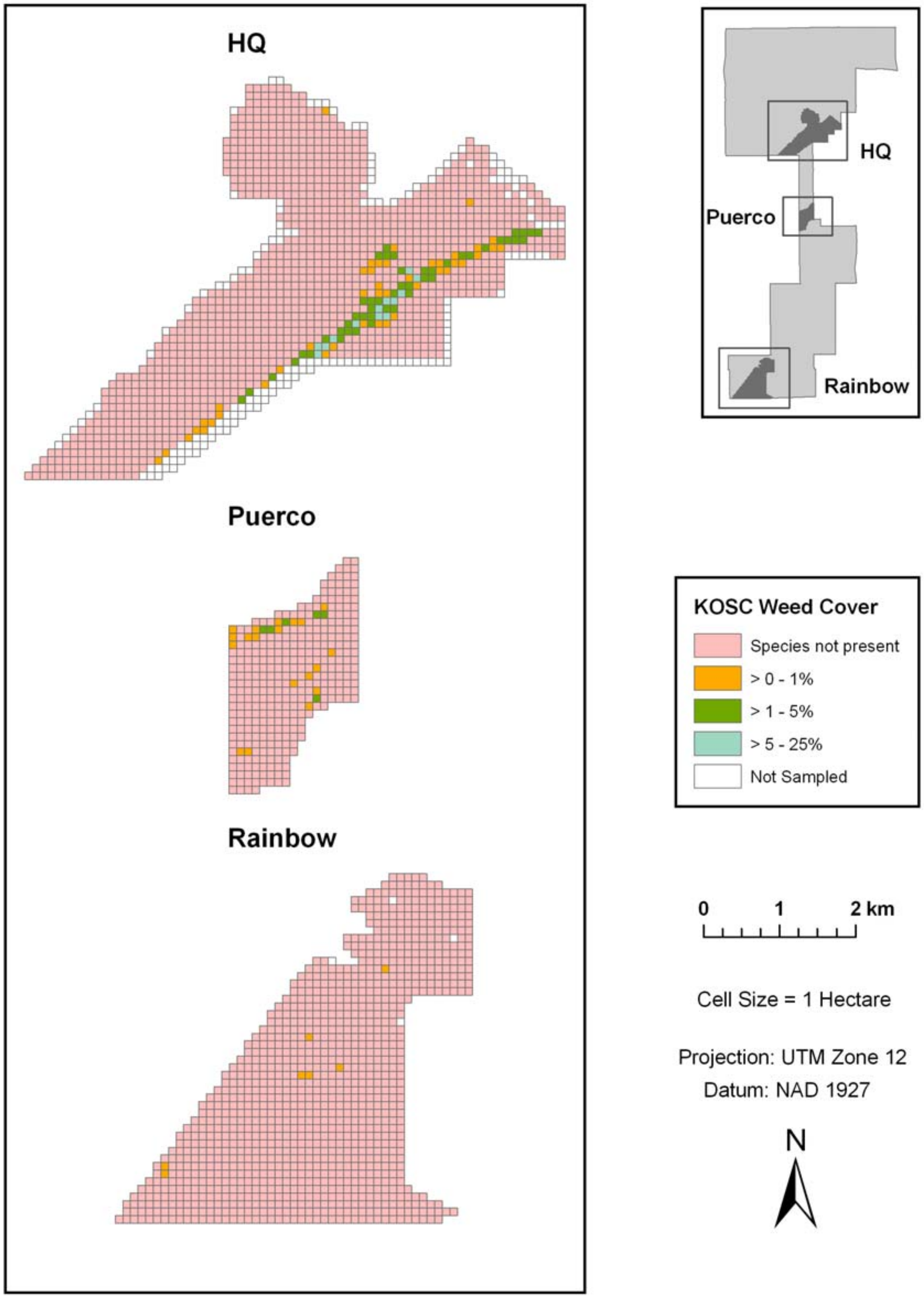
Appendix 1.21 *Erodium cicutarium*: Highest cover class and distribution



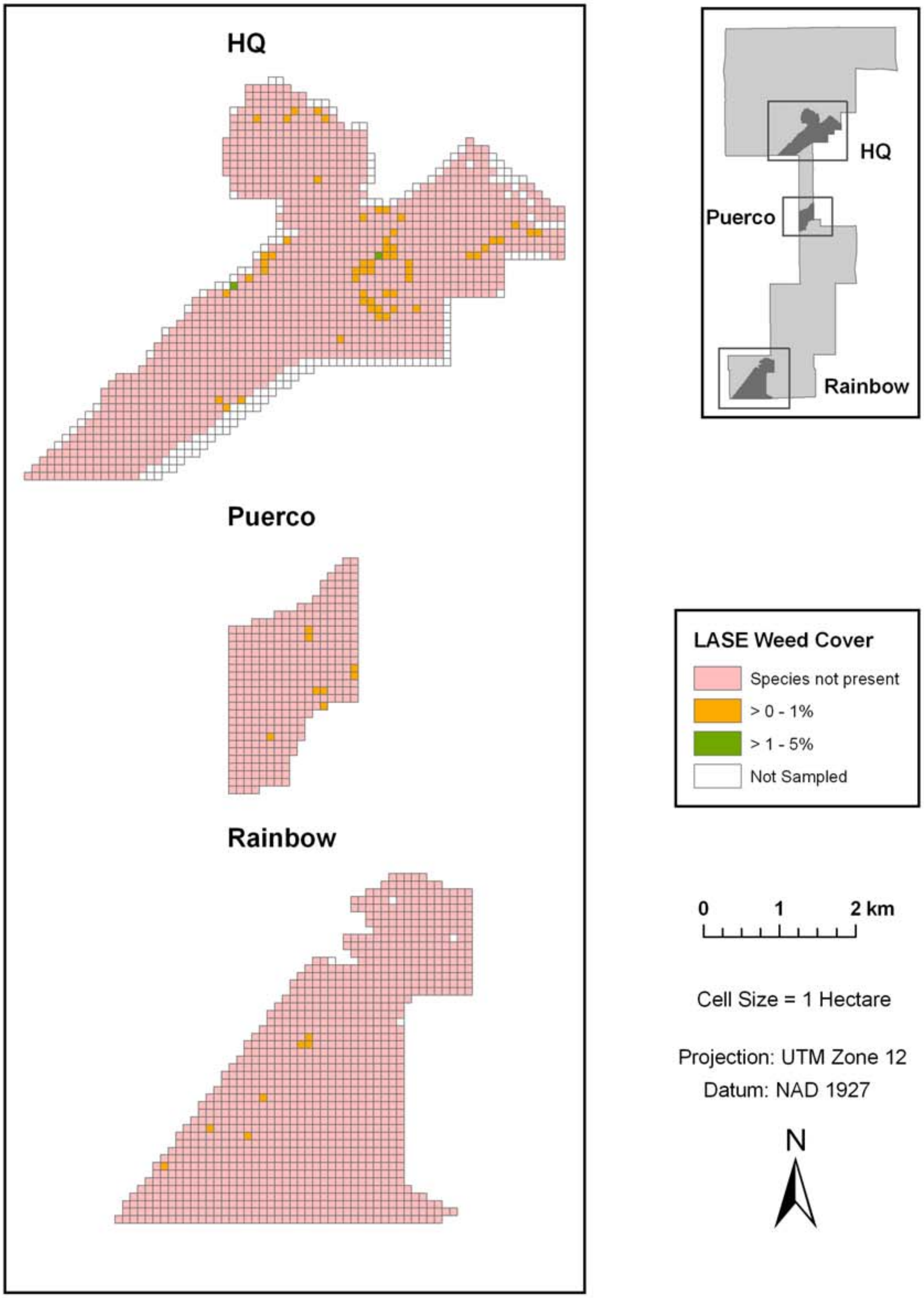
Appendix 1.22 *Halogeton glomeratus*: Highest cover class and distribution



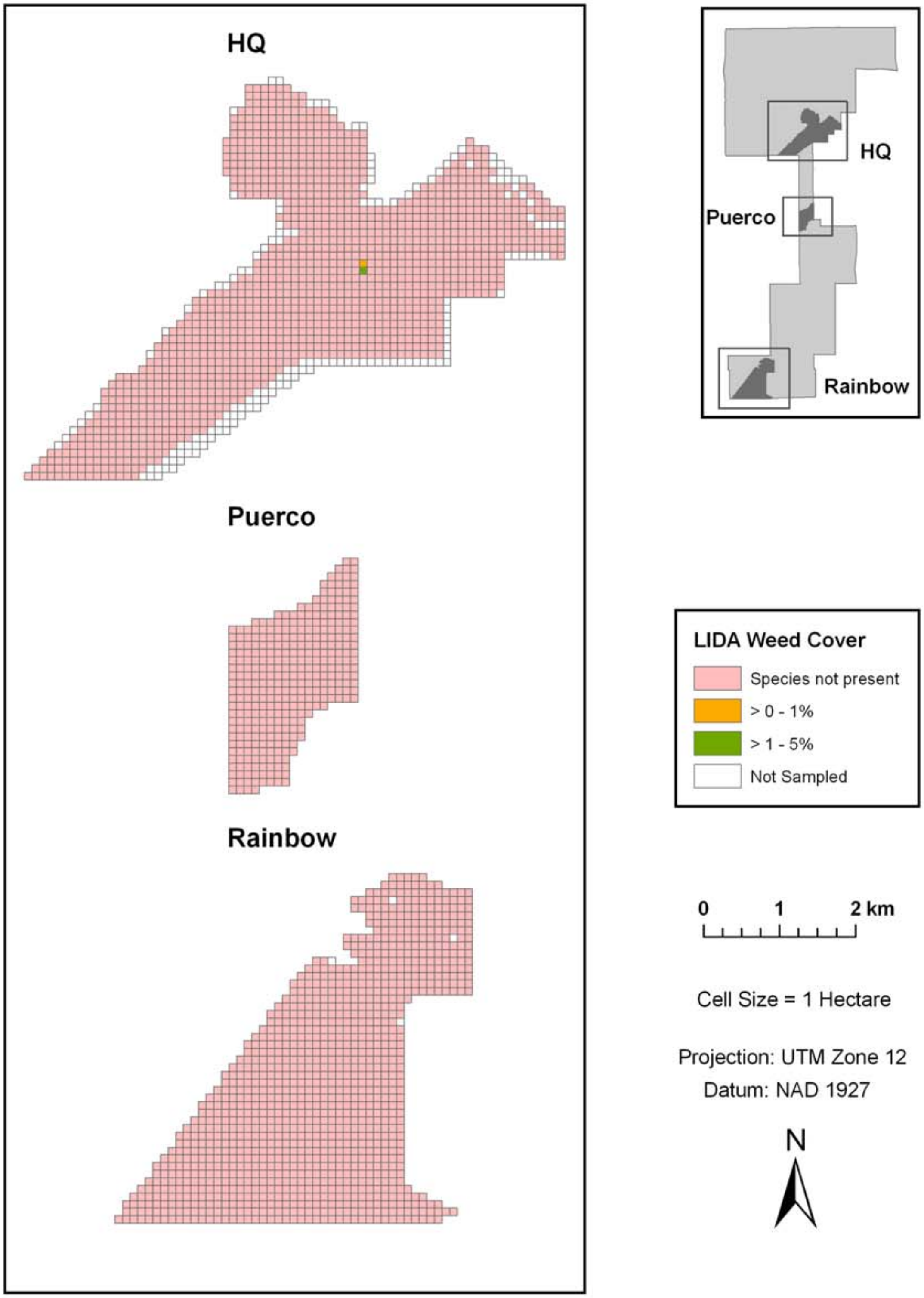
Appendix 1.23 *Kochia scoparia*: Highest cover class and distribution



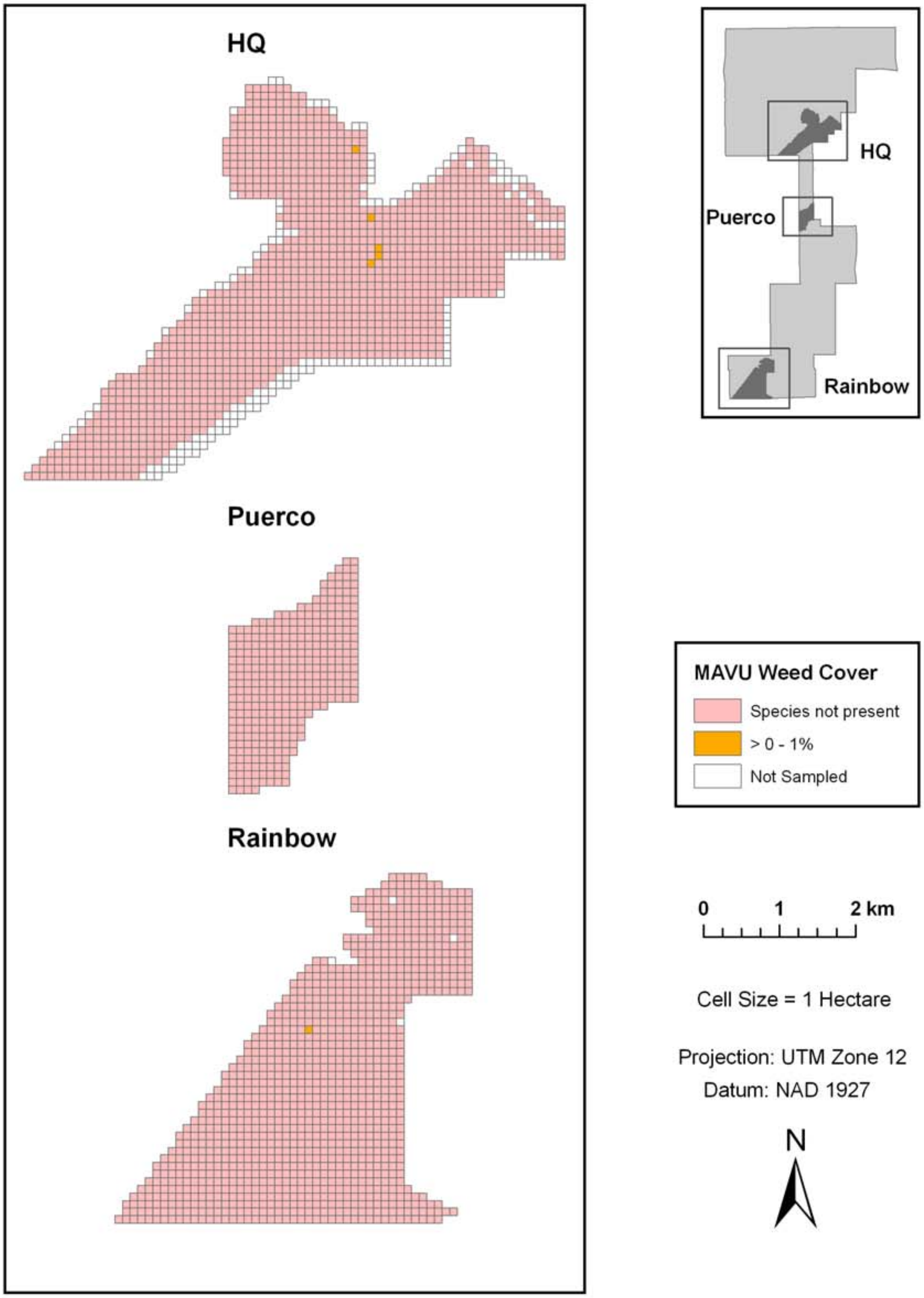
Appendix 1.24 *Lactuca serriola*: Highest cover class and distribution



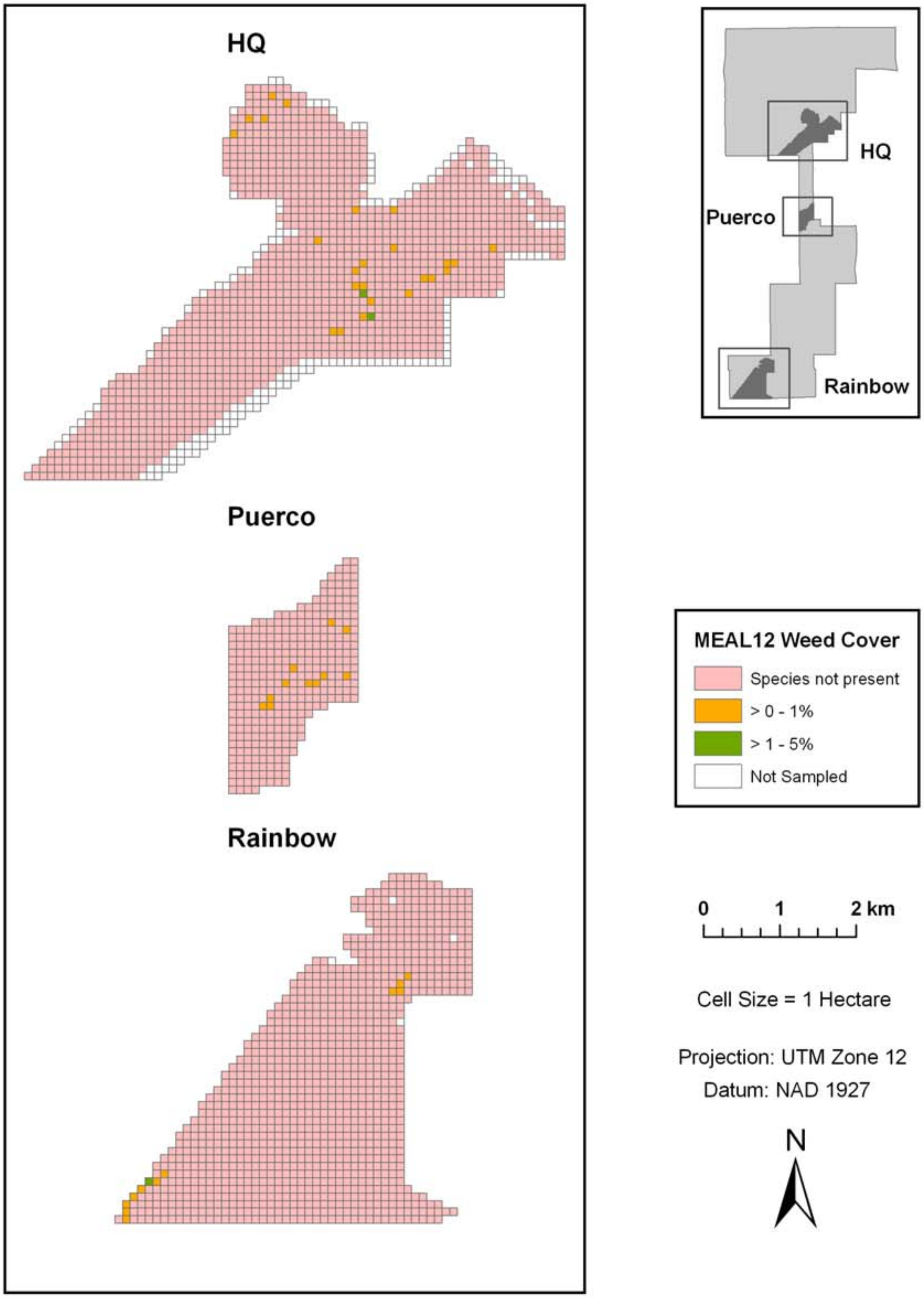
Appendix 1.25 *Linaria dalmatica*: Highest cover class and distribution



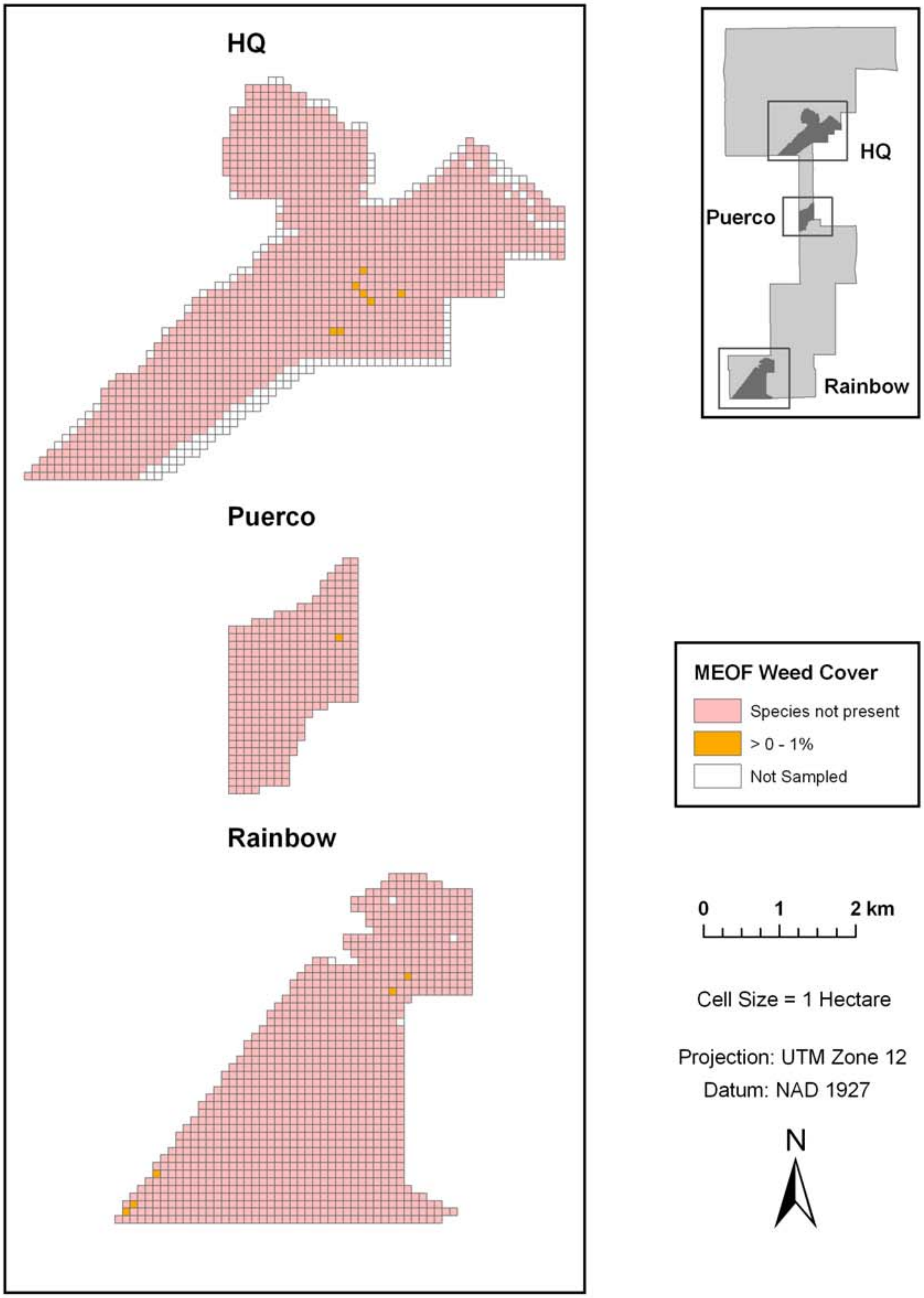
Appendix 1.26 *Marrubium vulgare*: Highest cover class and distribution



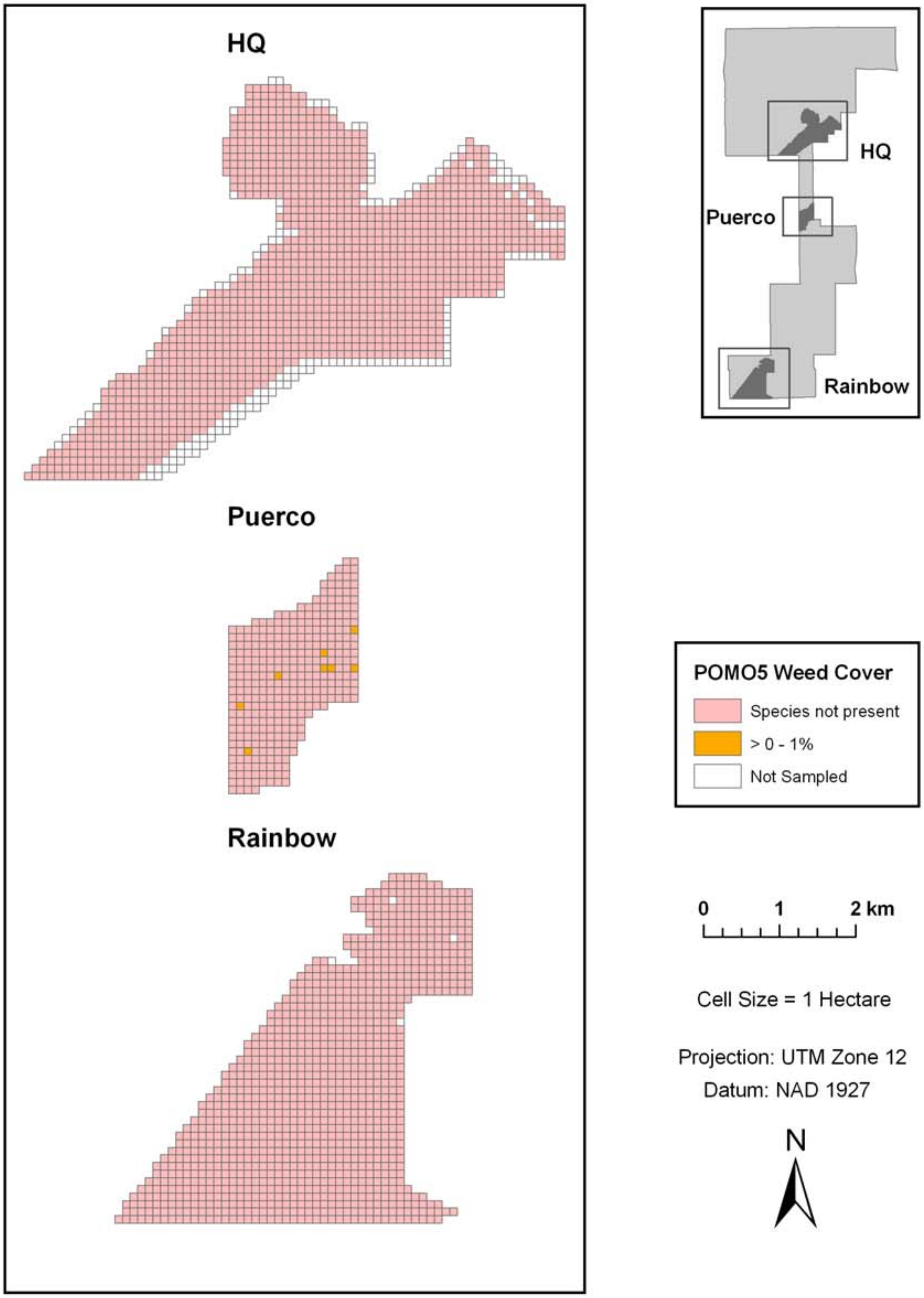
Appendix 1.27 *Melilotus alba*: Highest cover class and distribution



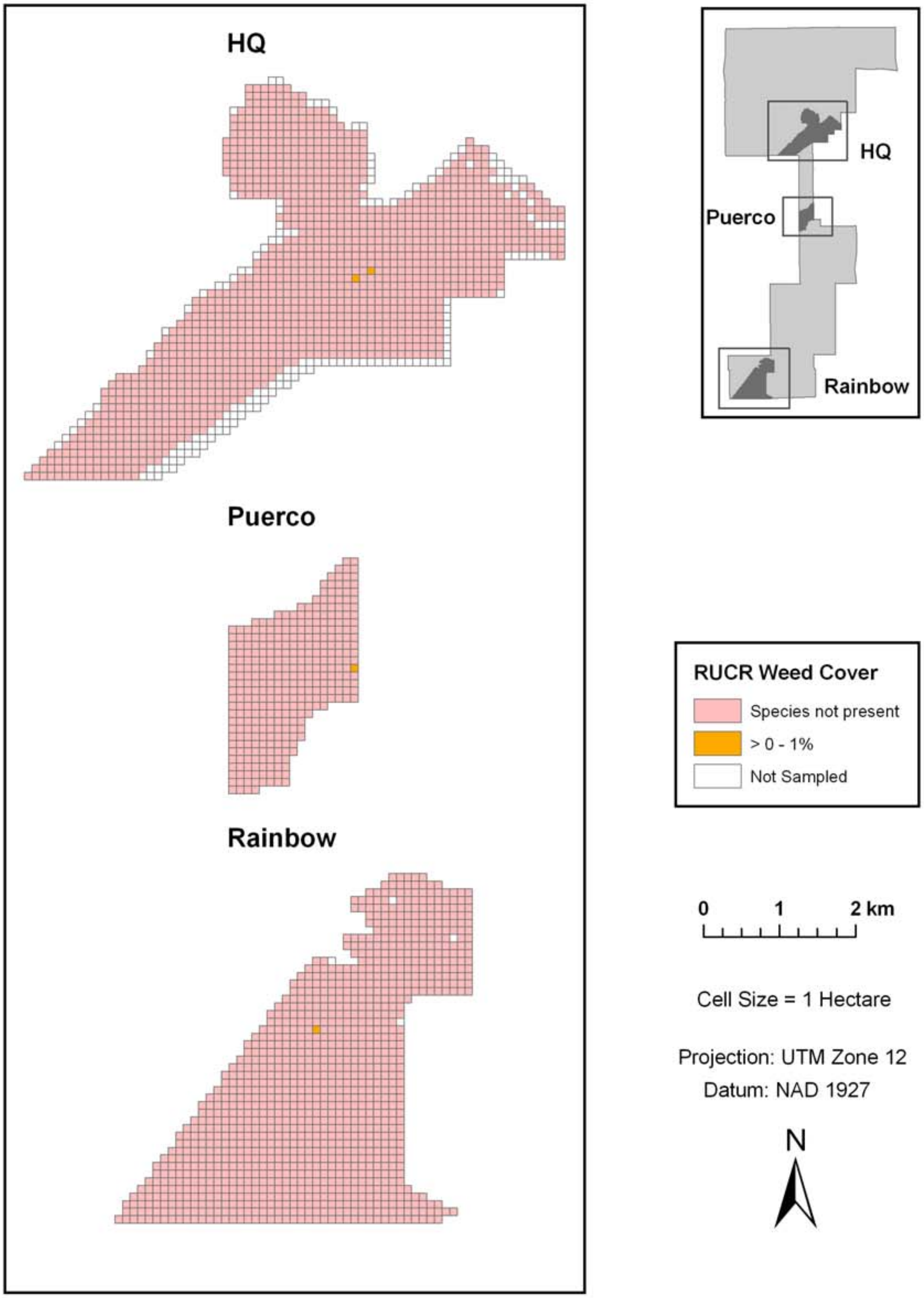
Appendix 1.28 *Melilotus officinalis*: Highest cover class and distribution



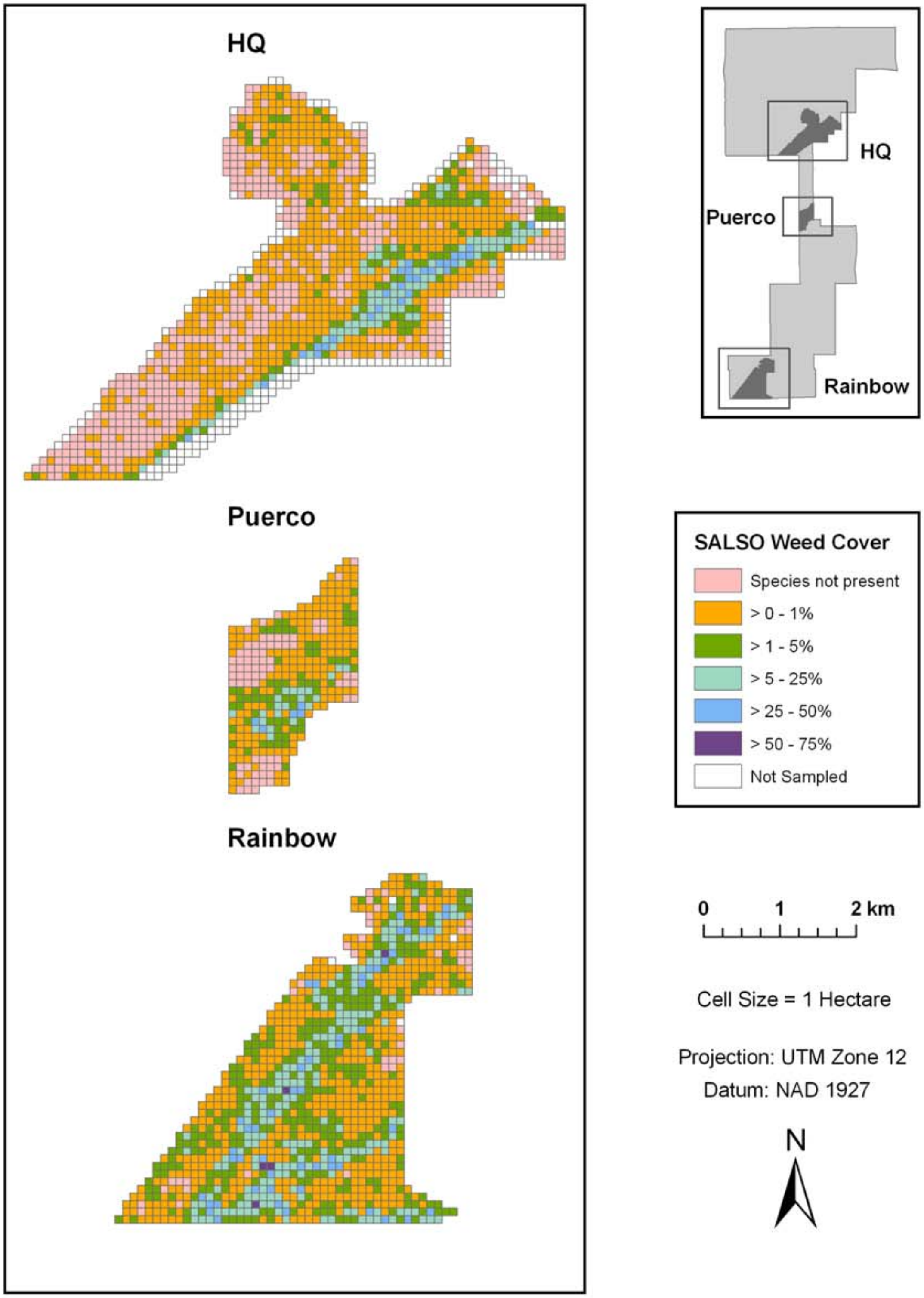
Appendix 1.29 *Polypogon monspeliensis*: Highest cover class and distribution



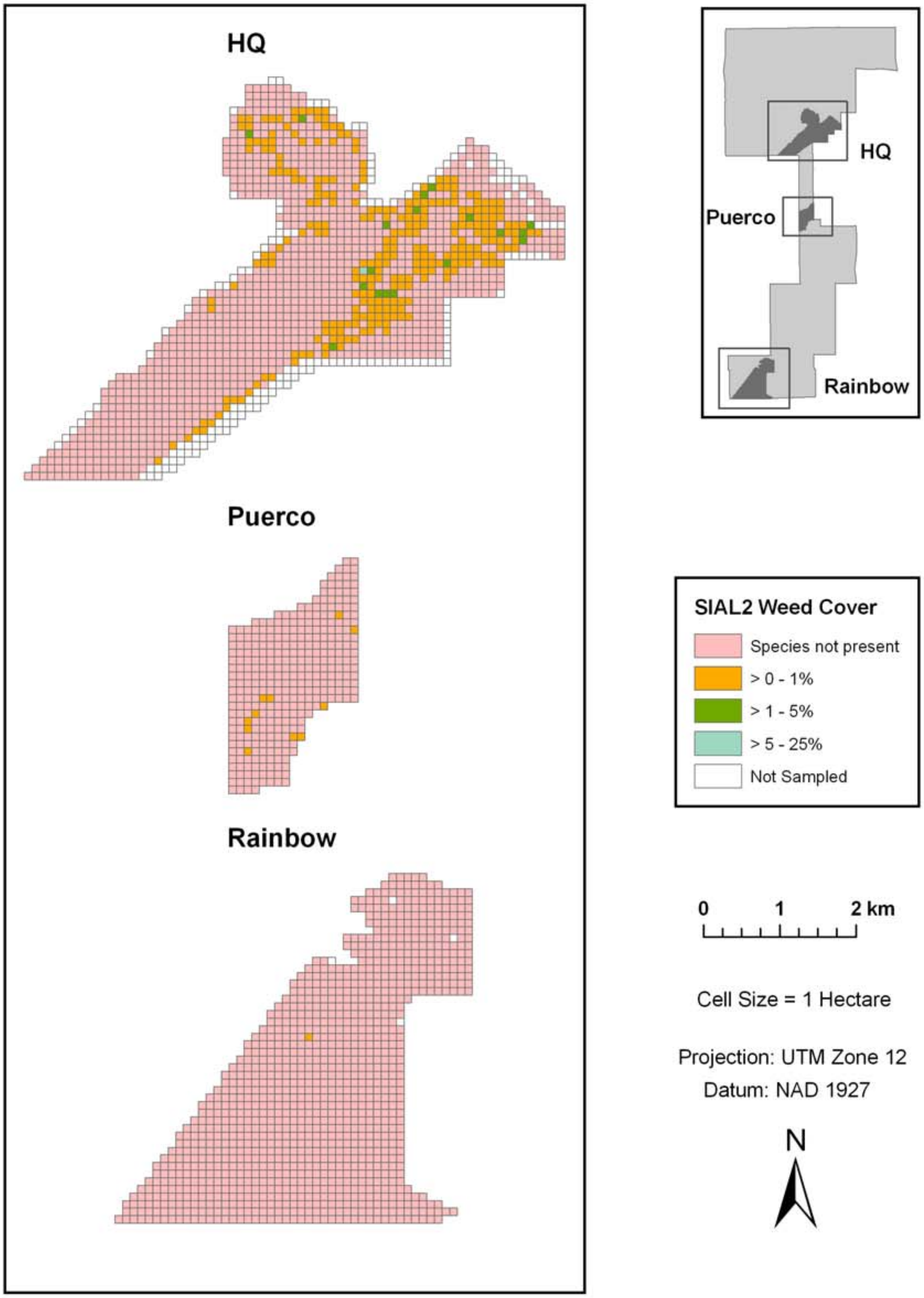
Appendix 1.30 *Rumex crispus*: Highest cover class and distribution



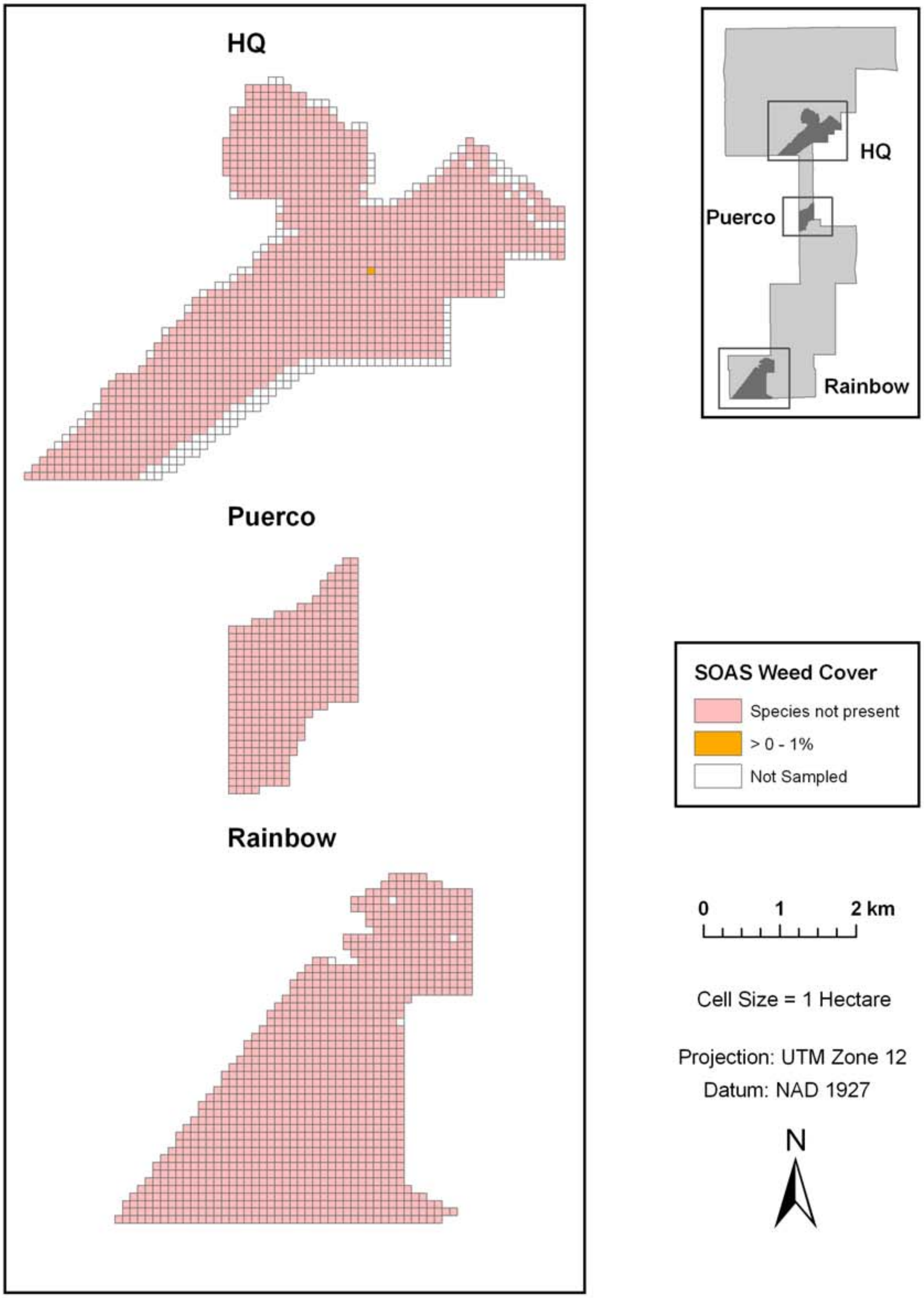
Appendix 1.31 *Salsola tragus*: Highest cover class and distribution



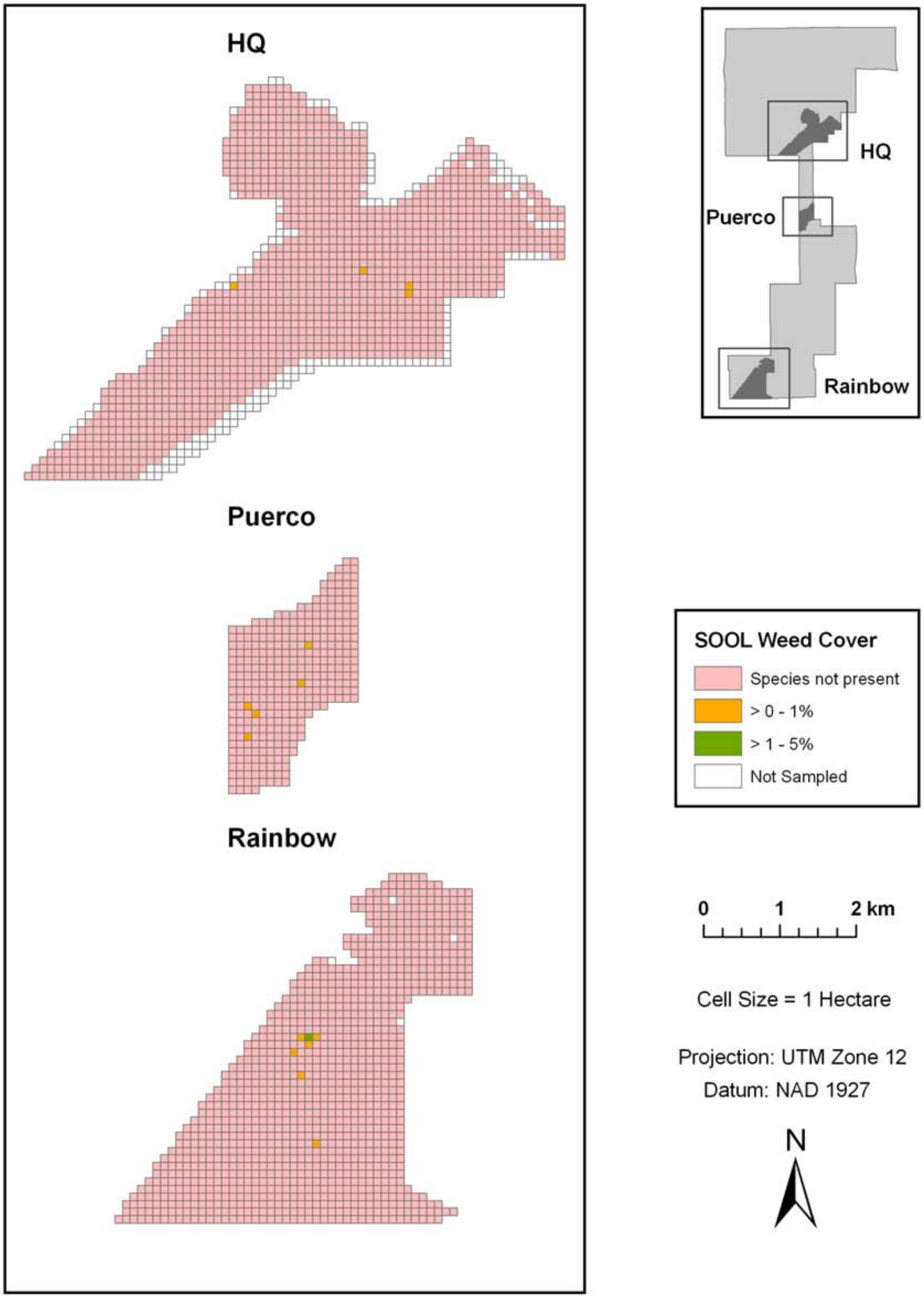
Appendix 1.32 *Sisymbrium altissimum*: Highest cover class and distribution



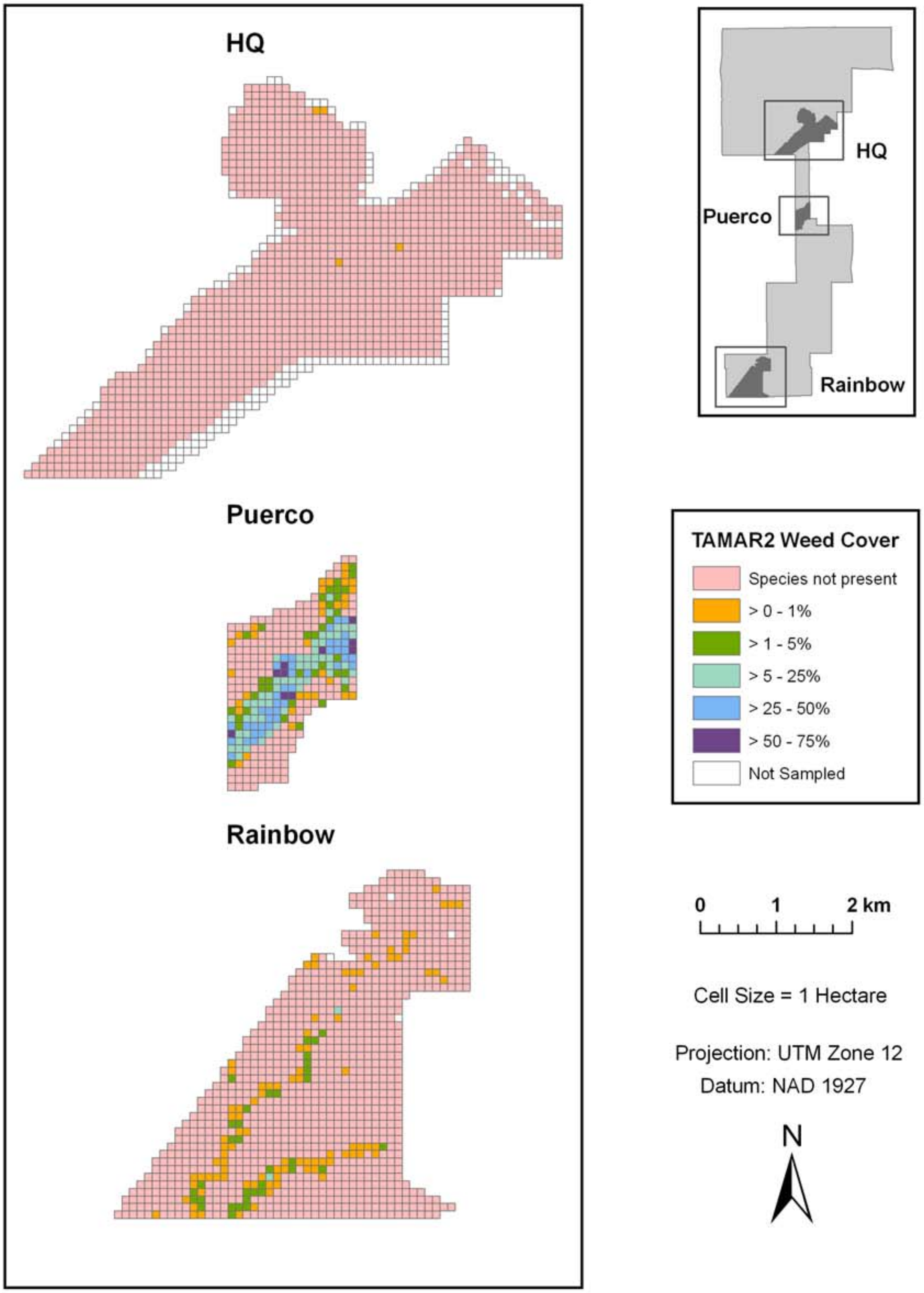
Appendix 1.33 *Sonchus asper*: Highest cover class and distribution



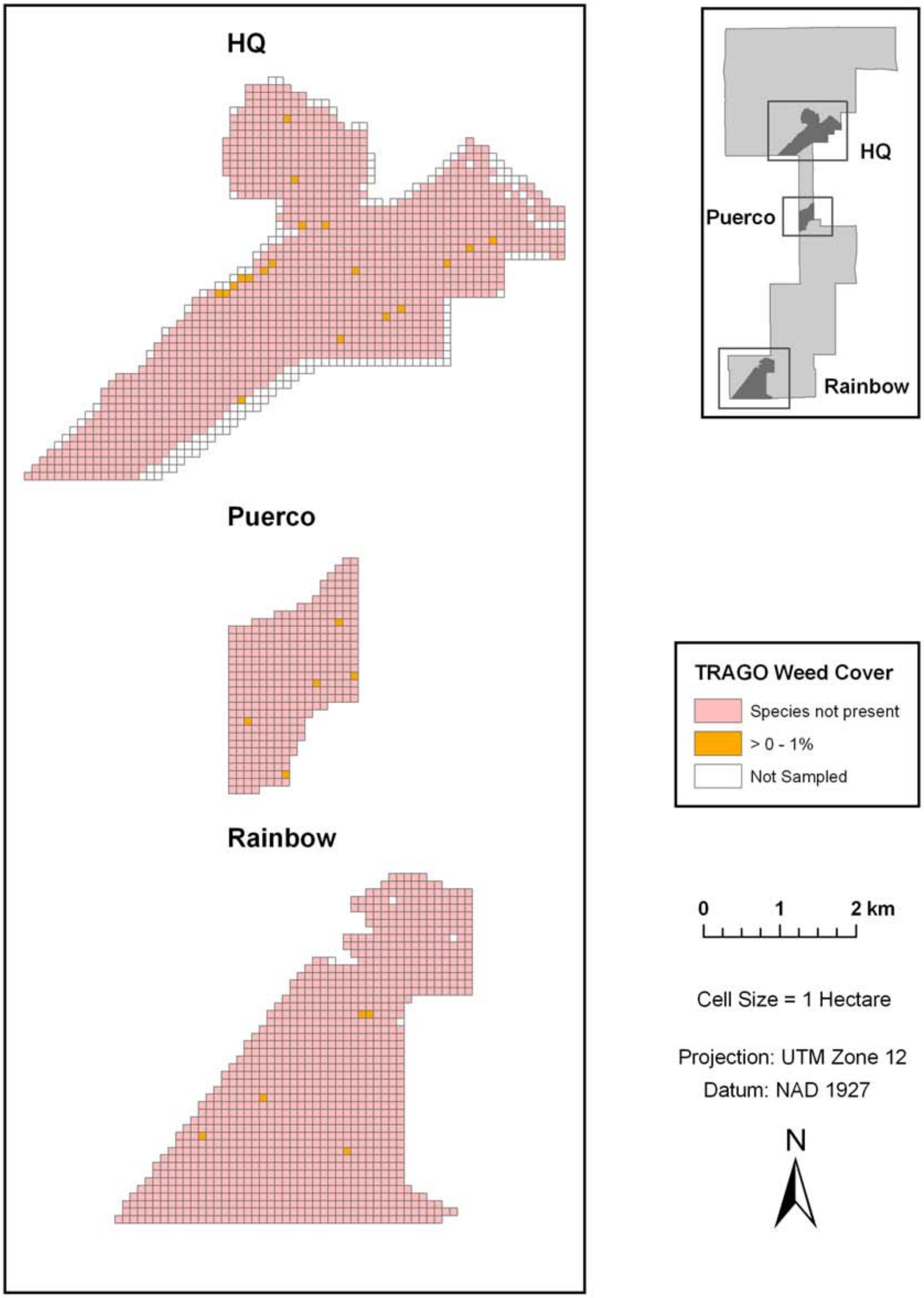
Appendix 1.34 *Sonchus oleraceus*: Highest cover class and distribution



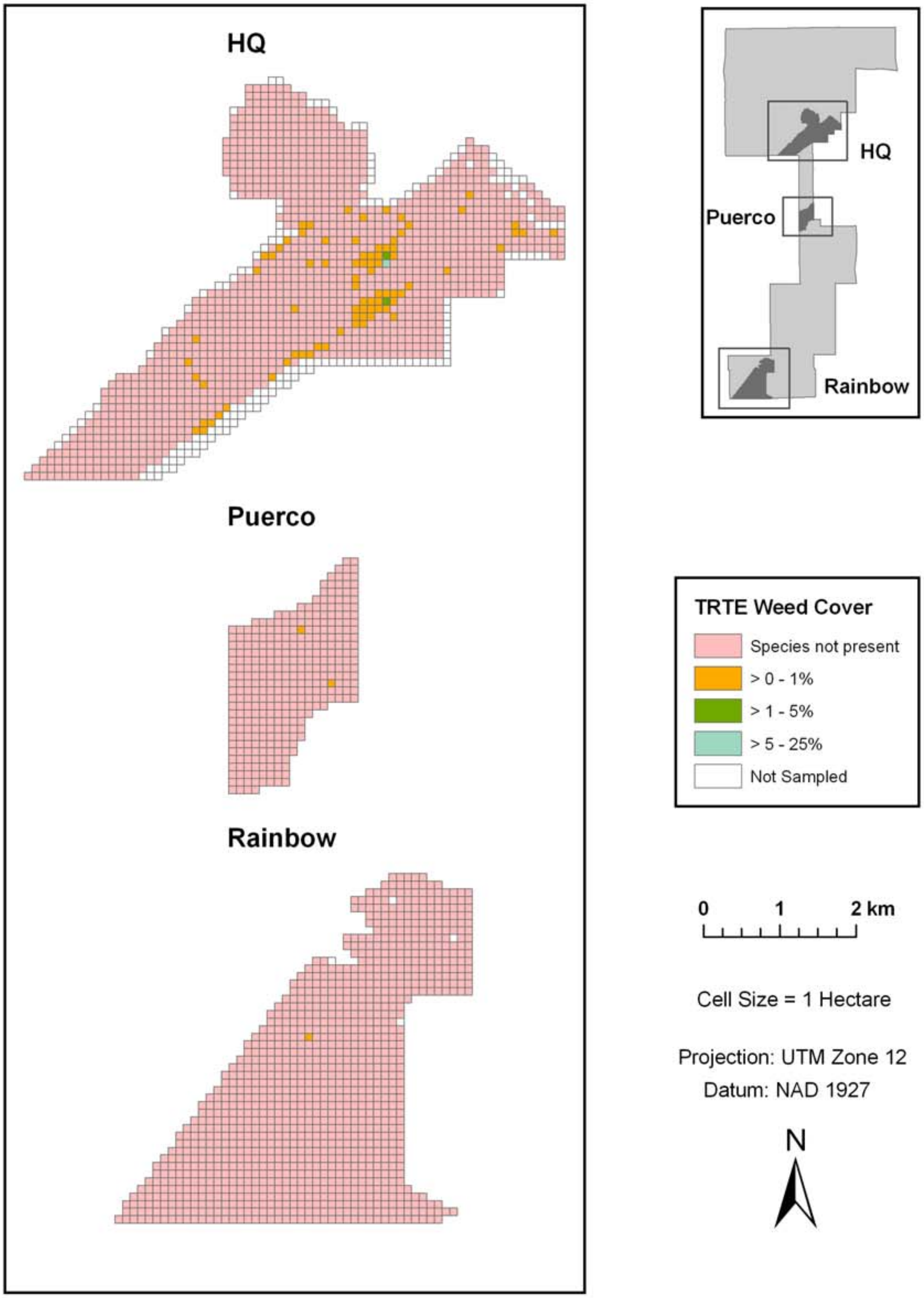
Appendix 1.35 *Tamarix chinensis*: Highest cover class and distribution



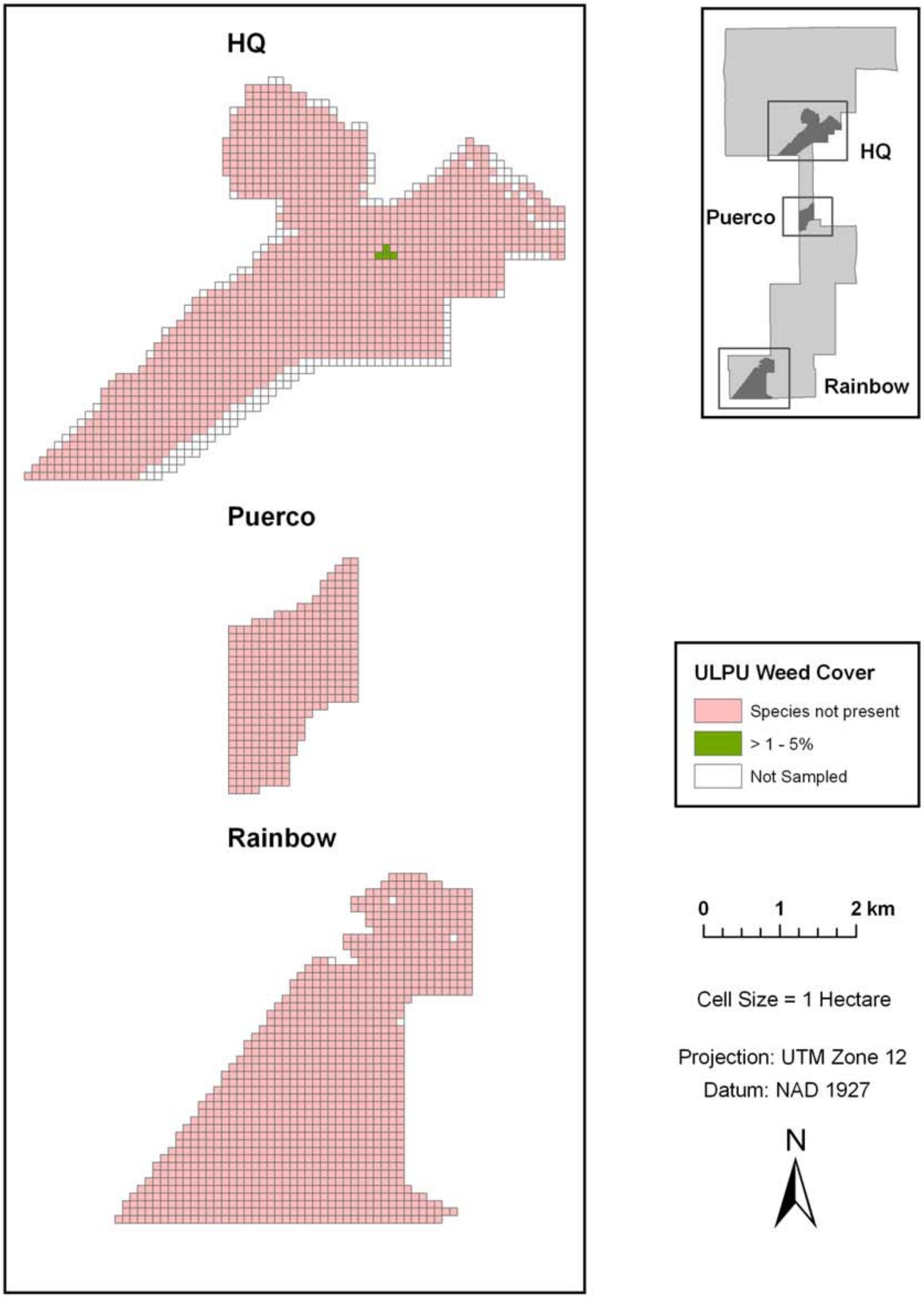
Appendix 1.36 *Tragopogon dubius*: Highest cover class and distribution



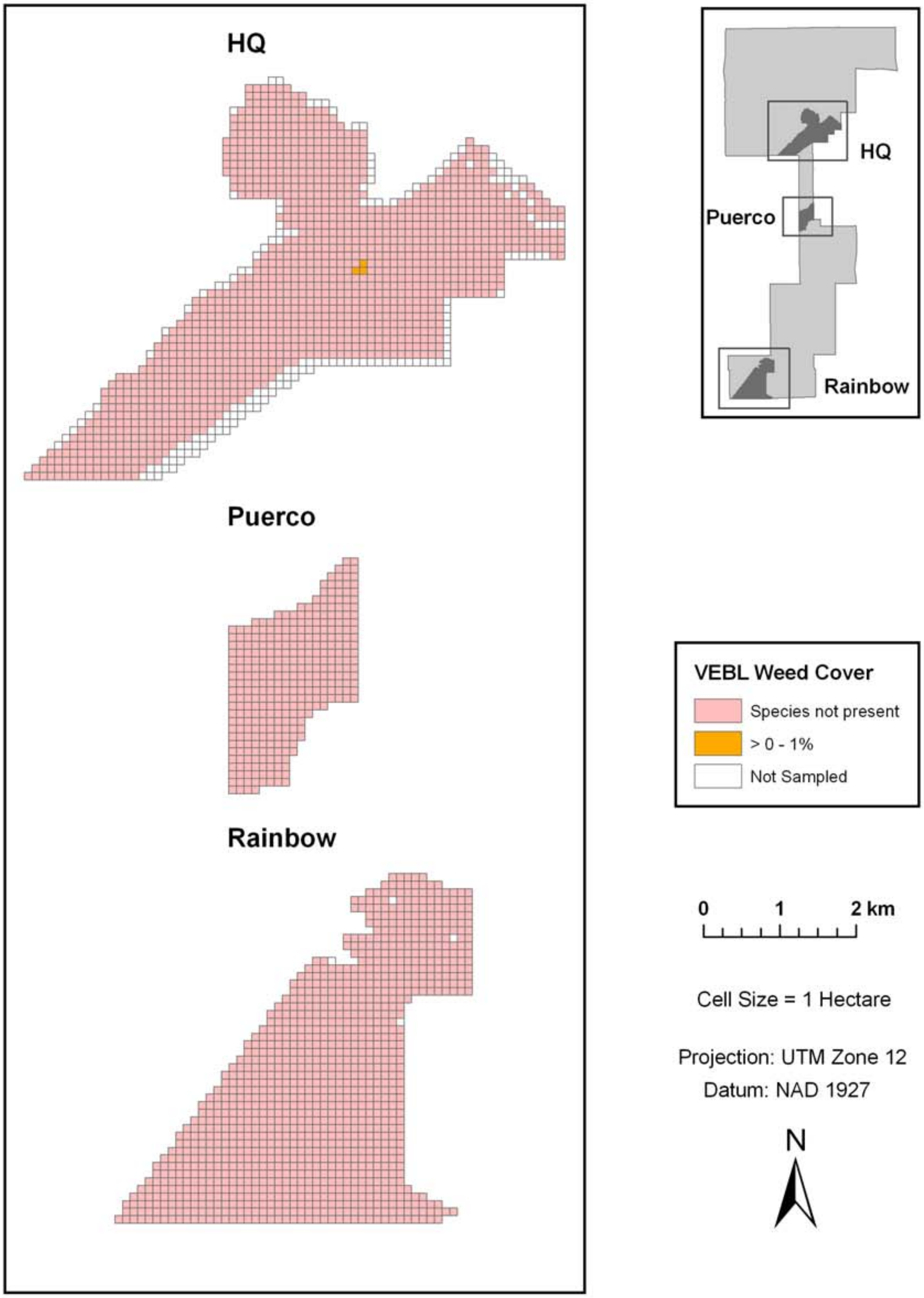
Appendix 1.37 *Tribulus terrestris*: Highest cover class and distribution



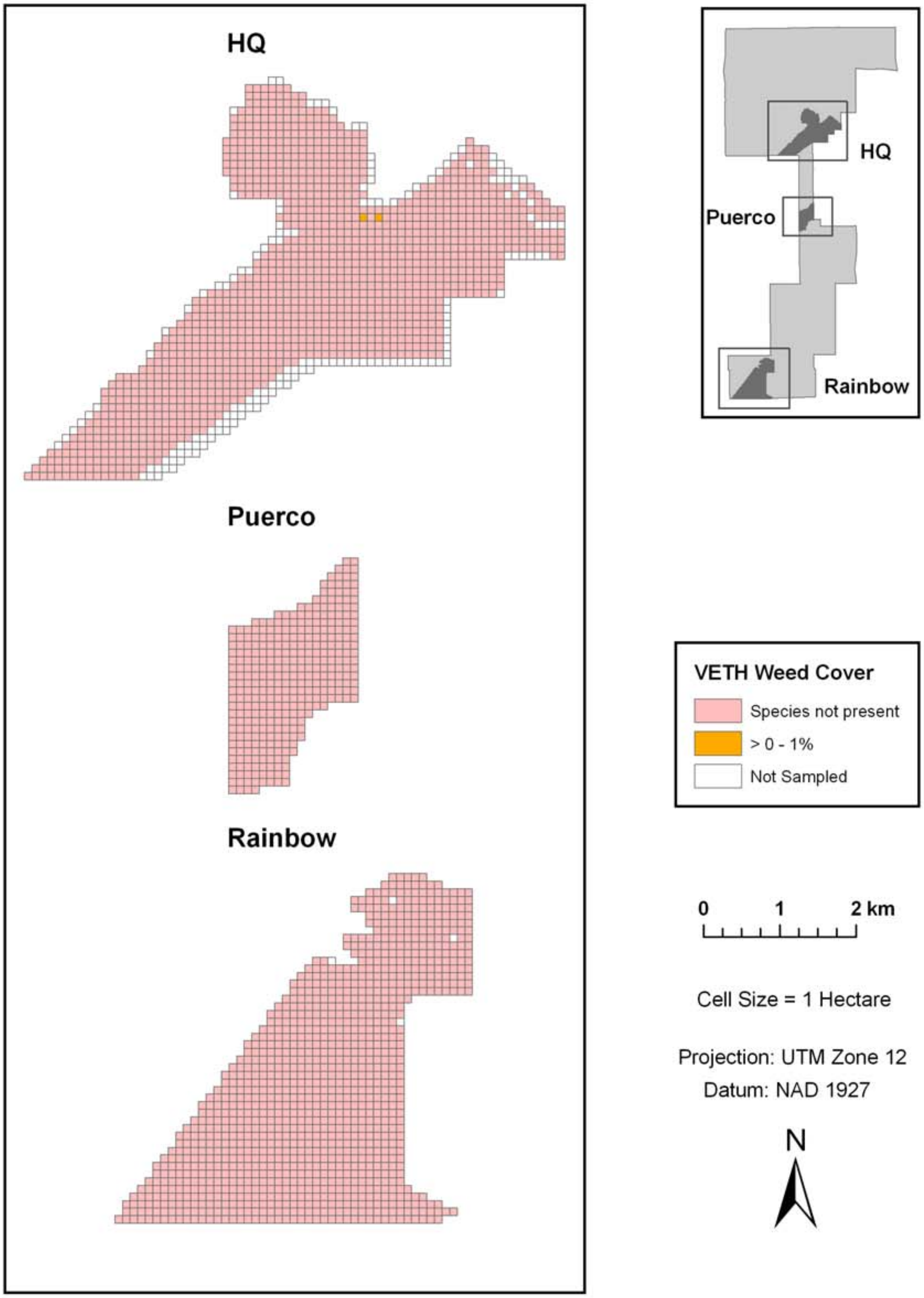
Appendix 1.38 *Ulmus pumila*: Highest cover class and distribution



Appendix 1.39 *Verbascum blattaria*: Highest cover class and distribution



Appendix 1.40 *Verbascum thapsus*: Highest cover class and distribution



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