



ECOLOGICAL-THREAT MAPPING The Sonoita Plain, Arizona

By Jelena Vukomanovic, Sandra Doumas, and W. R. Osterkamp

THE RESEARCH RANCH FOUNDATION

The Research Ranch Foundation is a private, 501c3 organization that promotes scientific research at the Appleton-Whittell Research Ranch (AWRR) of the National Audubon Society in Elgin, Arizona, and in similar semiarid environments. The Foundation assists in the management of the ranch to fulfill its goals to serve as a sanctuary for flora and fauna of native grasslands, to provide an undisturbed ecological benchmark, and to be a catalyst for thoughtful and sound use of the semiarid grasslands and savannahs of the American Southwest.

Related goals of the Foundation are to understand the histories of land-use activities at the Ranch and the surrounding area, to collect information on the physical and biological characteristics, and to provide limited areas for breeding selected endangered species whose native habitat is similar to that found on the Research Ranch.



Contents

4 Foreword

5 Acknowledgements

7 Overview

6 **FIGURE 1:** Study Area, The Sonoita Plain

8 **FIGURE 2:** House, Road, and Highway Locations in the Sonoita Plain

9 Ecosystem Threats of the Sonoita Plain

10 Threat 1: Poorly Planned Exurban Growth

11 **FIGURE 3:** Housing Densities in the Sonoita Plain

12 **FIGURE 4:** Photograph of Houses in the Sonoita Plain

13 **FIGURE 5:** Secondary Impacts Due to Housing and Roads in the Sonoita Plain

14 Threat 2: Water Availability

15 **FIGURE 6:** Sites of Registered Wells in the Sonoita Plain

16 **FIGURE 7:** Depth to Ground Water Beneath the Sonoita Plain

17 **FIGURE 8:** Sites of Registered Wells in the Sonoita Plain, 1970-2000

18 **FIGURE 9:** Water Levels Beneath the Sonoita Plain

20 Threat 3: Invasive Species

21 **FIGURE 10:** Native Vegetation Types in the Sonoita Plain

22 **FIGURE 11:** Areas Threatened by Invasive Species in the Sonoita Plain

23 Threat 4: Fire

24 **FIGURE 12:** Recently Burned Areas of the Sonoita Plain

25 **FIGURE 13:** Fire Return Interval Departures in the Sonoita Plain

26 Concluding Thoughts

27 References



Foreword

Many amenity-rich regions are experiencing rapid land-use change in the form of low-density residential development. This widespread land-use change, exurbanization, has profound implications for regional biological diversity and ecosystem function. In the United States, exurban land use occupies seven times more area than land with urban and suburban densities, and has increased at a rate of about 10 to 15% per year. Drivers of exurbanization include technological advancements and increases in tele-commuting, transportation and road-network improvements, and various push- (crime, crowding, poor education systems, etc.) and pull- (affordable or desirable housing, privacy, better schools, etc.) factors. The rapid and dispersed nature of exurban development raises numerous ecological concerns, including reduction of water availability to biota, fragmentation of habitat, increased

fire hazard, alteration of the food network, and change in vegetation owing to invasive species. Those same natural-resource amenities that attracted migration are often degraded by housing increases and associated development. Despite the enormous potential impacts arising from this widespread land-use change, exurbanization has received much less study than land-use change in suburban or urban areas.

This report is a series of what we've dubbed "development hazard maps" for the Sonoita Plain in southeastern Arizona. As part of The Research Ranch Foundation's (TRRF) Ecosystem Services Case Study Project, these maps are the products of an initial investigation into the ecosystem services and natural resources of a semiarid grassland area facing unrestricted residential development. The maps show areas

where (1) poorly planned exurban expansion poses a threat to ecosystem dynamics, (2) water use by humans and disruption of water movement threaten the regional ecological processes, (3) human actions threaten native flora, and (4) changed fire frequency poses long-term threats to native biota. The maps are advanced as tools to manage and plan activities in the Sonoita Plain and similar areas of semiarid grassland. The area described here is a healthy grassland ecosystem that is threatened by continuing development; nearby areas that have suffered ecosystem degradation provide comparisons and an ability to evaluate management approaches to avoid or mitigate further ecosystem compromise. It is our hope that a better understanding of the spatial extent of threats to ecosystem services will help to guide decision-making on the fate and best use of grassland ecosystems.



Acknowledgements

Ecological-threat Mapping, the Sonoita Plain, Arizona was made possible through the support of the Ariel Appeltan Fellowship program of The Research Ranch Foundation. All data for this report was collected in 2011 unless otherwise specified.

We thank Linda Kennedy, Director of the Appleton-Whittell Research Ranch of the National Audubon Society, for valuable input and guidance during the formative stages of the Threats report. For input on the invasive species map, we would like to thank Gita Bodner, Karen Simms, Matt Killeen, Patricia Guertin, Kristen Egen, and Emilio Carrillo. Steve Yool provided guidance on the creation of the fire maps, and we are grateful for all of his help. We thank Kristine Uhlman and the staff of the Water Resources Research Center, University of Arizona, for providing National Land Cover Data and information about ground-water resources in the Sonoita Plain. We also wish to thank Kyle Hartfield and the Arizona Remote Sensing Center, University of Arizona, for technical support with map production.

Credit goes to Michael McNulty for allowing us to use some of his beautiful photography in this publication. With his artistry, Michael captures the special beauty of the Sonoita Plain. You can see more of Michael's work at <http://photos.mcnulty.net/>

Finally, as indicated by credits at the end of this report, the Sonoran Institute and its personnel played a major role in the editing, layout, photography, and publication of this report. Their superb contributions are hugely appreciated.

Published January, 2013

STUDY AREA, THE SONOITA PLAIN

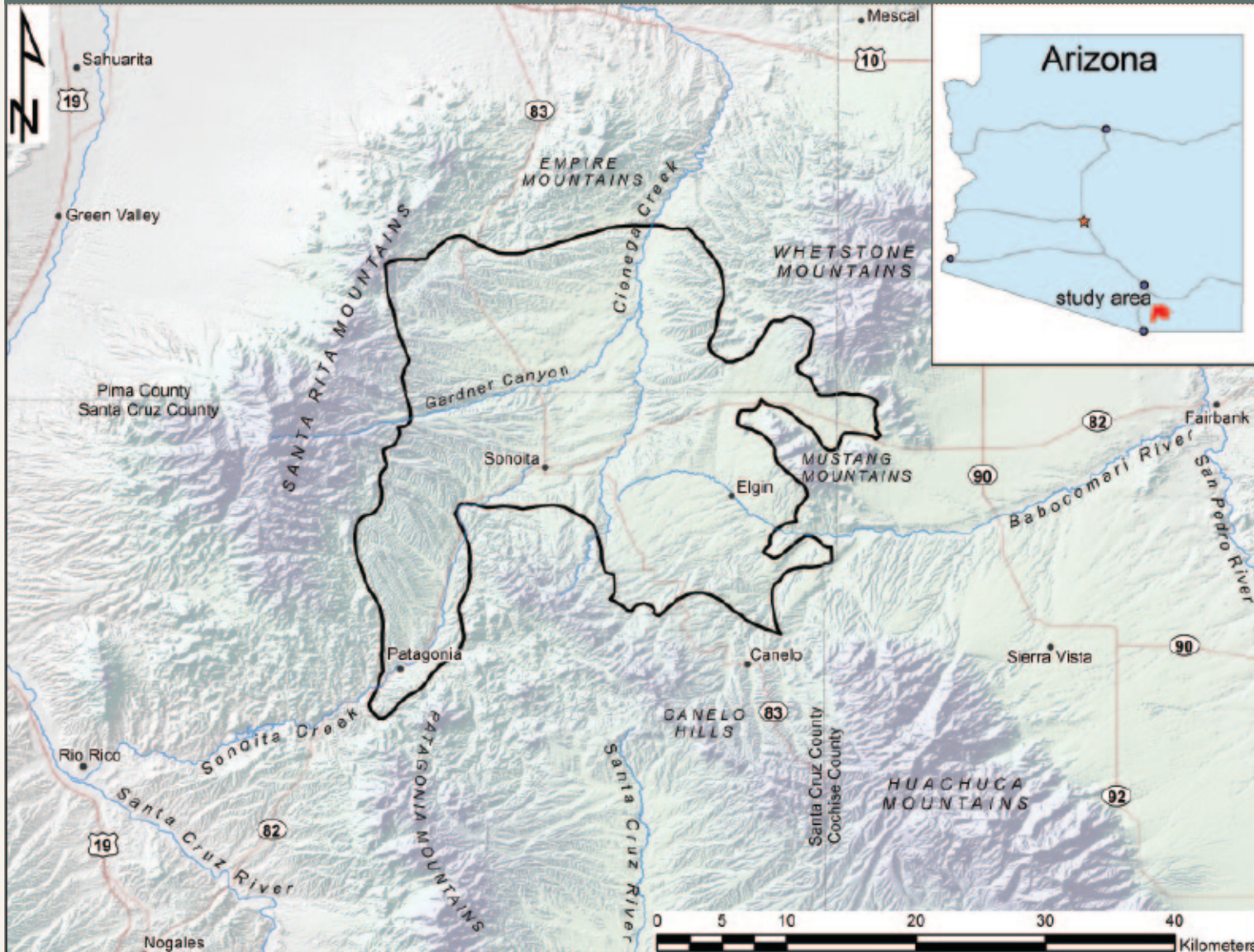


Figure 1. Map of the Sonoita Plain (study area) and surrounding areas. Bordering the Sonoita Plain on the west are the Santa Rita Mountains, the Whetstone Mountains on the northeast, the Mustang Mountains on the east, the Huachuca Mountains on the southeast, and the Canelo Hills on the south; inset map of Arizona shows the study area in red, highways as lines, Flagstaff, Yuma, Tucson, and Nogales as black dots, and Phoenix as a red star.

Overview

Large areas of grassland in semiarid areas of the Sonoran and Chihuahuan deserts in southwestern North America are yielding to low-density housing. The extension of exurban development into this landscape is placing increasing stress on these grassland ecosystems. This paper examines the threat of human-caused change resulting from the use of land, water, and biotic resources in a fragile native-grassland area of southeastern Arizona. The interactive hazards that result from the use of these resources threaten ecosystem function and can severely affect the water balance, biology, and ecological benefits of an area. Recognizing the extent to which these threats can diminish wildlife and vegetation, and the natural services they provide, is essential if healthy ecosystems are to persist.

Accordingly, the purpose of this study is to present hazard, or threat, maps for an area undergoing housing development—the Sonoita Plain (or Valley), near Elgin, Arizona (Fig. 1). The maps suggest changes in ecosystem services and the natural resources of a grassland due to unrestricted human encroachment; they show areas where (1) poorly planned exurban expansion poses a threat to ecosystem dynamics, (2) water use by humans and disruption of water movement threaten the regional ecological processes, (3) human actions threaten native flora, and (4) changed fire frequency poses long-term threats

to native biota. The maps are advanced as tools to manage and plan activities in the Sonoita Plain and similar areas of semiarid grassland.

Prior to Anglo-Saxon expansion, much of the Southwest supported lush grasslands with diverse ecosystems. Beginning about 1880, intense grazing and drought, coupled with infrequent floods, badly damaged the grasslands and caused deep incision of stream channels. Deterioration continues where poorly considered development compromises ecosystem resources. Although extensive grassland has been damaged, some ecosystems remain vibrant. Preservation of these areas has high national and regional importance, both for ecosystem valuation and to understand how to manage these critical resources wisely.

An evaluation of all Southwestern grasslands is impractical, so a smaller, representative area has been studied. Described is the Sonoita Plain, which has a healthy but threatened grassland. It has a large biological database due to research at the nearby Appleton-Whittell Research Ranch. And it has a water resource that, with groundwater extraction, may not continue to provide ecosystem support. The maps of this folio are displayed in geographic-coordinate system, GCS North American 1983, datum D North American 1983; layers requiring metric distances or areas were projected to NAD 1983 UTM Zone 12N.

HOUSE, ROAD, AND HIGHWAY LOCATIONS IN THE SONOITA PLAIN

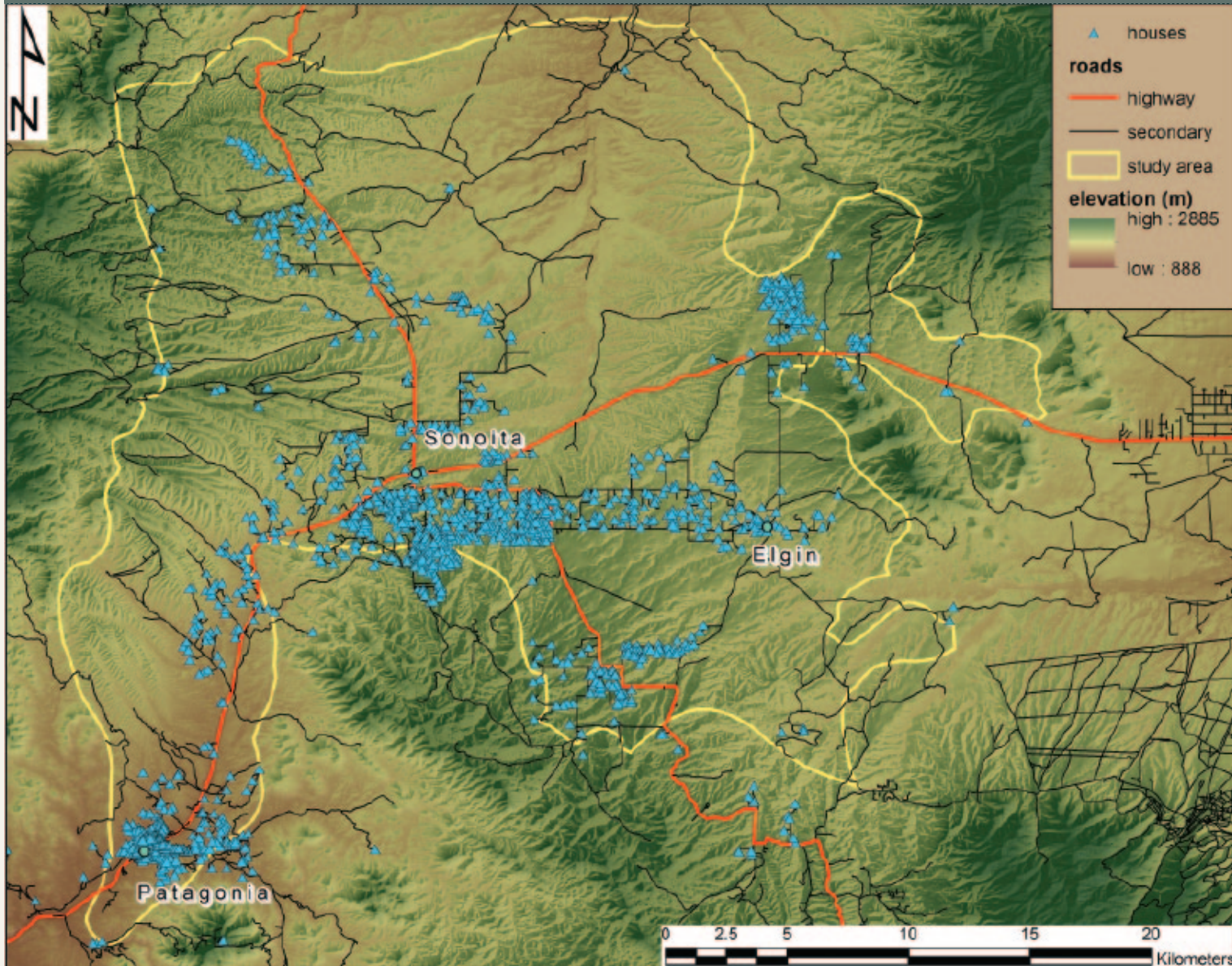


Figure 2. The greatest housing densities are along roadways near the towns of Sonoita, Elgin, and Patagonia, as well as in burgeoning residential developments in the northeast, northwest, and southern regions of the Sonoita Plain. (Houses manually located using aerial imagery from USDA Farm Service Agency, NAIP, 2010, coordinated with census block data, U.S. Census Bureau, 2010.)

Ecosystem Threats of the Sonoita Plain

The Sonoita Plain is in Pima, Santa Cruz, and Cochise counties, Arizona. Grassland elevations range from 1100 to 1600 m (meters), but bordering uplands approach 2900 m (Fig. 1). Land ownership is half public (Forest Service, Bureau of Land Management, and state) and half is private. Native vegetation includes perennial bunchgrasses with trees, shrubs, succulents, and forbs. The Sonoita Plain is mostly grassland, with savannas of scattered mesquite or oak, that relies entirely on rainfall averaging 430 millimeters per year (Bota, 1996). Sixty percent of precipitation falls between early July and early September, the monsoon period of peak plant productivity (Bock and Bock, 1998).

Arizona state highways (Routes) are shown on most of the maps. Route 82 extends through the study area from the southwestern tip of the Sonoita Plain to Patagonia and Sonoita and exits to the east between the Whetstone and Mustang mountains. Route 83 trends to the southeast from east of the Santa Rita Mountains to Sonoita, and

continues southeasterly toward the Huachuca Mountains and the Canelo Hills (Fig. 1).

Native grasslands provide numerous human services, many of which do not have monetary value. They maintain air quality by sequestering carbon, absorbing methane, and reducing nitrous-oxide emissions; they store a genetic library, ameliorate climate, and prevent soil erosion (Sala and Paruelo, 1997). Grassland soils contain large quantities of carbon that is released to the atmosphere if plowed, but the reverse process of accruing carbon is very slow (Burke et al., 1989). Similarly, native grasslands are reservoirs of biological diversity that may be severely reduced by cultivation or overgrazing (McNeely et al., 1995). Recovery may never occur if disturbance is large. Thus, the value of grassland services is important to decision-makers, researchers, and society, and assessing threats to grasslands is essential to estimate the vulnerability of their services and to guide decisions of their management.



Threat 1: Poorly Planned Exurban Growth

To halt the threat to ecosystems by human encroachment it is necessary to understand land-use changes in rural areas and to examine the extent, trend, and pattern of development. The density of exurban housing is generally much less than that in urban areas, and per-capita land use is much greater than in cities. Negatives of exurbanization are habitat loss, landscape fragmentation, altered hydrologic and fire regimes, and the spread of exotic and invasive plants and animals. These changes in land use are likely to continue, necessitating adjustments in land stewardship and causing changes to ecosystem services due to altered water, fire, and biotic processes. A notable benefit of low-density housing is an increase in diversity for some wildlife owing to increases in availability of water and shade, and reduction of predation.

Figure 2 shows house and road locations in the Sonoita Plain, and Figure 3 shows that presently their greatest densities are near Sonoita, Elgin, and Patagonia. These areas present the greatest ecosystem threats to (1) water availability by pumped wells, (2) a natural fire regime, owing to fire suppression and buildup of organic fuel, and (3) biota due to the spread of non-native and invasive plants. In this regard, the threats to water, fire, and biota cannot be separated from changes caused by poorly planned development.

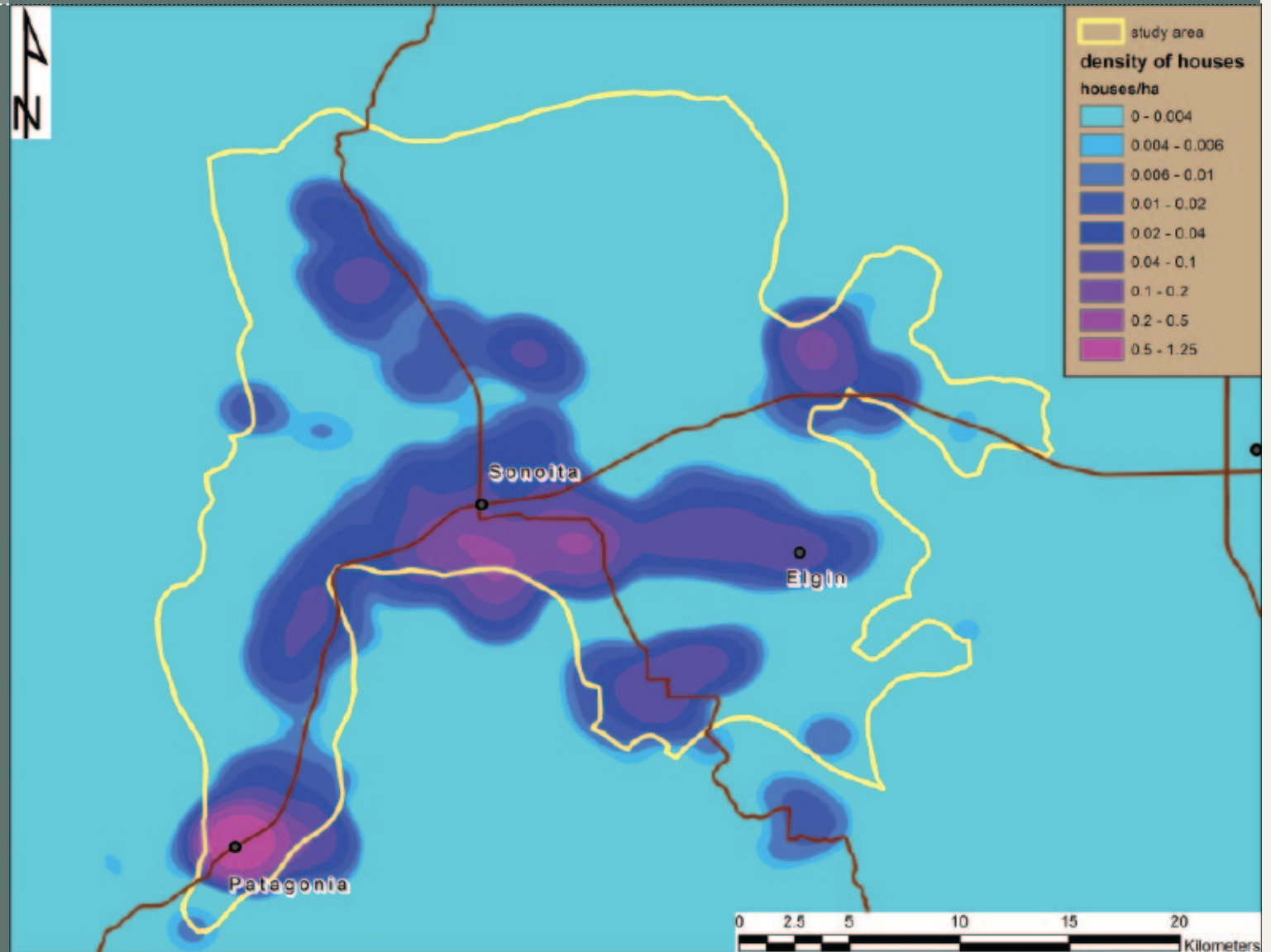
The impact of exurban development—in terms of maintaining ecosystem services—depends on the service considered, highlighting the challenge of predicting and managing ecosystem services under changing land-use patterns. The hazard maps of this study specify where the ecosystems of healthy grasslands may be most threatened by poorly regulated development (Figs. 3, 4, 5). Nearby areas with ecosystem degradation provide comparisons and an ability to evaluate management approaches that may prevent further damage.

Secondary effects of human occupation, which extend at least 100 m from houses and roads, include responses of wildlife and wildlife movement to changes in vegetation, changed conditions of runoff and infiltration, changes in dispersal of herbicides and related chemicals, increase or decrease of erosion, and noise. Figure 4 is a high-resolution aerial photograph of exurban houses near Sonoita. It illustrates the influence that homes of the area typically have within a 100-m radius. Each house is accessed by roads and driveways; each is surrounded by non-native vegetation, including trees, that provides flammable organic matter; and each locally alters natural runoff, infiltration, soil moisture, and soil-chemistry properties. The cumulative impact of these effects is depicted in the map of Figure 5,



HOUSING DENSITIES IN THE SONOITA PLAIN

Figure 3. Areas of highest housing densities, found near the towns of Sonoita and Patagonia, present the greatest threats to water availability, the natural fire regime, and wildlife.



PHOTOGRAPH OF HOUSES IN THE SONOITA PLAIN



Figure 4. Aerial photograph of an exurban-housing area in the Sonoita Plain showing disturbances within a 100-m radius of each house. (USDA Farm Service Agency, NAIP, 2010.)

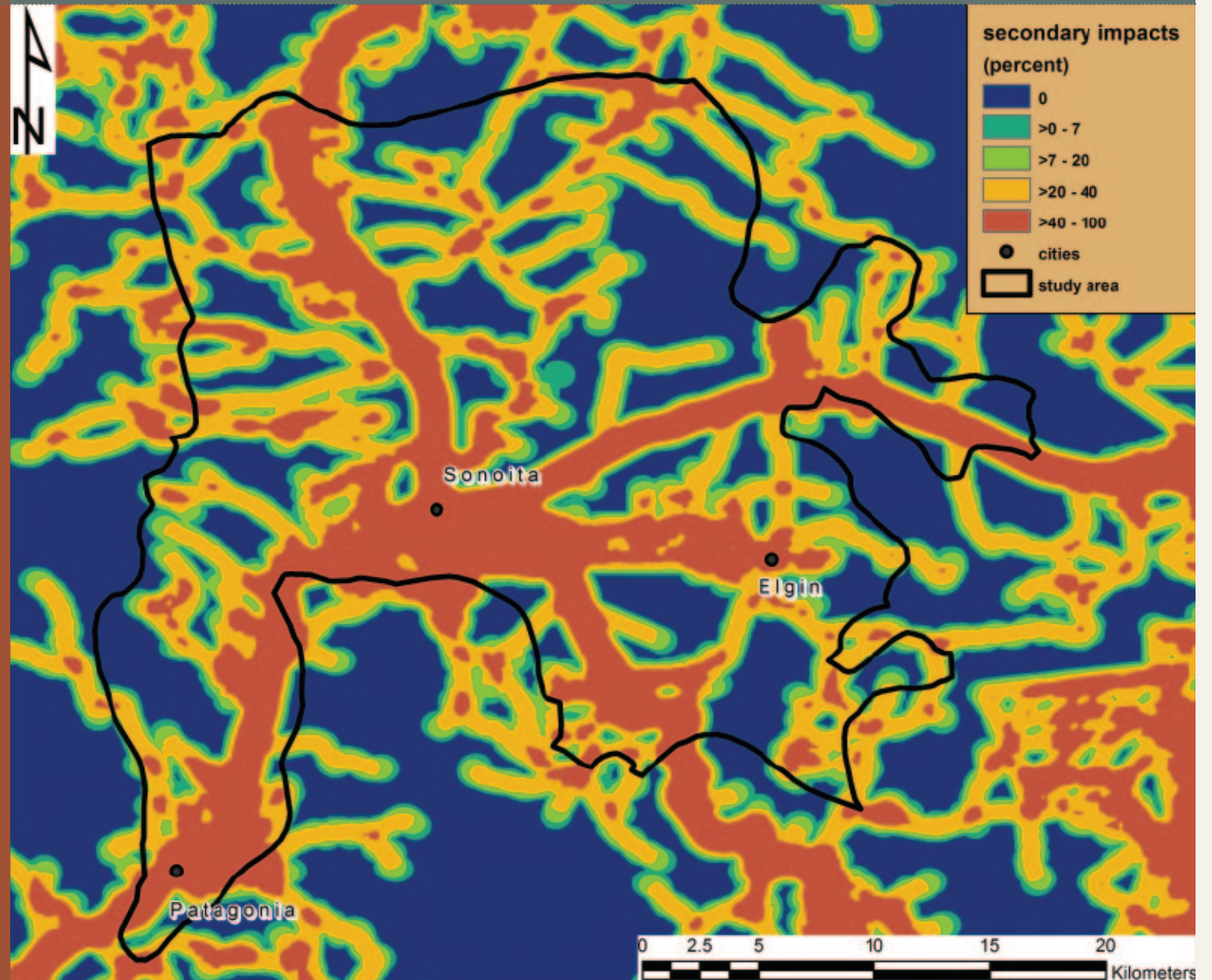
which represents the percent area within 500 m of each point that is affected by a house or road.

The total impact, whether for the small area of Figure 4, or throughout the Sonoita Plain, is a significant disturbance and threat to the biophysical system. Although the human benefits of exurban housing seem self-evident, the hazard to the ecosystem and the services it provides should be recognized.

The map of Figure 5 quantifies the secondary impacts of houses and roads on ecological processes of the Sonoita Plain. These impacts, as percent of affected 100-m² cells (unit areas) within a 500-m radius, are those that extend from houses or roads. Included are human influences on grassland vegetation near the houses and roads, as well as total replacement of grassland vegetation with landscaping or bare earth.

SECONDARY IMPACTS DUE TO HOUSING AND ROADS IN THE SONOITA PLAIN

Figure 5. Map of secondary impacts, as percentages, due to houses and roads. The strongest impacts, shown in yellow and red (more than 20 percent), occur along State Routes 82 and 83 (Fig. 1), where housing densities are greatest.



Threat 2: Water Availability

Water is fundamental to life and land-surface dynamics, and if water availability is reduced, both life and physical processes are threatened. Semiarid grasslands of the Sonoita Plain maintain a delicate water balance. Most rainfall quickly evaporates, some is absorbed by plants as soil moisture and is transpired to the atmosphere, some infiltrates and becomes ground water, and a minor proportion in the Sonoita Plain results in runoff and streamflow.

Springs, seeps, and well water of the Sonoita Plain are results of infiltration in uplands that recharges aquifers beneath the plain by ground-water flow from higher to lower elevations. Disruption of recharge in uplands such as the Santa Rita Mountains, or pumping of water from wells at rates greater than the recharge rate, jeopardizes water availability in wells and the water required for ecosystem function.

Figure 6 shows locations of registered wells of the Sonoita Plain, where most houses are dependent on well water. Thus, house and well locations of Figures 2 and 6 are similar except where wells were drilled for livestock and agriculture. The map of Figure 6 confirms that parts of the Sonoita Plain near towns have high well densities, thus large rates of water withdrawal that can exceed recharge. If the imbalance between

withdrawal and recharge is increased due to additional drilling of wells, ground-water availability may be reduced and all aspects of the ecosystem could be harmed.

Figure 7 shows depth to water in wells of the Sonoita Plain area. Greatest depths generally are in uplands, whereas the least depths to water are near Cienega Creek and Sonoita Creek. Many stream-corridor areas, where depth to water is less than 20 m, are underlain by thin deposits of unconsolidated alluvium; ground-water supplies in these areas appear vulnerable if numerous wells are pumped. Most upland areas, with large depths to water, are underlain by bedded rocks. Excessive pumping of water from them is likely to lower regional water levels and may cause lowered well yields and reduced discharges from springs and seeps that historically have been reliable water sources.

Increases in the number and density of registered wells in the Sonoita Plain area since 1970 are represented by the maps of Figure 8. Except near towns, many wells in 1970 were for livestock and agriculture. As shown by the 1980, 1990, and 2000 maps, the Sonoita Plain increasingly was developed, and the density of wells increased accordingly.



SITES OF REGISTERED WELLS IN THE SONOITA PLAIN

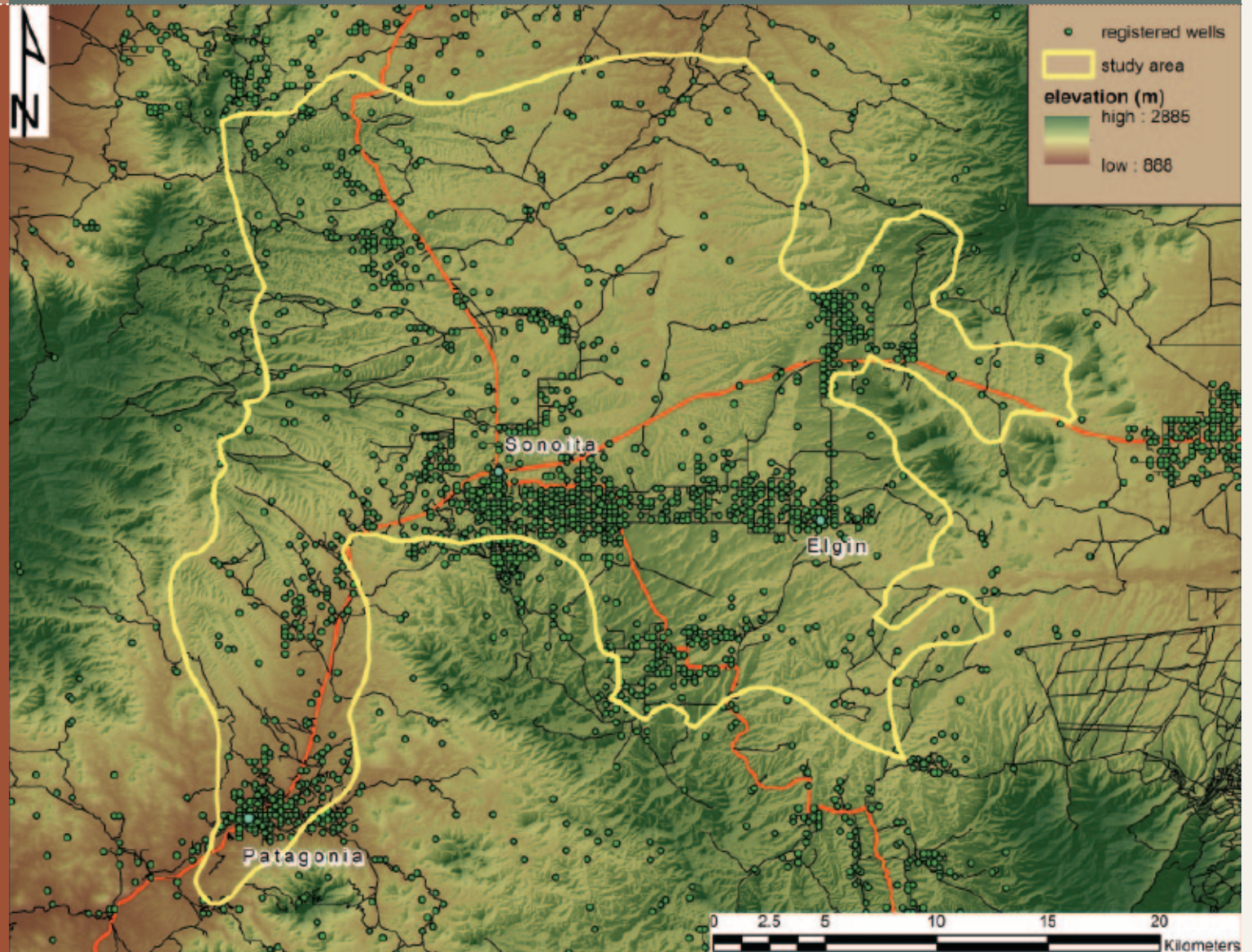


Figure 6. High well densities near towns threaten the balance between water withdrawal and recharge, which may reduce ground-water availability and harm all aspects of the ecosystem. (Well data extracted from Arizona Department of Water Resources Well Registry, 2011.)

DEPTH TO GROUND WATER BENEATH THE SONOITA PLAIN

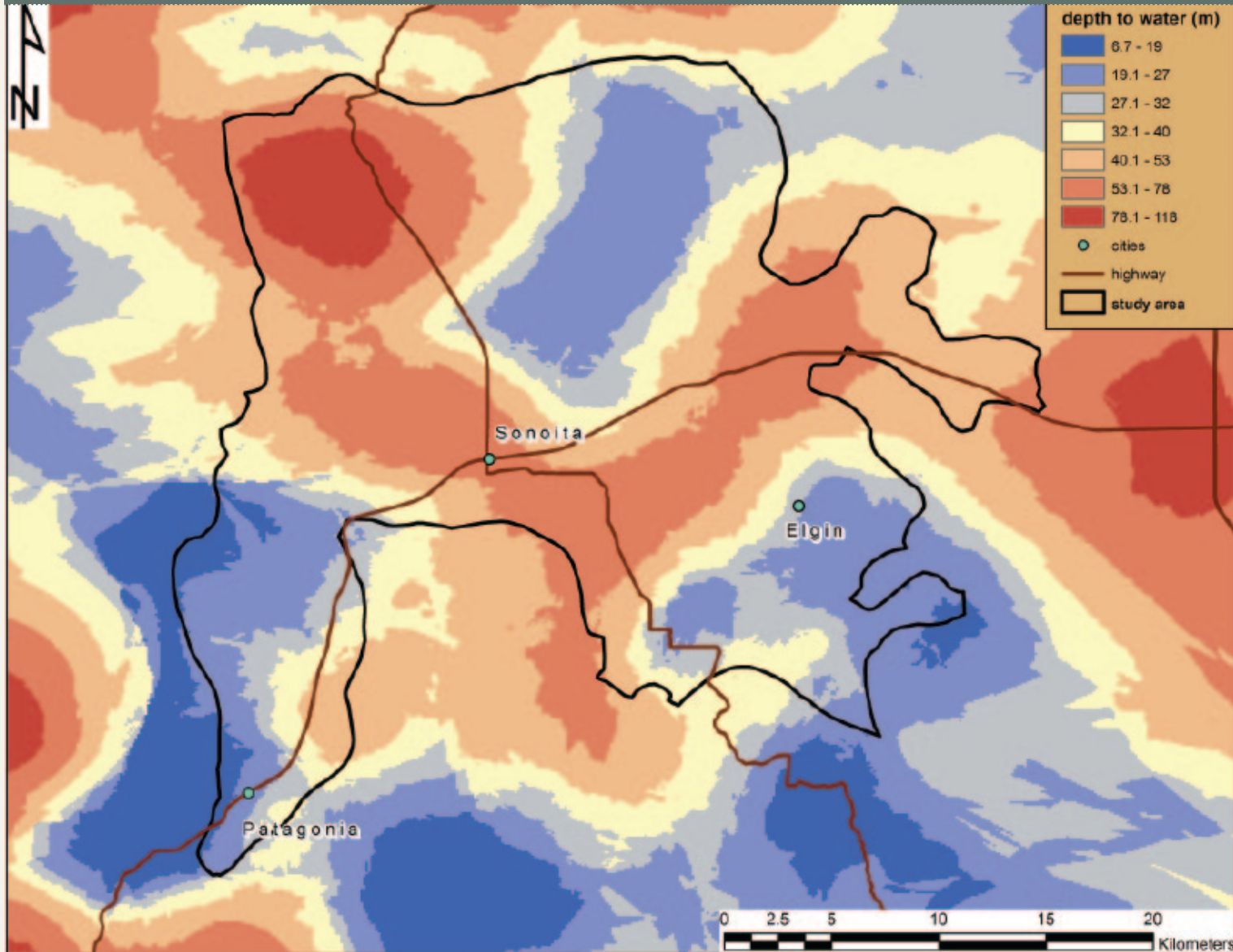


Figure 7. Map showing depth to water beneath the surface, as indicated by depth to water in wells, in the Sonoita Plain (bounded by black line) and surrounding areas. Excessive pumping in stream-corridor areas (shown in darker blue) can threaten ground-water supplies in these areas. Excessive pumping in upland areas underlain by bedded rocks (shown in orange) threatens water levels across the region.

Interpolated ground-water elevations beneath the Sonoita Plain, from water levels in a subset of registered wells (measured at the time of drilling), are shown in Figure 9. The highest ground-water elevations are in the Santa Rita Mountains and the Whetstone Mountains (Fig. 1). The lowest ground-water elevations are at stream channels—Cienega Creek in the northern study area and Sonoita Creek in the south.

A potential disturbance to water levels and water availability of the Sonoita Plain is the proposed Rosemont Mine (northwest edge of study area; Fig. 9). The projected depth below land surface of the open-pit mine is about 885 m, which is 670 m beneath the surface for much of the central Sonoita Plain. Rocks to be exposed by excavation at the mine are clastic and volcanic beds underlain mostly by limestones that dip steeply eastward before flattening to near-horizontal beneath the Sonoita Plain. Although the geology of the Sonoita Plain is inadequately understood, many of the rocks to be exposed at the mine extend beneath the Sonoita Plain. If excavation

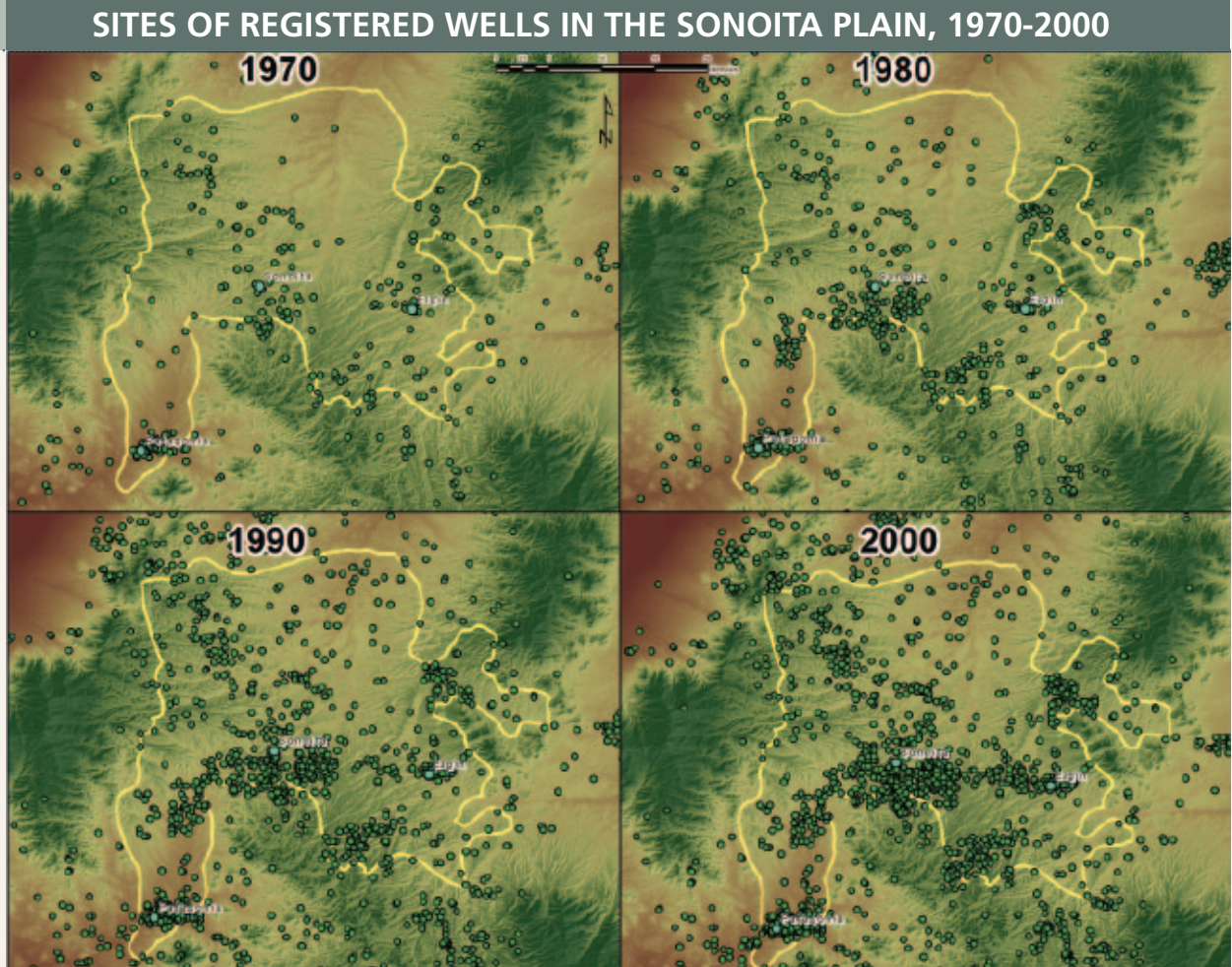


Figure 8. The density of wells in the Sonoita Plain has increased significantly since 1970, following a pattern of increased exurban development.

WATER LEVELS BENEATH THE SONOITA PLAIN

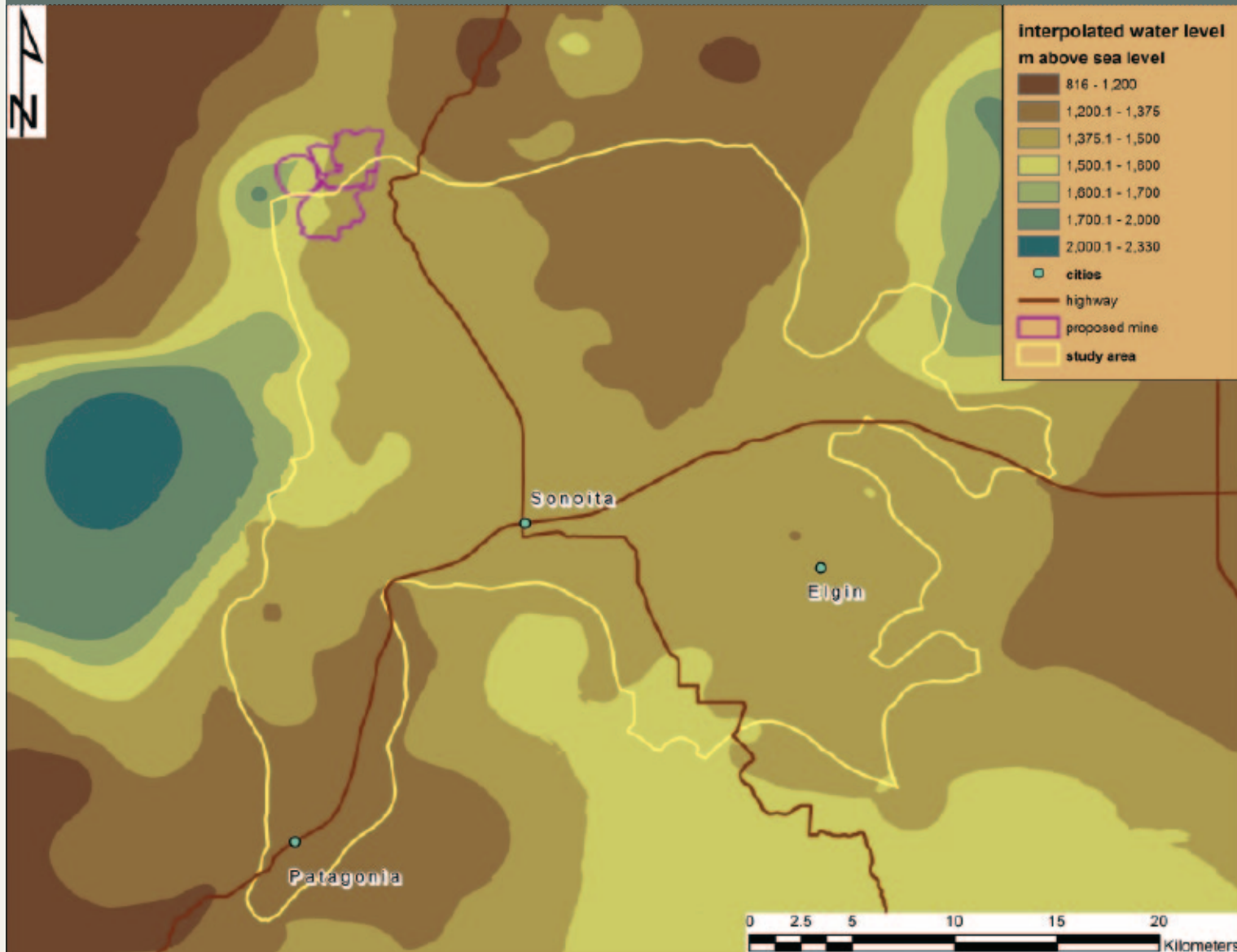
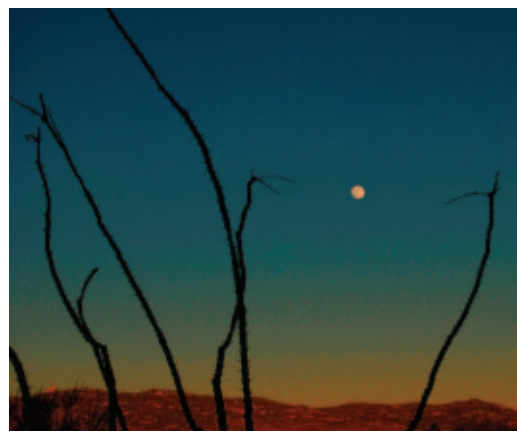


Figure 9. Map showing interpolated water levels beneath the Sonoita Plain as indicated by registered wells; areas bounded by purple lines are the open pit and tailings of the proposed Rosemont mine in the northeastern Santa Rita Mountains. Water availability across the area could be severely reduced if mine excavation drains ground water in rocks underlying the Sonoita Plain.

drains ground water in rocks at the mine to an elevation of 730 m, water availability of the Sonora Plain could be severely reduced.

A key ecosystem provision of grasslands is water for wildlife, and the water cycle controls this critical service. Important also is recognition that the water balance of semiarid ecosystems can change dramatically in response to changing climate. Recently, the Southwest has experienced pronounced drought that has reduced rates of streamflow and ground-water recharge, and has caused tree death in savannas owing to deficient soil moisture and increased vulnerability to insects. Research indicates that warming and drying in the Southwest will continue.



Threat 3: Invasive Species

Typically the threat to native vegetation by invasive plants begins with the introduction of exotic plants and seeds into developing areas. Many Southwestern grasslands, including the Sonoita Plain, are damaged by invasive species. Fire suppression and climate change may induce invasion by mesquite, agaves, and cacti, as well as conversion to savannas. Often native species are replaced by grasses from other climatic zones and continents, such as Lehmann lovegrass and Boer lovegrass. Exotic shrubs and trees that can spread seeds over large areas are common in exurban developments. Human activities, such as monocrop agriculture and urban uses, affect large areas and cause land-cover conversion. Given the ecological implications of exurban development, an improved understanding of the patterns, rates, and extents of the spread of invasive species in grassland ecosystems is needed.

Principal pre-development vegetation communities of the Sonoita Plain area are depicted in Figure 10. Dominant grasses were blue grama,

black grama, threeawn grass, wolftail grass, and plains lovegrass; herbs and shrubs included burroweed, groundsel, copper leaf, fleabane, malvastrum, and caltrop (Bock and Bock, 2000). Dominant plant species prior to intensive grazing of the late 1800s are not well known, but Bock and Bock (2000) speculate that plains lovegrass, sideoats grama, cane beardgrass, and the bunchgrasses tanglehead, crinkleawn, Texas beardgrass, and woolly bunchgrass were common.

A threat to native vegetation by invasive plants typically is induced by importing exotic plants and their seeds into areas of development. Figure 11 identifies areas where the threat by plant invasion appears significant. Because roads are important vectors for the spread of invasive species and provide excellent conditions for these plants to establish, the map of Figure 11 is based on road densities. The risk of plant invasion is greatest where the densities of houses and roads are high; low-risk areas are generally more distant from houses and roads.



NATIVE VEGETATION TYPES IN THE SONOITA PLAIN

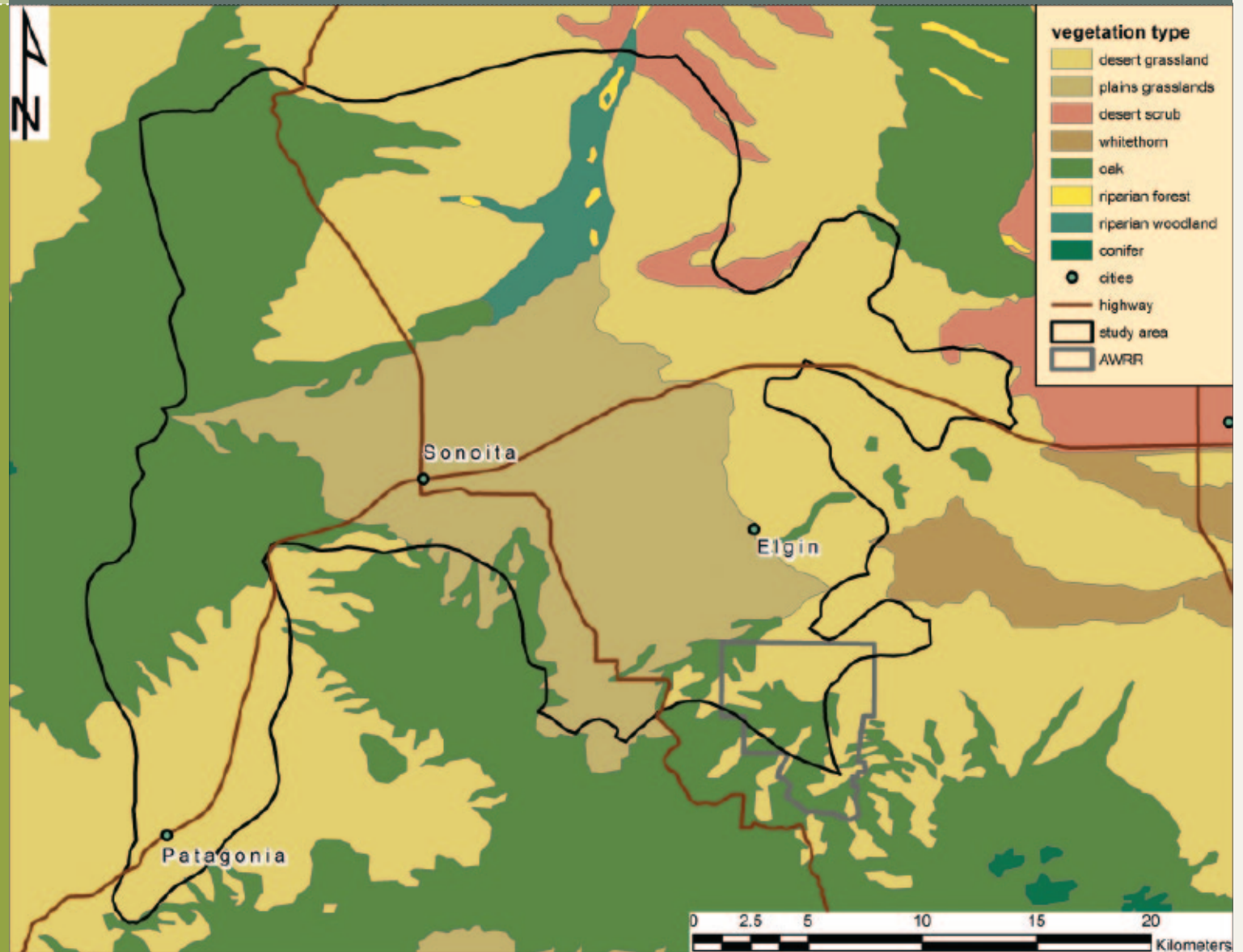


Figure 10. Map showing dominant pre-development vegetation types in the Sonoita Plain area (extracted from Arizona Game and Fish Department Natural Vegetation, obtained from Arizona Geographic Information Council, 2011). Semi-desert grasslands, comprising two-thirds of the Sonoita Plain, are particularly vulnerable to invasion by exotic love grasses.

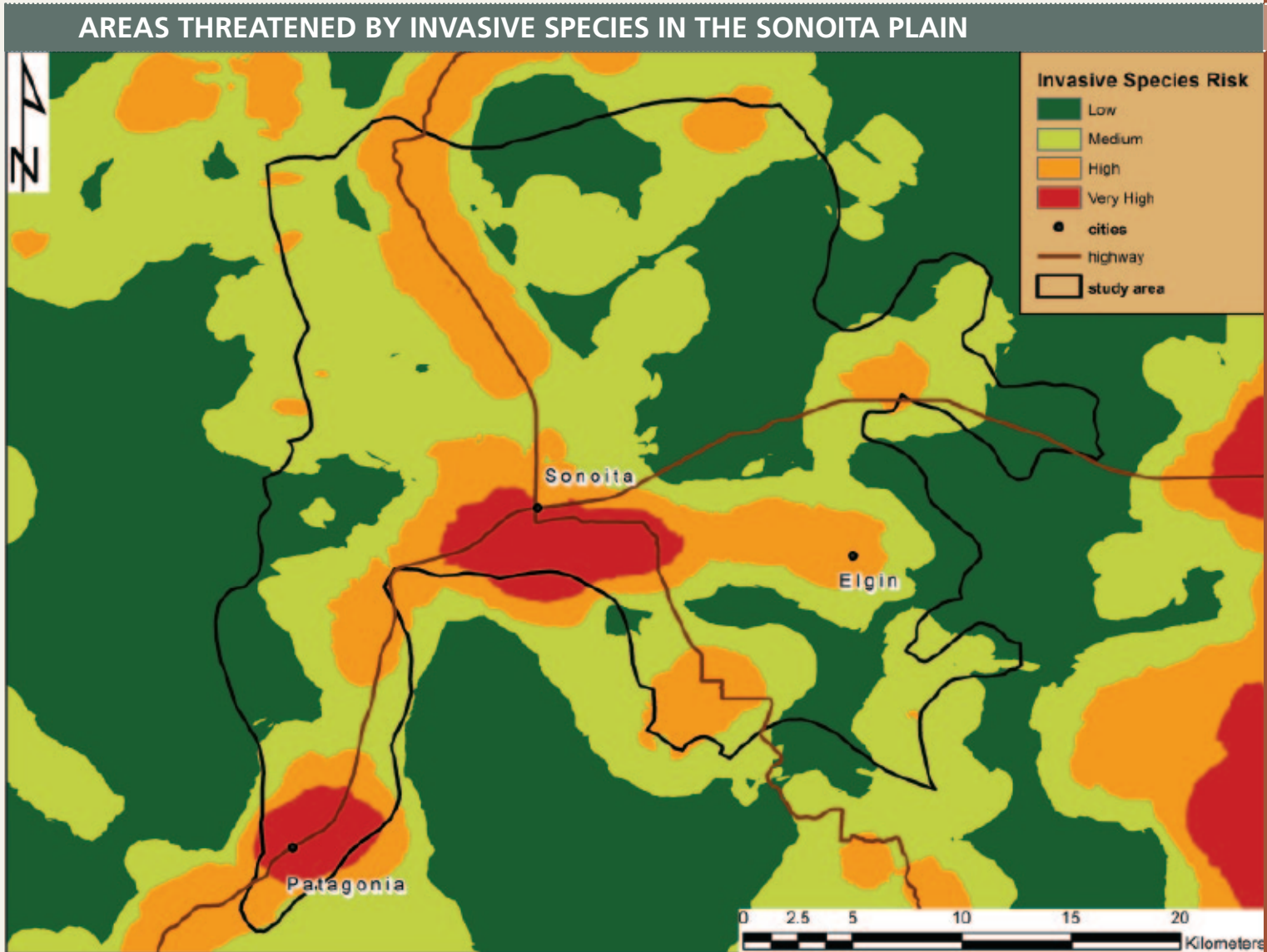


Figure 11. Map showing areas of the Sonoita Plain, mostly near towns and roads, where threats to native vegetation by invasive plant species appear likely.

Threat 4: Fire

Fire is a natural process in most plant communities, and the health of semiarid grasslands is particularly dependent on periodic burning. Fire ensures that fuel storage does not become excessive, helps maintain the food network, and prevents invasion by both native and exotic plant species. Exurbanization can alter fire frequency and promote intense fires owing to fire suppression and irrigation, which combine to increase the growth and storage of organic fuels. The human reaction is an intervention of naturally occurring fires to protect life and structures.

The amount of time since significant fire has burned and destroyed vegetation in the Sonoita Plain in recent years is shown in Figure 12. Much of the area has not been affected for at least 25 years, partly reflecting quick responses to extinguish grass fires. Parts of the Sonoita Plain that have experienced recent fires are mostly in bottomlands where stored organic fuels have been relatively large, in areas of relatively high elevation with trees, and near towns where fires may be started by humans.

The Fire Return Interval Departure (FRID) for an area is a metric derived from an inferred normal fire-return interval (FRI, the historical average, in years, between fires), and the elapsed years since the last fire. From tree-ring and fire-scar studies, average fire-return intervals for dominant vegetation classes are determined, and with

elapsed time since the last fire, the FRID index quantifies departures from the average fire-return intervals (Caprio et al., 1997; Keifer et al., 2000). The FRID index, as ratios, is: [(Years since last fire—Natural Fire-return Interval) / Natural Fire-return Interval].

The map of Figure 13, which is derived from data summarized by Figure 12, shows ranges of FRID-difference ratios for parts of the Sonoita Plain area. The fire return-interval departure ratios measure fuel buildup in forests or invasion of trees and shrubs into grasslands. A fire-return interval is typical for each vegetation type, a vegetation type characterizes each site, and elapsed time since the last fire can be identified for each site. Positive numbers (tan to deep red, relative danger; Fig. 13) indicate fuel storage and moderate to high potential for fire, whereas negative numbers (shades of green, good, or relatively safe) indicate a limited amount of fuel storage and low potential for fire. Fire potential, as represented by areas of tan and red, therefore, presently appears to be a moderate to major threat, or hazard, to ecosystems and ecosystem function throughout much of the Sonoita Plain (Fig. 13). Where fire has occurred within the last 15 years, however, particularly north of Sonoita, east of Elgin, and along the southeastern margin of the study area (Fig. 12), map colors are varieties of green, indicating minimal to normal fire hazard (Fig. 13).



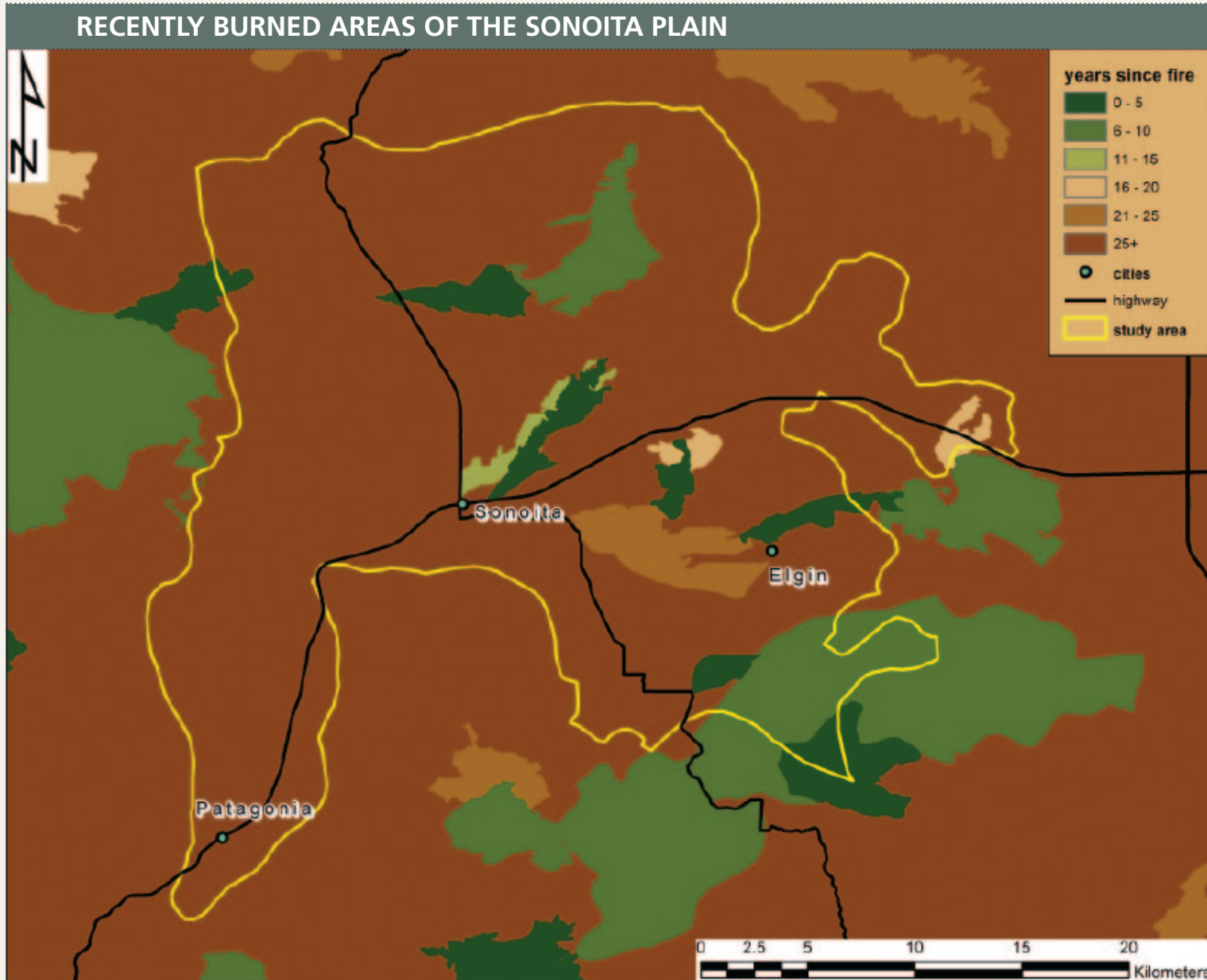
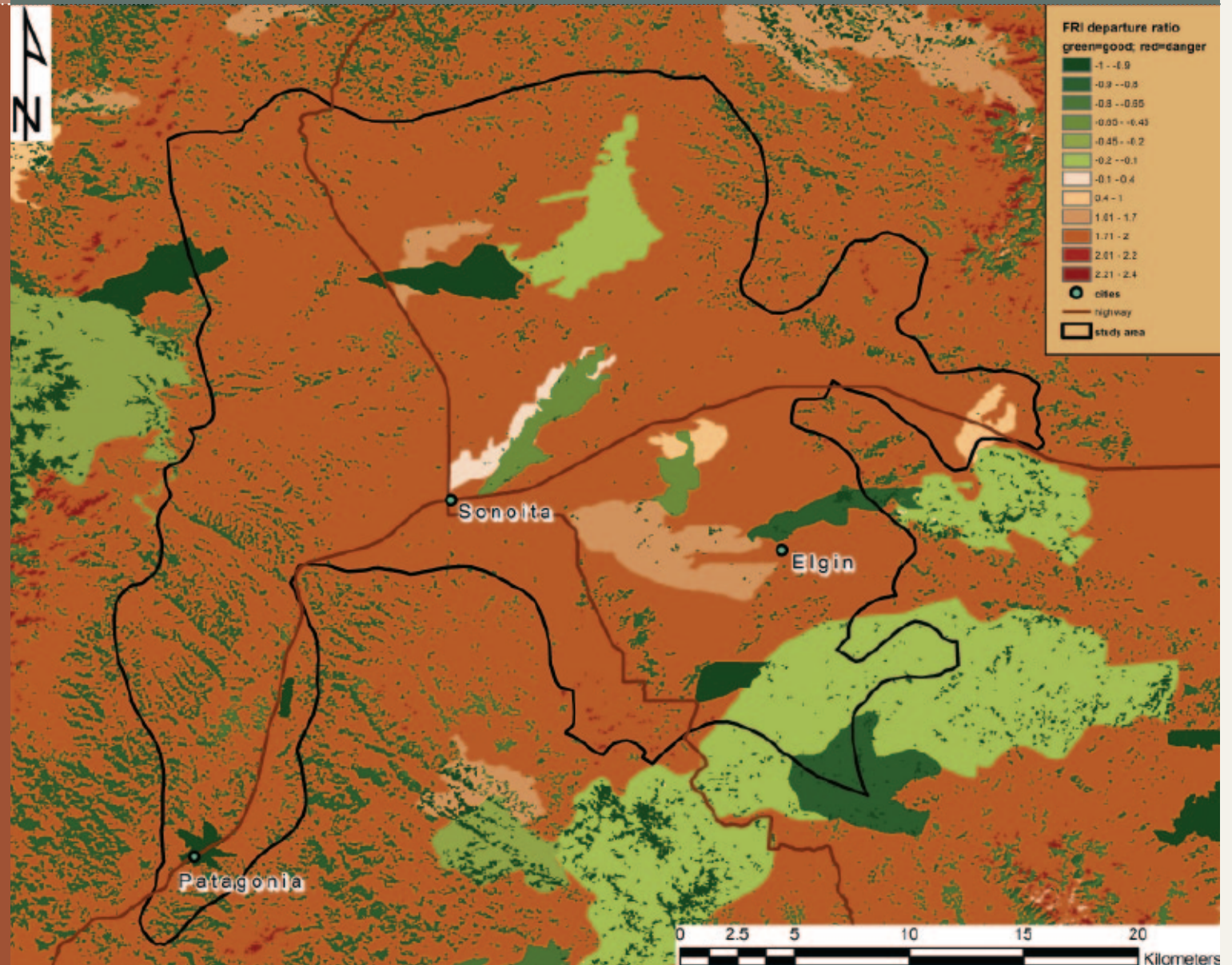


Figure 12. Map showing sections of the Sonoita Plain impacted by fire in recent decades. Records of fire perimeters extend 25 years into the past (data extracted from Monitoring Trends in Burn Severity, 2011). Fire suppression and irrigation resulting from exurbanization can alter fire frequency and promote intense fires.

FIRE RETURN INTERVAL DEPARTURES IN THE SONOITA PLAIN

Figure 13. According to the index, much of the Sonoita Plain shows a moderate to major threat of fire potential (vegetation data extracted from RS/GIS Laboratory, 2004).



Concluding Thoughts

Despite the narrow geographic scope, these maps were constructed with the intent that overall findings be applicable to large portions of arid/semiarid grasslands of the Sonoran and Chihuahuan deserts. The maps, which are based on publically available data and quantifiable criteria that can be generalized into a description of the threat to ecosystem health by human intervention, are designed for practical application by land and water managers, local decision-makers, and citizens groups, such as the Sonoita Crossroads Community Forum.

Many rural, sparsely grazed grassland areas of southern Arizona, southern New Mexico, and northern Sonora and Chihuahua continue to have healthy ecosystems, but other areas, many within 100 kilometers of urban settings such as Tucson, Arizona, and the El Paso/Ciudad Juarez area, have compromised ecosystem integrity. The maps provided in this folio describe a healthy grassland ecosystem that is threatened by short-sighted land and water use. Nearby areas that have suffered ecosystem degradation provide comparisons and the potential for management approaches to avoid or mitigate further ecosystem compromise.

As noted throughout this map folio, large areas of grassland in southwestern North America are being appropriated for rural housing, and the changes are diminishing the land, water, and biological assets. These evolving reductions in resources constitute significant threats, or hazards, to the grassland ecosystems, and they present challenges to those responsible for planning, development, and management of these landscapes. Property owners represent one audience for the materials of this folio, as minimizing the impacts on these resources can and should be applied in the management of individual parcels. A second audience consists of entities involved in private land planning and development. Addressing the hazards described herein in planning proposals, including subdivision plats, should be an integral part of all development activities. More importantly, these materials are specifically directed to local elected officials and community planners—those who have the legal authority to formulate and implement policies and plans that embody ecologically sound land-resource planning and stewardship. It is they in particular who can use the maps to maintain, in perpetuity, these important ecosystem functions of the arid Southwestern grasslands.



References

- Arizona Department of Water Resources Well Registry. 2011. <http://www.azwater.gov/azdwr/>, accessed March, 2011.
- Arizona Geographic Information Council. 2011. <http://agic.az.gov/portal/main.do>.
- Bock, C. E. and J. H. Bock. 1998. Factors controlling the structure and function of desert grasslands: a case study from southeastern Arizona. In: *The future of arid grasslands: identifying issues, seeking solutions*. University of Arizona, pp. 33-43.
- Bock, C. E. and J. H. Bock. 2000. *The View from Bald Hill*: University of California Press, Berkeley, 197 p.
- Bota, L. 1996. Modeling of ground-water flow and surface/ground-water interaction for Upper Cienega Creek Basin. Master of Science Thesis submitted to the University of Arizona Department of Hydrology and Water Resources.
- Burke, I. C., Yonker, C. M., Parton, W. J., et al. 1989. Texture, climate, and cultivation effects on soil organic matter content in U.S. grassland soils. *Soil Science Society of America Journal* 53: 800-805.
- Caprio, A., Conover, C., Keifer, M., and Lineback, P. (1997). Fire management and GIS: a framework for identifying and prioritizing fire planning needs. In: *Proceedings: Fire in California Ecosystems: Integrating Ecology, Prevention, and Management*.
- Keifer, M., A.C. Caprio, P. Lineback, and K. Folger. 2000. Incorporating a GIS Model of ecological need into Fire Management Planning. Proceedings of the Joint Fire Science Conference and Workshop, Crossing the Millennium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management, June 14-16, 1999, Boise, ID.
- McNeely, J. A., Gadgil, M., Leveque, C., et al. 1995. Human influence on biodiversity. In: *Global biodiversity assessment*, Heywood, V.H. (executive ed.), pp. 715-821. Cambridge, England: Cambridge University Press.
- Monitoring Trends in Burn Severity (MTBS). 2011. Individual fire-level datasets: Wildland Fire Leadership Council (<http://www.mtbs.gov>).
- Ricketts, T. and M. Imhoff. 2003. Biodiversity, urban areas, and agriculture: locating priority ecoregions for conservation. *Conservation Ecology* 8:1. [Online] URL: <http://www.consecol.org/vol8/iss2/art1>.
- RS/GIS Laboratory. 2004. 'Provisional' digital landcover dataset for the southwestern United States. College of Natural Resources, Utah State University (<http://earth.gis.usu.edu/swgap/>)
- Sala, O.E. and J.M. Paruelo. 1997. Ecosystem services in grasslands. In *Nature's services: societal dependence on natural ecosystems*, Daily, G.C. (ed.), pp. 237-252. Washington, DC: Island Press.
- U.S. Census Bureau. 2010. Census and TIGER/Line data for Santa Cruz, Pima, and Cochise Counties, Arizona, <http://www.census.gov/geo/www/>, accessed February, 2011.
- USDA Farm Service Agency, National Agriculture Imagery Program (NAIP). 2010. 1-m resolution aerial imagery, <http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai> obtained from Arizona Geographic Information Council, 2011.

FOR MORE INFORMATION, CONTACT:

THE RESEARCH RANCH FOUNDATION

P. O. Box 12987

Tucson, AZ 85732

Jelena Vukomanovic: jelena@email.arizona.edu

Sandra Doumas: sdoumas@email.arizona.edu

W. R. Osterkamp: wroster@usgs.gov

PRODUCTION CREDITS

Coordination: Ian Wilson, Sonoran Institute

Editing: Audrey L. Spillane

Design: Terry Moody

Printing: Arizona Lithographers

PHOTOGRAPHY CREDITS

Cover: Michael McNulty* (Las Cienegas)

Page 3: Peggy Clampet (prickly pear)

Pages 4–5: Michael McNulty (panorama of Las Cienegas, top: windmill in front of Las Cienegas National Conservation Area; middle: fern in the Santa Rita Mountains; bottom: Cienega Creek Natural Preserve)

Page 7: Sonoran Institute photo

Page 9: Jillian Cowles (wild delphinium)

Page 10: Ian Wilson photo (New Mexico thistle)

Page 14: Michael McNulty (Cienega Creek)

Page 19: Rhoda Preston Flint (“Victoria & Buck”); Terry Moody (top photo); middle and bottom photo courtesy of Rincon Institute

Pages 20–26: Terry Moody

*Michael McNulty’s photographs may be viewed at <http://photos.mculty.net/>

Published January, 2013