National Park Service
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Natural Resource Stewardship and Science

A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 20a - Biodiversity

Natural Resource Report NPS/SEKI/ NRR—2013/665.20a

ON THE COVER
Giant Forest, Sequoia National Park
Photography by: Brent Paull

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This document contains subject matter expert interpretation of the data. The authors of this document are responsible for the technical accuracy of the information provided. The parks refrained from providing substantive administrative review to encourage the experts to offer their opinions and ideas on management implications based on their assessments of conditions. Some authors accepted the offer to cross the science/management divide while others preferred to stay firmly grounded in the presentation of only science-based results. While the authors' interpretations of the data and ideas/opinions on management implications were desired, the results and opinions provided do not represent the policies or positions of the parks, the NPS, or the U.S. Government.

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Scope of analysis

We analyze biodiversity within Sequoia and Kings Canyon National Parks (SEKI). Based on available data, we define biodiversity to in four key groups. We assess mammals and birds as straightforward taxonomic groups. We assess reptiles (snakes, lizards, turtles) and amphibians (frogs, salamanders) as a single entity that we describe as the herpetofauna. We mention fish diversity sparingly. We do not assess fish diversity because the fish fauna is very low in diversity, largely non-native; poorly sampled; and covered in the Sensitive Animals portion of this NRCA. For example, the natural resources species list for the parks incudes 5 native fish taxa, of which only three have been observed in the observation database and these observations comprise less than half a percent of the fish observations within the parks. We assess plant diversity to include all vascular and non-vascular plant taxa (species, sub-species and varieties). We do not assess biodiversity of invertebrate taxa of fungi owing to little available data. Information exists on the distribution and abundance of individual invertebrate taxa, but these were excluded from the analysis as they are few and highly selective. We include a brief anecdotal assessment of invertebrate taxa based on the 1996 Sierra Nevada Ecosystem Report.

We focus our attention on assessing biodiversity using point count observations and plot data aggregated across a wide array of studies. Although data records begin in the late 19^{th} century, most of animal data (96%) have been collected since 1970 and all plot-based plant data we used were collected since 1985. Much of the data comes as a consequence of particular focal studies, resulting in large amounts of data accrued on particular organisms, or locations, over a relatively short period of time. These features of the collection of data sets constrain our capacity to use the data to do temporal analyses. Thus, we present our assessment, discuss limitations of interpretation imposed by data constraints and recommend future studies to improve assessments of the various components of biodiversity.

In assessing biodiversity, we must define terminology and report on word usage for this chapter. We refer to the number of species found in a location as species richness. Diversity is used in its ecological meaning to include species richness and a measure of the diversity of abundance of those species. Together, we treat these two entities, richness and diversity, as a reflection of biodiversity. Biodiversity may also include measures of ecological, functional, taxonomic, phylogenetic or genetic diversity represented in some spatial location. We do not include such measures within our assessment as these are beyond the scope of the critical questions posed or because measures to assess these levels of biodiversity (e.g., ecosystem functioning, or population genetic) are lacking.

In assessing biodiversity, we are concerned with Sequoia and Kings Canyon National Parks, which we refer to as SEKI or “the Parks”. When we compare different aspects of the Parks to diversity within the Sierra Nevada, specifically, we mean the Sierra Nevada Foothills and the High Sierra Nevada regions, as defined by the Jepson Manual of Plants (Hickman 1993).

Critical questions

Several critical questions emerged from discussions with Parks resource managers regarding biodiversity. We addressed these questions through analyses to describe the spatial distribution of vertebrate and plant biodiversity within the Parks at the present time. Natural Resource Condition Assessment (NRCA) identifies four focal objectives. The first objective is to estimate *reference conditions* for SEKI. In describing baseline biodiversity reference conditions for SEKI, we place species richness in the regional context of the state of California to better clarify the role of SEKI in protecting regional biological diversity. We compare metrics of diversity of SEKI to the Sierra Nevada, when those comparisons are available. We include a brief assessment of both rarity and non-native species specifically as they relate to broad patterns of diversity. The second objective is to describe the *spatial distribution of biodiversity* within SEKI, identifying elevation gradients in biodiversity, habitat associations to higher or lower levels of biodiversity, and where within SEKI we find peak biodiversity. The third objective is to identify *temporal trends in biodiversity*. The fourth objective is to identify *stressors*, including climate change, to that biodiversity. Critical questions within each of these four objectives include the following.

1. Biodiversity Reference Conditions
    - What are the baseline measures of species richness (how many taxa are there) and what is the species richness of SEKI in relationship to regional metrics?
    - What is the distribution of observed abundance (number of occurrences) among the major taxonomic groups, and does this conform to expectations?
    - How many non-native taxa are there in SEKI, and which taxonomic groups are most affected?
    - How many at risk taxa are there, and how does this compare to the region?
    - How does the flora and fauna of SEKI compare to regional estimates of diversity?
    - What information is required to improve the assessment of species richness within SEKI?
2. The Spatial Assessment of Biodiversity
    - How do you assess species richness given unequal sampling across the landscape/
    - How does species richness vary with elevation for the dominant groups (birds, mammals, herpetofauna and plants)?
    - How does species richness for these groups vary by land cover type?
    - Do different taxonomic groups (birds, mammals, herpetofauna, plants) show parallel gradients in diversity with elevation and land cover?
    - What is the elevation distribution of *dominant plant taxa* and is this useful as a baseline descriptor relative to future change?
    - Are there patterns to the location of rare and endemic taxa and do these match overall diversity patterns?
    - Are there specific regions within the parks (e.g., watersheds) that exhibit unusually high or low diversity?
    - What data are required to improve the spatial assessment of biodiversity?
3. Temporal Trends in Biodiversity
    - What is the evidence for trends in biodiversity with time?
    - Is there evidence that biodiversity is eroding, stable, or increasing?

- What types of information would be needed to improve the temporal assessment of biodiversity?

4. Stressors of Biodiversity
    - What are the focal stressors to SEKI biodiversity?
    - What information is needed in order to improve the assessment of stressor impacts on biodiversity?

Data sources

General Data Description

Sequoia / Kings Canyon National Parks (SEKI) have a long tradition of records keeping, and inventory efforts. We analyzed most of the species observation datasets from SEKI to assess biodiversity in the Parks. All datasets were provided by SEKI personnel. We obtained records for plants, birds, mammals, and vertebrates (Table 1). The single largest source of wildlife sightings was the Wildlife Observation Database (WOD) developed by David Graber and stewarded by Harold Warner, (SEKI wildlife biologists from the dataset origin to end of 2010). This is an ongoing set of records contributed by anyone who reports a sighting. It is mostly populated with records from SEKI employees, such as back country rangers and field biologists. The dataset includes general and haphazard observations as well as observations associated with specific focal species assessments, and observations collected as part of systematic park sampling. However, public records are also included after screening by taxonomic specialists.

Data that we use to assess biodiversity are a mixture of general observations and specific studies. For example, the two sources of information on birds come from the WOD, and from a systematic bird survey conducted by the Institute for Bird Populations (IBP). The IBP survey conducted repeated measures surveys along sampling transects, making 14,123 observations distributed across 109 species during 2003 and 2004. In contrast, the WOD contains 45,363 records with 216 species of birds, beginning with a band tailed pigeon observed in 1895. Similarly, the herpetofauna (n = 3708) and fish (n = 2474) observations in WOD are large and date back to the early 20th century. In contrast, Roland Knapp, University of California's Sierra Nevada Aquatic Research Laboratory (SNARL), has greatly augmented these observations (2041 reptiles and amphibians, 297 fishes) with high elevation lake surveys from 1997 through 2002.

Plant species observations had the most complicated data structure. For plants we identified three types of data sources: relevé plots, rapid assessment plots, and single species records. Data from individual plant surveys and specimen collections conducted in SEKI were assembled and made available to us by Sylvia Haultain, SEKI plant ecologist. Relevé plots are plant surveys that can be assumed to have recorded all the species present within the plot boundaries. As such, we treated them as locations for which absences of other species (not recorded) could also be inferred. Rapid assessment plots are typically composed of incomplete plant species lists. We treated these plots as presence-only locations for this project. Single species records provide only presence for one species. Herbarium samples and most wildlife records fall into this category and these provide a non-spatial list of plant diversity for the Parks.

Table 1. Species observation databases obtained from SEKI, from which biodiversity measures were assessed.

Category	Data Type	Dataset	Observations	
Animals	Single Species Observations	SEKI Wildlife Observations Database	66,554	
		Knapp Lakes Survey	12,378	
		IBP Landbird Inventory	14,123	
		Sub-Total	**93,055**	
Category	**Data Type**	**Dataset**	**Plots**	**Observations**
Plants	Relevé and other similar Vegetation Plots	Stephenson Gradient Analysis	228	4,194
		Natural Resource Inventory (1985-1996)	627	15,210
		Vegetation Mapping (2000-2003)	423	9,088
		Wetland Ecological Integrity (2008-2009)	110	2,724
		Paired Meadow Plots (1985 -2009)	10	3,102
		Plot Sub-total	**1,398**	**34,318**
Plants	Rapid Assessment /Special Purpose Plots	Vankat/Roy Vegetation TransectsPlots (1969/ 1996)	76	425
		Vegetation Mapping (2001-02)	123	721
		ibid Accuracy Assessment (2002-2004)	2,821	17,410
		Fire Effects Plots (1986-2009)	132	3,493
		Blister Rust Plots (1995-1999)	154	7,111
		Mineral King Analysis (1996-2000)	209	3,976
		Rapid Assessment Sub-total	**3,515**	**33,136**
Plants	Single Species	SEKI Herbarium Holdings		3,689
	Observations	Norris and Brennan Special Status Plant Surveys		282
		Inventory and Monitoring Special Status Plant Surveys		94
		Sub-total		**4,065**
Plants		**Totals**	**4,913**	**71,519**

By working with combinations of these databases we were able to identify the number of observations and species by taxonomic group that are used in this study (Table 2). Among the 2,771 fish observations in the SEKI data, all but 21 are non-native fishes.

Table 2. The number of records and the number of species assembled from the SEKI databases used in the analysis of park biodiversity.

Taxa	Observations	Species
Amphibians	3,004	11
Reptiles	2,745	23
Fish	2,771	10
Mammals	14,603	88
Birds	58,393	217
Plants	71,519	1,419 (1,561 master plant checklist)

This assembled database contains observations that date back into the 1800s. Despite the long time record, most observations are relatively recent (Table 3)

Table 3. The distribution of SEKI wildlife occurrence observations through time.

TIME PERIOD	Mammals	Birds	Herpetofauna
<1890	1	0	0
1890-1900	8	5	0
1900-1909	20	27	0
1910-1919	85	7	0
1920-1929	60	18	1
1930-1939	397	77	14
1940-1949	324	210	14
1950-1959	339	68	14
1960-1969	800	353	229
1970-1979	738	1,950	116
1980-1989	4,420	23,436	1,497
1990-1999	5,105	11,399	2,186
2000-2010	2,306	20,843	1,678
TOTAL	14,603	58,393	5,749

The Parks use a vegetation map using the national Vegetation Classification System (http://biology.usgs.gov/npsveg/ftp/seki/metasekispatial.html). Linking species observations to plant associations resulted in a limited ability to quantify species within the large number of plant associations. As a consequence, we cross-walked plant associations to the California Wildlife Habitat (CWH) land cover classification scheme. This resulted in a total of 26 land cover categories for assessment.

Spatial Sampling Intensity

We assessed the spatial sampling intensity to understand the degree to which the data can be used to characterize SEKI biodiversity. We do this with three simple measures. First, we examined sampling effort by elevation band, using 500 m increments. Second, we link sampling intensity to CWH land cover types. Finally, we aggregate WOD and plot-based plant samples to the geography of SEKI using bins of 5000 utm units (approximately XXXX km^2).

Not surprisingly, SEKI contains strong differences in the amount of habitat area by elevation (Figure 1).

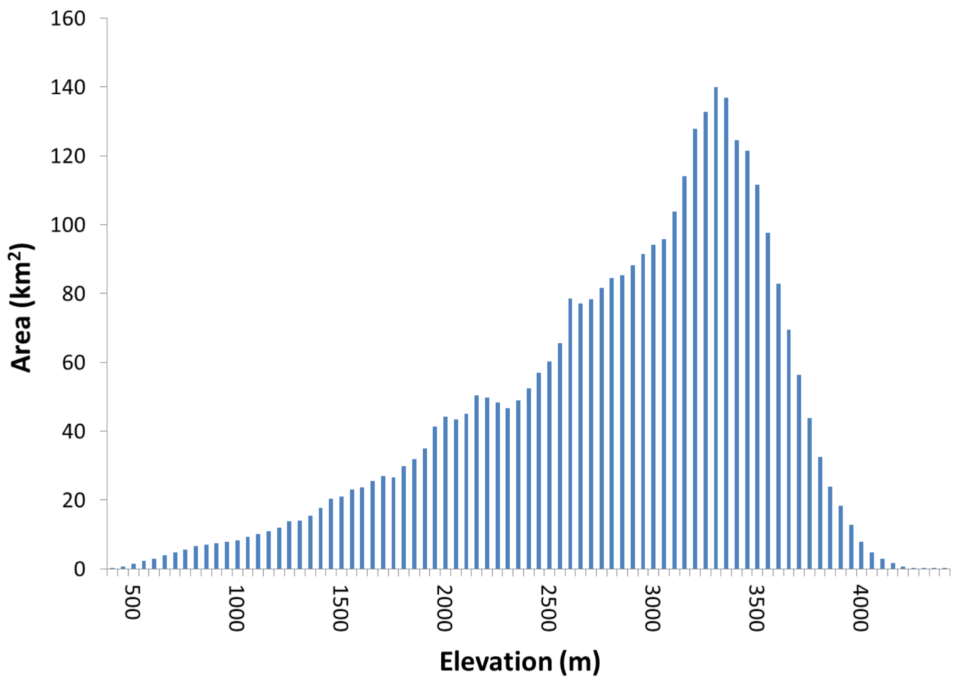


Figure 1. The land area (km^2) found in 50 m elevation bands in Sequoia and Kings Canyon National Parks.

Bird, Mammal and Herpetofauna

Most non-fish vertebrate observations are found at mid-elevations (Figure 2a). The greatest number of records (n = 3,121) are in the 2000-2500 m zone. However, once the area involved is factored in, the sampling intensity (observations per area in each elevation band), is highest at lower elevation zones (Figure 2a). When assessed per area, the greatest intensity of records is in the 0-500 m zone (Figure 2b). From 1000-2500 m, records comprise between 40 and 50 observations/km^2 (Figure 2b).

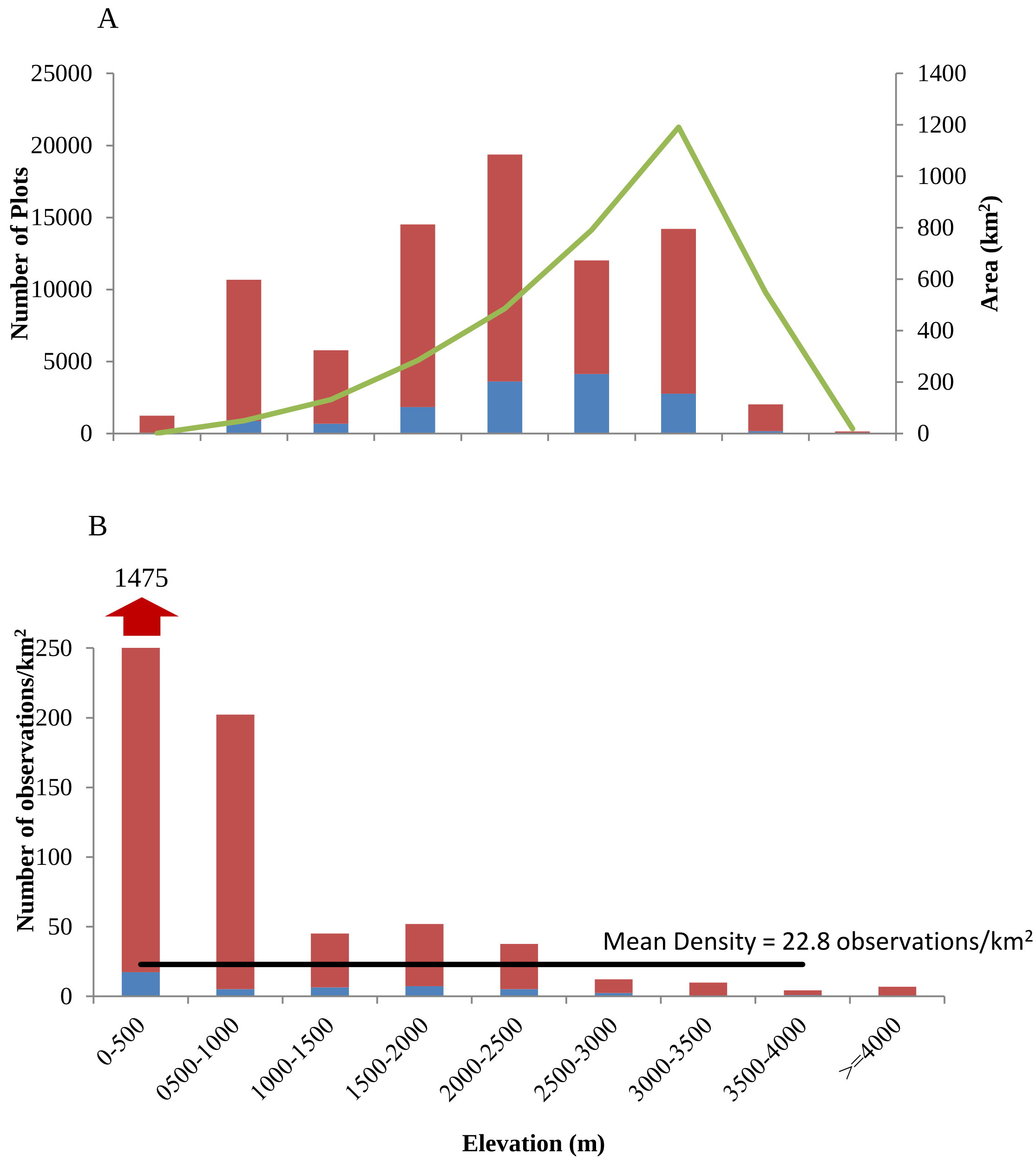


Figure 2. The sampling attributes of vertebrates observation records in Sequoia / Kings Canyon National Parks by elevation class (m). A) The number of observations in 500 m elevation bands. Green line indicates area within the SEKI. B) sampling intensity (number of observances / km^2). The black line represents the mean frequency of observations / km^2 over the study area. Red bars indicate observations from WOD, blue bars indicate observations from the Landbird inventory.

We can then also graphically map this sampling density by elevation (Figure 3).

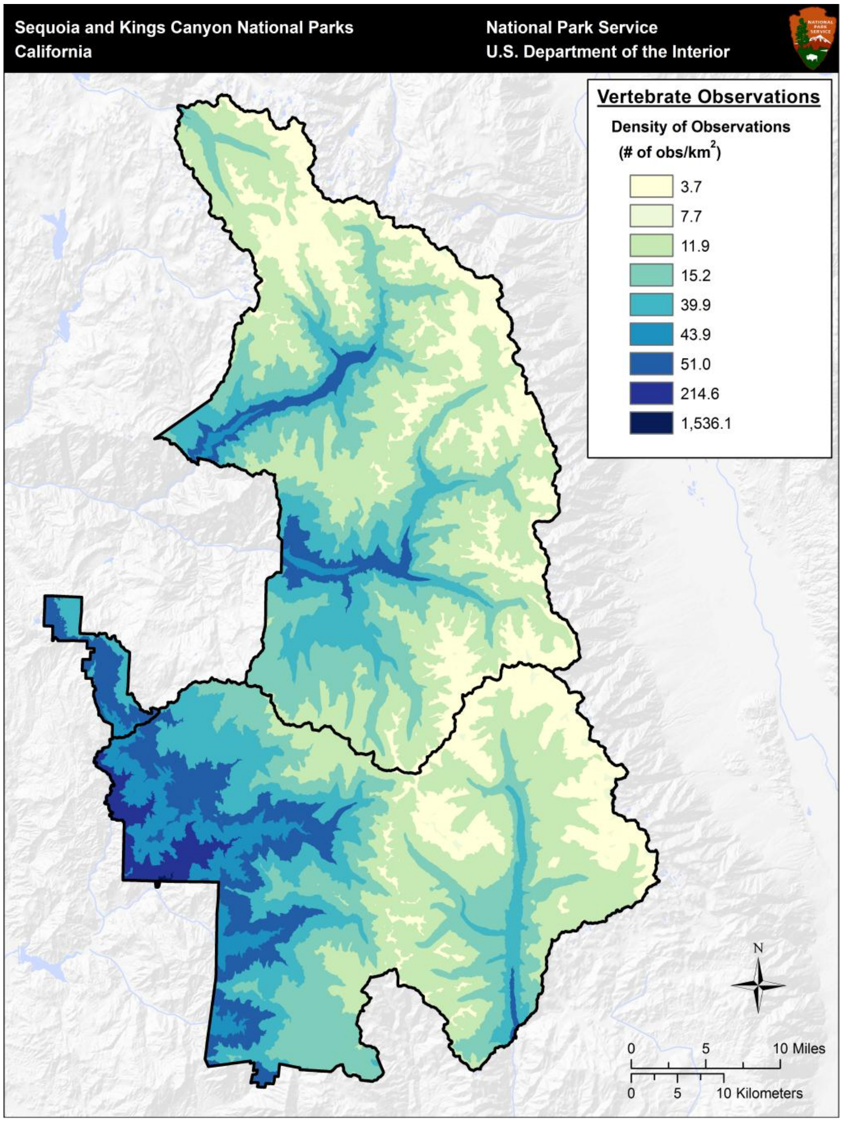


Figure 3. The sampling intensity of vertebrate observation records for Sequoia Kings Canyon national Parks. Observation density is calculated in 500 m elevation bands.

This general depiction of sampling density by elevation band does not, however, speak to the issue of how well distributed these observations are within those elevation bands. With over 90,000 observations, it is perhaps most illustrative to examine an example of distributions of a single taxonomic group in a sub-sampled region of the parks (Figure 4). Here we show the bird observations in the WOD (green dots) along with the bird transect data (red lines) collected by IBP for two sub-sections of the park. In both cases, we see that the IBP sampling, as a consequence of transects, has a tighter clustering of observations than the WOD, but both span a spectrum of terrain and vegetation types and are distributed across the region of sampling.

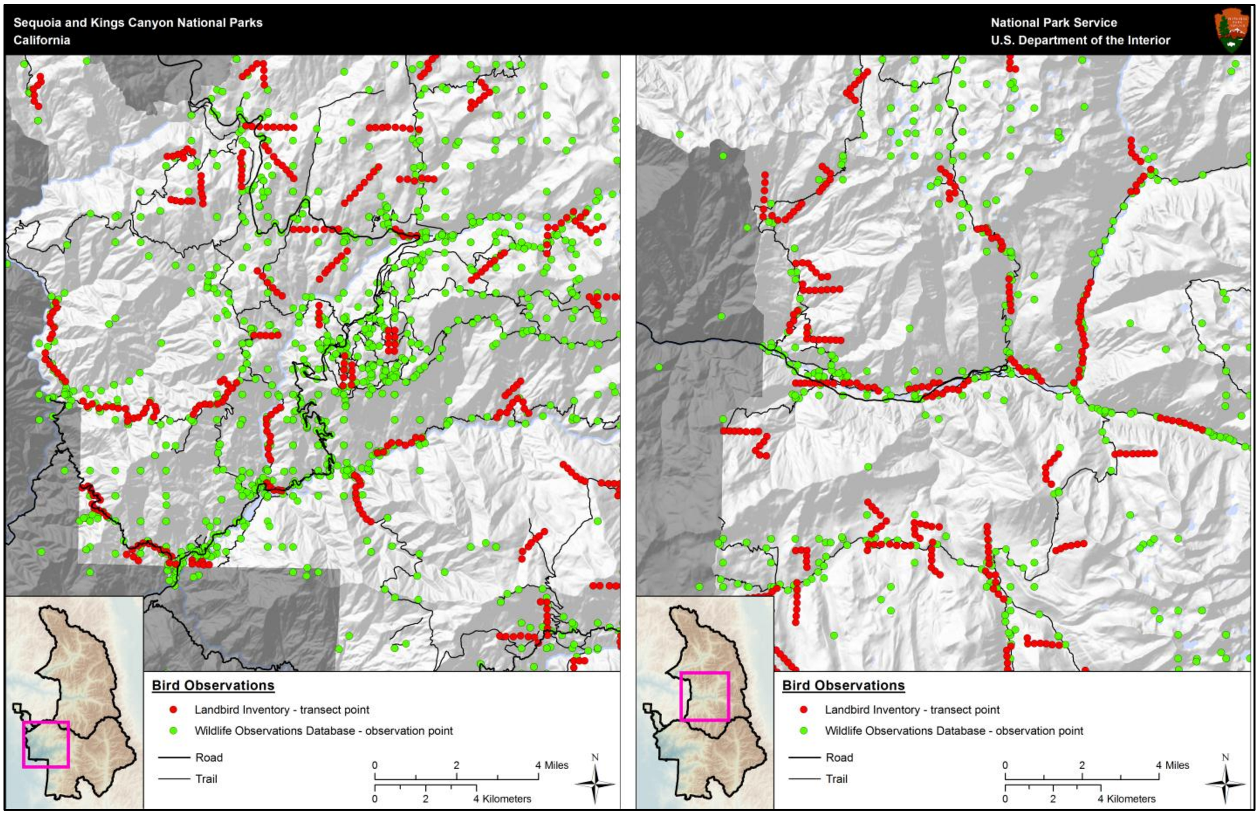


Figure 4. Two representative portions of Sequoia Kings Canyon National Parks depicting the spatial patterns of bird observations from the two large bird observation databases. The red lines represent the IBP transect sampling approach done in a formal bird survey, and the green dots represent the records collected haphazardly by observation, across a longer time period from the Park's Wildlife Observation Database (WOD).

Assessing the distribution of WOD occurrences within 25 km^2 grid (n= 183 cells), we find that grid cells aggregate between 1 and 6761 animal observations per grid cell (Figure 5). Thus, there are strong differences in our ability to discuss diversity across parks. We primarily describe diversity by elevation and by CWH land cover type. Our descriptions make the simplifying assumption that differences in sampling density are largely the result of access and not as a consequence of intrinsic differences in the abundance of animals at these various locations. Thus, we assume that all locations with an elevation band have equivalent species richness or diversity, or that all representatives of a particular land cover type have equivalent species richness or diversity. These are untested assumptions, and not likely entirely accurate.

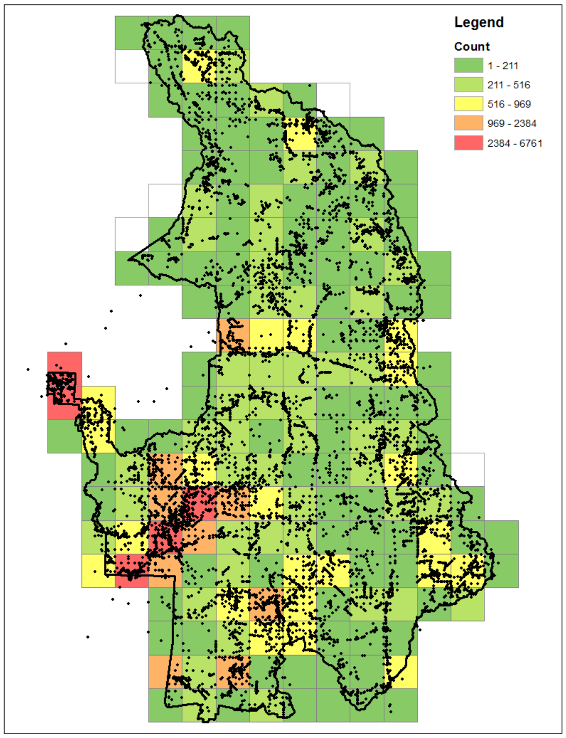


Figure 5. A map of SEKI gridded into 183 cells of 25 km^2 showing the number of vertebrate observations per cell. Low lying cells near popular visitation sites show the largest number of observations, although observations occur throughout the Parks.

Plant Observations

We assessed plant biodiversity by aggregating the various suites of plot-based plant data from the SEKI databases. Single species observation data is comprehensive in terms of species occurring within SEKI and helpful in verifying the plot-based species checklist, but these observations are not intended to capture the distribution of species on the landscape, and hence did not inform our assessment of the spatial distribution of biodiversity, and were excluded. We focused on the plot-based data because we want to characterize plant communities, spatially, by their typical species. The result is that we aggregated plots of varying sizes, collected at varying times, for varying purposes under the philosophy that each is an unbiased and reasonably comprehensive sample of vegetation.

With the plant data there are taxonomic issues to consider. Plants are often characterized by sub-species and varietal designations (discussed together here as “sub-specific designations”. Different researchers give different degrees of specificity of taxonomy when recording plot data. For example, *Abies magnifica* var. *shastensis* and *Abies magnifica* var. *magnifica* are both found within SEKI. While both of these sub-specific designations are found in the plot database (48 and 45 occurrences, respectively), the species designation *Abies magnifica* is found most frequently (78 occurrences). In order to most accurately account for diversity by elevation, land cover or spatial grid cell unit, we count species under the following contingency rules. If a species has sub-specific designations and only one sub-species or variety is found within that unit and non-differentiated full species observations are also found in that unit, then we assume that all un-differentiated occurrences of the full species are of the sub-specific designation also found within that unit. If multiple sub-specific designations are found within a unit, we count the number of taxa as the number of unique taxa, and we assign un-differentiated full species observations to the more common taxa for our calculation of abundance used for diversity measures. If only full species observations are found within a unit of species with sub-species designations, then we count the number of taxa, and the number of individuals simply at the full species level.

Another concern with plot data is that different plot sizes are used by different researchers. Plot size is correlated with the number of taxa that are likely observed in an area through the species – area relationship. There are far more small (< 0.1 ha) plots than there are 0.1 ha plots found in

SEKI (Table 2). Although a 0.1 ha plot is a standard size plot for sampling forest vegetation, this is a very large plot for sampling herbaceous communities. Thus, excluding small plots from our assessment may also exclude significant components of diversity. As a consequence, we sampled species richness and diversity using all plot and individual observation data combined (Table 2).

Like the vertebrate observations, most of the plant plot data were collected at mid-elevation (Figure 6a). Also like the vertebrate observations, the differential area of different elevation zones results in a sampling intensity pattern that has a peak plot density at low elevation (Figure 6b).

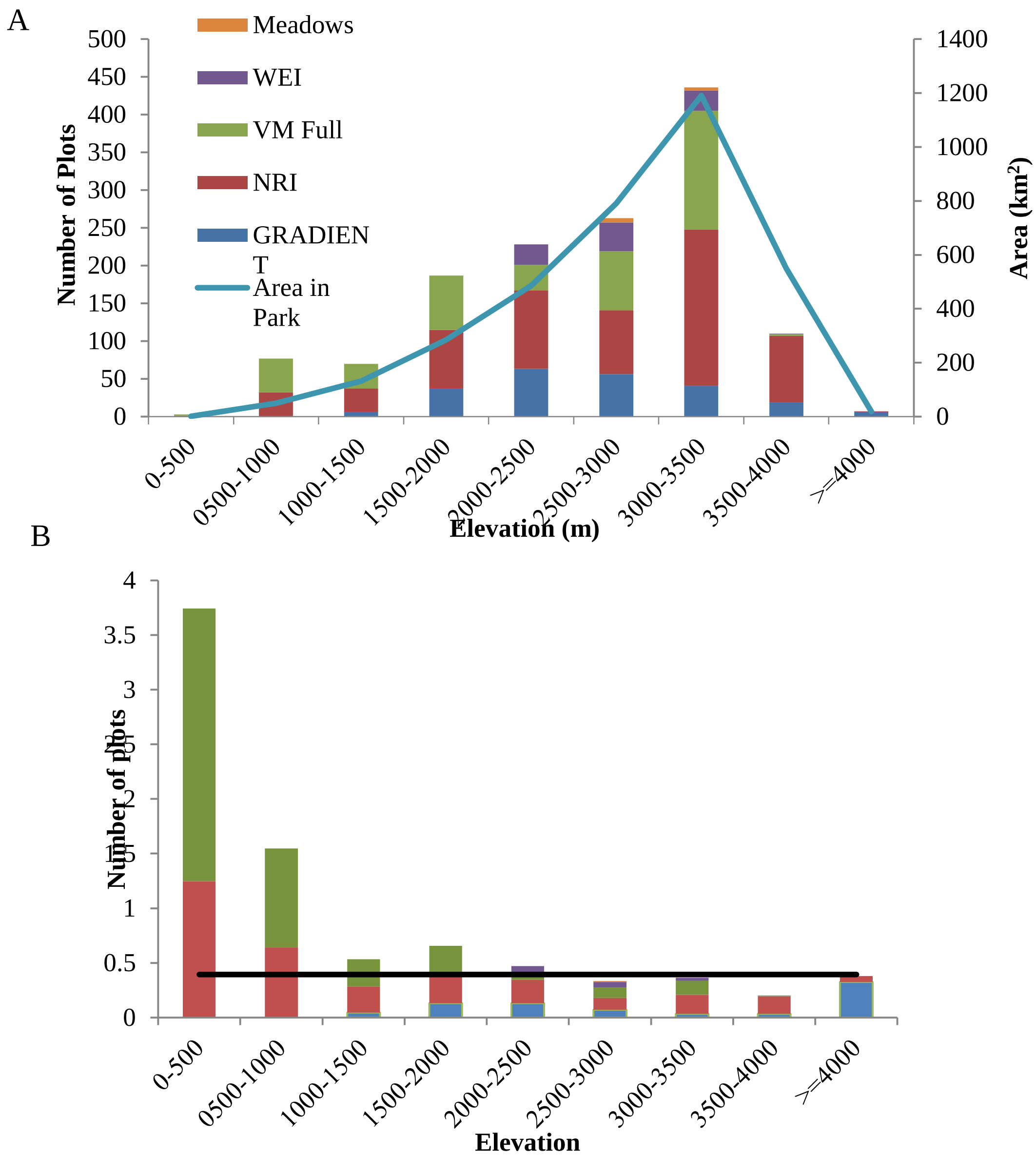


Figure 6. The sampling attributes of plant plot data in Sequoia / Kings Canyon National Parks by elevation class (m). A) The number of relevé plots (left axis) by elevation zones and the area (blue line, right axis) in each elevation class. The number of plots sampled by study shown in color. See text for explanation of acronyms. B) The sampling intensity (plots / km^2) by elevation zone for plants plots.

Another aspect of spatial patterning in plant sampling is how plots are distributed around the parks within the elevation zones (Figure 7), where Figure 7a identifies grid cells within the par where plots occur, and the Figure 7b, smooths this distribution based on the number of plots per 500 m elevation band. Examining the spatial distribution, we find that although there are particular locations that are well sampled (e.g., along roads and trails, giant sequoia groves), there are also plots that are well distributed around the park, suggesting that these plots may be capable of generally describing biodiversity of the park.

A) B)

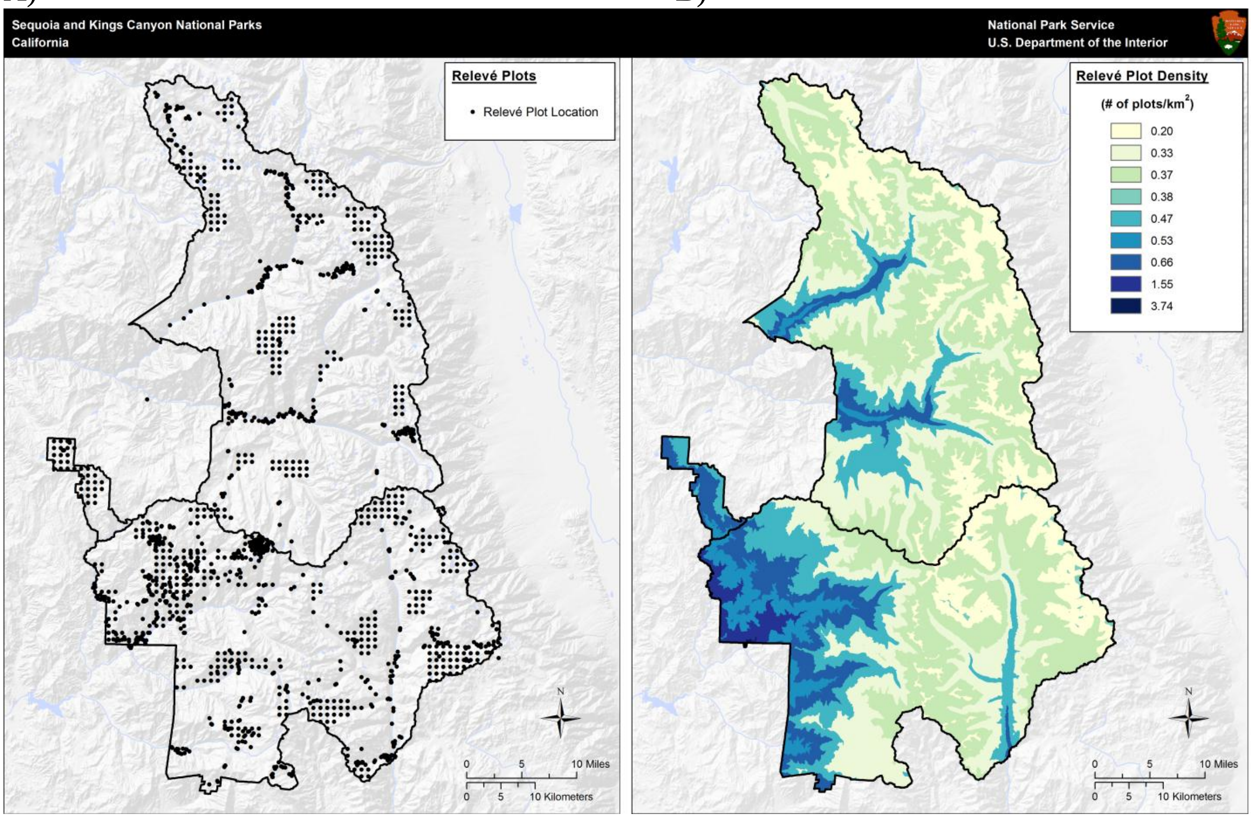


Figure 7. A map of (A) the relevé plot locations plotted on a gridded map of Sequoia Kings Canyon National Parks; and (B) the sampling intensity of relevé plots grouped into 500 m elevation bands.

A final source of data that we used for the biodiversity analysis was the SEKI vegetation map (http://biology.usgs.npsveg/seki/metasekispatial.html). This map was produced over an eight-year period, and covers the entirety of both Parks. The vegetation map uses the National Vegetation Classification Scheme (NVCS) at the Alliance and Association level, the levels at which dominant species are named in the land cover types. The map contains 82,089 polygons and 172 vegetation classes (Figure 8). We used this map to generate an elevation range for the dominant plant taxa of these 172 classes. This provides a baseline distribution of species that is highly tuned to the Parks' vegetation since the map's polygons are classified by vegetation types that identify the dominant plant species in each polygon type. Note that the designation of a polygon as a particular plant association does not guarantee the occurrence of that dominant plant species in that plot even though that will typically be the case. Nevertheless, the elevation range of the plant cover types, specifically within the bounds of SEKI, provide a baseline both of the elevation distribution of that land cover type and the elevation distribution of that dominant taxa within the Parks.

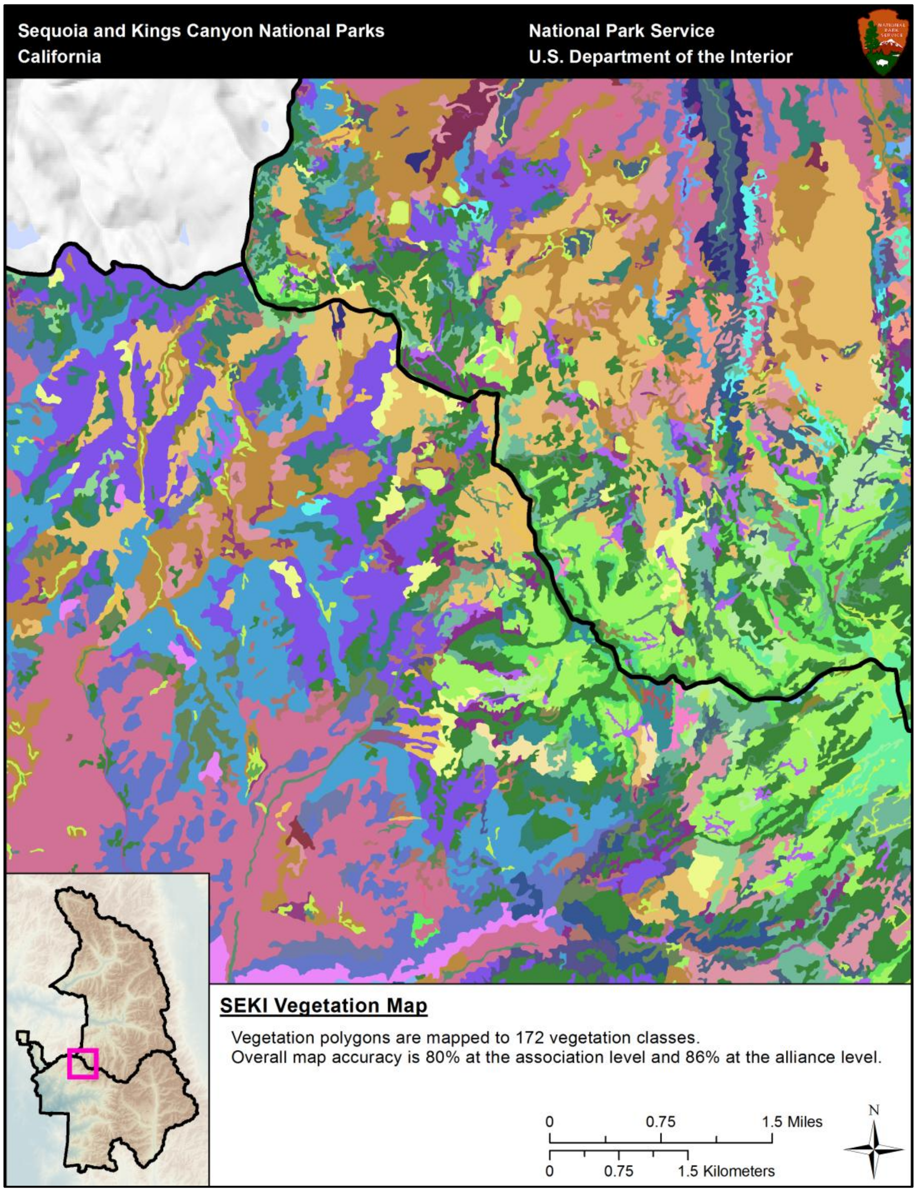


Figure 8. An example of the vegetation polygons found in the SEKI vegetation map.

Biodiversity Reference Conditions

Given that there has not been a comprehensive review of biodiversity within the Parks prior to this assessment, nor a comparable assessment within the region, we treat this report largely as the baseline reference condition for the Parks. We modify our assessment by known invasions of non-native taxa within SEKI. There are relatively few habitats (e.g., low elevation grasslands and savannas) and taxa (e.g., native fishes) that are strongly influenced by non-native invasions. We also modify this assessment based on the few known extirpations from SEKI (brown bear, California condor, the foothill yellow-legged frog). Thus, our baseline assessment considers the bulk of SEKI to be in a pristine condition. While the overall condition of biodiversity within SEKI is good, as we demonstrate in this chapter, to consider it pristine is an assumption with obvious faults. Nonetheless, as a baseline condition report, this is likely as good an assessment that we can make at the present time.

Baseline Measures of Species Richness

The number of observed species in Sequoia and Kings Canyon National Parks is presented in Table 4. Species lists of the birds, mammals, herpetofauna and plants are available from the Parks and, in the interest of space, are not included in this report. The species richness of SEKI is a function of its location and physical features. Prominent among these features are attributes that are globally associated with low (high elevation, arid habitats) as well as high (strong environmental gradients, position at the junction of major biomes) diversity. A primary

Table 4. An assessment of the species richness of Sequoia and Kings Canyon National Parks (SEKI) compared to diversity within the state of California for major taxonomic groups. Data on California diversity is based on NatureServe databases. and SEKI species lists were generated from the parks' wildlife observation databases (WOD). Percentages represent the percent of California diversity/species richness represented in SEKI.

Taxonomic	Group	California		Sequoia and Kings Canyon National Parks	
		Total	Native	Total (% CA total)	Native (% CA Native)
Birds		473	455	216 (45.6)	212 (46.4)
Mammals		318	311	89 (28.0)	84 (27.3)
Herpetofauna		187	177	34 (18.2)	33 (18.6)
	Amphibians	71	68	10 (14.1)	9 (13.2)
	Reptiles	112	106	23 (14.1)	23 (21.7)
	Turtles*	4	3	1 (25)	1 (33.3)
Fishes		190	146	10 (5.3)	5 (3.4)
Vertebrate, sub-total		1,355	1,266	381 (28.1)	363 (28.7)
Plants		10,133	8,883	1,562 (15.4)	1,365(15.3)
Total		11,488	10,149	1,943(16.9)	1,728(17.0)

* -freshwater turtles only

issue with respect to biodiversity, then, is how diverse are the parks relative to regional biodiversity? We sought to place SEKI within its regional context by comparing diversity of major taxonomic groups to statewide diversity (Table 4). This comparison suggests that SEKI has a strong capacity to capture and protect biodiversity in California. However, this comparison also highlights general challenges in assessing biodiversity.

For our comparison, we used SEKI species occurrence records, sample plot data, and species checklists to determine diversity within the parks. We use the NatureServe Data Explorer (http://www.conservationgateway.org/topic/tools) as the primary source for statewide diversity by taxonomic group. We chose this database because of its uniformity in treatment on issues such as data sources, taxonomic treatment and extra-range anomalous observations. The taxonomic treatment and species ranking should be the same as the California Natural Diversity Database (CNDDB) because state Natural Heritage organizations, of which CNDDB is one, inform the national database (NatureServe.org). Other available assessments (e.g., the Jepson manual count on plant species diversity) provide similar numbers of taxa.

The resulting assessment (Table 4) shows that between 5% and 46% of California's native species richness is represented within SEKI. It is not surprising that birds, a well-studied and highly mobile taxonomic group, have the highest fraction of state species found within the Parks. Fishes and amphibians, with low mobility, high habitat specificity and relatively little habitat at high elevation, have the lowest fraction of state species found within the Parks. Diversity of turtles within SEKI is very low (limited to western pond turtle), but California has low native diversity of turtles in general (i.e., 3 non-marine species).

The species richness of vertebrates and plants in SEKI is very similar to that of Yosemite National Park (http://www.nps.gov/yose/naturescience/index.htm). In both cases, these parks represent less than 1 percent of the land area of California, but capture upwards of 15% of its diversity.

We do not have quantitative data for invertebrate diversity. As a consequence, we briefly assess likely invertebrate diversity based on chapters from the summary provided in the Status of the Sierra Nevada (SNEP) reports (Erman 1996, Kimsey 1996, Shapiro 1996). Shapiro (1996) evaluated the status of butterflies, while Erman (1996) evaluated the status of aquatic invertebrates, and Kimsey (1996) provides a general synopsis of terrestrial insects. Each analysis reports a moderately high invertebrate diversity for the Sierra Nevada, but low levels of endemic species. For example, there are just three Sierra Nevada endemic butterflies out of a fauna that includes 173 taxa (species and sub-species; Shapiro 1996). Similarly, Kimsey (1996) reports one to three endemic taxa of terrestrial insects in each of the King, Kaweah, Kern and Tule Riversheds. Erman (1996) reports 11 endemic taxa out of a suite of 128 caddisflies of the southern Sierra Nevada. Beyond these brief reports, it is difficult to ascertain the diversity of the parks' invertebrates relative to other regions, much less the status of these taxa and how this fauna has changed through the 20th century.

The Distribution of Abundance

The distribution of abundance across these taxonomic groups fits expected S-shaped curves for each of the four groups with sufficient data sets to analyze (mammals, birds, herpetofauna, plants). Further, each curve fits a similar shape of abundance versus rank abundance (Figure 9), The typical S-shaped curve indicates a few taxa with strong abundance, many taxa with moderate abundance and a few rare taxa. Mammals show this S-shaped curve despite our suspicion that this reflects the differential observability of species more so than the abundance, with the large and easily observed mule deer and black bear as the most abundant taxa. We anticipate that body size should be inversely correlated with abundance (Lomolino et al 2010). As a consequence, small mammals, as a group, are likely much more abundant than the large mammals that dominate the observation count (mule deer (*Odocoileus hemionus*) n= 2644; black bear (*Ursus americanus*) n = 2464; coyote (*Canis latrans*) n = 849). In contrast, 72% of the 39 taxa observed 20 or fewer times within SEKI are mice, shrews, voles, bats, chipmunks, all small mammals. For mammals, the distribution of abundance is not likely to reflect actual abundances.

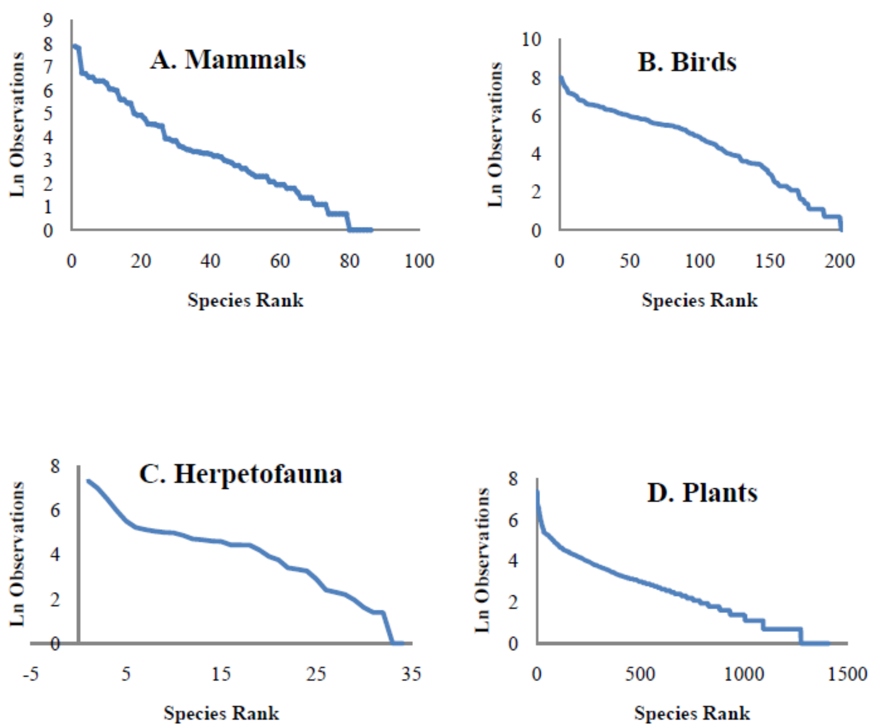


Figure 9. Rank abundance plots for mammals, birds, herpetofauna and plants of Sequoia Kings Canyon National Parks.

Non-Native Taxa

True reference conditions should reflect a non-native species diversity of zero. Nevertheless, the number of non-native taxa for most groups, relative to California as a whole, is similar to the fractional representation of native diversity relative to the state. For example, there are 35 non-fish, non-native vertebrates listed by NatureServe to occur in California, of which 9 (23%) are found in the Parks. In addition, there are a total of 100 observations of these 9 non-native vertebrate species, making up less that 0.2% of all wildlife observations. Although there may be reporting bias resulting in under-reporting non-native taxa. Virginia opossum (35), wild turkey (19), domestic cats (16), chukar (13) and bullfrog (9) represent over 90% of non-native observations in these groups. These non-native observations are well-distributed throughout SEKI (Figure 10).

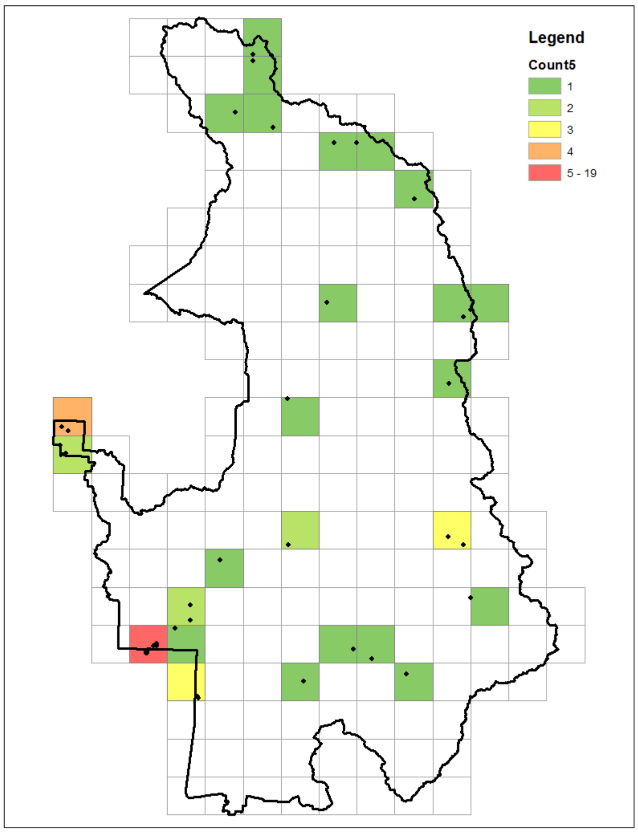


Figure 10. A map of Sequoia ad Kings Canyon National Parks showing observations of non-native vertebrate taxa. Note the pattern that few cells have any observations, most strongly sampled cells in general, have the largest number of non-native observation, and that non-native taxa are well-distributed around the parks.

Plant diversity reflects a similar pattern of relatively modest diversity of non-native plant taxa as recorded in the plot-based data. There are a total of 940 observations of 78 non-native taxa that appear in the plot records. This represents just 2.9% of the over 32,000 species observations and just 6% of the 1237 plant taxa observed in plots. This result is somewhat in contrast to the 197 non-native taxa listed on the SEKI plant list, representing 12.6% of the entire species list. This difference is likely the result of a number of localized weeds found in SEKI that do not occur in the plots.

Fish represent a sharp contrast to other taxonomic groups. The five native fishes of SEKI, according to the SEKI natural resources species list include two narrowly endemic sub-species of rainbow trout (Little Kern Golden Trout (*Oncorhynchus mykiss whitei*), Kern River Rainbow Trout (*O. mykiss gilberti*)), the encroaching riffle sculpin (*Cottus gulosus*), the rare California roach (*Lavinia symmetrics*), and the unconfirmed hardhead (*Mylophardodon conocephalus*). Non-native fish, primarily trout (rainbow, (*O. mykiss*), brown (*Salmo trutta*) and brook (*Salvelinus fontinalis*)) represent over 99.5% of fish observations in the WOD. Thus, the fish communities of SEKI are severely compromised both in terms of non-native fish occupying formerly fishless habitats (see Chapter on Sensitive Animals Assessment), but also because native species represent few of the observations even in habitats with a historic native fish fauna. This is in part due to the known seeding of high elevation lakes with trout for fishing (Bradford 1989; Bradford et al. 1998), which has led to decline in high elevation amphibians (Knapp and Mathews 2000).

At Risk Taxa

There are a modest number of taxa within SEKI that have special designation (Table 5). Rare plants are treated separately in a different chapter, and thus are considered just briefly here. Among the vertebrates, five mammals, two birds, four amphibians and one fish are listed under the Federal Endangered Species Act or are considered rare (receiving a rank of G3 or rarer for species or T3 or rarer for subspecies by Nature Serve). The lack of listed species, plants in particular, may result from several interacting forces. SEKI has been protected for a long time, and hence populations may be less damaged from habitat loss and degradation. Dominated by high elevation habitats, the system is relatively intact from non-native species, another primary driver of endangerment. Finally, because SEKI is already public land under protected status, there is reduced political pressure to list taxa, particularly narrow endemics, under the Endangered Species Act. Because of this last effect, we look to other sources to evaluate the frequency of rarity among park biota. Mapping at-risk taxa, as with non-native taxa, shows a broad distribution of occurrences (Figure 11).

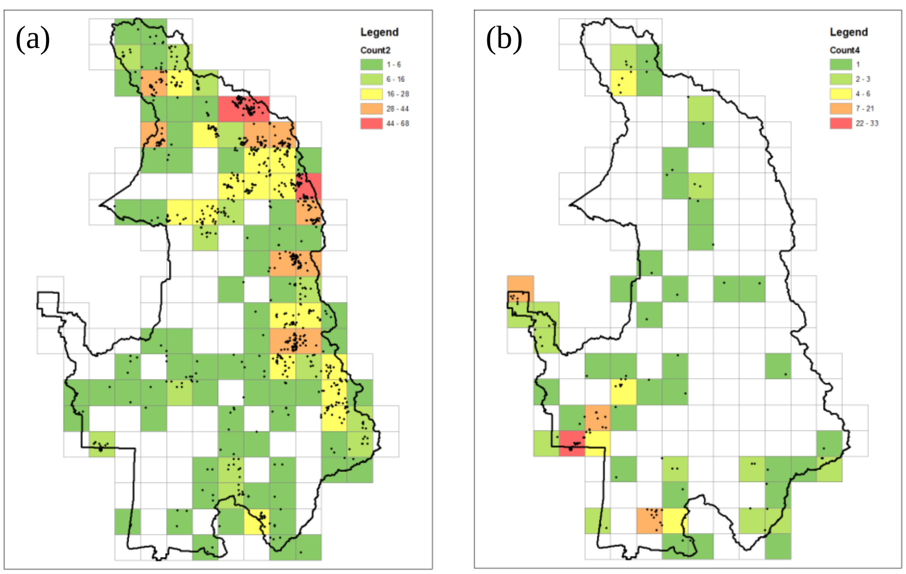


Figure 11. Maps of Sequoia and Kings Canyon national Parks showing (a) listed; and (b) non-listed but rare vertebrate taxa occurrences in the park.

Table 5. Species of special concern occurring in Sequoia and Kings Canyon National Parks. Species of special concern are defined here as those that are: a) federally listed by the Endangered Species Act as threatened (LT) or endangered (LE); b) designated as G1 - G3 by Nature Serve as full species; or c) Designated as T1-T3 as subspecies by Nature Serve**.

Taxonomic Group			Federal Listing	NatureServe Ranking**	Status in SEKI
Mammals					
	Sierra Nevada Bighorn Sheep	*Ovis canadensis sierrae*	LE	G4T1	at risk
	Brown bear	*Ursus arctos*	LT	G4	extirpated
	Sierra Nevada red fox	*Vulpes vulpes necator*		G5T1T3	at risk
	Pacific fisher	*Martes pennanti*		G5T2T3Q*	at risk
	California Wolverine	*Gulo gulo lutens*		G4T1Q	possibly extirpated
Birds	California condor	*Gymngyps californianus*	LE	G1	extirpated
	Northern spotted owl	*Strix occidentalis occidentalis*		G3T3	at risk
Amphibians					
	Mountain Yellow-legged frog	*Rana muscosa*	PS:LE,C	G2	at risk
	Foothill yellow legged frog	*Rana boylii*		G3	extirpated
	Yosemite toad	*Bufo canorus*	*C*	G2	unknown
	Sequoia slender salamander	*Batrachoseps kawia*		G2G3	unknown
	Kings River slender salamander	*Batrachoseps regius*		G1	unknown
Reptiles	None				
Fish	Little Kern Golden Trout	*Oncorhynchus mykiss gilberti*		G5T1	at risk

* refers to the west coast distinct population

** *The NatureServe Rarity Ranking System***.** Prefix G refers to the geographic region of concern (G – global status; N – national, S – sub-national status); The prefix “T” refers to the rank of the sub-specific group described in the table; the number refers to the status within that geographical scope (1= critically endangered; 2 = imperiled; 3 = vulnerable; 4 = apparently secure; 5 = secure); ad “Q” refers to questionable rarity status of the taxa

The rare plant chapter reports 77 rare plant taxa that appear on the California Native Plant Society (CNPS) database (CNPS 2011) that also are listed on the SEKI plant checklist of 1362 native plant taxa (5.6%). Thus, rare plant frequency for SEKI represents a low frequency relative to California as 2190 of 8883 (25%) native plant taxa are listed as rare in the California flora by CNPS. The CNPS ranks species in four lists. 1A. Plants presumed extinct in California (n = 27). 1B. Plants that are rare, threatened or endangered in California and elsewhere (n = 1116). 2. Plants that are rare, threatened or endangered in California, but more common elsewhere (n = 481). 3. Plants that require more information. This is a review list of potentially rare species with taxonomic issues (n = 56). 4. Plants of limited distribution and on the CNPS watch list (n = 580).

The low frequency of rare taxa, relative to the state of California supports the notion that a relatively intact system with low habitat loss, fragmentation, degradation and few non-native species in high elevation region, results in few rare species in SEKI relative to many other parts of the state. We analyzed a set of 47 taxa listed by CNPS as most endangered (lists 1A&B and 2 by CNPS terminology) and occurring within either Fresno or Tulare counties. These 47 taxa are dominated by perennial herbs (n = 33), followed by annual herbs (n= 10), along with a few (4) shrubs. None of these taxa are federally listed. Tompkin's sedge (*Carex tompkinsii*) is a state listed rare plant (CR). With respect to global rarity ranks, few species found in SEKI are at the rarest end of the spectrum (critically endangered(G1) = 3 species; threatened (G2) = 9 species). Most taxa are either vulnerable (G3 = 20 species) or regionally secure as a species, with a subspecies that is at greater risk of loss (globally secure species (G4 or G5, endangered, threatened or vulnerable sub-species (T1-3) = 15 species). The largest number of taxa occurring at mid-elevations (2000 to 3500 m) (Table 6).

Table 6. The reported median elevation of recorded zones of distribution for the 47 rare plant taxa identified by the California Native Plant Society as occurring in Fresno or Tulare county and appearing on the SEKI plant checklist.

Elevation (m)	Number of taxa
<1000 m	7
1000-1500	2
1500-1999	6
2000-2500	9
2500-3000	13
3000-3500	8
3500-4000	3

Regional Biodiversity Context

The California floristic province is notable for being both floristically diverse and containing a large number of endemic plants (Stebbins and Major 1965; Raven and Axelrod 1995). Among the vertebrate groups, there are well-recognized geographic centers of diversity among amphibians such as the *Ensatina* salamanders and the slender salamanders (Jockusch and Wake 2002, Wake 1997), each of which contain a number of California endemic species. SEKI contains representatives of each of these salamander groups. What is perhaps less well recognized is the degree to which many mammals of a mostly northerly distribution find their southern range terminus in the Sierra Nevada. These range boundaries are often close to SEKI as the parks represent the highest portion of the Sierra Nevada mountain range. Graber (1996) reports that 112 species of native mammals regularly use the Sierra Nevada, and 81 of these have been recorded within SEKI. Among the 81 native mammals in SEKI, 30 appear to be at or near their southern range limits, with another 5 species as nearly endemic to California. This pattern suggests that SEKI may be a significant repository of genetic variation among species and have significance for global biodiversity because of the relative isolation of populations from the remainder of their distributions. The significance of SEKI being at the southern extent of species ranges may also have consequences in terms of climate change, with the possible of migration of species to higher latitudes and elevations.

Approximately 50% of California's 8,883 native plant taxa are found in the Sierra Nevada, with 405 endemic plant taxa in the Sierra Nevada (Shevock 1996). In many respects, SEKI does not stand out as housing a particularly unique flora or fauna, as a whole. For example, the state of California is second in the nation in terms of the number of federally listed endangered plant species with 186 listed plant taxa. None of these occur within SEKI. Similarly, among the 2245 plant taxa tracked by the California Native Plant Society (CNPS 2011), 260 are found in Fresno and Tulare counties, yet, only 47 are found in SEKI. While SEKI represents an impressively diverse flora, we conclude that it is not a flora that is particularly rich in rare or narrowly endemic plant taxa.

Perhaps the most significant component of SEKI as a biodiversity repository is its extensive regions of high elevation and their potential as refuges for species affected by global climate change. Predictions of range shifts for plant species related to global climate change generally suggest an increase in plant diversity moving into the parks (Loarie et al 2008, Ackerly et al. 2010). Among the rare and endemic plants, the southern Sierra is generally richer than the northern or central Sierra, with the largest numbers of Sierran rare and endemic plants being found in the Kern, Kings and Kaweah River basins (Shevock 1996). Most of the single watershed endemic taxa of the Kern River identified by Shevock (1996) are found at the lower to mid elevations, and lie outside the Parks boundaries. For example, just under 25% of the single watershed endemics of the Kaweah, Kings and Kern River basins identified by Shevock (1996) are found on the SEKI plant checklist. However, SEKI contains the headwaters of each of these three major river basins and may see greater frequency of these endemic species if species migrate upwards within drainages as a consequence of climate change.

Future Data Needs

The flora and fauna of SEKI are reasonably well known, probably more so than most US National Parks. The glaring exception, in terms of quantitative data for assessment, are in the invertebrates. The invertebrates represent a large and diverse group of animals and SEKI is likely to house a significant diversity. Montane invertebrate surveys are currently underway (J. Holmgren, personal communication), but these could be expanded to include lower elevations. Obviously, this would be an enormous undertaking.

Spatial Analyses

Unequal Sampling and Data Treatment

We used the SEKI observation databases to examine spatial patterns of species richness. A simple approach is to count the number of species observations in each 500 m elevation band in SEKI. The pattern of vascular plant species richness varies by elevation from 23 species (highest elevation) to 617 species (2500 – 3000 m) (data not shown). This depiction of plant species richness, however, does not account for sampling effort or area within SEKI.

Another type of assessment would count the number of species observations in each vegetation polygon type, using the Park's vegetation map or the California Wildlife Habitat (CWH) classification. There is, however, a fundamental problem with this sort of analysis. Namely, uneven numbers of plots within each elevation band, or CWH classification type, provides an uneven opportunity to sample species richness. All else being equal, we expect to capture more species where more plots are sampled. This problem is well illustrated in Figure 12 where vascular plant total species richness (blue bars) and plot sample size (green dots) are plotted against elevation. When a higher number of plots are associated with lower diversity, as in 3000-3500 m compared to 2500-3000 m, then we are certain about the relative diversity of the two categories. However, when increasing diversity is associated with increasing sampling density, as is the case when comparing diversity between 1000 and 3000 m, then we can't be certain whether it is higher diversity or just more intense sampling that is driving the higher species richness (Figure 12).

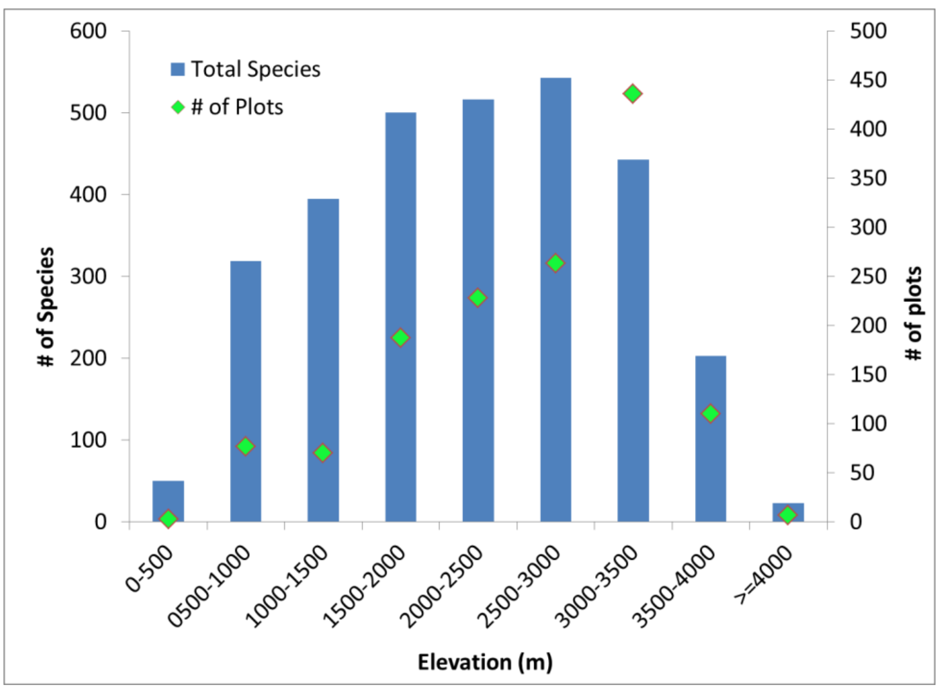


Figure 12. A plot of the number of vascular plants species (blue bars) and the number of relevé plots (green dots, right axis) plotted as a function of 500 m elevation class.

We used rarefaction to account for differences in sampling intensity (Gotelli and Colwell 2001; Colwell et al. 2004; Chao et al. 2009; Gotelli and Colwell 2011). Rarefaction is a random re-sampling of data, replicated at a variety of sample sizes in order to estimate an expected species richness, and a confidence interval around that species richness for a given sample size (Hurlbert 1971, Heck et al 1975). The result is a curve of expected species richness given any particular sampling intensity (Figure 13). An expected species richness value for each taxonomic group was determined at various sample sizes using individual-based rarefaction. This analysis was done in R (R Development Core Team 2008), using the ‘rarefy’ function in the ‘vegan’ package (Oksanen et al. 2010). This function is based on the rarefaction formula developed by Hurlbert (1971) and the standard errors of Heck et al. (1975). There are two methods to project species richness (the Chao estimator and the ACE estimator). We present the Chao1 projected species richness, but both results are presented in the Appendix.

Two observations emerge from these rarefaction results. First, with enough sampling, species richness estimates approach an asymptotic level of complete sampling. Second, the estimated variance around species richness estimates is low at very low sample sizes and returns to zero at complete sampling (Figure 13). This apparent level of confidence at low sample sizes reflects the average diversity found in a single sampling unit. Sampling variance is zero when using all of the data, because data resampling of all data always returns the exact same result. In the case of individual animal observations, the species richness of a single observation is, obviously, 1. Again, the low variance at complete sampling results from the fact that the data sampling is using all of the data and therefore would come to the same estimate of species richness every time.

To report an estimate of species richness that is based on even sampling, we must choose a sampling effort. We selected a cut-off for a rarefaction species sampling number based on the shape of the rarefaction curves and a desire to map the entirety of the landscape (i.e., all elevation zones or CWH habitat). This selection is subjective and differs for each taxa. For example, Figure 13 shows that the expected species richness would vary strongly depending on selecting a cut-off for reporting expected species richness at a sample size of 500 or 1500. However, the relative assessment of the species richness in the two communities would not differ. If there were a third curve on this graph for another elevation zone, with, for example a total of 400 samples, we would then need to balance the trade-off of assessing species richness at a slightly lower sample size, increasing uncertainty, versus not being able to assess this third elevation zone. Our general criteria was to seek the largest possible sample size threshold that allowed an assessment of greater than 85% of the total landscape, as long as the rank order of the richness assessments among categories was stable with a larger sample (i.e., the shapes of the curves are similar across classifications). Rarefaction curves are presented in the Appendix in each case.

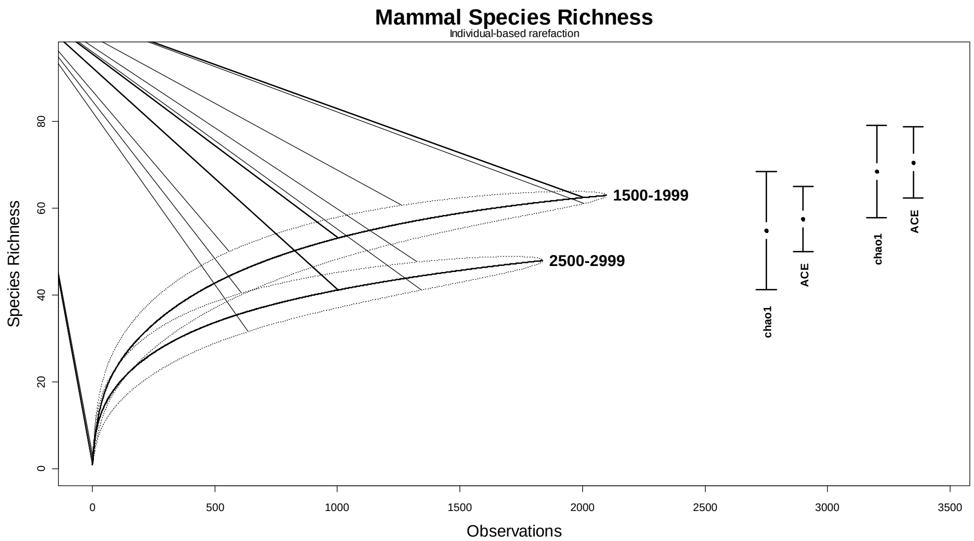


Figure 13. An example of a rarefaction curve for mammal species richness at 1500-2000 m elevation compared to 2500-3000m elevation.

Comparison of species richness among samples is done by comparing the curves where the number of individual observations (n) is equal to the sample size of the smallest sample. This sample size corresponds, nearly always, to fewer species than have actually been observed in the more well-surveyed sites. The intent, however, is not to determine the maximum number of species observed *within* a habitat class, but the relative numbers of species observed *among* habitat classes. If the observed number of species in the smaller sample falls outside the confidence interval of the larger sample, then you can reject the null hypothesis and determine that the species richness significantly differs at the significance level corresponding to the confidence interval.

We also use rarefaction to determine a minimum sampling intensity from which we can estimate richness. There are, for example, vegetation types within SEKI that are sufficiently poorly sampled by either wildlife observations or vegetation plots, that we likely do not have adequate power to report on their actual species richness. We expect species richness to saturate with observation intensity, and find that reporting on species richness using a sampling intensity that does not change slope and begin to level off can be misleading. For each taxonomic group, based on sampling within vegetation types and by elevation, we calculate rarefaction statistics to determine the level of sampling required to adequately report species richness. We then also report the classes for which we can assess species richness, and the fraction of the landscape that this covers.

In assessing the classification scheme for analyzing species patterns, we determined that the CWH classification system, with 35 habitat types, allows a more thorough coverage for a SEKI species richness assessment. In most cases, we had adequate data to map the diversity of polygons defined by CWH types to cover between 85% and 97% of the area of the Parks. In contrast, a more finely resolved vegetation classification (e.g., Plant Alliance level) contains too many different habitat types for the data. Initial rarefaction results using birds and mammals suggested that if we were to use the Alliance level there would be much of the SEKI landscape for which we had no biodiversity assessment because too many habitat types were too poorly sampled to assess species richness. This poses a daunting challenge given the formidable amount of sampling data available.

We also tested the effect of treating all observations within regions as robust as opposed to considering stray, or rare observations as anomalous. In this case, we devised two rule-based protocols for excluding stray occurrences. In the first, we treated all cases with three or fewer observations within a particular elevation, or land cover type, as anomalous when there are other elevations, or land cover types that include more than three observations. Second, we included only those observations that captured 95% of all observations, ranked in order from most to least frequently observed. In both cases, elevation classes or land cover types could be excluded from apparent occupancy because of low frequency occurrences. For moderately rare species, where there are few occurrences to begin with, these rules may strongly limit the number of elevation bins or land cover types in which these species participate in overall species richness. This was, essentially, a sensitivity analysis. These data restriction rules made little difference for the outcome, so we present only the case with all observations included, but report the full results in the appendix.

In addition, there are several measures of diversity that balance measures of species richness and evenness in the distribution of abundance. We focused on the Shannon-Weiner index and Simpson’s index of diversity. These measures vary in the degree to which they weight rare occurrences (McCune and Grace 2002). We chose to present the inverse of Simpson’s diversity measure because it is less sensitive to rare occurrences, and should mute impacts of uneven sampling as a consequence (McCune and Grace 2002). The Inverse Simpson is asymptotically related to rarefied species richness, is equivalent to Fisher’s α, and is closely related to Shannon’s index but is less sensitive to rare occurrences (Hill 1973).

In each of the aforementioned cases where we chose amongst options for presenting a measure of richness (total observed species, predicted richness at a specified sampling intensity, Chao and ACE projected species richness through rarefaction; Shannon and Simpson indices of diversity; observation inclusion rules). In each case, the choice of the specific metric results in small overall difference in the relative consideration of richness or diversity.

Species Richness and Diversity by Elevation

Rarefaction of bird occurrences by elevation resulted in an assessment of all elevation categories, estimating species richness at a sample size of 1000 birds (Table 7). We observed a pattern of decreasing richness with elevation, but with relatively little reduction in bird species richness until the highest elevation (Table 7). The total number of species observed is an estimate of relative diversity, but one that is subject to misinterpretation if there are strong differences in sampling effort among different elevation bands. However, differences in the numbers of observations in different units may also be driven by differential densities of target organisms in different habitats, resulting in different observation numbers despite similar observation effort. In this case, it would be more appropriate to use total species number as a measure of diversity.

We would expect to see differences in patterns of the distribution of diversity against elevation if there were strong differences in the evenness of bird communities by elevation, since diversity is a combined measure of species richness and the evenness in the distribution of abundance. Alternatively, since diversity includes all observed species at an elevation band, we might also observe differences in pattern if there were species richness differences that were generated from uneven sampling of different elevation bands. Instead, gradients Simpson's diversity are well correlated with those of total species observed ($r^2 = 0.63$) and the four estimates of species richness ($0.78 < r^2 < 0.95$)

Table 7. Species richness and diversity estimates for bird observation for Sequoia and Kings Canyon National Parks by 500 m elevation category. Bird observations include both the Wildlife Observation Databases as well as those collected by the Institute for Bird Populations. Rarefaction results are presented at the 1000, 3000 and 5000 observation cutoff as well as the Chao estimator of asymptotic species richness with standard error (s.e.). The total number of species, with the number of observations, and the inverse of Simpson's diversity index are also presented. NA = not available, insufficient data.

	Expected species richness					
Elevation Range (m)	**n = 1000**	**n = 3000**	**n = 5000**	**Chao Projected species (s.e.)**	**Species Observed (number of obs.)**	**1/Simpson***
0-999	116.9	144.4	157.8	196 (14.7)	171 (8,324)	60.3
1000-1499	123.1	144.8	NA	176.1 (21.0)	149 (3,725)	56.8
1500-1999	109.2	131.9	141.9	175.1 (12.2)	158 (11,569)	52.3
2000-2499	104.4	130.1	142.1	179.7 (7.4)	168 (15,152)	44.4
2500-2999	101.5	127.0	139.3	170.9 (10.3)	154 (9,274)	37.7
3000-3499	92.6	120.7	133.6	159.9 (7.8)	148 (9,432)	29.0
>=3500	79.9	NA	NA	102.5 (10.4)	86 (1,309)	16.0

Mammal species richness assessments are challenging to interpret because observations are strongly driven by interspecific differences in the ability to detect individuals. Approximately 40% of the mammal diversity is found in generally difficult to detect groups such as nocturnal bats (n = 14 species) and fossorial or ground dwelling pocket gophers, mice, shrews, and voles (n = 19 species). In contrast, more than half the mammal observations are found among six, large (mule deer (*Odocoileus hemionus*, n= 2644); black bear (*Ursus americanus*, n = 2464); coyote (*Canis latrans*, n= 849)) or otherwise notable (yellow bellied marmot (*Marmota flaviventris*, n = 820); chickaree (*Ochotona princeps*, n = 710); pika (*Tamiasciurus douglasii*, n = 710) species. Peak species richness and diversity occurred at mid (1500 m- 2500 m) elevations (Table 8).

Table 8. Species richness and diversity estimates for mammal observation for Sequoia and Kings Canyon National Parks by 500 m elevation category. Rarefaction results are presented at the 500, 1000 and 1500 observation cutoff as well as the Chao estimator of asymptotic species richness with standard error (s.e.). The total number of species, with the number of observations, and the inverse of Simpson's diversity index are also presented. NA = not available, insufficient data.

	Expected species richness					
Elevation Range (m)	**n = 500**	**n = 1000**	**n = 1500**	**Chao Projected species (s.e.)**	**Species Observed (number of obs.)**	**1/Simpson***
0-999	28.4	36.1	41.1	55.2 (7.8)	47 (2420)	7.4
1000-1499	38.2	45.7	NA	52.6 (4.0)	49 (1390)	9.9
1500-1999	42.3	52.3	57.9	67.5 (5.3)	62 (2095)	9.3
2000-2499	38.6	46.4	51.0	68.2 (9.7)	59 (3126)	9.1
2500-2999	33.7	41.2	45.7	54.9 (6.8)	48 (1839)	8.9
3000-3499	31.5	38.7	43.4	63.1 (10.4)	52 (2973)	10.7
>=3500	24.3	NA	NA	40 (NA)	25 (561)	6.5

Species richness and diversity measures for mammas are less consistent than for birds. Projected species richness, based on a sample of 500 observations, peaks at just over 42 species in the 1500-2000 m elevation category. By contrast, Simpson's diversity index peaks at 3000 to 3500 m in elevation (Table 8). The dominance of bear and mule deer observations may strongly influence this outcome. Estimated mammal species richness relatively even across elevation, varying only from 31 to 42 taxa at 500 observations in all but the highest and lowest elevation categories. As for the extremes in elevation, note that the estimated species richness, with 500 observations, is little changed from the actual number of species observed above 3500 m (estimated species = 24.3; actual number of observed species =25; number of observations = 561). In contrast, the actual number of species observed in the lowest elevation category (n=47) is far higher than an estimated sample of 500 individuals (n= 28.4). This higher number of observed taxa is largely the result that species richness estimates are being generated from a much larger number of observations (n= 2420) at low elevation. The intervening elevations have both higher numbers of total species observed and total observations, but also a higher number of species expected given a sample of 500 observations. Perhaps not surprisingly, correlations between Simpson's diversity and total number of species observed ($r^2 = 0.50$) and the four estimates of species richness ($0.04 < r^2 < 0.42$) is far lower than for birds.

The herpetofauna shows a fairly strong elevation gradient with peak diversity and richness at low (< 2000 m) elevations and strongly declining richness and diversity metrics above 2500 m (Table 9). The far fewer observations of herpetofauna (n = 5749) is counterbalanced by far fewer species to observe (n = 34) in terms of diversity measures. We chose to use a sample size of 250 observations as a minimum cutoff value for species richness assessment. We expect a robust projection of overall species richness for the herpetofauna because of their relatively low diversity, low capacity for detection bias and low movement capacity compared to birds and mammals. Despite fewer observations, rarefaction results were all strongly correlated with

Simpson's diversity ($0.76 < r^2 < 0.85$). Similarly, Chao estimated of species richness at a sample size of 250 correlate strongly with total observed species ($r^2 = 0.92$).

Table 9. Species richness and diversity estimates for herpetofaunal observation for Sequoia and Kings Canyon National Parks by 500 m elevation category. Rarefaction results are presented at the 250, 400 and 500 observation cutoff as well as the Chao estimator of asymptotic species richness with standard error (s.e.). The total number of species, with the number of observations, and the inverse of Simpson's diversity index are also presented. NA = not available, insufficient data.

	Expected species richness					
Elevation Range	**n = 250**	**n = 400**	**n = 500**	**Chao Projected species (s.e.)**	**Species Observed (number of obs.)**	**1/Simpson***
0-999	24.4	26.5	27.5	35 (17.1)	30 (874)	12.7
1000-1499	21.8	23.4	23.9	24.2 (1.0)	24 (513)	10.0
1500-1999	24.1	26.1	27.2	35.5 (23.6)	28 (571)	8.3
2000-2499	21.7	23.0	23.4	25 (NA)	24 (684)	7.6
2500-2999	16.7	18.7	19.5	20.75 (2.3)	20 (581)	4.5
3000-3499	9.5	10.8	11.4	15 (0.7)	15 (2199)	2.7
>=3500	7.8	NA	NA	11 (NA)	8 (270)	1.6

Assessing plant species richness and diversity is distinguished from vertebrate diversity in a number of important ways. First, plants are sampled in vegetation plots. This plot data is associated with a project (e.g., Stephenson gradient plots, Vankat plots, giant sequoia plots). As a consequence, these data are more systematically assessed, but also less randomly distributed. Plot data also include abundance information. However, to assess species richness, we used presences in plots as occurrences, as in the WOD. There are also taxonomic uncertainties associated with the plant data. For example, taxa that contain multiple sub-species within the park are not always designated by their sub-species. We adopted the rule that any undesignated sub-species taxon was the same as any other sub-species within that habitat. If no other sub-species were noted within that habitat, then the taxon was counted as an undesignated full species.

Plants exhibit a pattern of species richness that is strongly divergent from that of the vertebrate taxa. Estimated species richness, numbers of observed species, and projected species totals are each maximized at mid-elevations (1500 – 3000 m), whereas Simpon's diversity is lowest from 1500-2500 m (Table 10). In the case of plants, the large number of observations allows robust estimations of species richness. The distinction of the Simpson's diversity measure is likely driven by mid-elevation communities dominated by stronger differential abundance within plots.

Table 10. Species richness and diversity estimates for plant observation for Sequoia and Kings Canyon National Parks by 500 m elevation category. Rarefaction results are presented at the 2000, 3500 and 8000 observation cutoff as well as the Chao estimator of asymptotic species richness with standard error (s.e.). The total number of species, with the number of observations, and the inverse of Simpson's diversity index are also presented. NA = not available, insufficient data.

Elevation Range	Expected species richness					
	n = 2000	n = 3500	n = 8000	Chao1 projected total (s.e.)	Total observed species (n)	Inverse Simpson†
0-999	322.8	388.6	NA	514 (29.9)	**393 (3631)**	94.3
1000-1499	376.3	462.4	NA	666.6 (42.8)	**469 (3647)**	80.8
1500-1999	363.9	452.2	590.4	782 (38.2)	**598 (8363)**	56.8
2000-2499	382.2	468.0	596.6	781.5 (28.7)	**650 (11,352)**	69.2
2500-2999	404.5	482.9	590.7	738.0 (22.7)	**647 (12,774)**	89.5
3000-3499	320.9	383.0	474.9	661.0 (35.7)	**524 (12,429)**	85.5
>=3500	241.7	NA	NA	343.0 (25.6)	**258 (2432)**	83.0

Finally, plant taxa are a more diverse taxonomic group and experience more turnover from one habitat to the next. We calculated Sorensen's dissimilarity index for habitats by elevation in order to assess the degree to which vegetation changes as elevation increases. The diagonal elements of Table 11 represent adjacent elevations. These data show that the adjacent bands of vegetation differ more at low elevations than at high elevation.

Table 11. Community turnover as assessed by the conditional Sørensen's measure of dissimilarity among plant communities at different elevations. The data demonstrate higher dissimilarity at lower adjacent elevation bands. Adjacent elevation categories are bold-faced for emphasis.

Elevation Range	0-999	1000-1499	1500-1999	2000-2499	2500-2999	3000-3499
1000-1499	**0.3766**					
1500-1999	0.4453	**0.2623**				
2000-2499	0.5751	0.3966	**0.2726**			
2500-2999	0.6768	0.5139	0.4130	**0.2705**		
3000-3499	0.7990	0.7015	0.5725	0.3779	**0.1851**	
>=3500	0.8488	0.7403	0.6473	0.5000	0.2481	**0.1124**

In contrast, turnover for the animal groups was lower, varied, and often peaked between adjacent elevations at mid-elevation points (Table 12). Dissimilarity in birds peaked at 3000 m, while herpetofauna peaked at 2500 m. Similar to plants, mammal turnover declined with elevation. In all cases the lowest adjacent elevation class turnover was at 3500m.

Table 12. Community turnover as assessed by the conditional Sørensen's measure of community dissimilarity among vertebrate assemblages at different elevations. The data demonstrate higher dissimilarity at lower adjacent elevation bands. Adjacent elevation categories are bold-faced for emphasis. Rows and columns both represent 500 m elevation bands.

A. Birds	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500
1000-1500	**0.0738**					
1500-2000	0.0823	**0.0940**				
2000-2500	0.0893	0.0805	**0.0823**			
2500-3000	0.1039	0.1477	0.1429	**0.0974**		
3000-3500	0.1554	0.2230	0.1824	0.1419	**0.1216**	
>=3500	0.0814	0.1860	0.1163	0.1047	0.0698	**0.0349**
B. Mammals	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500
1000-1500	**0.2340**					
1500-2000	0.2340	**0.1633**				
2000-2500	0.1702	0.1633	**0.1695**			
2500-3000	0.4255	0.3125	0.0833	**0.1458**		
3000-3500	0.3617	0.3469	0.1154	0.2308	**0.1458**	
>=3500	0.4000	0.2400	0.0400	0.0800	0.0000	**0.0000**
C. Herpetofauna	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500
1000-1500	**0.0417**					
1500-2000	0.0357	**0.0417**				
2000-2500	0.0833	0.1667	**0.0417**			
2500-3000	0.1500	0.2000	0.1000	**0.1000**		
3000-3500	0.1333	0.2667	0.1333	0.1333	**0.0000**	
>=3500	0.2500	0.3750	0.2500	0.2500	0.0000	**0.0000**

Summary of Species Richness and Diversity by Elevation

Our four focal taxonomic groups strongly vary in overall species richness, but do not vary strongly in the pattern of that richness and diversity with elevation. High elevation sites decline in species richness and diversity in all taxonomic groups, however this pattern is strongest among the ectothermic herpetofauna (Figure 14). A specific comparison of species richness is compromised by different rarefaction cutoff points related to sampling intensity. However differences in species richness are large among the groups. Nevertheless, the distribution of this diversity is similar in that each group shows a clear diminution of diversity at the highest elevation. Groups differ, however, in whether peak diversity is at the lowest elevation and steadily decline in diversity (birds and herpetofauna) or peak in diversity at mid-elevation with complex patterns of mid-elevation diversity (plants and mammals) (Figure 15).

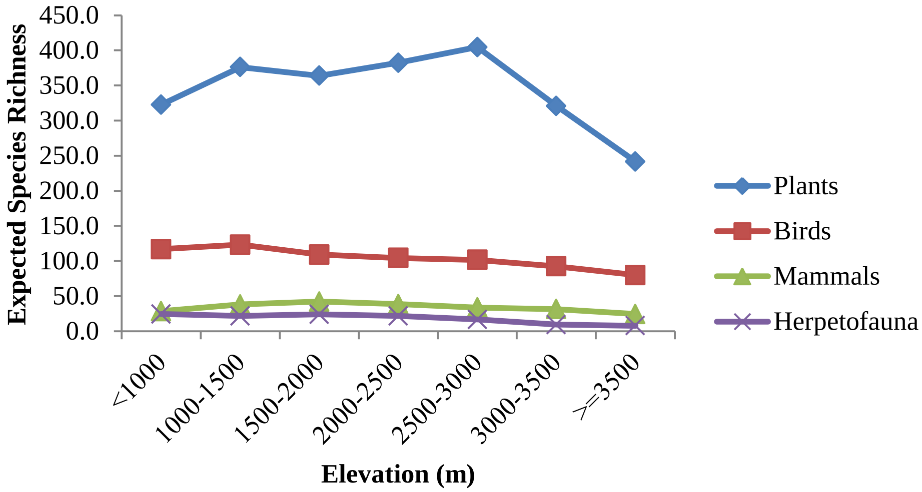


Figure 14. Summary of expected species richness as a result of rarefaction. Rarefaction sample sizes vary among groups, with more species rich groups having larger samples, and larger cut-offs in the rarefied number of observations (plants: n=2000; birds: n = 1000, mammals: n = 500; herpetofauna: n =250). Thus, species richness is not directly comparable. However, the pattern shows consistent reduction of diversity at high elevation and peak diversity varying between the lowest and some mid elevation point.

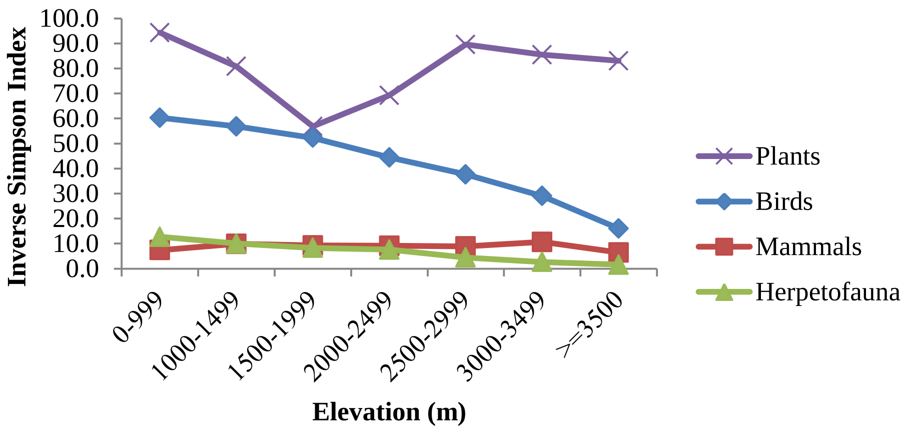


Figure 15. Summary of the inverse of Simpsons Diversity Index across all taxonomic groups assessed across the 500 m elevation bins for Sequoia and Kings Canyon National Parks.

Species Richness and Diversity Assessment by Land Cover Type

We further assess the distribution of diversity by habitat category. The CHW coverage for SEKI contains 26 different land cover types (Table 13) that vary strongly in the amount of area covered within the parks. Rarefaction of each group resulted in some number of communities that are not adequately sampled in order to distinguish species richness. We do not map projected species richness for under-sampled polygons.

Table 13. The amount of CWH land cover type in Sequoia and Kings Canyon National Parks.

Land Cover Type	Area (Hectares)	Percentage of SEKI	Land Cover Type	Area (Hectares)	Percentage of SEKI
Alpine Dwarf Shrub	674	0.2	Perennial Grass	1109	0.3
Annual Grass	206	0.1	Pinyon - Juniper	3097	0.9
Aspen	2492	0.7	Ponderosa Pine	198	0.1
Barren	112262	31.7	Red Fir	19973	5.6
Blue Oak Woodland	662	0.2	Subalpine Conifer	58100	16.4
Chamise Chaparral*	4033	1.1	Giant Sequoia	4613	1.3
Jeffrey Pine	16490	4.7	Sagebrush	6526	1.8
Juniper	8492	2.4	Sierra Mixed Conifer	31151	8.8
Lodgepole Pine	20689	5.8	Urban	30	0
Mixed Chaparral	2861	0.8	Valley Foothill Riparian	138	0
Montane Chaparral	12375	3.5	Water	4718	1.3
Montane Hardwood	21514	6.1	White Fir	5245	1.5
Montane Riparian	8747	2.5	Wet Meadow	8069	2.3

* - the CWH land cover type is Chamise – Redshank Chaparral, but since redshank does not occur within SEKI, we shortened this name to Chamise Chaparral.

We identified observation locations by land cover in order to and assessed diversity measures. Despite small amounts of many land cover types, a strong majority of the park remains assessable, with over 85% of the habitat of the parks assessed for the herpetofauna, the most restrictive group and over 90% of habitat area for the other groups.

Poorly sampled habitats pose a specific problem. We do not know, *a priori*, the degree to which these habitats have few observations as a consequence of lower sampling opportunity (less sampling effort) or because of lower densities of animals to observe, or poor human accessibility with which to observe animals. Given that many of the animal occurrences are from casual observations (rather than systematic surveys), then small sample size may, in fact, be an honest indication of reduced diversity, low animal density, low human access, or all three. To assess this, we examined the relationship between habitat area and the number of observations. If effort, accessibility and density were equivalent, then we would expect there to be a linear relationship between habitat area and the number of observations. For each vertebrate group, there was a near linear relationship between the area of a habitat occupied in the park and the number of observations with two exceptions (Figure 16). Barrens and sub-alpine conifers, the two most abundant cover types, are under-sampled relative to their abundance (Figure 16). The lower number of observations in the two largest cover types (barren and sub-alpine conifer), however, is likely a consequence of these land cover types supporting fewer organisms and fewer taxa, and hence resulting in fewer observations. It should also be noted that "barren" land cover type is used to describe the wide variety of areas including high plateaus of SEKI as well as isolated barren areas at lower elevations, and is therefore, one of the less well-defined habitat classes. This pattern of a linear relationship, with these same two outlying observations, was repeated for birds and herpetofauna (graphs not shown).

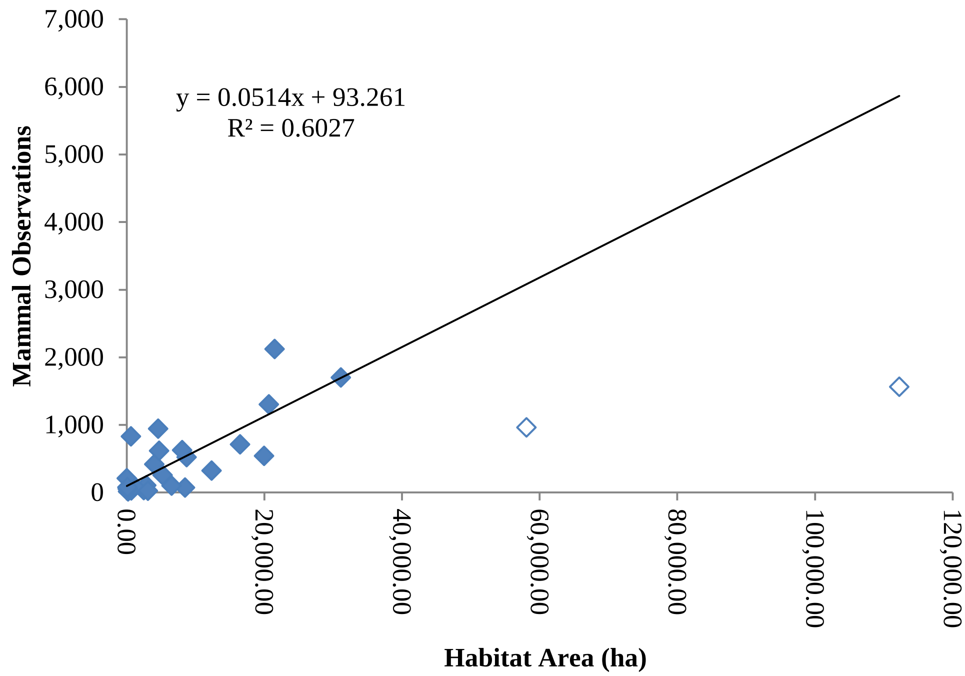
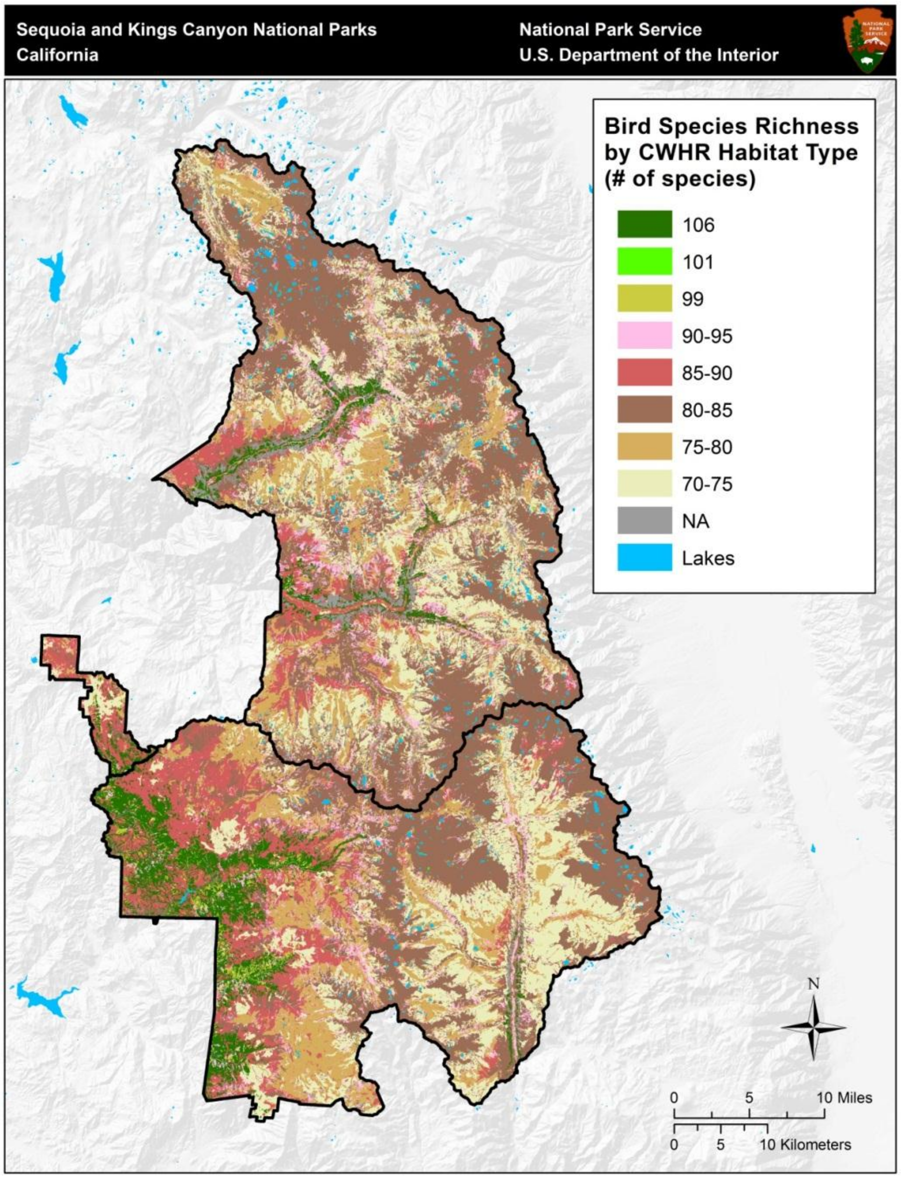


Figure 16. The relationship between the number of mammal observations and land cover type area for Sequoia Kings Canyon National parks. The data show that, other than for the two largest land cover types (barren and sub-alpine conifer, shown in open circles) that there is a linear relationship between habitat area and the number of observations. This indicates a lack of sampling bias by habitat. The same pattern holds for bird and herpetofauna sampling in terms of a linear relationship with barrens and sub-alpine conifer zones being outliers with fewer samples relative to the area than expected.

Together, these observations indicate that area, rather than animal density is likely explaining the observation numbers over most of the landscape. As a result, we are more confident in the diversity estimates within cover types. For brevity, we present the full diversity measures in the appendix, along with figures to support rarefaction cutoff measures, and focus our attention on the data used to create maps of diversity measures.

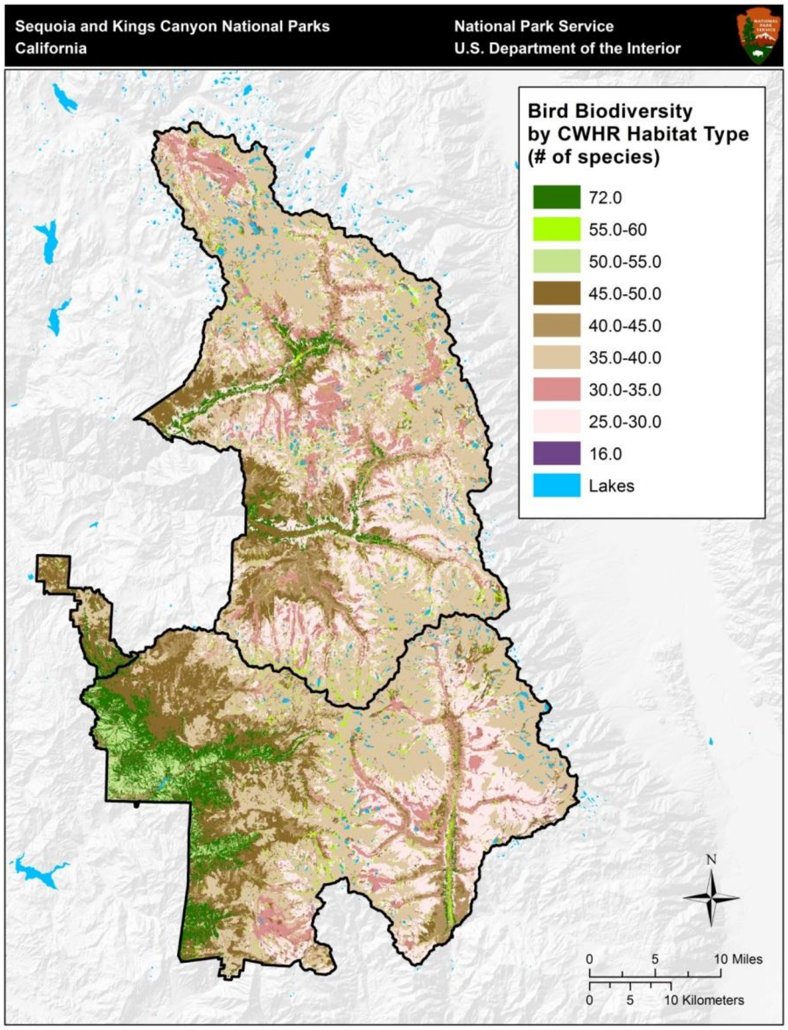
Examining bird species richness by land cover types reveals a more nuanced version of bird diversity than is projected by simple elevation categories (Table 14). Mapping of avifauna richness (Figure 17) and diversity (Figure 18) shows the importance of the major river canyons within the Parks as areas of high bird diversity. The low-lying southwestern region has the highest diversity, and this peak diversity is associated with montane hardwoods, montane riparian habitats and water. This does not, however, completely align with where the largest number of bird species has been observed. The largest number of bird species observed is in the montane hardwood habitat (n = 167, 62,104 observations). The Sierra Mixed Conifer and Barren habitats are the next two highest sites with respect to the number of species observed. These habitats, however, have been very highly sampled (8886 and 4623 observations, respectively) and this is far higher than some other species rich habitats (e.g., montane riparian: 2544 observations). Mapping the species richness patterns (Figure 17), generally reinforces the patterns observed by elevation and highlights the low lying areas as important for bird diversity. The map of diversity by habitat (Figure 18), however, visually reinforces the role of the distinct river drainages of SEKI to create isolated zones of high bird species richness and diversity.



Figures 17. Projected species richness of birds for CWH land cover types of Sequoia and Kings Canyon National Park based on a rarefaction of bird observations with a sample size of 400 observations per habitat.

Table 14. Bird diversity measures for Sequoia and Kings Canyon National Parks by CWH land cover type. Projected species richness is based on rarefaction. Species observed is the total number of species sampled in that habitat type, along with the number of observations. Chao is a method of calculating estimated species richness, and a standard error around that species richness. Simpson is a diversity measure that includes species number as well as a weighting based on the distribution of abundance, where more even distributions increase diversity. NA = not available, insufficient data.

Cover type	Projected species richness n=400 (s.e.)	Species Observed (number of obs.)	Chao Projected species (s.e.)	1/Simpson*
Alpine Dwarf Shrub	NA	36 (89)	46.9 (8.4)	16.2
Annual Grass	NA	73 (220)	91.5 (10.2)	43.4
Aspen	NA	56 (221)	64 (6)	26.0
Barren	84.7 (4.1)	154 (4623)	205.7 (31.2)	37.3
Blue Oak Woodland	84.4 (3.9)	136 (2890)	159.2 (13.5)	45.2
Chamise - Chaparral	87.1 (3.2)	110 (1244)	129 (13.3)	52.2
Jeffrey Pine	82.6 (3.7)	129 (3739)	139 (7.6)	42.1
Juniper	74.3 (0.8)	75 (413)	91.5 (10.4)	30.7
Lodgepole Pine	75.6 (3.6)	130 (4280)	144.9 (9)	32.2
Mixed Chaparral	98.8 (2.0)	104 (486)	117.6 (7.8)	52.9
Montane Chaparral	90.6 (3.6)	124 (1756)	136.2 (8.3)	49.5
Montane Hardwood	106.0 (3.9)	167 (6104)	182.4 (9.6)	71.9
Montane Riparian	94.2 (3.7)	138 (2544)	157.5 (12.1)	57.3
Perennial Grass	92.4 (3.0)	108 (755)	138 (19)	56.4
Pinyon - Juniper	NA	43 (84)	70.3 (16.9)	25.0
Ponderosa Pine	72.9 (2.2)	80 (659)	85.5 (5)	47.5
Red Fir	80.0 (3.7)	123 (2536)	142.3 (12.4)	37.0
Subalpine Conifer	70.1 (3.7)	124 (4275)	140.5 (10.4)	25.9
Giant Sequoia	73.8 (3.5)	121 (4070)	132.3 (8.3)	38.5
Sagebrush	77.5 (2.9)	92 (749)	119.6 (17.8)	37.9
Sierra Mixed Conifer	86.3 (3.8)	156 (8886)	183.6 (17.8)	47.5
Urban	76.8 (3.4)	113 (2322)	132 (13.3)	42.9
Valley Foothill Riparian	NA	62 (222)	95.3 (21.8)	28.3
Water	100.9 (4.0)	139 (1279)	160 (11.4)	48.2
White Fir	77.7 (3.5)	108 (1230)	135 (15.2)	37.9
Wet Meadow	89.4 (3.6)	129 (2575)	138.1 (6.6)	47.9



Figures 18. Species diversity of birds for CWH land cover types of Sequoia and Kings Canyon National Park based on the inverted Simpson's diversity index based on all bird observations per habitat. The Simpson diversity index weights both the number of observations per habitat as well as the distribution of abundance.

Mammal species richness and diversity patterns by land cover type presents some of the most challenging data to interpret (Table 15, Figure 19,20). Species numbers are moderately consistent with land cover projected to contain between 20 and 38 species in adequately sampled habitats.

Depicting the distribution of species richness (Figure 19) and diversity (Figure 20) maps of the Park show a complex and somewhat non-congruous pattern of peak species richness at mid-elevation and peak Simpson's diversity measures at even higher elevation types. It is unclear how much of these patterns may be driven by specific studies to understand bat and small mammal distributions at higher elevations.

Table 15. Mammal diversity measures for Sequoia Kings Canyon National Parks by CWHR habitat category. Projected species richness is based on rarefaction. Species observed is the total number of species sampled in that habitat zone, along with the number of observations. Chao is a method of calculating estimated species richness, and a standard error around that species richness. Simpson is a diversity measure, (inverse Simpson's shown) that balances species richness with the distribution of abundance, where more even distributions increase diversity. NA = not available by lack of data.

Cover Type	Projected species richness n = 250	Species Observed (number of obs.)	Chao Projected species (s.e.)	1/Simpson*
Alpine Dwarf Shrub	NA	12 (29)	17 (17.1)	9.0
Annual Grass	NA	8 (16)	9 (3.4)	6.7
Aspen	NA	10 (32)	16 (NA)	6.3
Barren	28.2	50 (1563)	74 (23.3)	9.9
Blue Oak Woodland	20.2	29 (826)	34.6 (7.5)	7.0
Chamise Chaparral	19.9	24 (418)	69 (NA)	6.6
Jeffrey Pine	28.9	42 (708)	118.5 (179.5)	10.6
Juniper	NA	17 (70)	22.3 (8.3)	6.9
Lodgepole Pine	29.6	47 (1303)	53.1 (6)	10.5
Mixed Chaparral	NA	21 (102)	25.7 (5.9)	7.8
Montane Chaparral	28.7	31 (324)	38.2 (9)	6.9
Montane Hardwood	28.3	55 (2120)	66.1 (10.4)	9.2
Montane Riparian	38.3	48 (522)	54.6 (6)	10.0
Perennial Grass	NA	23 (96)	26 (4)	11.9
Pinyon - Juniper	NA	8 (25)	11.3 (7.6)	2.3
Ponderosa Pine	NA	18 (54)	22.2 (6.1)	10.1
Red Fir	28.8	36 (540)	39.5 (4.2)	8.4
Subalpine Conifer	23.8	38 (961)	51 (12.7)	10.6
Giant Sequoia	33.0	49 (941)	55.9 (6.8)	7.1
Sagebrush	NA	20 (101)	29.3 (16.5)	8.6
Sierra Mixed Conifer	33.6	56 (1701)	62.9 (6.8)	9.6
Urban	NA	22 (210)	27 (17.1)	8.0
Valley Foothill Riparian	NA	13 (76)	18 (10.2)	3.2
Water	32.5	45 (613)	56.7 (9.6)	12.0
White Fir	27.9	28 (254)	35 (13.2)	7.9
Wet Meadow	27.2	36 (626)	47 (12.5)	8.9

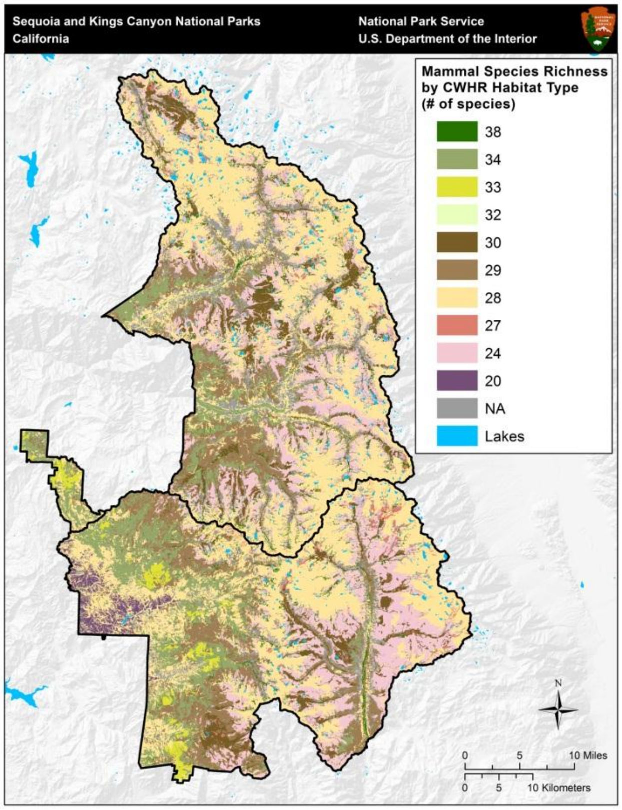


Figure 19. Projected species richness of mammal for CWH land cover types of Sequoia and Kings Canyon National Park based on a rarefaction of mammal observations with a sample size of 250 observations per habitat.

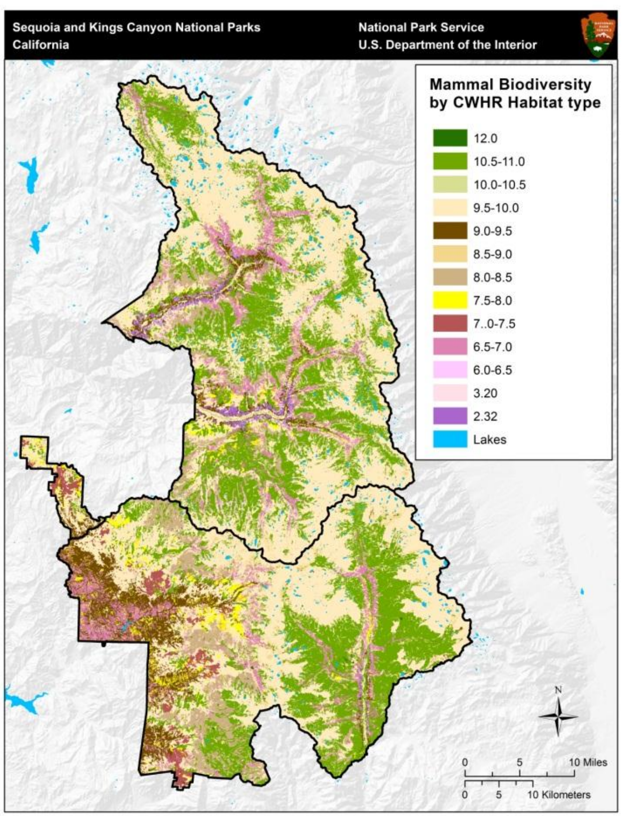


Figure. 20. Mammal diversity for CWH land cover types of Sequoia and Kings Canyon National Park based on the inverted Simpson's diversity index, based on all observations per habitat. The Simpson diversity index weights both the number of observations per habitat as well as the distribution of abundance. Higher numbers indicate higher diversity.

Mapping of species richness (estimated at a sample size of 100 observations) and Simpson's diversity shows remarkable spatial concordance in the herpetofauna (Table 16, Figure 21,22). Lower habitats are strongly more diverse (Figure 22) and have higher species richness (Figure 21) than those habitats at higher elevation. These patterns reinforce the depiction of a gradient of decreasing diversity from low to high elevation, with the riparian areas of the major river drainages being very important. Somewhat intermediate between birds and mammals, the herpetofauna appear to have high diversity in the low lying habitats, but also the mid-elevation zones that connect these major watersheds within the parks (Figure 21,22).

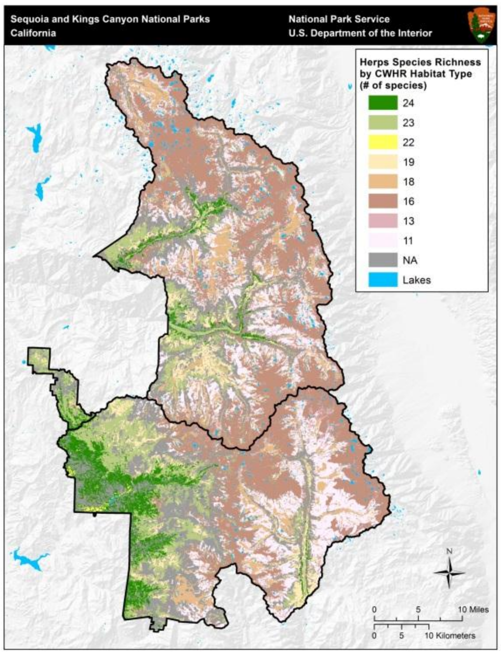


Figure 21. Projected species richness of herpetofauna for CWH land cover types of Sequoia and Kings Canyon National Park based on a rarefaction of reptile and amphibian observations with a sample size of 100 observations per habitat.

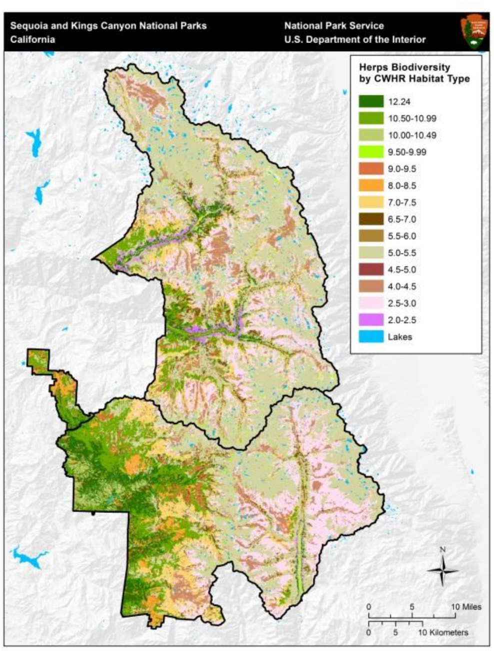


Figure 22. Herpetofauna diversity for CWH land cover types of Sequoia and Kings Canyon National Park based on the inverted Simpson's diversity index based on all observations per habitat. The Simpson diversity index weights both the number of observations per habitat as well as the distribution of abundance.

Table 16. Herpetofauna diversity measures for Sequoia Kings Canyon National Parks by CWHR cover type. Projected species richness is based on rarefaction (n = 100). Species observed is the total number of species sampled in that habitat zone, along with the number of observations. Chao is a method of calculating estimated species richness, and a standard error around that species richness. Simpson's diversity index is a measure (inverse Simpson's shown) that balances species richness with the distribution of abundance, where more even distributions increase diversity. NA = Not available, insufficient data.

Cover Type	Projected species richness n = 100	Species Observed (number of obs.)	Chao Projected species (s.e.)	1/Simpson*
Alpine Dwarf Shrub	NA	3 (4)	3.5 (3.7)	2.7
Annual Grass	NA	7 (8)	14.5 (23.6)	6.4
Aspen	NA	8 (14)	8.6 (1.8)	7.0
Barren	13.8	20 (513)	22 (5.3)	5.1
Blue Oak Woodland	18.9	24 (289)	26 (5.3)	10.8
Chamise Chaparral	18.9	20 (121)	25 (10.2)	10.1
Jeffrey Pine	17.0	20 (238)	21 (3.4)	5.3
Juniper	NA	8 (26)	8.5 (3.7)	5.2
Lodgepole Pine	13.6	18 (282)	18.8 (2.3)	4.2
Mixed Chaparral	NA	18 (55)	21 (4)	8.1
Montane Chaparral	18.9	19 (102)	22.3 (7.6)	7.0
Montane Hardwood	20.4	29 (786)	35 (NA)	12.2
Montane Riparian	19.4	24 (264)	25.5 (3.5)	9.7
Perennial Grass	NA	10 (12)	46 (NA)	8.0
Pinyon - Juniper	NA	6 (25)	6.3 (1.9)	2.3
Ponderosa Pine	NA	9 (18)	11.5 (4.9)	4.9
Red Fir	NA	16 (87)	19.3 (7.6)	7.3
Subalpine Conifer	8.2	13 (266)	23.5 (31.1)	3.0
Giant Sequoia	18.4	19 (110)	22.8 (6.5)	8.4
Sagebrush	NA	7 (31)	7 (1.3)	4.4
Sierra Mixed Conifer	20.2	25 (411)	26 (3.4)	10.9
Urban	NA	8 (13)	8.5 (1.5)	7.3
Valley Foothill Riparian	NA	11 (19)	20.3 (16.5)	5.6
Water	8.2	23 (1314)	27.2 (6.1)	2.8
White Fir	NA	15 (56)	22.5 (23.6)	9.4
Wet Meadow	9.7	18 (542)	19 (2.2)	2.9

The sample size for plants is very large. As a consequence, we have a greater capacity to assess species richness, and for a broader array of land cover types than other groups (Table 17). Species richness and diversity is also higher than for the other taxonomic groups (Table 17). The analysis of species richness by elevation demonstrated that mid-slope elevations were the most specious with respect to plants. The CWHR land cover analysis identifies this as moderately a complex pattern. Montane riparian is identified as a very diverse habitat, but giant sequoia forest as a fairly low diversity type. At high elevation, sub-alpine mixed conifer and alpine dwarf shrub span the low to high end of the species richness spectrum. The result is a very heterogeneous map of diversity both with respect to species richness (Figure 23) and diversity (Figure 24).

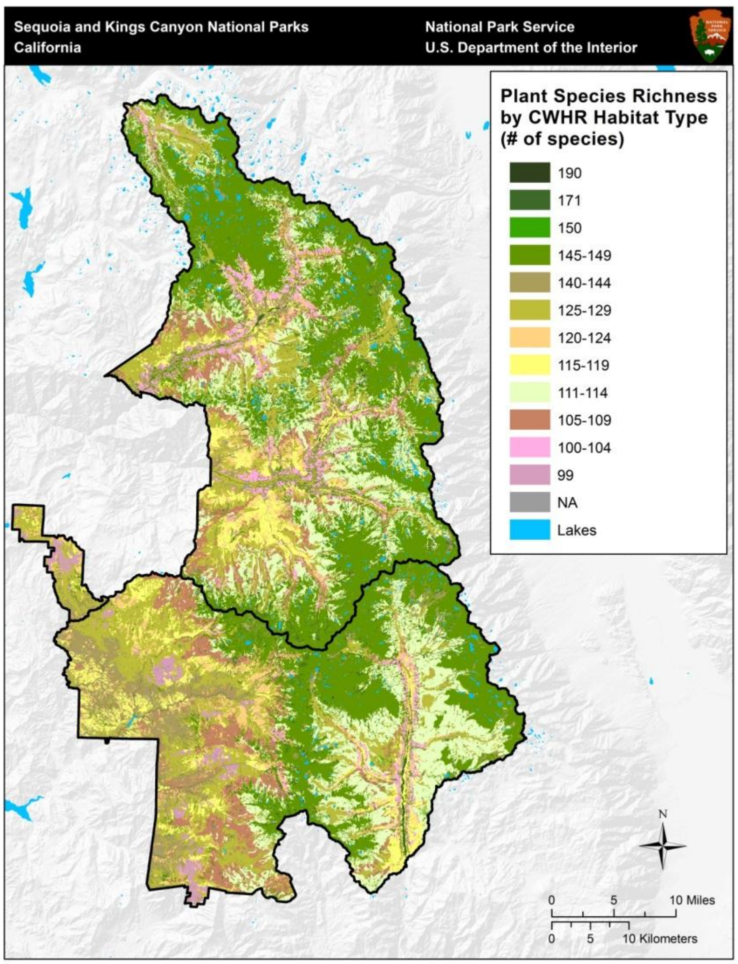


Figure 23. Projected species richness of plants for CWH land cover types of Sequoia and Kings Canyon National Park based on a rarefaction of plant observations with a sample size of 250 observations per habitat.

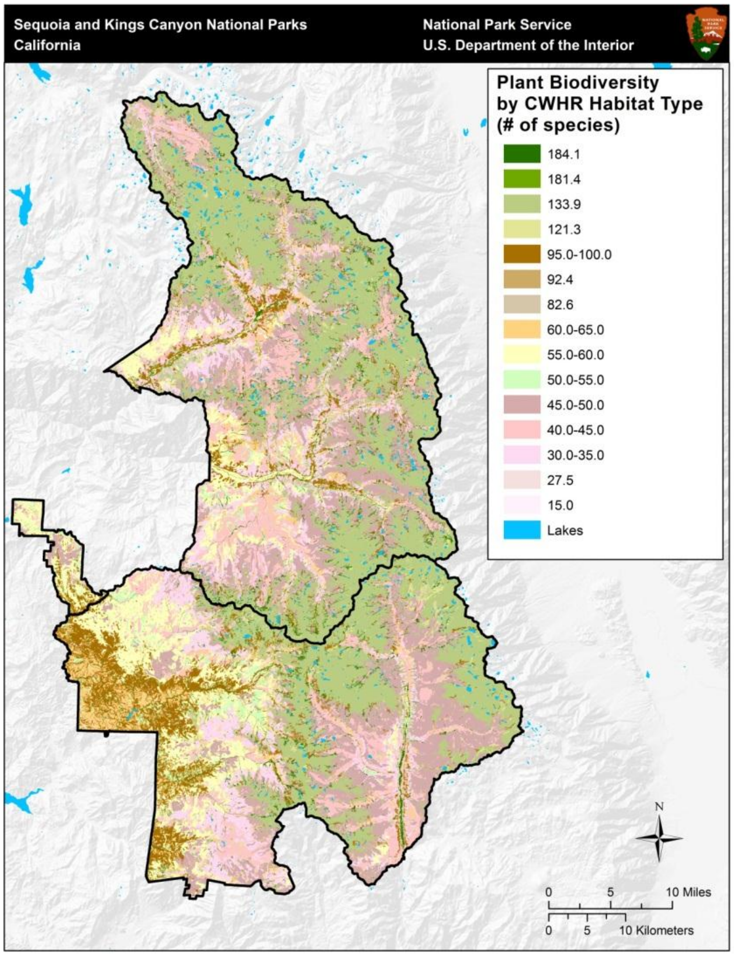


Figure 24. Plant diversity for CWH land cover types of Sequoia and Kings Canyon National Park based on the inverted Simpson's diversity index based on all observations per habitat. The Simpson diversity index weights both the number of observations per habitat as well as the distribution of abundance.

Table 17. Plant diversity measures for Sequoia and Kings Canyon National Parks by CWHR cover type. Projected species richness is based on rarefaction (n = 275). Species observed is the total number of species sampled in that habitat zone, along with the number of observations. Chao is a method of calculating estimated species richness, and a standard error around that species richness. Simpson is a diversity measure, (inverse Simpson's shown) that balances species richness with the distribution of abundance, where more even distributions increase diversity. NA = Not available, insufficient data.

Cover Type	Projected species richness n = 275	Total observed species (n obs)	projected total (chao1)	1/ Simpson*
Alpine Dwarf Shrub	152.8	172 (335)	362.8 (57.5)	104.0
Annual Grass	NA	37 (54)	77.6 (27.2)	27.5
Aspen	115.2	142 (381)	382.9 (86)	35.5
Barren	154.7	617 (5639)	782.8 (32.3)	143.6
Blue Oak Woodland	128.6	186 (578)	271.2 (26)	62.7
Chamise Chaparral	119.8	202 (931)	267.3 (21.5)	65.6
Jeffrey Pine	122.5	439 (3179)	655.9 (45.1)	42.5
Juniper	112.5	241 (992)	474.7 (60.4)	36.8
Lodgepole Pine	132.5	496 (4523)	696.0 (43.3)	43.8
Mixed Chaparral	111.6	205 (846)	347.0 (39.9)	54.8
Montane Chaparral	128.6	405 (2630)	625.0 (47.5)	66.1
Montane Hardwood	145.4	577 (4890)	739.7 (32.4)	97.3
Montane Riparian	176.5	579 (3032)	768.3 (36.2)	195.7
Perennial Grass	157.8	229 (480)	500.4 (67.1)	89.2
Pinyon - Juniper	106.0	106 (275)	170.6 (25.0)	34.3
Ponderosa Pine	NA	26 (54)	44.2 (18.6)	15.5
Red Fir	115.1	351 (2319)	471.1 (28.1)	39.8
Subalpine Conifer	117.8	451 (5063)	621.0 (38.3)	47.7
Giant Sequoia	101.6	273 (2660)	398.1 (35.7)	45.6
Sagebrush	157.3	327 (1061)	466.0 (31.8)	114.4
Sierra Mixed Conifer	130.8	605 (7167)	811.4 (40.6)	58.4
Urban	NA	53 (60)	182.4 (73.5)	48.6
Valley Foothill Riparian	NA	62 (109)	104.0 (20.9)	44.2
Water	194.1	274 (456)	541.1 (57.6)	186.0
White Fir	129.7	268 (1088)	435.7 (43.0)	54.3
Wet Meadow	145.9	514 (5594)	695.9 (40.4)	129.5

Spatial Assessment of Overall Biodiversity

Biodiversity attributes across taxa and land cover types were then aggregated to gain an overarching view of the distribution of biological diversity in SEKI (Table 18, Figure 25). To construct this synthetic assessment, we first aggregated four measures of biodiversity for each taxonomic group. We ranked the biodiversity of the 26 CWH land cover designations using (1) predicted species richness, (2) total species observed, (3) the Chao estimation of species richness and (4) the inverse of Simpson's diversity index. An average land cover type rank was calculated using the rank of each land cover type summed across these four biodiversity measures. We then averaged the ranks of cover types across the four taxonomic groups (birds, mammals, herpetofauna and plants) to gain an overarching rank for each of the 26 habitat types. We then divided these ranked habitat values into five classes and mapped these (Figure 25).

Low elevation habitats score high on most measures of biodiversity, with mid-elevations coming close behind (Figure 25). The river canyons combine land cover types that score high for biodiversity (Montane Riparian), along with those that are poorly sampled and received low scores (e.g., Aspen). Nevertheless, the overarching spatial depiction reinforces the taxon specific maps as a consequence of similarity among the cover types that score high for biodiversity. The average correlation in ranks among taxa is high (ave = 0.70, max = 0.82 (birds x herpetofauna); min = 0.47 (herpetofauna by plants)).

Table 18. The rank average biodiversity rank of CWH land cover classes ordered from highest (most diverse) to lowest. Biodiversity averages were calculated as an average of the ranks across birds, mammals, herpetofauna and plants for four measures of biodiversity (predicted species richness, Chao estimate of species richness, total number of species observed, and Simpson's diversity index).

Cover type	Average Biodiversity Rank	Cover type	Average Biodiversity Rank
Montane Hardwood	3.69	Subalpine Conifer	12.81
Montane Riparian	3.96	Red Fir	13.17
Sierra Mixed Conifer	4.63	White Fir	13.21
Water	6.56	Mixed Chaparral	14.98
Barren	7.00	Sagebrush	15.98
Jeffrey Pine	9.69	Urban	17.38
Perennial Grass	9.90	Juniper	19.58
Montane Chaparral	10.25	Ponderosa Pine	19.63
Wet Meadow	10.31	Valley Foothill Riparian	20.50
Blue Oak Woodland	10.75	Alpine Dwarf Shrub	20.79
Lodgepole Pine	10.94	Aspen	21.29
Chamise - Redshank Chaparral	11.69	Annual Grass	21.67
Giant Sequoia	12.06	Pinyon - Juniper	24.54

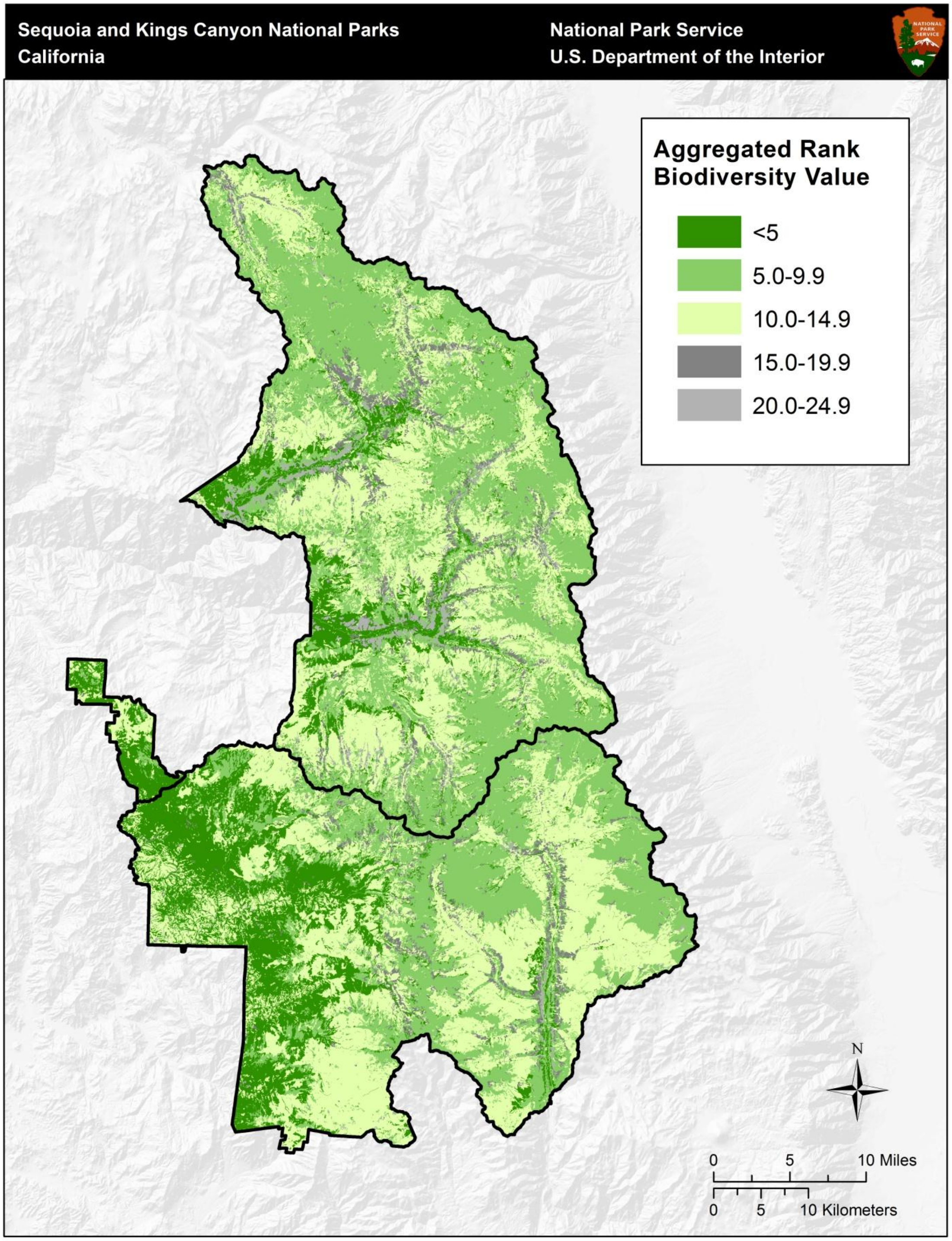


Figure 25. The distribution of biodiversity within Sequoia and Kings Canyon National Parks as depicted by aggregated CWHR rank habitat value among birds, mammals, herpetofauna and plants using total species observed, rarefaction estimates of species richness, Chao1 diversity estimations and the Simpson diversity index. High ranks (low numbers) represent high diversity regions.

Assessing the Elevation Distribution of Indicator Plant Species

We used the SEKI vegetation map to document reference conditions for vascular plants in terms of their elevation distribution. Vegetation polygons are identified by either small suite of dominant or a characteristic indicator species for each association **(**e.g., mountain misery (*Chamaebatia foliosa*) dwarf shrubland **).** Seventy indicator / dominant plant species are named in the vegetation map. The naming of a particular polygon is indicative of the presence of that species, but does not require that each taxa be found in each instance of that association. By taking the mean elevation of each polygon in which each species is named, an elevation distribution for each species, as documented by the map, can be developed. We calculated the mean elevation distribution for these species, the standard deviation, and minimum and maximum elevation records (Figure 26). These elevations can be interpreted as reference elevations for these 70 species with respect to expected future elevation range shifts that may be induced by climate change within the park. These taxa all have described elevation breadths through taxonomic treatments (e.g., the Jepson Manual; Hickman 1993), but those elevation breadths span the entire range of taxa, whereas the vegetation map, with polygons linked to specific vegetation types spanning a parks-specific elevation range, allows a description of elevation range that is highly tuned to the Parks.

(a)

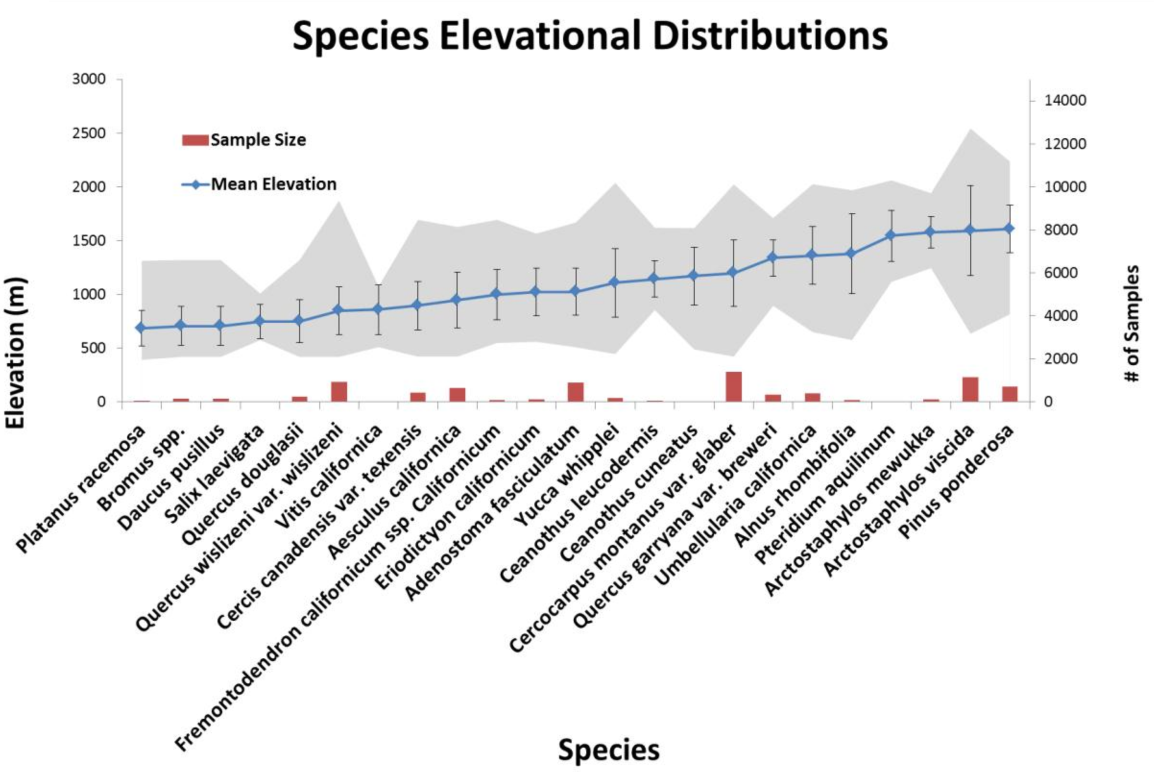
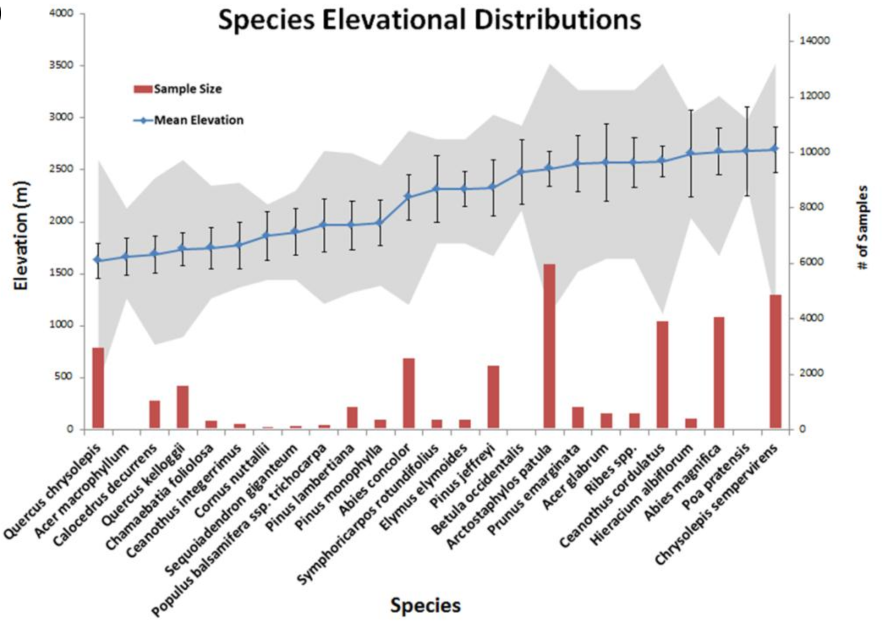


Figure 26. Elevation distribution of dominant and indicator species in SEKI as derived from the Parks' vegetation map. Mean elevation (blue dots), standard deviation (bars), maximum and minimum elevation records (gray shade) by elevation, where (a) low elevation species.

(b)



(c)

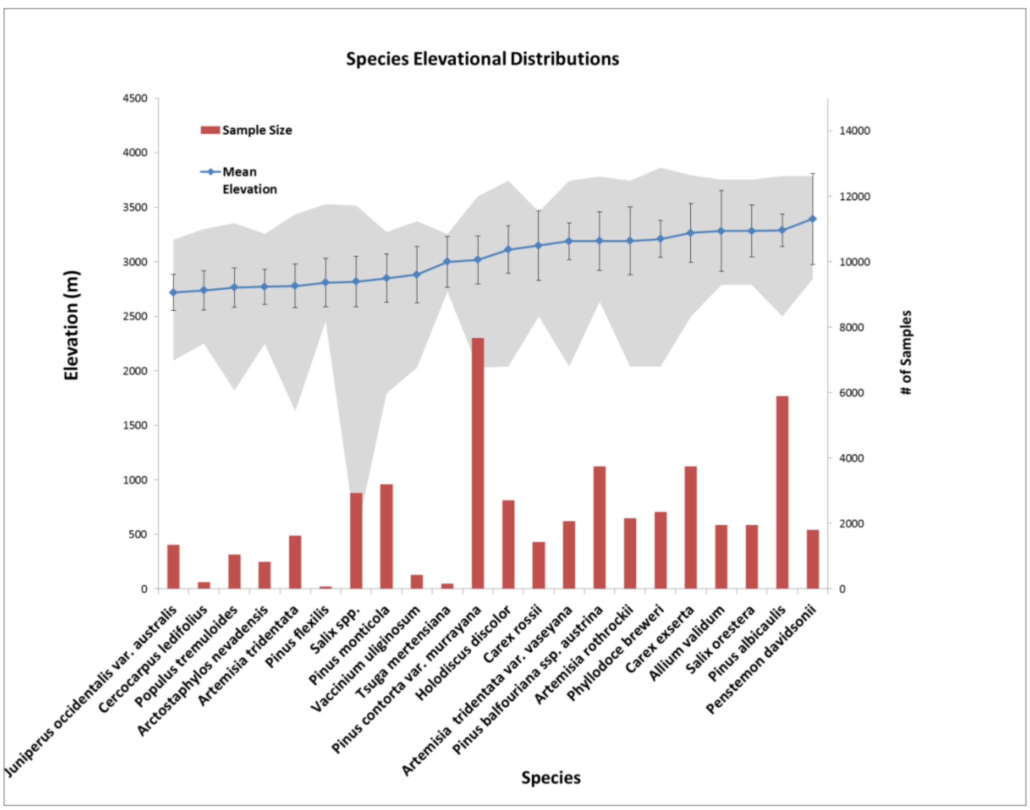


Figure 26 (continued). Elevation distribution of dominant and indicator species in SEKI as derived from the Parks' vegetation map. Mean elevation (blue dots), standard deviation (bars), maximum and minimum elevation records (gray shade) by elevation, where (b) middle, and (c) high elevation species.

Assessing Data Needs

Spatial analyses of diversity are best performed on data that are collected with an experimental design in mind. Thus, an ideal data set would strive for observations that are sampled in relative proportion to the abundance of habitats, and randomly located within these elevation bands or habitat types. These data are exceedingly expensive to obtain and not realistically achieved in the near term. Nevertheless, there is a need to assess patterns in biodiversity. Simple measures that can be considered are to examine spatial patterns and strive to increase under-sampled locations. Where possible, estimates of density of vertebrates on the landscape may help disentangle issues of sampling intensity and animal density with respect to sampling species richness. Finally, mammals pose a particularly challenging group to assess, given strong differences in the capacity to observe individuals. Systematic surveys of small mammals are required in order to assess mammal species richness and abundance. These systematic surveys will need to consider how to reduce observation bias linked to body size.

Temporal Analysis

What is the Evidence for Trends in Biodiversity

The species observation data, albeit substantial, have a limited capacity to evaluate temporal trends. Wildlife observation data increase substantially in numbers of observations in the late 1970s or later. Wildlife observations and vegetation plot data are populated with information gathered on studies in a particular region for a particular purpose, creating time frames when the species composition of data entries is particularly unrepresentative. As a consequence, there may be many observations of a particular sort during a particular period of time that are not replicated before or afterward. Thus, the overall data can then provide a false sense of change. Given that large caveat, we examined what the observation data show in order to analyze what may be trends in diversity through time. To do this we classified observations into decadal sets of observations for the 1980s onward, and in one large bin for observations prior to 1980. We also classified observations by 500 m elevation band in order to sample similar faunal communities. We restricted this analysis to birds, mammals and herpetofauna. Plant data are particularly clustered in time and particularly linked to specific projects. As such, individual studies, such as the revisiting of Vankat plots, or remote sensing assessments of changes in community dominance are likely more powerful measures of plant composition change

We divided Wildlife Observations into three or four groups. There are an abundance of data from each of the 1980s, 1990s, and 2000s. Some taxa also allowed assessment of species richness prior to 1980. Birds, for example, are a high diversity group with few observations prior to 1980, leading us to a very poor capacity to assess diversity within elevation bins. We adopted the strategy to assess species richness using rarefaction and with the same minimum sample size cut-offs as used in the habitat assessments. We then plotted predicted species richness (and the standard error of this estimate) by elevation zone for each decade (Figure 27).

Bird species richness show a signal of declining species richness at low, but not high elevations (Figure 27a). We do not have an assessment of species richness in the 1000-1500 m band for the 2000's as a consequence of too few samples, but the number of species observed at these elevations in the 1980s were significantly higher than during later periods. Species richness estimated above 1500 m did not demonstrate this decline through time. This analysis, of course, embeds issues with temporal patterns of individual observers. If specific individuals contribute large portions of data to the data set over a specific period of time, then any experimental design associated with individual studies (e.g., surveying foothill birds) can bias temporal analyses.

Mammal observations, likewise, depict a complex relationship. Pre-1980 observation data are very species rich relative to other categories. Similar to birds, we suspect that much of this complexity may be an artifact of specific studies aimed at describing park diversity during different periods that resulted in high species richness assessments that have not been fully replicated in all subsequent decades. Even discounting the pre-1980 data, however, we observe declining species richness at low elevations, similar to the birds (Figure 27b). Also similar to the bird data, this decline in observed species richness through time is not apparent above 1500 m.

The herpetofauna do not show strong patterns with respect to species richness change through time (Figure 27c). In this case, we excluded the Knapp data (high elevation surveys from the

2000's) from this particular assessment, however, because this study is specifically designed to sample particular habitats, and is thus less representative.

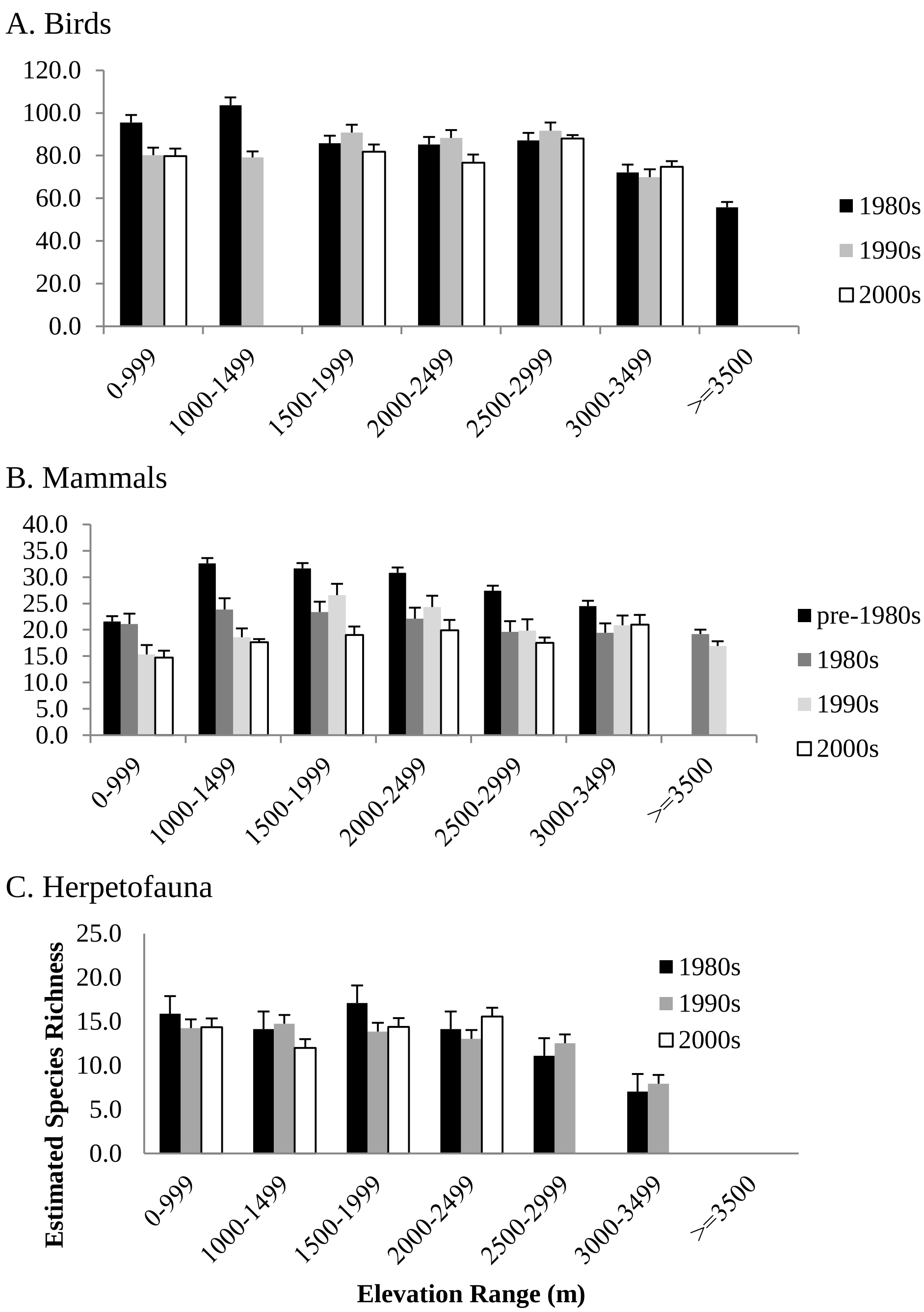


Figure 27. Estimated change in species richness of (A) birds, (B) mammals; and (C) herpetofauna through time (by decade) across elevation. Rarefaction was run to estimate species richness in each decade. Elevation bins lacking bars are a consequence of an inadequate number of observations at that elevation during that decade to make a species richness estimate. Rarefaction cut-off values were the same as those used to assess habitats.

We also assessed temporal trends in diversity using the inverse of Simpson's diversity index (Figure 28). Again, we divided observations by elevation category and by decade. In this case, we plot each diversity assessment by time for each elevation band. Given that diversity is simply based on the number of observations within time periods and elevation groups, all measures can be calculated. However, the pre-1980 estimates for some groups are based on sparse data.

Bird diversity, as with species richness, declines from the 1980s to the 1990s and 2000s at the low elevations (< 1500 m) (Figure 28A). Unlike species richness, diversity also appears to decline slightly at mid-elevations (1500 – 3000m) through the time periods. High elevation bins show no indication of changing diversity.

Mammal diversity exhibits a strong pattern of apparent decline in diversity at all elevations from throughout the period assessed (Figure 28B). While these declines may be real, there also may be special circumstances to suggest that the pattern is at least partly an artifact. Since Simpson's diversity index weights both species richness, depicted in Figure 27B, and evenness, we interpret the declines in diversity to be a function of evenness of observations in the dataset. This could happen for three reasons. First, if early mammal assessments focused more on collections than more recent observations, then we would expect observations to be more balanced across the array of observed taxa. Second, if haphazard observations are tied to people in the park, and there are more people in the park, then the highly observable species (black bear, mule deer, coyote, etc) should become apparently more common through time. Third, if programs for managing certain species, such as bear, begin to contribute observations to the database, we would expect a bias in the reporting of those species to occur in concordance with those programs. With a stronger dominance of data records among the more visible taxa, evenness should decline, and with it, diversity.

A. Birds

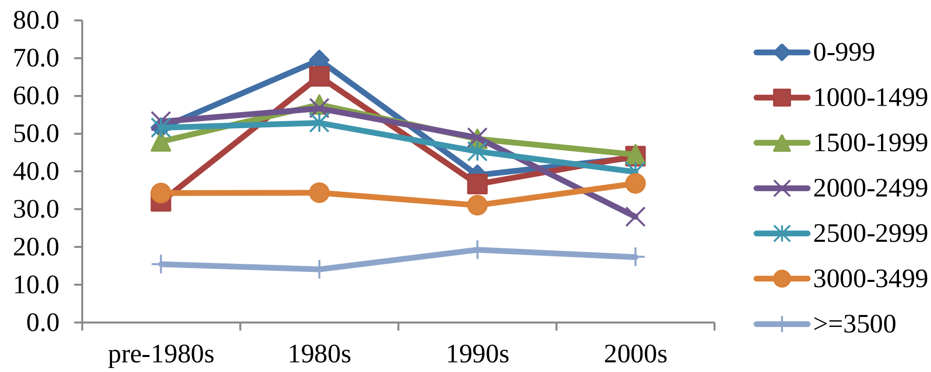
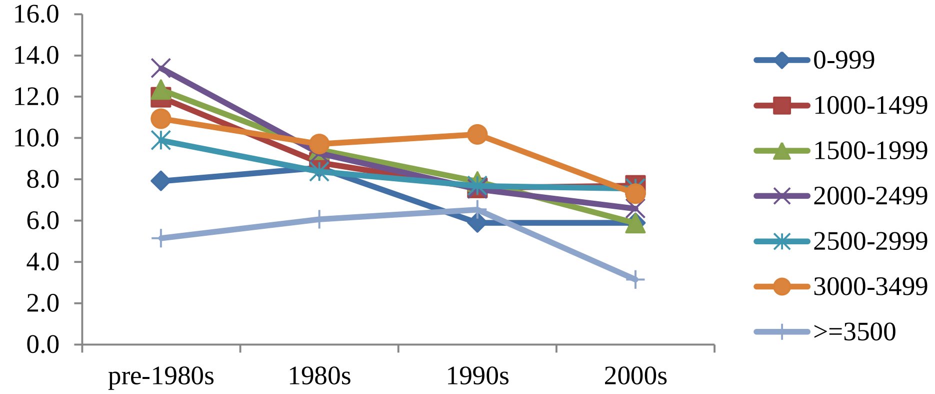


Figure 28. Simpson's diversity for (A) birds.

B. Mammals



C. Herpetofauna

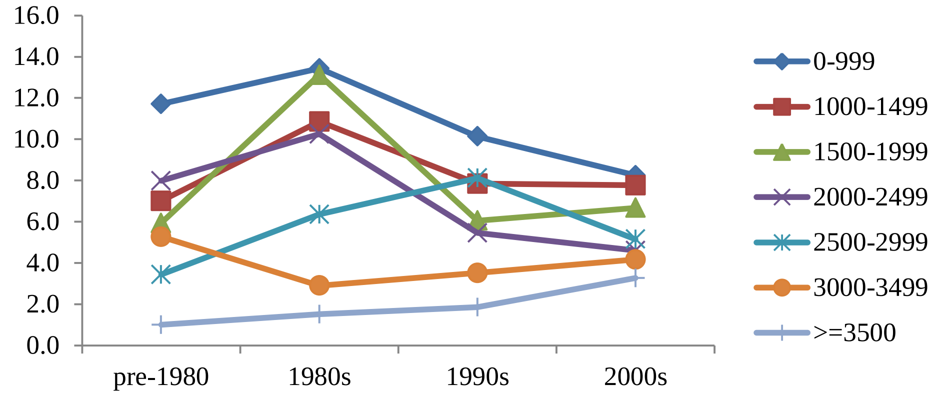


Figure 28 (continued). Simpson's diversity for (B) mammals; and (C) herpetofauna through time, assessed in 500 m elevation bins.

Temporal trends in animal assessments can also be informative with respect to the time frame across which species have been observed, and temporal trends in the abundances of individual taxa. The assessment completed for this report is selective and representative and not comprehensive. For mammals, for example, we find several species observed early in the time frame and then not subsequently re-observed (Table 19). Most of these mammals were infrequently (1-3 times) observed when observed at all. Some rarely viewed taxa (river otter (*Lutra canadensis*), muskrat (*Ondatra zibethicus*)) are most likely mistaken observations and likely to have never occurred within the Parks. Many observations of difficult to find taxa appear to come in time clusters (e.g., 1986-89), suggesting focal studies. Nevertheless, if one expects observations to be a stochastic process, then we expect these species represented by single observations to be distributed throughout the time series, and they are not. The majority of mammals in the Parks, for example, require researchers to specifically look for and identify them in order to be observed. Hence, temporal trends in infrequently observed mammals is likely a stronger reflection of observer effort than population change. There is a single taxon (western mastiff bat, *Eumops perotis*) observed in the database over the most recent 20 years with no previous observations, whereas we have 13 taxa that are observed prior to 1990, but not since. Nevertheless, we still can not distinguish this as a trend in diversity as opposed to the timing of specific studies targeted at finding this harder to identify small mammals.

In terms of species losses, the only mammal that has been confirmed as extirpated in the Parks is the brown bear (*Ursus arctos*). Other rarely viewed taxa remain suspect as having been extirpated wolverine (*Gulo gulo*), and wapiti (*Cervus elaphus*). Some rarely viewed taxa are questioned in terms of the veracity of their observations and they are likely to have never occurred within the Parks (river otter (*Lutra canadensis*), muskrat (*Ondatra zibethicus*), gray wolf (*Canis lupus*)).

Table 19. Mammals not found in the Wildlife Observation Database since 1990.*

Common Name	Latin Name	# obs	last observed
A. Mammals not recently observed in the Wildlife Observation database			
Allen's chipmunk	*Tamias umbrinus*	1	1916
Brown Bear**	*Ursos arctos*	6	1924
River otter	*Lontra canadensis*	3	1941
Pinyon mouse	*Peromyscus truei*	3	1942
Muskrat	*Ondatra zibethicus*	2	1962
Hoary bat	*Lasiurus cinerus*	1	1973
Wapiti**	*Cervus elaphus*	2	1978
California mouse	*Peromyscus californicus*	1	1979
B. Taxa observed in the 1980's, but not since			
Silver-haired bat	*Lasionycteris noctivagans*	1	1981
Ornate shrew	*Sorex ornatus*	4	1986
Western harvest mouse	*Reithrodontomys megalotis*	3	1988
Vagrant shrew	*Sorex vagrans*	2	1988
Montane shrew	*Sorex monticolus*	10	1989

* 1 species, the Western mastiff bat, *Eumops perotis*, 1 observation in 1995.

** considered extirpated

Bird data do not exhibit a similar pattern (Table 20). There is a strong correlation ($r^2 = 0.84$) among the ranked abundance of birds in the first and second half of the observation time series, suggesting a stability of the bird community. There are 37 birds that appear only on one side of the middle of the dates of observations (1985) or the other. The 28 taxa that only appear in the latter half of the record are mostly rare strays that appear for short periods of time (e.g., rose-breasted grosbeak) or unusual species that appear to colonize for a period (e.g. long eared owl). Among the 9 taxa observed only in the first half of observations, 5 were observed exclusively in the 1970s and 1980s, and three (tundra swan, surf scoter, harlequin duck) were singletons observed prior to 1960. Only the California condor is a species observed across a stretch of time that is now extirpated from the Parks. Thus, there is no strong record of changes in occurrences of birds within the Parks.

There are no apparent trends or patterns among the herpetofauna with respect to taxa observed in the first or second half of all observations. The rank abundance across taxa between the first and second half of Wildlife Observation database records are strongly correlated ($r^2 = 0.91$). There are no apparent losses or gains in taxa. Four rarely observed taxa (long nosed snake (*Rhinocheilus lecontei*, 5 observations, 1982-1985), sequoia slender salamander (*Batrachoseps kawia*, 2 observations in 1964), side-blotched lizard (*Uta stansburiana*, 1 observation in 1933);

long-nosed leopard lizard (*Gambelia wislizenii*, 1 observation in 1986) do not appear to depict a pattern of species loss or gain. Three observations of foothill yellow-legged frog (*Rana boylii*) from 1940 to 1970 represent a species loss from the park (D. Boiano, personal communication).

Table 20. Birds observed rarely and exclusively either in the first half (pre-1985) or second half (post 1985) of the Wildlife Observation Database, along with the range of dates observed. The California condor, currently extirpated from the parks, stands out as a striking exception with 42 observations before 1982.

A. Species with no observations in first half	Number of observations	Range of dates
American white pelican	2	1990-1992
barn swallow	3	1986
barred owl	1	2004
black storm-petrel	1	1994
bohemian waxwing	1	1989
broad-winged hawk	2	2002-2007
bufflehead	3	1993-2005
Caspian tern	2	2002
chestnut-sided warbler	1	1986
common loon	2	1989-2007
common yellowthroat	2	1998-2000
ferruginous hawk	5	2003-2007
gadwall	2	1997
gray catbird	1	1994
great-tailed grackle	3	2000
gyrfalcon	1	2000
hooded oriole	3	1996-2001
horned grebe	2	1994
ladder-backed woodpecker	1	1994
long-eared owl	17	1987-2003
northern pintail	2	1997
northern shoveler	1	2005
northern shrike	1	1997
purple martin	3	1987-1991
rose-breasted grosbeak	1	1986
summer tanager	5	1988-1999
white-tailed kite	3	1996-2002
white-tailed ptarmigan	8	1992-2006
B. Species with no observations since 1985	**Last observed**	**Range of dates**
California condor	42	1899--1981
gray flycatcher	4	1982-1985
vesper sparrow	3	1974-1982
harlequin duck	2	1937
eastern kingbird	1	1985
red-necked phalarope	1	1980
surf scoter	1	1957
tundra swan	1	1907
Lucy's warbler	1	1984

In addition to observing differences in species richness through time, we briefly assessed the most frequently observed species among birds, mammals and herpetofauna to try and determine if there has been a change in abundance. We did this by assessing the frequency of observations of dominant taxa by decades of observation. We define dominant taxa to be the 5 most abundant taxa in each group. This makes the observation number relative to the total observations for that decade. Only the black bear (*Ursus Americana*) and mule deer (*Odocoileus hemionus*) among the mammals stands out for striking patterns (Figure 29). Black bear show a sharp increase in observations through time, a pattern that correlates well with statewide estimates of black bear densities. In addition, the decline and recovery of mule deer is also reflected with statewide patterns (http://www.dfg.ca.gov/wildlife/hunting/biggame.html).

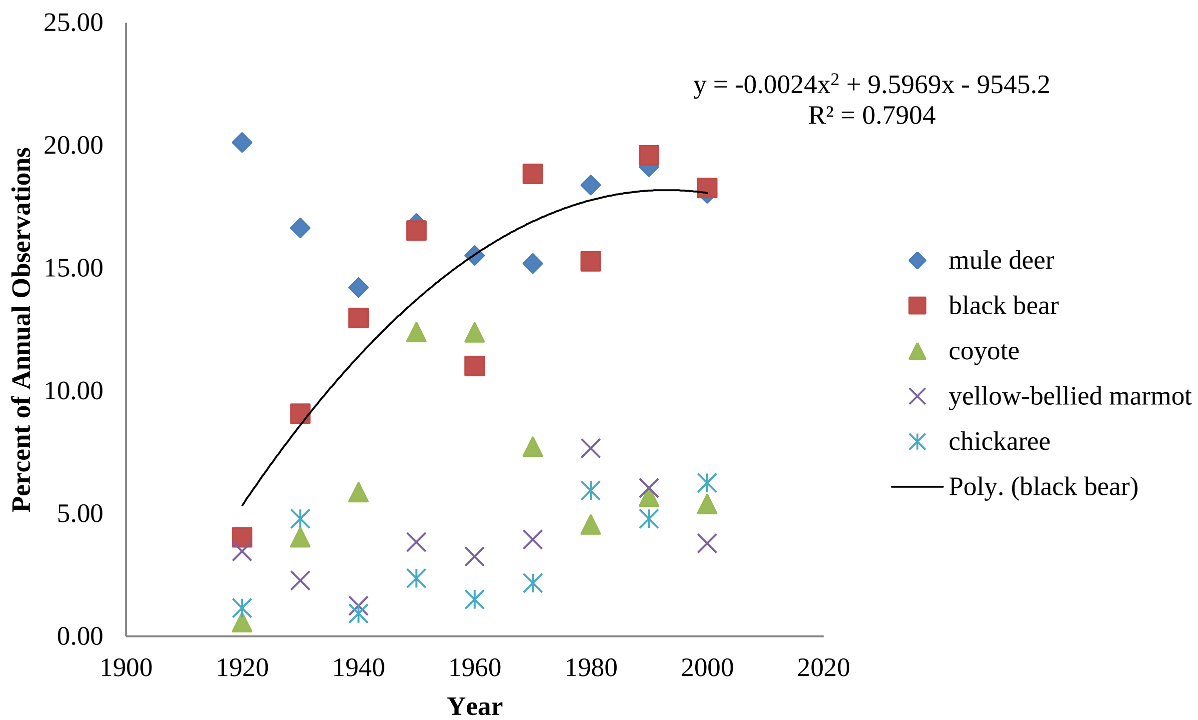


Figure 29. Changes in the relative frequency of observation of the five dominant mammal taxa in the Wildlife Observation database.

Data Needs

As with previous sections, the amount of data available is substantial, however the haphazard collection of most of these data constrain detailed analysis. Collecting systematic data is expensive and time consuming. However, targeted data collection may be feasible. Given that the bird data are relatively robust, assessing trends in birds may be in order. Similarly, given the perceived threat of climate change and fire to lower elevation communities, targeted assessments at these lower elevations may be possible and would help refine estimates of temporal trends.

Analysis of Uncertainty

Analysis of the available data sets highlights two simple observations. First, the observation data set is incredibly rich, with over 90,000 observations in the wildlife observation database and 53,000 plant observations in plot data. Other notable efforts in observations are the Knapp lake survey and the Institute for Bird Populations survey. Second, despite the richness of these data sets, there simply is not adequate data structure (e.g., systematic surveys) in some geographical areas, and across some taxa, to make specific conclusions about overall biodiversity. We focus data uncertainty in two areas: 1) individual uncertainties generated by observation error (spatial and ID) and sampling error and sampling bias and 2) uncertainty generated by aggregating observations into community assessments

Observation Error, Sampling Error and Sampling Bias

Some of issues of observation and sampling error and bias are simple and straightforward to grasp, but difficult to fix. For example, in the wildlife observation database are six observations of gray wolf (*Canis lupus*), two are post 1990. It is virtually certain that none of these observations were actually wolves; the Parks are outside the historic distribution for this species. We observed that the slender salamanders (*Batrachoseps* sp) were listed in the mammal database. We corrected this oversight. Where we found obviously erroneous observations, we eliminated them from our treatment of species richness.

There are also observations of individuals that represent (a) poor sampling of a taxa across a broad distribution, (b) a major range shift during the past century of observations, or (c) data entry errors. For example, all seven observations of black-tailed hare (*Lepus californicus*) since 1953 have been above 2000 m, whereas the single earlier observation (in 1918) was at 542 m. In contrast, the single early observation (1916) of the California pocket mouse (*Chaetodipus californicus*) was at 3256 m, whereas the 6 subsequent observations (1933, and 4 in the 1980s) are all between 540 and 750 m. These examples represent cases where we do not have the justification for removing them, yet they remain suspect.

Other problems of non-representative sampling relate to stray observations. Birds present the most clear-cut case of these observations. There are a large number of bird observations where the species is relatively large and easily determined, but severely out of place in the Parks. For example, most of the 28 bird taxa observed just 1 or 2 times in the combined bird observation data sets most are likely vagrants within SEKI (e.g., surf scoter (*Melanitta percillata*), black storm petrel (*Ocenondroma melania*)). These are likely anomalous occurrences, stray migratory events or other exceptional events that do not reflect the biodiversity of the Parks. Lacking an objective mechanism to exclude stray observations, we generally left these in the data set for analysis. This problem is likely far more pronounced in birds than other taxa given the high mobility of birds.

A third problem associated with observations is related to observation bias. If species are more likely to be observed, then the frequency of observation poorly reflects abundance. This does not seem to be a strong factor in birds, plants in plots, or herpetofauna (with the possible exception of the slender salamanders, *Batrachoseps*). However, this is a very significant problem with mammal observations. Mule deer (*Odocoileus hemionus)*. and black bear (*Ursus americana*), two of the largest mammals in the Parks, represent 35% of all observations. In fact, the top 12 taxa represent 75% of all observations and include just two taxa (pika (*Ochotona princeps*), chickaree (*Tamiasciurus douglasi*) with individuals that weigh less than 200 g. In contrast, 75% of the 32 taxa observed 10 or fewer times weigh less than 200 g (Figure 30). Thus, the data are the exact opposite of what we would expect given the relationship between body size and energetic consumption (White el at 2007). Oddly, this bias in data does not result in a different shaped curve of abundance by rank order (Figure 9). The shape of all four curves is similar, and similar to those observed in other locations and other taxa (Ricklefs and Miller 2000).

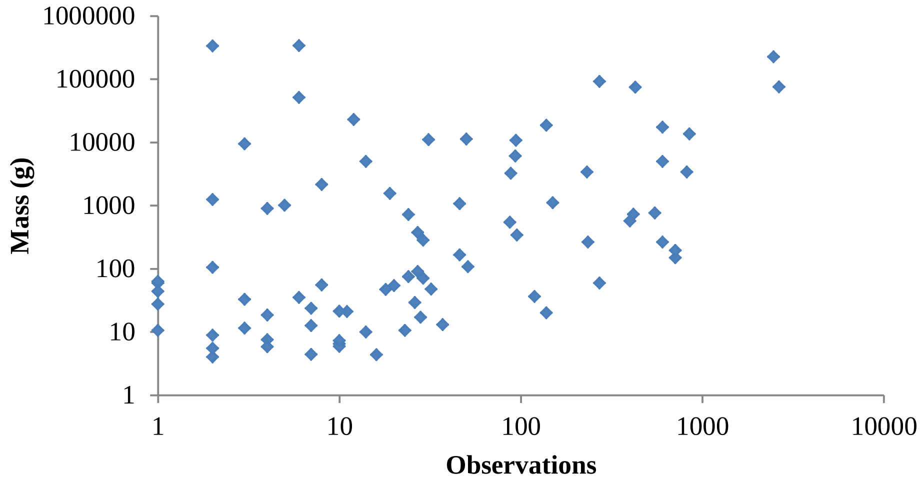


Figure 30. The relationship between body mass and the number of observations of mammals of Sequoia and Kings Canyon National Parks. The positive relationship suggests that observations do not reflect actual abundance as much as it represents observability and the truly uncommon taxa are likely those that are both rarely observed and large (grizzly bear, grey wolf, elk, river otter, mink, muskrat, desert cottontail, black-tailed hare).

For temporal analyses the WOD provided the opportunity to explore whether trends could be assessed or not. In most cases such data sets are too small for historical trend analyses. We implemented an analysis that split the observations into decadal time series. While this is a somewhat novel approach to the use of rarefaction curves, we are able detect changes in species richness that have been normalized for sampling bias, and for which a standard error can be generated. In the end, we have high confidence in a few simple statements regarding trends: (a) few vertebrates (California condor (*Gynmogyps californicus*), brown bear (*Ursus arctos*), wapiti (*Cervus elaphus*), foothill yellow legged frog (*Rana boylii*) have gone extinct from the park; (b) black bear (*Ursus americana*) populations have increased; (c) mule deer (*Odocoileus hemionus*) populations declined and rebounded.

Habitat Assessments

We would have preferred to use Park defined vegetation community types, the Alliance or Association-level classes recorded in the Parks' vegetation map, for our analyses of diversity by community type. The data for all groups, however, is not adequate. The parks would require a massive data gathering effort to systematically survey species richness in all of the parks-defined community cover class types. Thus, we focused our assessment on California Wildlife Habitat

(CWH) land cover types. Even with this simpler classification of the landscape, we often do not have a sufficient number of observations to make clear statements regarding the relative diversity of different communities. For example, the number of observations, compared to the total species richness of mammals in the wildlife observation database for each of the 26 different CWH cover types found in the Park, shows that there are a large number of CWH cover types that are estimated to have low diversity, but may be so because of few observations (Figure 31).

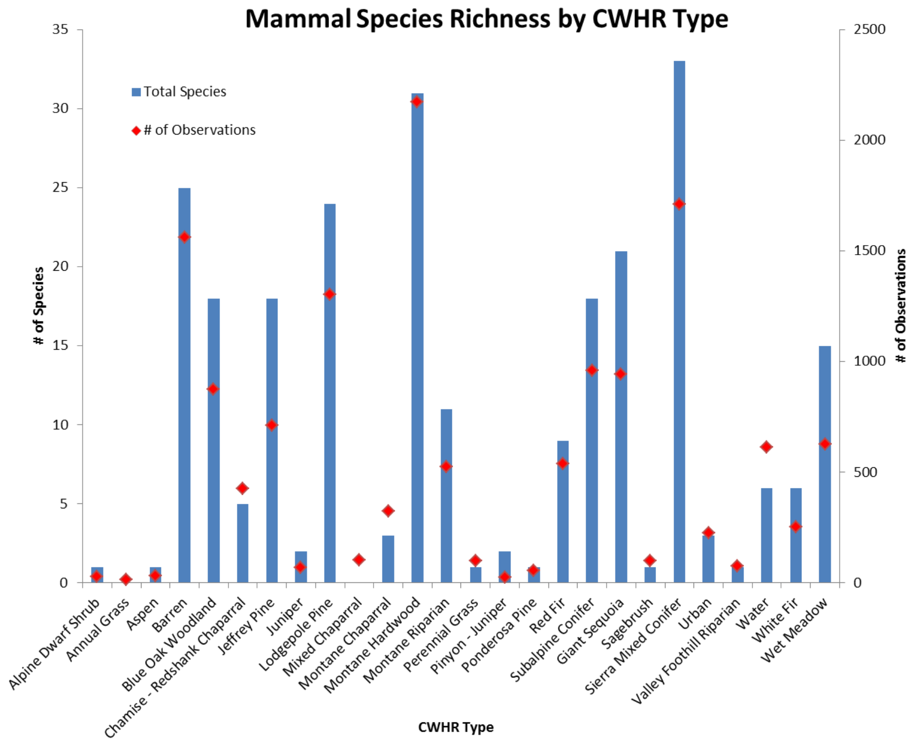


Figure 31. The number of vertebrate species (blue bars, left axis) associated with different CWH cover types, shown with the number of observations made in habitat type (red dots, right axis. The red dots (number of observations), may exceed the length of the blue bars (number of species) or not, as they are plotted on different scales.

In order to be assured that a species richness projection is representative, we require a minimum threshold of number of observations. Simply put, we can’t expect to accurately assess species richness if there are insufficient observations from that CWH type. Without specifying, for the moment, what constitutes adequate sampling, observe that the 10 community types with the lowest observed species richness (e.g., alpine, annual grass) are also the 10, and the only 10, types with sample sizes of fewer than 100 individual observations. The obvious conclusion is that 100 observations are not adequate to assess species richness and we know little about mammal species richness in these habitats. Thus, no matter what we do, we will have community types where our assessments of diversity remain highly uncertain.

A second issue of concern in assessing actual species richness of habitat types is that of unequal sampling. This challenge is well illustrated by Figure 12. This figure aggregates plant species richness within elevation categories (bars) and compares that to sampling intensity (green dots indicate number of sampled plots at that elevation. Species richness is maximized in the 2500-3000 m range, while sampling intensity peaks at 3000-3500 m. Thus, we can assert that there are more species at 2500-3000 m than 3000-3500m. In contrast, as species richness increases from the lowest elevation up to 3000, so does sampling intensity. From these observations alone, we cannot definitively assert that any one elevation results in maximum species richness. That said, we used rarefaction to standardize data sets, but then checked the outcome with respect to the raw data. In most cases the estimated species richness at some sampling threshold is correlated to observed species totals and diversity indices by a correlation (r^2) greater than 0.96. This suggests that the relative diversity will be very similarly assessed using any of our focal metrics. The actual predicted numbers of species, however changes based on sampling intensity.

Interactions with other focal resources

Biodiversity encompasses many of the other, more taxonomically targeted focal resources of this NRCA. The reports on birds, foothills, intact forests, sensitive plants, giant sequoias, meadows and invasive plants are all examining single or multiple species. As a consequence, we tried to place these elements in a wider context for the biodiversity chapter. Foothills, meadows, and intact forests are focal elements that represent ecosystems within the Parks. As such, each of these types would have its own component biodiversity. Changes in the condition of those elements would potentially directly affect the status of biodiversity in those systems. Declines in condition of those components may make them more susceptible to invasive species, which also tends to negatively impact biodiversity.

Birds, giant sequoias, and sensitive and invasive plants are focal elements that by definition are part of the biodiversity. These focal elements provide a more detailed look at the species they represent, and as such may provide some insight as to how overall biodiversity in the Parks is changing due to increases or decreases of species found in these categories.

The environmental focal elements: climate, water quality, water quantity, fire regimes, and air pollution are all factors that can positively or negatively impact individual and groups of species, and therefore impact biodiversity. Declining environmental quality negatively impacts species ability to survive and reproduce, thereby potentially impacting the mandate of the National Parks to preserve species and ecosystems.

Stressors

The patterns of biodiversity described are essentially a description of a set of biotic conditions as a consequence of a species pool, history and environmental conditions. As such a change in these environmental patterns could drive change in biotic diversity. Biotic change through gain or loss of suitability for reproductive success for each species may be driven by any of a number of stressors to the current environment. While some trends are known from SEKI, we know from an additional suite of studies in the Sierra Nevada that change in many ecological systems of these mountains is occurring. It is reasonable to suspect that patterns occurring further north in the Sierras, may also be occurring in SEKI. We highlight the possible effects of 6 stressors on integrity and vulnerability on focal resource, where appropriate.

- Air quality. Although there are known air quality impacts to a variety of individual species, there is no overarching assessment of impacts of air quality on overall biodiversity. It is useful top note, however, that air quality impairment is highest at low elevation and this is concordant with the high levels of biodiversity at low elevation for herpetofauna, mammals, and birds. Plant diversity peaks at elevations where air quality impairment is beginning to decline. Air quality impacts, such as ozone, have known negative impacts on both plant and animals. Amphibians appear particularly vulnerable to low air quality. Several species of Sierra Nevada plants are known to suffer from ozone damage.

- Land use/fragmentation. Understanding biodiversity is likely to be integrally related to land use and fragmentation on a regional scale. Many of the mammals of concern, for example, have large ranges and require habitats outside the Parks. We do not attempt an analysis of land use fragmentation within this chapter, as it is a portion of the Landscape Ecology assessment. However, we strongly recommend overlaying the spatial patterns of diversity within the Parks with a landscape measure of habitat heterogeneity (habitat turnover, habitat patch size). These are likely to be correlated and this would assist in identifying key landscape features for protection of diversity.
- Climate change. Species are responsive to climate change (Parmesan 2006). This report does not attempt to model how climate change may impact the distribution of diversity. Neither the spatial resolution of the climate models, nor our understanding of the degree to which climate drives the distribution of species is sufficiently strong to make robust forecasts on a sweeping scale, such as assessing all of the Parks' biodiversity. Sierra Nevada species, however, are responding through shifts in phenology as seen in butterflies (Forister et al. 2009), through changes in their range extents as measured in small mammals (Moritz et al. 2008), and by increases or decreases in recruitment and mortality levels of conifers (Van Mantgem et al. 2007, 2009). These changes have all been tied to changing climate.
- Invasive species. Invasive species provide a strong opportunity for interaction with native biodiversity. Despite this, there seems to be only a few cases where this is an obvious problem. First, and foremost among these are the non-native fishes of the high Sierra lakes. Fish introductions have well-documented impacts on native amphibians and likely have strong impacts on aquatic invertebrates. These impacts are considered within the Sensitive Animals chapter.
- Altered fire regimes. Changed fire regimes have a strong potential impact on the distribution of community types as well as the biodiversity housed within those community types. Fire resource managers define a fire return interval departure (FRID) as the number of expected normal fire return intervals, for a particular vegetation type, have passed since the last fire. The FRID map for SEKI demonstrate a recurrent theme: the most vulnerable portion of the Parks are at low elevation. In this case, vulnerable means that the fire return intervals are most out of synch with historic fire intervals. These are also the very locations where we might expect high intensity fires to result in type conversion toward more xeric (chaparral and grasslands) from more mesic (woodlands and forests) community types. These type conversions would have strong, and likely negative, impacts on park biodiversity. Biodiversity values for are high at low elevations and this makes this biodiversity vulnerable to future fire conditions.
- New disease paradigms. Emerging disease has the potential to dramatically alter composition within forested communities and change the nature of those communities in their capacity to house biodiversity. We find no direct evidence for those changes through this work, but other published studies do assess the impact of forest disease on forest structure and chytrid fungus on amphibian communities. Insects and pathogens also have the capacity to outbreak and cause severe damage to forested systems. The frequency of these events in the western US is on the rise. These impacts are likely to hit the mid-slope conifer forests the most severely, and this is where bird diversity and plant diversity is at peak value and mammal and herpetofaunal diversity is near peak.

- Stress synergisms. Many stressors can have synergistic effects. For example, climate change is likely to interact with air quality issues, particularly ozone damage, which negatively impacts pines, particularly *P. ponderosa* and *P. jefferyi* (Grulke et al. 2003; Peterson et al. 1991). Air quality, as well as altered fire regimes, pathogen outbreaks such as white pine blister rust, and greater incursions of invasive species all are stressors that may increase pressures on the native biodiversity under future climate conditions.

Assessment

Considering the aggregate of biodiversity information, we evaluated condition as good, moderate or poor for three attributes across each of our focal taxonomic groups. For birds, mammals, herpetofauna and plants we classified information on condition in terms of (a) extirpations and rarity; (b) non-native species impacts; and (c) diversity and richness (Table 21). We chose to roll up information in this manner because we separately roll up information on biodiversity to analyze condition spatially. In each case, we use a verbal argument based on relative values of few or many taxa being vulnerable to extirpation, non-natives or biodiversity being generally high or low for different groups.

Table 21. A Table of summary metrics of biodiversity status.

Metric	Integrity Measure	Condition	Summary Comments
Birds	Extirpations and Rarity	Good	Few rare taxa and globally threatened taxa were historically found in the Parks. Although California condors used the Parks, it was not likely primary habitat and they are the lone confirmed extirpation. Re-introduction programs may succeed in bringing them back.
	Non-Native Species	Good	Only four non-native species are found in the Parks. Brown headed cowbirds and turkey are likely the most difficult problems.
	Diversity and Richness	Moderate	Diversity and species richness are high, but have declined since the 1980's.
Mammals	Extirpations and Rarity	**Moderate**	Brown bear and possibly wolverine and Sierra red fox have been extirpated. Some large mammals (fisher) are at risk. Other species of concern (bighorn sheep, pika) have moderately large populations at the moment, but are considered at risk to future stressors.
	Non-Native Species	**Good**	Five introduced mammals are present in the Parks. These do not appear broadly problematic to park biodiversity.
	Diversity and Richness	**Good**	Diversity remains high, but also difficult to assess because the majority of diversity is driven by difficult to assess groups (e.g., nocturnal, fossorial and arboreal species).

Table 21. A Table of summary metrics of biodiversity status (continued).

Metric	Integrity Measure	Condition	Summary Comments
Herpetofauna	Extirpations and Rarity	Moderate	Few extirpations have been observed, but several taxa appear vulnerable. *Batrachoseps* are little known, narrow endemics. High elevation amphibians remain at risk
	Non-Native Species	Good	There is one invasive amphibian in the Parks (bullfrog) and its impacts appear localized.
	Diversity and Richness	Good	Herpetofauna appears to be stable. Ensatinas may be declining, but this is not certain.
Fishes	Extirpations and Rarity	Poor	Very few native populations are observed. All native salmonids are at high risk of genetic introgression with non-native fishes.
	Non-Native Species	Poor	Non-native fish dominate in formerly fishless ecosystems. Non-native fish dominate in formerly fish occupied habitats.
	Diversity and Richness	Poor	Low native species diversity and all are in decline.
Plants	Extirpations and Rarity	Good	There are relatively few known rare plants from the Parks. There are likely undetected extirpations of perennial grasses and forbs from foothill grassland and savanna habitats that pre-date formal surveys.
	Non-Native Species	Good	All parts of California are characterized by some degree of invasion by non-native plants. SEKI is no different. Other than the dominance of non-native annual grasses in the grasslands and savannas at low elevation, however, there are relatively few habitats that appear to suffer from strong invasive species management problems. High elevation reduces this stress. Po-active weed management also significantly reduces this threat.
	Diversity and Richness	Good	Diversity is high and well distributed throughout the Parks. The strong plant dissimilarity measure suggests a high degree of spatial heterogeneity of plant types.

Finally, we present a spatial roll-up of biodiversity condition (Figure 32). We assessed the spatial status of biodiversity in three ways. First, we used the Simpson's index of diversity of observations found in each of the HUC10 (major) watershed units. Second, we used the overall habitat roll-up (Figure 25) to assess value by habitat. We then scored each HUC10 watershed as a weighted, by area, average habitat value score. Third we used the predicted number of species for each taxonomic group within habitats as an estimator of biodiversity. Similar to the second method, we weighed the rarefaction scores by the fraction of each HUC10 watershed represented by each of the 26 CWHR habitats. We then estimated the contribution of each taxonomic group (birds, mammals, herpetofauna and plants) by taking a standard score: (observed – expected)/expected, where the expected is the average score across the 12 HUC10 watershed units. We then summed the standard scores across taxonomic groups and scored those consistently positive as "good"; those consistently negative as "poor" and the rest as "moderate." These three estimators gave a very similar projection of overall diversity condition (Figure S13 in the Supplemental Information). We present a combined graph that depicts each watershed unit as high, medium or low with respect to biodiversity (color) and the confidence (bars) (Figure 32). When all three measures agreed, then confidence was high (three black bars), when two out of three measures were adjacent to the third (e.g., two goods and a medium), then the HUC10 scored the majority category and a medium confidence (two black bars). In one case (the northernmost watershed) the watershed scored differently on each of the three methods, as was scored with low confidence one black bar).

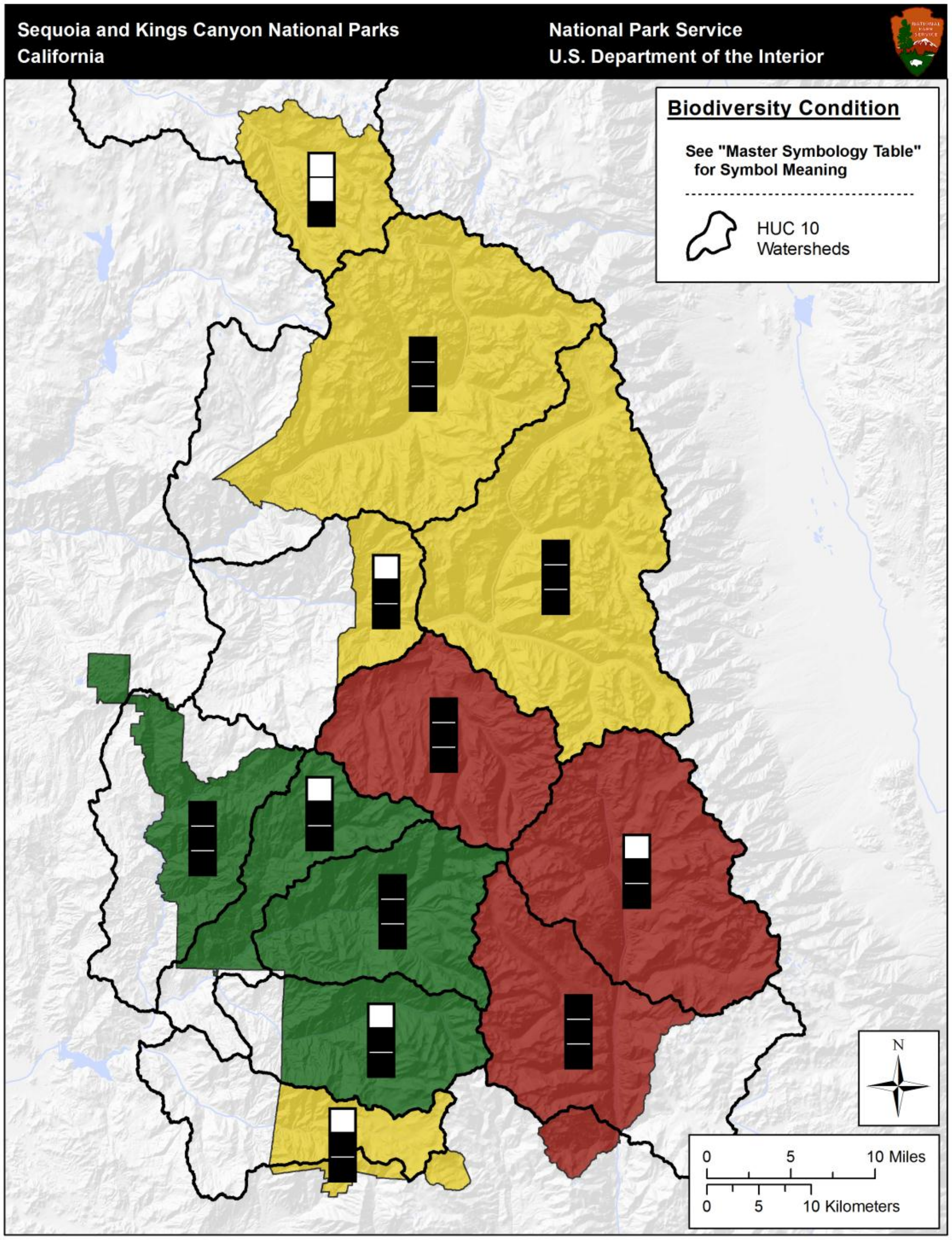


Figure 32. The HUC10 spatial roll-up of habitat condition. Given the large number of observations, we scored confidence as high. Given small trends in species presences at different elevation, we have little evidence to score units as anything other than reasonably stable. Color codes reflect the baseline levels of biodiversity, rather than condition per se. Each watershed has some compromised biodiversity and some intact biodiversity.

Our final assessment, breaks this roll-up down by taxonomic group (birds, mammals, herpetofauna and plants) and summarizes each spatially at the HUC-10 watershed level(Figure 33a-d). Once again, there are many possible ways to assess biodiversity status by HUC-10. We summarize several (Table 22, Table SI). We have used the inverse of Simpson's Index and estimated species richness as consistent measures of biodiversity. For our HUC-10 summary, we used a combination of those metrics where we weighted the index value returned for each land cover type by the amount of land cover of that type within each HUC-10 watershed. For taxon specific assessments, we present the Simpson's diversity index, and show in Table 22 that this measure generally has low variability among HUC-10 watersheds (Table 22), as does the estimated species richness of each land cover type aggregated across all types and weighted by proportionate area f each watershed. An alternative approach would be to simply sum the number of species observed in each watershed unit, and calculate a Simpson's Index based on that. Given the large variance in observation density, this may result in strong differences in estimated richness driven solely by sampling. For our graphical depiction we show the distribution of Simpson's diversity index, summarized as a weighted average of index scores by land cover type (Figure 33).

Table 22. Summary values of Taxon specific metrics of diversity values summarized within HUC-10 watershed units. We report on the average (standard deviation) of the number of observatins and number of species observed within each HUC-10 watershed. We also calculated the Simpson's Diversity index for observations by taxa within each unit. In contrast. Estimated species richness was based on different sample sizes by each group: birds n = 1000; Mammals n = 300, herpetofauna n = 124; plants n = 1183.

		Birds	Mammals	Herpetofauna	Plants
Watershed	**Number of Observations**	4853 (3850.4)	1185.6 (919)	422.83 (309.6))	3986.6 (1999.5)
Watershed	**Number of Species Observed**	134.25 (24.47)	44 (11.13)	19 (6.54)	496.83 (159.9)
Watershed	**Simpson's Index**	46.02 (15.0)	9.74 (2.09)	6.93 (4.03)	108.08 (47.3)
Watershed	**Estimated Species Richness**	106.5 (13.4)	31.1 (3.6)	(15.5 (5.36)	319.3 (57.3)
Land Cover	**Weighted Species Richness Estimate**	82.40 (3.83)	26.88 (1.30)	13.50 (1.07)	129.8 (5.48)
Land Cover	**Weighted Simpson's index**	41.16 (5.69)	9.42 (0.40)	6.60 (1.85)	84.77 (16.63)

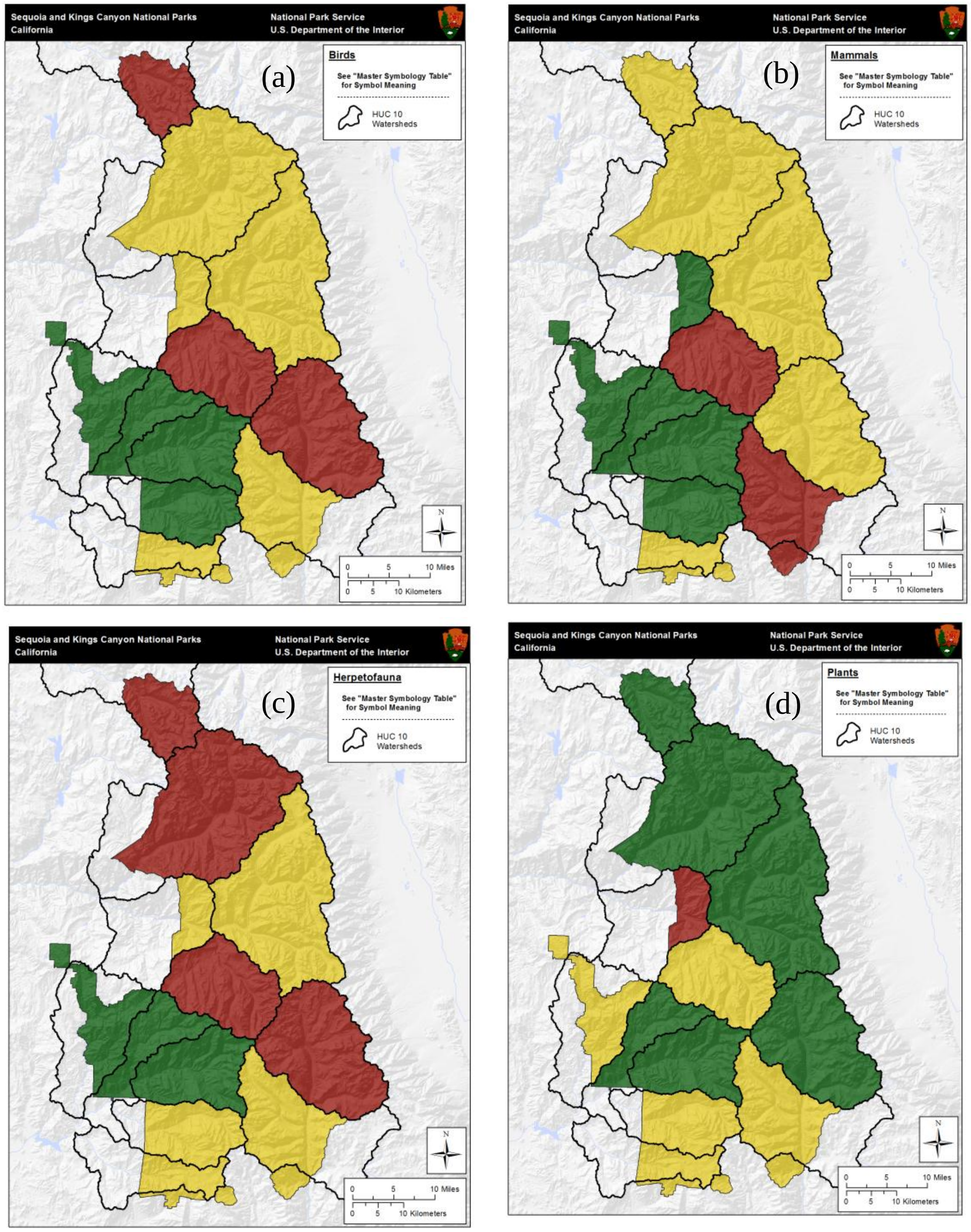


Figure 33. The HUC10 spatial roll-up of habitat condition by taxonomic group based on Simpson's Diversity Index. Color codes (green = high, yellow = intermediate; red = low) reflect the baseline levels of biodiversity, rather than condition per se. Each watershed has some compromised biodiversity and some intact biodiversity. Maps include: (a) birds, (b) mammals, (c) herpetofauna, and (d) plants.

Level of confidence in assessment

Our overall confidence in this assessment is very high. This is despite numerous places where data uncertainty is moderately large. The reason that analytic confidence is high is because of the numerous forms of data that all point in the same general directions with respect to the level of biodiversity in SEKI, the degree to which that biodiversity has been degraded or altered, the spatial distribution of biodiversity and the degree to which this spatial distribution has changed.

Gaps in understanding

A systematic means of collecting data specifically to address trends in status and condition of biodiversity is lacking. Monitoring for biodiversity in a structured way that would allow such an assessment is likely beyond the capacity of the Parks given the current resources. Assessing status and trends at a habitat or ecosystem level, through remotely sensed data may provide some information, but is not likely to be adequate. The wildlife observation database remains a highly valued resource, although there are indications that there is a reduced capacity for park biologists to contribute to continued observations at the intensity of the 1980's and 1990's. If so, this will reduce the capacity of the Parks to assess biodiversity in the future.

Recommendations for future study/research

We provide three general recommendations for future study of biodiversity within SEKI. There are many other recommendations that could be made. We feel that these are three critical ones.

First, with an abundance of high elevation sites, SEKI may become a repository of plant diversity that shift upslope with warming temperatures. Early detection of such patterns would be very valuable to determine if this is happening on its own, requires dispersal assistance, or is even needed to protect this diversity.

Second, the Parks represent the highest and southernmost portion of a large mountain range in North America. As such, they represent the southern terminus of a broad array of mammal species. Population genetic studies to assess the contribution of these taxa to the overall genetic biodiversity of US mammals are needed.

Finally, remote sensing and satellite tracking technologies are likely 3-5 years away from the potential to mark organisms with very small tags that can be detected from wildlife observatories in orbit. These kinds of technologies, deployed in large, very wild, and difficult to access parks, such as SEKI, could revolutionize our understanding of how wildlife is doing in this region. In particular, the small mammals are poorly understood in the Parks.

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