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26

Status of Terrestrial Insects

ABSTRACT

Insects are potentially powerful indicators of habitat richness, pollution, and environmental perturbations. The most informative groups for these measures are insect herbivores and detritivores (debris feeders). Predators and parasites or parasitoides (insects whose larvae develop on and eventually kill a single host) are less informative because they are far less influenced by environmental conditions than by prey or host availability. Unfortunately, the insect species of California, including those of the Sierra Nevada ecoregion, are not well known. There are two basic reasons for this: (1) collections of California insects are incomplete or lacking for many regions, and (2) we lack the systematic entomology expertise to identify the California insect fauna. However, based on the limited information available, there are estimated to be about 100,000 insect species in California. Of these, 10% may be new to science, 12% are endemic to California, and only 0.9% are endemic to the Sierra Nevada. Most Sierran terrestrial endemic insect species belong to the families of wasps and bees, and of grasshoppers. Examining thirty-five families in six orders of terrestrial insects reveals two major areas of endemicity: the Owens Valley and high-altitude areas above 2,000 m (6,000 ft). Changes to these environments can make them unsuitable for the endemic species.

INTRODUCTION

California has a great variety of ecosystems and environmental conditions. Accordingly, California also has a rich and highly diverse insect fauna. In fact it may have the largest percentage of endemic insect species in America north of Mexico. There are thirty-two orders of insects; thirty-one of these occur in California (the exception is the order Zoraptera), and within these orders there are roughly five hundred families of insects in California.

One of the more recognizable geographic features in California is the Sierra Nevada Mountains. These mountains cover roughly one-sixth of the state and consist of a number of ecological zones, ranging from high-altitude tundra to low-altitude riparian sites, black oak forest to Great Basin sagebrush desert. Large numbers of insect species occupy all these zones, although some ecological zones have far more insect diversity than others. The majority of California insects are widespread and have distributions that fit five major patterns: Pacific Northwest, southern California coastal, Central Valley, Great Basin, and Mojave/Sonoran desert.

Because of the enormous number of insect species and the many different biological adaptations, insects should prove sensitive indicators of habitat quality and richness. Unfortunately, the incomplete state of our knowledge about insects makes it difficult to use them as environmental indicators or to make many generalizations about the insect fauna of California. Even though many entomologists have been working in California during the past hundred years, we still simply do not know, with any accuracy or completeness, what species occur in the state, or where they occur. For the majority of insect species it is impossible to determine distributions without having specimens collected from each locality in hand. Few species, if any, can be identified in the field.

Museum collections are inadequate in their representation of the California insect fauna. Most collections have been put together for teaching programs, specific research projects, or pest survey programs, or because of proximity to tourist sites. Each of these sources of collection materials influences known distributions of insects and results in some interesting information gaps. These gaps are caused by a number of phenomena. One is the teaching effect, one of the best examples of which occurs in the vicinity of the Sagehen Creek Field Station, run by the University of California. Entomology classes have collected at this site for decades, and diversity probably reflects the amount of collecting done there rather than the comparative richness of the fauna, because data for other sites in the state are inadequate. Based on collection records, this alpine valley has the highest recorded family diversity in Califor-

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nia. A total of 396 families of insects has been recorded at this site, as opposed to substantially fewer numbers observed elsewhere (personal observation). In fact, most of the state has never been examined. Published distribution maps of insect species tend to show some amusing patterns. One of the most noticeable is perhaps best termed casino distributions, where the largest number of insects was collected along and between Interstate Highways 80 and 50 through the Sierra to Reno. Then there are landmark distributions. These occur in various national parks, such as Yosemite, Death Valley, and Lassen. Fourth is a seasonal component. Most sites are visited during only a small part of the year, usually in the summer or spring months. Clearly, not all insects are active at these times. Finally, there is collector artifact. Every collector "sees" different insect species. Typically a researcher can take a group of students to the same site at the same time to collect insects and have each come back with different species. In addition, it is physically impossible for one person to collect everything at one time. Different guilds of insects require different, sometimes incompatible, collecting techniques.

Next we come to the third part of the equation—species identification. Despite rumor to the contrary, it is impossible to identify 99% of insects to the species level in the field. Most insects are tiny, less than 5 mm (0.25 in) in length. Even professional systematists are probably unable to identify more than about 2,000 species in their groups of study. Assuming there are 100,000 insect species in California, at least fifty specialists would be required to identify everything just based on numbers, particularly because many features that distinguish insect species are subtle and can be seen only under the microscope. It is safe to say that there are not fifty taxonomic specialists currently studying species that occur in California. In 1985 there were probably thirty professional insect systematists in the state. By 1995 that number had dropped to twenty-two. We are losing taxonomic expertise at an alarming rate. Thus our ability to pinpoint areas of endemicity is waning as well. It is also important to realize that many species in California are still undescribed. Particularly in certain groups such as moths, wasps, beetles, and flies, at least 10% of the species may be new to science.

However, despite these data gaps some general patterns based on published monographs and museum collections appear. Overall, few terrestrial insect species are endemic to Sierra Nevada ecosystems, and of these most are found at high altitudes or in the Owens Valley, for reasons discussed later in this chapter.

METHODS

Distributions of insect species were taken from studies published in the Bulletin of the California Insect Survey (Bohart and Grissell 1975; Bohart and Horning 1971; Bohart and Schlinger 1957; Bright and Stark 1973; Camras and Hurd 1957; Foote and Blanc 1963; Grigarick and Stange 1968; Hardy 1961; Huckett 1971; Hurd 1951, 1955; Hurd and Linsley 1951; Hurd and Michener 1955; Linsley and MacSwain 1951; Menke 1979; Merritt and James 1973; Middlekauff 1960, 1969; Strohecker et al. 1968; and Wasbauer and Kimsey 1985), from other monographs (Bohart and Kimsey 1982; Otte 1981, 1984), and from specimens in the Bohart Museum of Entomology, University of California, Davis. Characteristics of species treated in these studies are outlined in tables 26.1 and 26.2.

These studies cover only a small percentage of the California insect fauna, but the group of families treated represents a broad enough range of terrestrial habits (Borror et al. 1989; Richards and Davies 1977) to make some generalizations. However, it must be emphasized that species that appear to be endemic to California, and, more specifically, to the Sierra Nevada region, may not actually be so. Collections of material from within California and from surrounding states are inadequate to make this determination. Another problem inherent in relying on older taxonomic studies is that the species names used may no longer be valid. In Strohecker et al. (1968) three of the sixteen species of grasshoppers listed as endemic to California are actually California populations of much more widespread species (Otte 1981, 1984). Thus some so-called California endemics may actually be much more widespread than indicated in the literature. Conversely, some California populations may represent unrecognized endemic species. It is also true, particularly in California, that old collection localities may have changed drastically over time, becoming, for example, shopping districts, ski slopes, or parking lots. To further confuse the picture, there are also new species in the state that remain to be described. I estimate that roughly 2% (or 2,000) of the insect species are undescribed and new to science. The point in discussing these problems is that we lack sufficient information to evaluate the California insect fauna in any detail. Underlying these problems is a severe shortage of taxonomic expertise.

FINDINGS

Insects as Indicators of Habitat Richness

It would be natural to assume that the large number of insect species would provide a very fine-grained picture of habitat diversity. This assumption is undoubtedly valid if insect groups are carefully chosen, based on their biological attributes. Most insect species (between 60% and 80%) are parasites or parasitoids of plants, animals, or other insects. These groups tend to be poor indicators because they are restricted to particular habitats only indirectly or not at all. Additionally, some species are host specific, and these are typically found in a subset of the host's distribution. Their absolute distribution within the host's range is more likely to be dic-

TABLE 26.1

Characteristics of the insect orders, families, genera, and species considered in this chapter, with a rough estimate of the number of world species in each family.

Insect Order	Family	Number of California Species	Number of California Endemic Species	Number of Sierran Endemic Species	Total Number of Genera Treated	Percentage of Total Species Endemic to California	Percentage of Total Species Endemic to Sierra	Percentage of Total Endemic California Species That Are Sierran	Estimated Number of Total World Species
Orthoptera[a]	Tetrigidae	7	1	1	2	14.3	14.3	100.0	500
	Acrididae	143	49	13	40	34.3	9.1	26.5	2,000
	Eumastacidae	6	2	1	2	33.0	16.7	50.0	100
	Tanaoceridae	4	2	0	2	50.0	0	0	500
Hemiptera[b]	Hebridae	6	0	0	2	0	0	0	100
	Mesoveliidae	2	0	0	1	0	0	0	100
	Hydrometridae	1	0	0	1	0	0	0	50
	Macroveliidae	3	1	0	2	33.0	0	0	100
	Veliidae	10	0	0	2	0	0	0	200
	Gerridae	7	0	0	3	0	0	0	200
	Nepidae	3	1	0	1	33.0	0	0	200
	Belostomatidae	8	2	0	3	25.0	0	0	500
	Corixidae	30	4	1	7	13.3	3.3	25.0	1,000
	Ochteridae	1	0	0	1	0	0	0	100
	Gelastocoridae	4	0	0	2	0	0	0	100
	Naucoridae	10	3	0	2	30.0	0	0	500
	Notonectidae	11	0	0	2	0	0	0	1,000
Diptera	Micropezidae[c]	7	1	0	2	14.3	0	0	500
	Anthomyidae[c]	204	25	2	18	12.3	1.0	8.0	10,000
	Conopidae[d]	48	4	0	7	8.3	0	0	1,000
	Stratiomyidae[c]	61	3	1	12	4.9	1.6	33.3	2,000
	Tephritidae[a]	123	19	0	32	15.4	0	0	5,000
	Bibionidae[c]	23	6	3	3	26.1	13.0	50.0	500
Coleoptera	Platypodidae[a]	1	0	0	1	0	0	0	500
	Scolytidae[a]	185	16	0	43	8.6	0	0	1,000
	Rhipiphoridae[d]	22	7	0	2	31.8	0	0	200
Hymenoptera	Megachilidae[e]	200	53	5	12	26.5	2.5	9.4	5,000
	Melectidae[e]	15	1	0	3	6.7	0	0	100
	Mutillidae[d]	28	3	0	1	10.7	0	0	2,000
	Siricidae[a]	14	1	0	4	7.1	0	0	100
	Anthophoridae[e]	9	1	0	1	11.1	0	0	5,000
	Cephidae[a]	5	0	0	3	0	0	0	100
	Sphecidae[b]	112	13	1	9	11.6	0.9	7.7	30,000
	Pompilidae[b]	75	3	0	15	4.0	0	0	1,000
	Scoliidae[d]	8	0	0	3	0	0	0	500
	Chrysididae[d]	196	18	2	17	9.2	1.0	11.1	2,000
TOTALS (36 families):		1,592	239	30	263	15.0	1.9	12.6	73,750

[a]Herbivores. [b]Predators. [c]Scavengers/detritivores. [d]Parasitoids. [e]Pollinators.

TABLE 26.2

Biological characteristics of some insect orders found in California, with percentages for each order found in the Sierra Nevada ecoregion and the number of endemic species in that group found in California in general.

	California Endemic Species					Immatures in Different Habitats Than Adults	Total Number of Species Considered
Insect Order	Herbivores	Predators	Parasitoids	Scavengers	Pollinators		
Orthoptera		0	0	0	0	no	160
Percentage	100						
Number of Species	54						
Hemiptera	0		0	0	0	no	96
Percentage		100					
Number of Species		11					
Diptera		0			0	yes	466
Percentage	14		14	72			
Number of Species	19		4	43			
Coleoptera		0		0	0	yes	208
Percentage	67		33				
Number of Species	16		7				
Hymenoptera				0		yes	662
Percentage	20	20	30		30		
Number of Species	1	16	5		224		

tated by historical accident and dispersal capabilities than by absolute environmental factors. Other species may attack a number of host species, and this is also not usually environmentally informative. Then there is the question of dispersal. Small-bodied parasitoids, such as aphids or mymarid wasps, may be poor fliers but are readily dispersed as aerial plankton by air currents. Predators are also poor indicators because they are generally effective dispersers, and their distributions are more often determined by the availability of appropriately sized hosts than by environment. Primary consumers, such as herbivores and detritivores, are very likely the most valuable environmental indicators because they are directly linked to plant communities and are, therefore, directly susceptible to environmental conditions.

Insects often have complicated life cycles, which allow them to finely subdivide the environment and avoid competing with their own offspring for resources. In the majority of species, adults occupy one habitat, larvae another, as discussed later. An extreme example of this habitat partitioning can be seen in some wasps, such as the tiphiids, where even males and females occupy different habitats, except during mating. In certain groups, therefore, occupying different niches during different life stages also makes them sensitive environmental indicators.

Orthoptera (Grasshoppers)

All grasshoppers are plant feeders. Those in immature stages are simply smaller, flightless versions of adults and occupy the same habitats. Some adults are also flightless. There are apparently thirteen species endemic to the Sierra Nevada, found primarily at high altitudes on, for example, granite slopes, or in the Owens Valley (Otte 1981, 1984; Strohecker et al. 1968).

Hemiptera (True Bugs)

As with the Orthoptera, immature true bugs are smaller, flightless versions of the adults. All species considered here are predators of other insects in aquatic habitats. Less than 10% of these species are endemic to California, and apparently only one, Caenocorixa kuiterti (Corixidae), is endemic to the Sierra Nevada (Menke 1979).

Diptera (Flies)

Flies have complex life cycles. Adults are winged, and many are powerful fliers. Larvae are soft-bodied and limbless, occupying cryptic, sheltered habitats. Larvae of Micropezidae, Anthomyidae, Stratiomyidae, and Bibionidae are generally scavengers or detritivores (debris feeders) in terrestrial habitats. Most California endemic species are in these families, particularly in the Anthomyidae, although few are endemic to the Sierra Nevada. None of the phytophagous Tephritidae (fruit flies) or Micropezidae are endemic to the Sierra, nor are the conopids, which are parasitoids on wasps, bees, and grasshoppers (Camras and Hurd 1957; Foote and Blanc 1963; Hardy 1961; Huckett 1971; Merritt and James 1973).

Coleoptera (Beetles)

Only three groups of beetles have been monographed for California, which is a poor representation for this huge order of insects. The Platypodidae and Scolytidae are bark boring in trees, and the parasitoid family Rhipiphoridae attacks primarily larval wasps and bees in their nests. None of these has

species endemic to the Sierra Nevada, even though at least the Scolytidae are primary pests of pine and fir trees of the Sierra (Bright and Stark 1973; Linsley and MacSwain 1951).

Hymenoptera (Wasps, Bees, and Ants)

Hymenoptera have biologies very different from the other orders considered in this study. The majority of sawflies have free-living herbivorous larvae and winged, nectar-, pollen-, or insect-feeding adults. Bees are the most important animal pollinators of flowering plants. Wasps are either parasitoids or predators of other insects. Both bees and wasps have helpless larvae that are placed either in or on a host or in a nest by the adult female. Of these groups the largest number of endemic species, to both California in general and the Sierra Nevada specifically, are some of the bees (Megachilidae) and predatory sphecids and their parasites (Chrysididae) (Bohart and Grissell 1975; Bohart and Horning 1971; Bohart and Kimsey 1982; Bohart and Schlinger 1957; Grigarick and Stange 1968; Hurd 1951, 1955; Hurd and Linsley 1951; Hurd and Michener 1955; Middlekauff 1960, 1969; Wasbauer and Kimsey 1985).

Areas of Endemicity

Few insect species are endemic to the Sierra Nevada. However, of the groups considered in table 26.1 certain generalizations can be made (figure 26.1). Most endemic species are found in the Owens Valley in Inyo County or are high montane, occurring at elevations above 2,000 m (6,000 ft), particularly above the tree line. Most of the endemic Orthoptera (grasshoppers) occur at high elevations, generally above the tree line in the Sierra. In the Hymenoptera (wasps, bees, and ants) and nonaquatic Diptera (flies) the majority of endemic species occur in the Owens Valley. Finally, a smaller number of species in these orders and the others detailed earlier occur at middle elevations in the western-slope of the Sierra.

CONCLUSIONS

Reasons for Low Sierran Endemicity

Rough estimates made by the author suggest that 100,000 insect species exist in California, about 12% of which are endemic to the state. However, only 0.9% of the terrestrial species are endemic to the Sierra Nevada. Why there are so few Sierran endemic species of insects relative to California as a whole is a complex story that can be broken down into two components: ecological and historical. Ecologically, at least from the perspective of the majority of insect families, the Sierra Nevada offers few unique habitats. Most are shared with other western states and Mexico. Alpine and western-slope Sierra Nevadan habitats between 700 and 1,000 m (2,000 and 5,000 ft) form a nearly continuous corridor with the northern California Coastal, Siskiyou, and Cascade Mountains. The eastern slope of the Sierra Nevada shares the majority of species with the Great Basin habitats of Nevada and Utah. The only parts of these mountains that function as habitat islands are the high-altitude, boreal sites and perhaps the far southern end of the mountain range.

From a historical perspective there are other factors as well. The geological structure of California that we see today is relatively recent. The uplift of the Sierra Nevada and Coastal Mountains began less than ten million years ago. The entire western coastal region of North America was uplifted, forming a continuous corridor with the Cascades and Rocky Mountains. As a result new species have had relatively little time to develop in the Sierra Nevada, particularly because most of the Sierran habitats are not physically isolated from other regions. Insects do not speciate rapidly. Personal observations of insects found in Ice Age (Pleistocene) deposits, such as cave deposits and tar pits, indicate that these were essentially modern species. These remains, as well as insects fossilized in amber, copal, mudstone, and other materials, suggest that speciation generally takes many tens or even hundreds of thousands of years. Many species are found in both the Coastal Mountains of California and the Sierra. However, the farther south in the Sierra, the more isolated populations have become, and, as expected, the higher the number of endemic species. Based on current information, the Owens Valley in Inyo County is the site of highest endemicity of terrestrial insects in the Sierra Nevada region. Insect species there appear to have been isolated for a considerable period from both the rest of the Sierran species to the west, by the precipitous eastern slope, and the Great Basin species to the east, by the White Mountains.

Management Implications

The implications of land use in these areas of concentrated endemism must be considered. High-montane species often occur in sites ideal for ski slopes. Removing vegetation from these sites damages the site for species such as flightless grasshoppers. Clearly, water is an issue of importance on the east side of the Sierra Nevada and particularly for the Owens Valley. Drastically changing drainage and flow patterns in this habitat clearly changes the suitability of the area for many of these endemic species.

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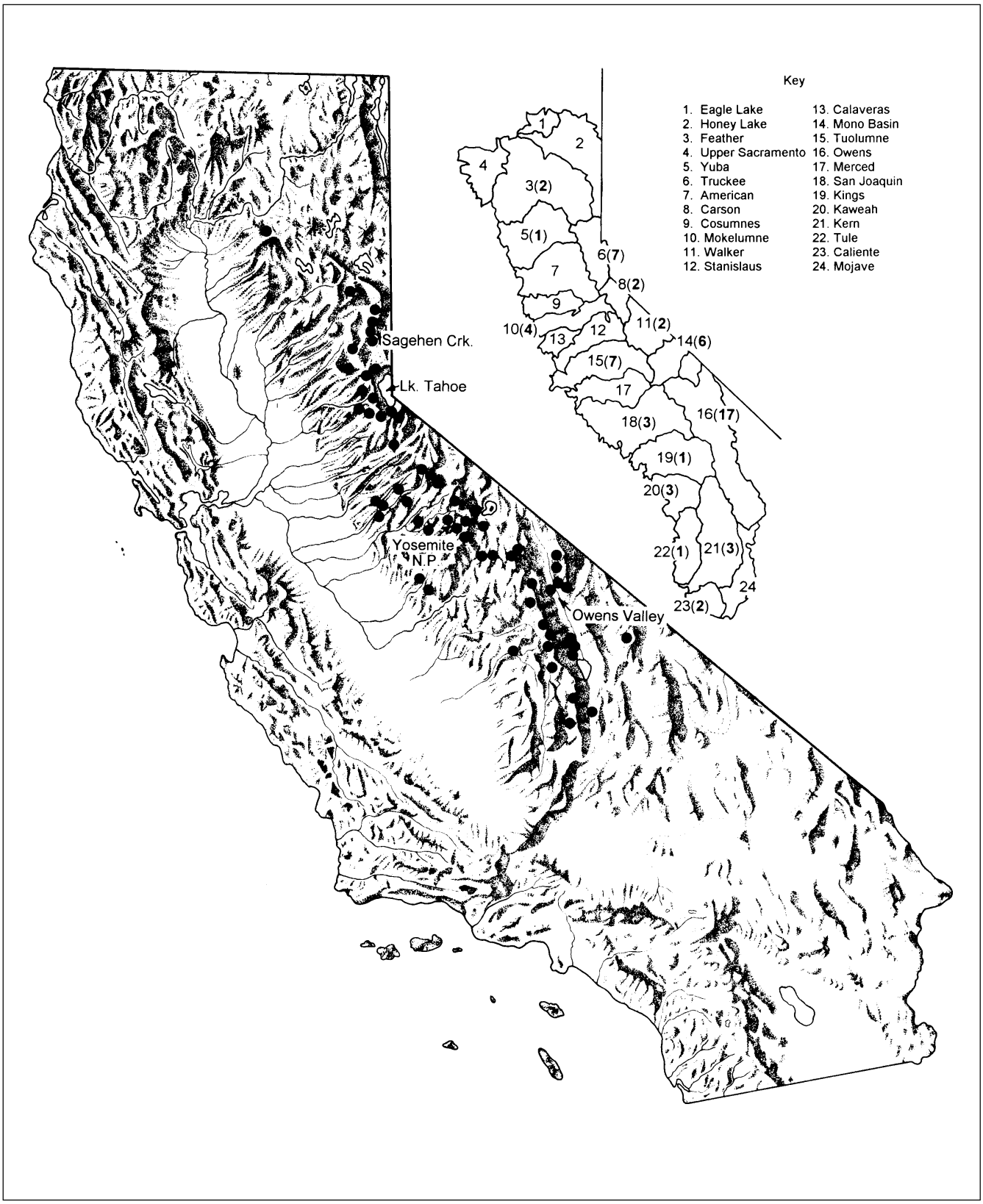

FIGURE 26.1

Distribution of endemic species in the Sierra Nevada ecoregion. Numbers of endemic species, in parentheses, found in each of the major river basins in the study area, numbered to the left of the parentheses.

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Back to CD-ROM Table of Contents