Status and Change of Amphibian and Reptile Populations and Habitat Conditions in Lentic Ecosystems in the Lake Tahoe Basin

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by

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Problem Reference and Literature

Aquatic ecosystems, including associated riparian habitat, support many dependent and closely associated wildlife species, thus making a substantial contribution to the biological diversity of any area. In drier biomes, aquatic ecosystems occupy a relatively small proportion of the landscape, and thus their contribution to biological diversity is concomitantly greater. A low density of aquatic ecosystems translates into small populations of dependent species, with a high probability of some degree of metapopulation structure. This is particularly true for lentic-associated biota given that lentic ecosystems are intrinsically discrete, especially if intervening habitats are inhospitable due to natural conditions or human alteration (Marsh and Trenham 2001). Further, lentic ecosystems are particularly vulnerable to degradation because of sensitive physical and chemical balance required to sustain their biological integrity, and when altered they require lengthy recovery periods. Thus, persistence of populations of lentic-associated species within a given landscape is particularly sensitive to environmental degradation and habitat loss. Recent research has shown potential interactions between amphibians and fish (e.g., Knapp et al. 2001, Philliod and Peterson 2001), specifically exotic fish exacting heavy predation on native amphibians. Research on biotic perturbations in high elevation lake ecosystems indicate that while both vertebrate and invertebrate communities showed low resistance to introduced fish predators (i.e., they declined dramatically in response to the predator), they recovered quite quickly following removal of fish. However, responses were variable and apparently dependent on dispersal abilities and proximity of source populations of species for recolonization (Knapp et al. 2001).

Conservation of aquatic ecosystems and populations of associated biota hinges on the ability to identify key stressors and associated thresholds for population persistence. The distribution and density of aquatic habitats will greatly affect the rate of exchange of individuals among sites and thus the probability of persistence of a given species. The degree to which populations of aquatic associated amphibian and reptile species exhibit metapopulation structure has been debated (Marsh and Trenham 2001) but some predictions can be made. In general, the probability of population persistence per habitat unit generally would be lower in a landscape with few, widely spaced habitat units separated by a relatively inhospitable (i.e., non-aquatic and hostile) environment compared to a landscape with many, closely spaced habitat units. Of course the true difference between such landscapes in terms of how they might influence metapopulation dynamics would be determined by the habitat specialization, environmental tolerances, and dispersal characteristics of each species.

The Lake Tahoe basin provides a model landscape for testing hypotheses about the persistence of aquatic associated vertebrate species under conditions of limited habitat availability and a range of degradation and loss of aquatic habitats. The Lake Tahoe basin is a topographically confined, high elevation basin on the western edge of the Great Basin. A recent assessment of the status of aquatic ecosystems in the Lake Tahoe basin (Manley et al. 2000) concluded that lentic ecosystems (standing water, including lakes, wet meadows, and bogs) were at risk of degradation and loss based on their condition and levels of protection compared to lotic ecosystems. Lentic and lotic ecosystems provide different suites of resources for aquatic associated wildlife, and although some overlap in species occurrence is common among these aquatic types, many species are primarily associated with either lentic or lotic habitat types. In the high elevation environment of the Lake Tahoe basin, small mountain streams appear to offer limited habitat for the majority of aquatic-associated vertebrates, particularly amphibians and snakes (Manley et al. 2000), thus our study focused on lentic ecosystems as the primary habitat for these species in this landscape.

Six amphibians were identified as focal species in the *Lake Tahoe Watershed Assessment* (Manley et al. 2000), indicating that each merits conservation attention. The long-toed salamander (*Ambystoma macrodactylum*) has declined in some areas of California (Jennings 1996), little is known about the salamander's natural history in alpine environments (Tyler et al. 1998). Mountain yellow-legged frogs (*Rana muscosa*) and Yosemite toads (*Bufo canorus*) are California species of special concern, Federal Candidates for listing (Jennings and Hayes 1994, California Department of Fish and Game 2004, U.S. Fish and Wildlife Service 2004), and USDA Forest Service sensitive species (USDA 1998). The geographic range of the Yosemite toad lies primarily south of the basin, from Alpine County south to Fresno County in the Sierra Nevada. Although there are a few historic records of its occurrence in the basin, it is unlikely that its populations will be re-established in the basin given that is it has experienced significant declines within its primary range over the past 50 years. Pacific treefrogs (*Hyla regilla*) and western toads (*Bufo boreas*), relatively common throughout the state, appear to have declined in the Sierra Nevada (Martin unpublished manuscript 1992, Drost and Fellers 1996). Bullfrogs (*Rana catesbeiana*) and probably northern leopard frogs (*Rana pipiens*) were introduced to the basin (Zeiner et al. 1988, Jennings and Hayes 1994) and bullfrogs in particular have been implicated in the decline of some frog species in California (Moyle 1973). Northern leopard frogs did not appear to have established a population in the basin, and have not been recorded in the basin since the 1940s.

Long-toed salamanders are the only salamanders confirmed to breed in the Lake Tahoe basin. They breed chiefly in temporary ponds at low elevations and in permanent fishless ponds at higher elevations (Basey and Sinclear 1980, B. Shaffer, pers. comm., K. Leyse pers. comm.). Adults spend most of the year underground (Anderson 1967). Larvae appear especially vulnerable to predation by trout (Jennings 1996, Tyler et al. 1998). Kezer and Farner (1955) showed that elevation and lake area affected the timing of metamorphosis of long-toed salamanders. Individuals may remain in the larval stage over the winter (Kezer and Farner 1955), perhaps accounting for their susceptibility to trout predation. In addition, larval salamanders appear to be more common in waters with high densities of aquatic macroinvertebrates (Tyler et al. 1998). Apart from effects of introduced fish (e.g., Pilliod and Peterson 2001), little information is available on effects of human disturbance.

Western toad and Pacific treefrog, breed in diverse habitats over a wide elevational range (Stebbins 2003). Toad populations appear to be in decline in California's Central Valley (Fisher and Shaffer 1996) and in the Sierra Nevada (Drost and Fellers 1996). The reasons for decline remain unclear. Though toads are mostly protected from predators as adults by their poisonous parotoid glands, they are vulnerable to many predators as tadpoles (Morey 1988). Little information exists on whether introduced fish prey on toad tadpoles and whether human disturbance has direct effects on toads. Pacific treefrogs are one of the most abundant and widely distributed amphibians in the western U.S. While they are not thought to be declining across their range, regional studies have shown moderate decreases in numbers of populations (Drost and Fellers 1996) and recent studies in the southern Sierra Nevada have demonstrated negative effects of predatory non-native trout on treefrog presence and abundance (Matthews et al. 2001). Mountain yellow-legged frogs are known from only 2 localities within the Lake Tahoe Basin. They are declining throughout their geographic range (Fellers et al. 2002). Non-native fish introductions, chytrid fungus (likely a secondary factor), and pesticides (wind borne) are believed to be the major culprits (Knapp and Mathews 2000, Davidson 2004, R.A. Knapp, pers. comm.).

Three species of garter snakes comprise the aquatic reptile fauna of the Lake Tahoe basin: the common garter snake (*Thamnophis sirtalis*), the western terrestrial garter snake (*T. elegans*), and the Sierra garter snake (*T. couchii*) (Zeiner et al. 1988). Garter snakes are poorly studied in the basin, and concern exists about their populations throughout the Sierra Nevada (G. Fellers pers. comm.). Habitat relationships of the basin's garter snakes have not been previously studied. All three species in the basin occur primarily near water (Zeiner et al. 1988), despite differences in their common names. Garter snakes are predators of amphibians (Zeiner et al. 1988), thus it may be informative to assess their distributions along with those of amphibians. In addition, some concern exists about the fate of garter snake populations due to the decline of a major component of their prey base (Jennings et al. 1992, Matthews et al. 2002). In addition to amphibians, garter snakes also prey on fish and possibly insects (Stebbins 2003). Garter snakes occupy various aquatic and terrestrial habitats (Fitch 1941), with only western terrestrial garter snakes occurring above 2400 m (8000 ft) (Zeiner et al. 1988).

Objectives

The primary objective of study was to characterize the distribution, status, and change of aquatic amphibian and reptile species in their primary habitat (lentic ecosystems) in the Lake Tahoe Basin. We used a combination of data on presence, abundance, and local and surrounding habitat conditions to address the following specific objectives:

- Determine the current status of aquatic amphibian and reptile populations and associated habitat conditions at lentic sample sites

- Describe the change in the status of populations and habitat condition over the past 5 to 7 years
- Determine what habitat characteristics are useful at predicting the occurrence or abundance of individual species and serve to improve estimates of proportion of sites occupied
- Determine what, if any, species, population metrics, or condition measures appear to be effective indicators of the biological integrity and biodiversity of lentic ecosystems
- Provide recommendations on the design and implementation of a monitoring program for aquatic amphibians and reptiles and associated lentic habitat conditions

We posed a number of null hypotheses about the status and change of aquatic amphibian and reptile species that were tested.

- Observed and estimated proportion of sites occupied and abundance did not change significantly between the two sample periods for any aquatic amphibian or reptile species
- Species richness of each taxonomic group did not change over time
- Habitat amount and condition did not change between the two sample periods
- Habitat condition and the diversity, occurrence, or abundance of aquatic amphibian and reptile species are correlated within and among sample periods

Study Area

The study is located in the Lake Tahoe basin of California and Nevada (Fig.1). The 131,000 ha basin contains the largest alpine lake (~50,000 ha) in North America and is bounded by the crest of the Carson Range on the east and the Sierra crest on the west. The basin encompasses an elevational range from approximately 2000 m to 3500 m. Precipitation ranges from 30 to 200 cm per year around the basin, increasing from Lake Tahoe to the surrounding ridges, and reaching its highest levels along the crest of the Sierra Nevada mountains forming the western border of the basin (Daly et al. 2002). The Lake Tahoe basin has 63 major watersheds, over 330 lakes, 3 marshes, 2 fens, and hundreds of acres of meadow, of which an unknown number are perennially wet. This diversity of aquatic ecosystems is high relative to other areas in the Sierra (Murphy and Knopp 2000).

Over the past two decades, aquatic habitat degradation, fragmentation and loss are suspected to be responsible for drastic widespread declines in amphibian populations (Fellers et al. 2002). Lentic ecosystems in the Lake Tahoe basin, have undergone significant alteration by humans in recent decades and their integrity is of concern (Elliott-Fisk et al. 1997, Lindstrom 2000, Manley et al. 2000). Lakes are a primary focus of recreational activities in the basin, including boating, camping, and fishing. Several lake outlets in the basin have been dammed, while several small ponds have been drained (this report). Further, much of the marshland on the south shore of Lake Tahoe has been developed for housing and businesses. Nonnative trout have been introduced into nearly all aquatic ecosystems in the basin (Elliott-Fisk et al. 1997); many lakes continue to be stocked annually by the California Department of Fish and Game. Introduced bullfrogs have spread to marshes and lakes along the south shore of Lake Tahoe, and pose a threat to the persistence of native amphibian species.

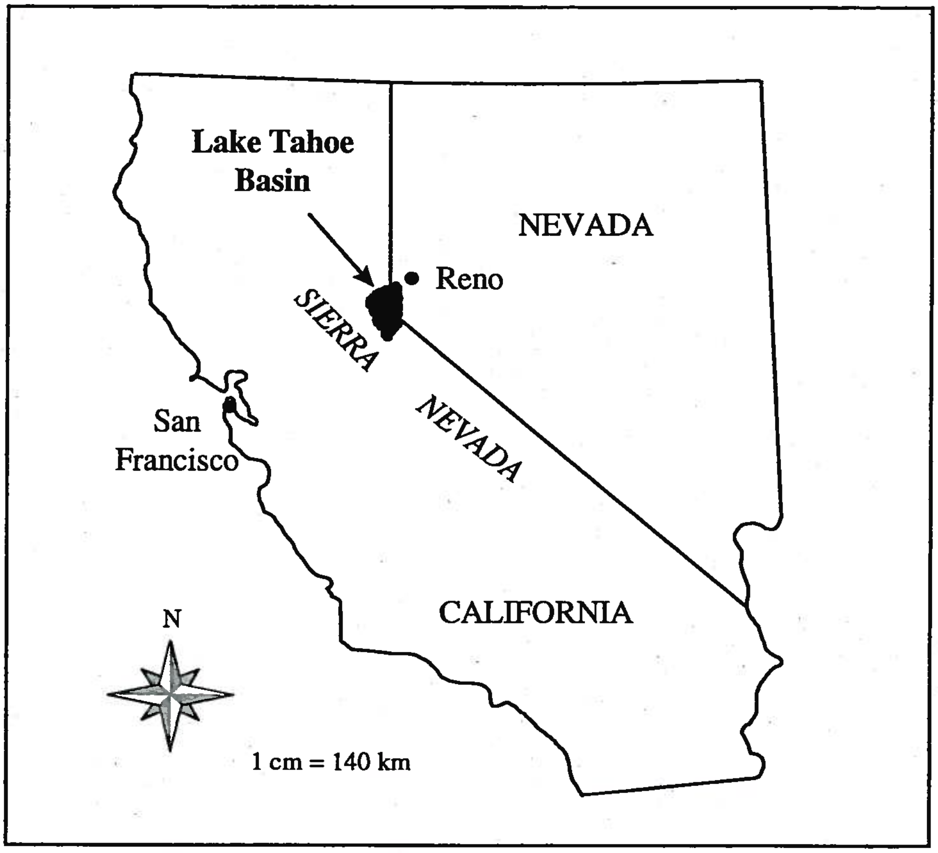


Figure 1. Location of the Lake Tahoe basin.

Methods

Sampling Design

The multiple objectives of the study dictated a complex sampling design. Two categories of sites were sampled: 1) "original" monitoring sites were those selected in the first sample period, 1997 and 1998; and 2) "new" monitoring sites were those selected and surveyed only in the second sample period (2003 and 2004). A total of 192 sample sites were investigated, and a total of 152 unique sites were sampled at least once over the course of the eight year project (Fig. 2).

Sites Sampled in 1997 to 1998

The first sample period for characterizing the status of aquatic amphibian and reptiles and habitat conditions in lentic habitats spanned 1997 and 1998. In 1997 and 1998, 88 lentic habitat units (i.e., the original monitoring sites) comprised of 72 lakes and 16 wet meadows were selected and sampled. The sample was selected in a manner that represented lentic habitat units along three primary environmental gradients in the basin:

elevation, size, and basin orientation (i.e., side of the basin). We used the USGS digital map of all lakes in the Lake Tahoe basin (" waterbody layer") as our sampling frame (see Manley and Schlesinger 2001). We randomly selected approximately equal numbers of lakes from each of 12 elevation-orientation-size classes (Table 1). We then evaluated the representation of lakes in areas with different levels of development based on U.S. Forest Service's Recreation Opportunity Spectrum map.

No complete map of wet meadows was available for selecting wet meadow sample sites. Thus, we randomly selected four, 1 mi^2 sections in each of the four elevation/orientation classes, and then selected one wet meadow in each section for a total of 16 wet meadows (Table 1). Wet meadow sites represent size and disturbance in proportion to their occurrence in each of four elevation/orientation classes (same classes used for lake selection). Forty-eight of the 88 sites were surveyed in 1997, and the other 40 were surveyed in 1998; the set of sites sampled in each year were equitably distributed among the 12 elevation-orientation-size classes. In this first sample period, only one visit was conducted per site per year, and all data were collected during that visit (for more details, see Manley and Schlesinger 2001).

Table 1. Distribution of 152 sample of lentic sites relative to three primary environmental features: elevation, size, and orientation. The break between high and low elevation sites was 2300 m. Small sites were ≤ 0.5 ha, medium sites were > 0.5 - 5 ha, and large sites were > 5 ha.

	Lakes						Meadows		
Elevation	High			Low			High	Low	
Size	S	M	L	S	M	L	-	-	TOTAL
Original 88:									
Eastside	7	6	5	7	8	2	3	4	42
Westside	6	7	3	9	4	8	3	6	46
Additional 64:									
Eastside	10	3	0	3	2	0	3	5	26
Westside	7	2	6	5	6	5	3	4	38
Total sample (#):									
Eastside	17	9	5	10	10	2	6	9	68
Westside	13	9	9	14	10	13	6	10	84
Basinwide	30	18	14	24	20	15	12	19	152
Total sample (%):									
Eastside	36.2	90.0	100	31.3	71.4	33.3	-	-	-
Westside	13.3	31.0	64.3	25.9	76.9	100	-	-	-
Basinwide	34.9	64.3	77.8	16.6	51.3	78.9			

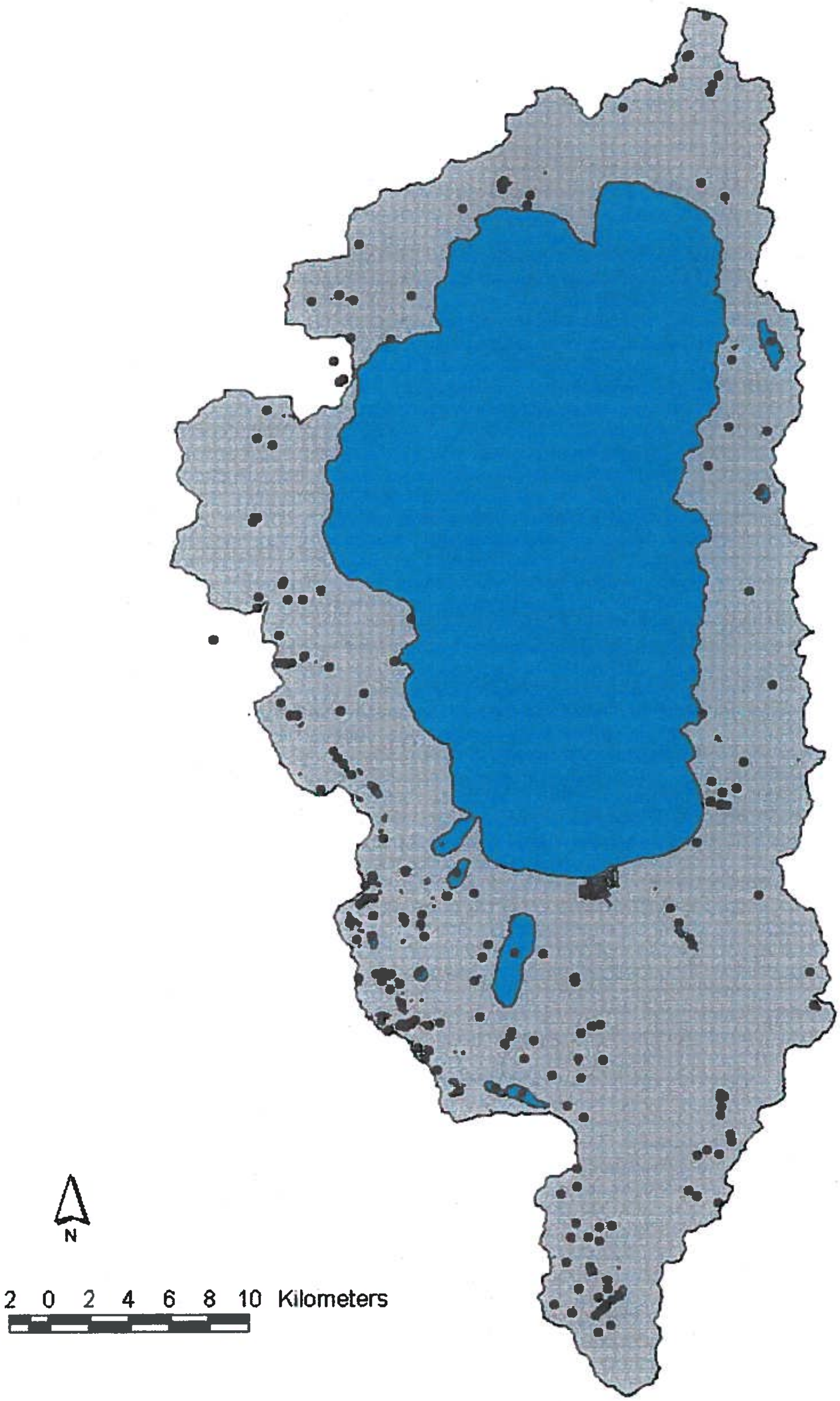


Figure 2. Distribution of all lentic sample sites in the Lake Tahoe Basin

Sites Sampled in 2002 to 2004

The second sample period spanned 2002 to 2004. The second sample period consisted of resampling the original monitoring sites and sampling new sites to increase the total number of sample sites to strengthen inferences about current status and future change (see Appendix A for full accounting of number of sites sampled and resampled in each year). In 2002, a representative subset of 47 of the original 88 sites was resurveyed. In 2003, all but four of the original 88 sites were resampled (including all but one of the sites from 2002) and 12 new sites were selected and sampled. The 4 original sites not sampled in 2003 were either drained (Divot Pond), dry every year (Meadow of Honor), or located on private land for which we were not granted access (Incline Lake and Edgewood Lake). In 2004, 30 original sites were randomly selected from the 47 original sites resampled in 2002 to create a 3 consecutive year sample history for 30 sites. In addition, 52 new sites were sampled in 2004. For the purposes of establishing a stronger data set for analyzing population dynamics of the long-toed salamander, we also resampled 23 sites that had long-toed salamander detections in one or more previous sample years. Data from these sites were only used in special analyses for the long-toed salamander. Between 2003 and 2004, a total of 64 new monitoring sites were sampled, bringing the sample size in the second sample period to 148 sites (not counting the 4 sites lost from original 88). All new sites were selected in the same manner as the original 88 sites so the combined sample represented the three strata (elevation, size, and orientation) as equitably as possible. The resulting distribution of new sites among the 12 elevation-orientation-size classes was not equitable because some classes had few remaining sites in the basin and we sampled them all (Table 1).

Multiple visits were made to most sites each year in the second sample period to improve the probability of species detections and enable the estimation of probability of detection and proportion of sites occupied. Most detection methods are imperfect, in that they may not detect species when they are present. Multiple visits enables the use of statistical techniques (maximum likelihood estimation) to estimate the probability that an individual of a given species will be detected if it is present, based on a given detection method and level of survey effort. Multiple visits were only conducted at subset of sites in some years because of funding limitations. In 2002, 22 of the sites were surveyed twice and the remaining 23 sites were surveyed once. In 2003, all 96 sites were surveyed twice, and in 2004, 78 sites were surveyed twice, including 26 original sites and all 52 of the new sites added in 2004.

Complete Sample

The complete sample of sites varied between 2 and 17 sites in each elevation-size-orientation category, with the variability primarily a function of availability (occurrence and access) (Table 1). Basinwide, the number of sites per elevation-size category ranged from 12 to 30, with the smaller numbers of large lakes sites compared to small lakes, and more meadows at high elevation than low. The number of lakes at high and low elevations were similar in number (n = 62 and 59, respectively). The percent of the total population of sites represented by the sample varied by elevation-size-orientation category, reflecting the varying abundances of sites in each category. The waterbody data layer for the basin indicated 335 waterbodies in the Lake Tahoe basin, including Lake Tahoe. A greater proportion of large sites (approximately 75%) were sampled compared to medium and small sizes, simply because there were fewer of them, but only a slightly smaller proportion of medium sized sites (50 to 64%) were sampled. Small sites were most abundant in the basin, particularly on the westside, where there were approximately 40% of all sites and 50% more small sites (n = 145) compared to the eastside (n = 89. The loss of Divot Pond represents a loss of one eastside, low elevation, small site. If access to the other two sites from sample period 1 (Edgewood Lake, Incline Lake) is not regained, then the sample is reduced by two additional low elevation sites on the eastside, one small and one medium sized.

Amphibian and Reptile Survey Methods

Amphibian and reptile survey methods were relatively consistent over the course of the two sample periods (Appendix B). Two detection methods were used: visual encounter surveys and pole seining. Visual encounter surveys consisted of walking 100% of the perimeter of lakes and ponds, or by walking 100% of the interior of wet meadows (Fellers and Freel 1995). At lakes, observers walked one to several meters inside the bank of the lake or pond unit while following the perimeter (Fig. 3). When two observers were required, they began to survey at the same point and surveyed in opposite directions until they met. In meadow habitats, observers meandered from side to side covering the entire width of the meadow with each new trajectory (Fig. 4). In meadows, when standing water was too deep to walk through, observers walked the perimeter of the water body.

Surveys were conducted between 0800 and 1700 hrs. Observers recorded the duration of searches and the area searched. In all habitat types, observers spent approximately 15-20 minutes per 100 m surveyed, with the clock stopped when extra time was needed to identify species, count tadpoles, maneuver around obstacles, or collect specimens for tissue collection (see Appendix C). Observers spent most of the time walking in the water, searching through emergent vegetation with a long-handled dip-net and overturning rocks, logs, and debris to reveal amphibians and reptiles (Fellers and Freel 1995). All amphibian and reptile species seen or heard were recorded, including species, life stage (egg, tadpole, juvenile, adult; Corkran and Thoms 1996), and number of individuals (or egg masses); associated substrates were also recorded (e.g., on rock, silt, bank etc.). The species and number of all waterbirds and mammals detected during the perimeter survey were also recorded, but these data are not presented here (see Appendix D).

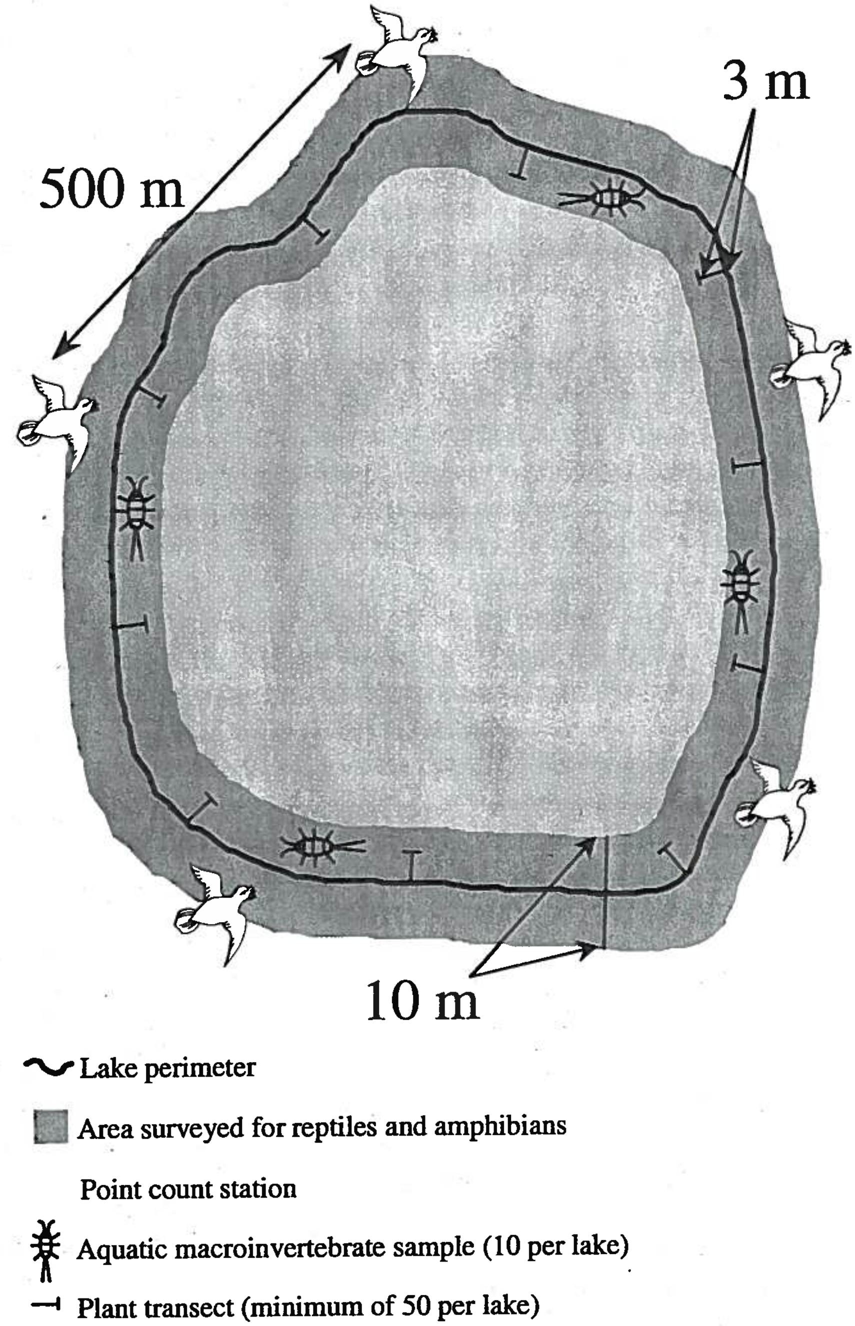


Figure 3. Schematic of biological sampling conducted at each lake sampled in the Lake Tahoe basin. [Note: Waterbird sampling was conducted as part of the study, but the results are not reported here].

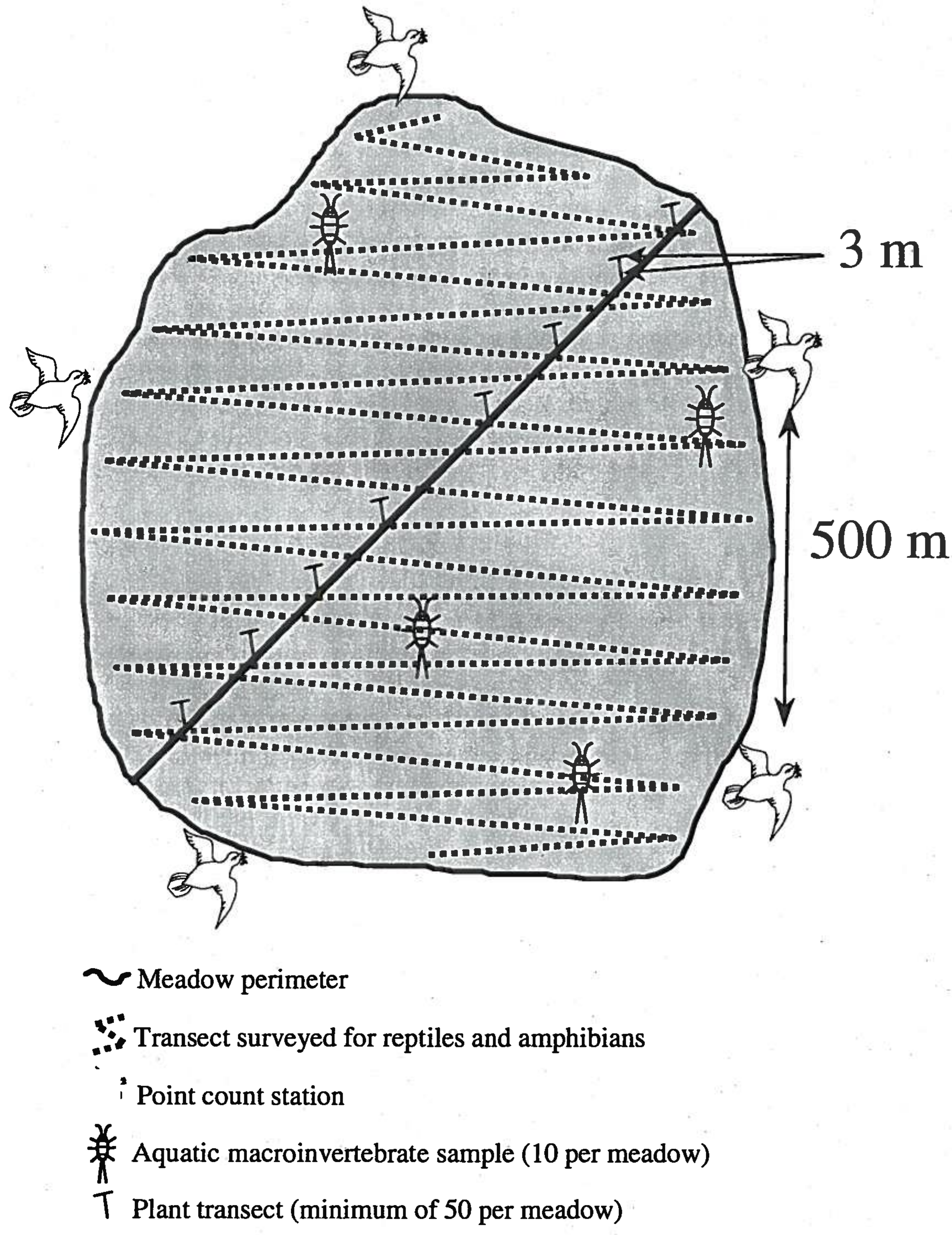


Figure 4. Schematic of biological sampling at wet meadows in the Lake Tahoe basin. [Note: Waterbird sampling was conducted as part of the study, but the results are not reported here].

Fish Surveys

The presence and abundance of fish were recorded during each survey. During visual encounter surveys, observers noted the presence, abundance, and species of fish to the lowest taxonomic level possible: minimally fish were recorded as trout or non-trout (Moyle 1976). If fish were detected during visual encounter surveys, their abundance was recorded in categories: none, few = 1-3, or many = 10s to 100s. If no fish were observed during visual encounter surveys, and the water was greater than 1 m deep, then observers conducted a snorkel survey by snorkeling along the surface of the sample site using a mask, snorkel, and fins to determine presence/absence of fish. In larger lentic habitats, snorkeling was conducted from an inflatable raft. Lakes were snorkeled until fish were observed or for a maximum of 10 min for lakes less than 1 ac with 2 additional min per ac (for a maximum of 30 min) for larger lakes. These methods were considered reasonably reliable to determine presence and general abundance (few vs. many), but not for estimates of absolute numbers of fish.

Environmental Measurements

Habitat and environmental features were described at each sample unit surveyed, including resample sites, new individual sites, and sites sampled within watersheds around occupied sites. These variables fall into two categories: variables measured in the field and variables derived from GIS data layers. Habitat and environmental measures changed slightly between the two sample periods (Appendix B). At a subset of sites and years, habitat variables were measured during both survey visits in a given year.

The following data were collected at each lentic unit in each year. Variations in methodologies among sample years are noted and schematics of sampling are shown in Figs. 3 and 4:

- Unit area. Observers estimated area by estimating average length and width, and pacing the circumference (meters). Field measurements were checked against digital data. Sample unit area and perimeter were obtained from digitized USGS topographic maps or from USGS (1994) for wet meadows derived from that source.
- Maximum depth. For shallow sample units, observers waded when possible to the deepest part of the sample unit and measured the depth to the nearest 0.1 m using a PVC pipe or other measuring device. For deeper sample units up to 30 m, observers employed a reel with a lead sinker attached to a heavy fishing line on which 1 m increments were delineated. Depth was determined by lowering the line to the bottom from an inflatable raft. Maximum lake depth was recorded as the greatest depth (to the nearest 0.5 m) obtained from 5 measurements in locations likely to be at or near the deepest part of the sample unit. Values for deep sample units with known depths were obtained from Schaffer (1998) or from knowledgeable individuals.
- Littoral depth and substrate. A minimum of 30 littoral zone transects were established at each lentic unit to quantify shoreline depth, substrate, woody debris, and emergent vegetation. At lakes and ponds, transect locations were determined according to paced or timed intervals as one moved around the perimeter of the lake so that at a minimum of 30 or 50 transects (depending on the protocol for the year) were measured. For lakes and ponds, each transect consisted of a visualized line

running perpendicular to the shoreline and extending 3 m into the water from the existing shoreline. For wet meadows and fens, a randomly determined starting point was selected for a straight line across the longest dimension of the meadow. Observers walked from that point to the opposite end of the meadow, determining transect starting points by pacing the distance between points to ensure that 30-50 transects were conducted per habitat. Transects direction was based on a random compass bearing from the observers position. For each transect, observers recorded the depth at 1m , 2m, and 3m (end of the transect), and the percent of transect occupied by each of 6 substrate types (silt, sand [particle size <2 mm], pebbles [2 to 75 mm], cobbles [5 to 300 mm], boulders [>300 mm], or bedrock). In addition, the dominant substrate was also recorded (i.e., substrate covering the greatest proportion of the transect). In contrast, in 1997/98, only the dominant substrate was assigned to each transect (as per Knapp and Matthews 2000).

- Littoral vegetation and woody debris. Along each 3 m littoral zone transect, the presence of littoral zone plant species intersecting the transect line were recorded, including noting whether the plants were submergent, floating on surface, or emergent (breaking the surface of the water) or overhanging (< 10 cm above the water). All plants intersecting each transect were identified to species whenever possible or at a minimum to life form (rush, sedge, willow, pond lily, grass, alder, other shrubs, aspen, cottonwood, pine, fir, other herbaceous, other conifer or deciduous trees) was recorded. Littoral zone plants were defined as rooted underwater or unattached and floating on the surface. In addition the presence of overhanging vegetation ($\leq$ 10 cm above the water) was recorded. Woody debris was also recorded along each transect. For all logs $\geq$ 10 cm diameter at the large end that intersected the transect, we recorded the species (if possible), diameter at each end of the log, and length. In contrast, in 2002 and 2003, plant presence was not recorded, and in 1997/98, characteristics of woody debris were not recorded.
- Shoreline substrate and vegetation. Shoreline substrates and vegetation were characterized along transects that extended from the water body edge to 2 m into the surrounding terrestrial zone. For each transect, observers recorded the percent of the transect occupied by each of 6 substrate types (silt, sand [particle size <2 mm], pebbles [2 to 75 mm], cobbles [5 to 300 mm], boulders [>300 mm], or bedrock), and the presence of each of the following plant categories intersecting the transect: rush, sedge, willow, pond lily, grass, alder, other shrubs, aspen, cottonwood, pine, fir, other herbaceous, other conifer or deciduous trees. Plants were identified to species when possible. These data were only recorded in 2004.
- Invertebrates. In 1997/98, invertebrates were sampled by conducting 10 standard sweeps (1 m left to right and return) using a D-net around the sample unit at regular intervals in a diversity of littoral zone habitat types. The presence of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Tricoptera) was noted and the abundance class recorded for all macroinvertebrates in the net (1 to 3, 4 to 10, 11 to 50, 51 to 100, 101 to 250, 250 to 500, and >500). Mayfly, stonefly, and caddisfly frequencies were summarized as the proportion of samples (10 sweeps) per sample unit containing individuals from each order. An index of macroinvertebrate abundance was calculated for each sample unit by adding the minimum value in the range for each of the 10 abundance classes recorded, adding the maximums for each

class, and averaging the 2 sums. Invertebrate data were not collected in the second sample period (2002-2004).

- Inlets and Outlets. The number of inlets and outlets > 10 cm in width was recorded for each sample unit during surveys in 2004 only. Inlets and outlets are defined as the composite of flows coming from or going to a single source. In some cases, outlets or inlets were braided but were recorded as one.
- Disturbance. Disturbance was described within 10 m and between 10 m and 30 m of the high watermark in lentic habitats (disturbance was not described in the field in 1997-98):
    - area of each type of road (m^2) - hwy, paved road, dirt road
    - area of trails (m^2)
    - area of other compacted areas (m^2)

Data Analysis

Three data sets based on site-year combinations were created to describe status and change of populations and habitats in different time periods (Appendix A). The 84 original sites first sampled in 1997/98 and resampled in 2003/04 were used to characterize the two sample periods and evaluate change between them. Sample data from 1997-1998 for these 84 original sites constituted the first data set and were used to characterize sample period 1. Sample data from 2003-2004 for the 84 original sites constituted the second data set and were used to characterize sample period 2 for the purposes of evaluating population and habitat change. We chose data from 2003/04 to characterize the second sample period because they maximized the time between sample periods. We used 2004 data for 17 of the original sample sites surveyed that year; they were the subset of randomly selected original sites to be sampled that year at which 2 visits were conducted and habitat data were collected. We used 2003 data for the remaining 67 original sites. We chose not to use multi-year data to characterized per-site population and habitat conditions for sample period 2 because we did not want among-year variation in conditions to be reflected in only one sample period. The third data set consisted of all randomly selected sites (original and new) sampled from 2003 and 2004, and consisted of the 84 original sites and 64 new sites. This data set was used to characterize the current status of populations and habitat conditions.

Site Condition Status

We derived three sets of variables from field and GIS data sources (Appendix E). One set of variables ("core" variables) was derived from field-based data and described environmental conditions in both sample periods: littoral zone substrates, and vegetation, and coarse woody debris. Data collected from multiple transects at each sample unit were tallied to represent the percent of transect on which a particular substrate, each vegetation type or coarse woody debris occurred. Littoral transects that were dry were excluded from analysis. The following core variables were derived that could be compared among all sample years: percent of transects dominated by different substrate types and percent of transects with coarse woody debris, emergent, submergent, floating and overhanging vegetation present. These variables are presented in graphs and compared visually only for this draft report. A second set of variables was only recorded in the second sample period. ("additional" variables). These variables were useful in evaluating habitat relationships of individual amphibian and reptile species and provide a more sensitive measure of change between current and future conditions. The third set of variables ("GIS" variables) were generated using remotely-sensed data in the form of GIS data layers. Remotely-sensed data represented conditions in the year 2000. The exception to this was precipitation, which was represented by a 44 year average (1960 to 2004). The variables generated were as follows:

- Physical site characteristics: elevation, orientation to Lake Tahoe, size, and number of inlets and outlets;
- Environmental setting: annual precipitation, vegetation types; and
- Disturbance and administrative boundaries: development index based on land use.

The amount and type of each vegetation series was derived from IKONOS imagery obtained in 2002. The CWHR (Mayer and Laudenslayer 1988) vegetation classification system was used to represent vegetation types. For the purposes of summary statistics and analysis, the 12 vegetation types encountered within 200 m of sample sites were lumped into eight classes (Table 2).

Table 2. Vegetation classes used to describe vegetation surrounding 148 lentic sample units sampled in 2003 and 2004 in the Lake Tahoe basin.

Vegetation class	CWHR vegetation type
Mixed conifer	Jeffrey pine
	White fir
Subalpine conifer	Subaline conifer
	Red fir
Lodgepole pine	Lodgepole pine
Shrub	Mixed chaparral
	Montane chaparral
	Sagebrush
Meadow	Meadow
Aspen	Aspen
Riparian	Montane riparian
Barren	Barren

Change in Site Condition

Field-based condition variables were the only variables that are measured in each time period in a manner that could reliably reflect change. Field-based condition variables shared between the two sample periods were limited to maximum depth and the frequency of occurrence by transect of littoral substrates, emergent vegetation, and logs (n = 9 variables). Unfortunately, disturbance in the vicinity of the lentic sites was only measured in the second sample period, but will be available for future comparisons. A paired t-test was performed to compare values for the 9 condition variables between the two sample periods.

Population Status

Field observations were used to characterize presence and abundance of each species by life stage: egg masses, larvae, adult (adult includes all life stages older than larvae, such as metamorphs and subadults). Individuals detected during visual encounter surveys were used as the basis for calculating naïve (observed in the field) and estimated proportion of sites occupied in each sample period. If a lentic unit was visited more than once within a given year, the maximum abundance was used to represent the site.

Species richness (count of unique taxa) was calculated based on naïve estimates of occupancy for each sample site for each year. Amphibians and reptiles were considered separately for calculations of species richness. The total number of species in the basin is so low that this measure is not greatly informative and is relatively insensitive to change. However, we calculated it for comparison to the 1997-98 reported species richness (Manley and Schlesinger 2001). Estimates of species richness could be calculated based on probability of detection to derive a more accurate measure of richness, but it is not likely to improve the value of this measure.

We used an adjusted estimate of proportion of sites occupied to describe the status of species in each sample period. Naïve estimates based on field observations are an underestimate of the true proportion of sites occupied because detection probabilities in the field are not 100%. For example, suppose that we visit n sites exactly once and the estimate the proportion of sites with presence, P, with the observed proportion of sites with presence, $\dot{P}$. We know that $\dot{P}$ tends to underestimate P as the expectation of $\dot{P}$ is $E(\dot{P}) = P(1-q)$ where q is one minus the detection probability. Also, the variance of $\dot{P}$ is $P(1-q)(1-P(1-q))/n$. We used a maximum likelihood function to estimate the per-visit probability of non-detection (q) of each species for each survey method (MacKenzie et al. 2002) using PROC NLMIXED (SAS vers. 8.3). Multiple visits within a sample season are required to estimate the proportion of sites occupied, and we only had multiple visits in the second sample period. Therefore, we assumed that detection probabilities were constant across monitoring sites within and between the two sample periods, and used estimates of probability of detection to estimate proportion of sites occupied for both sample periods. The model for calculating likelihood for detection and presence, as per MacKenzie et al. (2002), is as follows

$$L(\psi, q) = \left[\psi^{n.} \prod_{t=1}^{T} (1-q_t)^{n_t} q_t^{n.-n_t} \right] \times \left[\psi \prod_{t=1}^{T} q_t + (1-\psi) \right]^{N-n.} \quad (1)$$

where ψ is the probability that a species is present, $q_t = 1 - p_t$ where p_t is the probability that a species will be detected when present at time t, N is the total number of surveyed sites, T is the number of sampling occasions (i.e., visits), n_t is the number of sites with detections at time t (i.e., visit number), and $n.$ is the total number of sites at which the species was detected at least once. We used results from all surveys conducted in 2002-2004 to estimate q for each species. The standard errors of the estimates were estimated as part of the iterative process to determine the maximum likelihood estimates. We used the negative of the inverse of the observed Fisher information statistic determined by the second derivatives of the log likelihood function with respect to each of the parameters (Pawitan 2001) to estimate the covariance matrix of all of the parameters.

We then used the following formula to estimate the proportion of sites occupied, P, for each species in both sample periods

$$\hat{P} = \dot{P}/(1-\hat{q}^{t}) \tag{2}$$

where $\hat{P}$ is the estimated proportion of sites occupied, $\dot{P}$ is the observed, or naïve, proportion of sites with presence, $\hat{q}$ is the estimate of the probability of non-detection, and T is the number of visits per site. In this study, the number of visits per site differed between the two sample periods and within the second sample period. T was equal to 1 for the 1997-98 sample period; for the 2003-04 sample period, T was represented by the average number of visits per site ($\bar{x}$ = 1.64 visits per site) across the 84 sites. We estimated the variance of $\hat{P}$ using the Delta method (Bishop et. al. 1975). If the estimated variance of $\hat{q}$ is $\sigma_{\hat{q}}^2$ and that of $\dot{P}$ is $\hat{\sigma}_{\dot{P}}^2 = \dot{P}(1-\dot{P})/n$, then the estimated variance of $\hat{P}$ using the Delta Method is

$$\hat{\sigma}_{\hat{P}}^2 = \frac{\hat{\sigma}_{\dot{P}}^2}{(1-\hat{q})^2} + \frac{\dot{P}^2\hat{\sigma}_{\hat{q}}^2}{(1-\hat{q})^4} \tag{3}$$

For example, suppose $n = 105$, $\dot{P} = 0.23$, $\hat{q} = 0.665$, and $\hat{\sigma}_{\hat{q}}^2 = 0.06^2 = 0.0036$. Then $\hat{P} = \min(1, 0.23/(1-0.665)) = 0.686567$ and

$$\hat{\sigma}_{\hat{P}}^2 = \frac{\hat{\sigma}_{\dot{P}}^2}{(1-\hat{q})^2} + \frac{\dot{P}^2\hat{\sigma}_{\hat{q}}^2}{(1-\hat{q})^4} = \frac{0.23(1-0.23)}{105(1-0.665)^2} + \frac{0.23^2 \cdot 0.0036}{(1-0.665)^4} = 0.0301503 \tag{4}$$

which makes the estimated standard error of $\hat{P}$ as $\hat{\sigma}_{\hat{P}} = 0.173538$. Maximum likelihood estimates are always equal to or greater than the original naïve estimates, such as in the example the maximum likelihood estimate (0.687) is almost twice as high as the original naïve estimate (0.23).

Population Change

Population change between the two sample periods was analyzed based on the set of 84 original sites surveyed in both sample periods. We determined change by calculating the confidence interval for the difference in the estimated proportion of sites occupied for each sample period and then compared the values. We also did a more qualitative comparison of the change in site status (based on field observations of presence or absence) between the two time periods for each species. The variance of the difference was calculated as follows

$$\sigma_{P_2 - P_1} = \sqrt{SE(\hat{P}_1)^2 + SE(\hat{P}_2)^2} \tag{5}$$

where $SE(\hat{P}_t)$ is the standard error of the estimated proportion of sites occupied at sample period t. A 90% confidence interval was used to evaluate the significance of the difference between the two sample periods.

The relative conservation value of sample sites was determined based on temporal occupancy patterns. We calculated a persistence index (PI) for each site based on two factors: occupancy rate (the number of years a site was occupied) and duration (span of time over which occupancy occurred). Occupancy rate was calculated as the number of years observed at a site divided by the number of years the site was surveyed. Although the number of visits per site varied between 1 and 2 among years, there was no bias among sites so a relative ranking of sites would not be affected. Occupancy rates ranged from 0 to 1, and were ranked as follows: values ranging from 0.25 to 0.49 were assigned a value of 1, 0.50 to 0.74 were assigned a value of 2, and > 0.75 were assigned a value of 3. Duration was evaluated based on occupancy in each of the two sample periods, and provided additional evidence of habitat quality and its ability to consistently supporting populations over time, and sites were ranked as follows: sites with detections only in sample period 1 (1997-1998) were assigned a value of 1, sites with detections only in sample period 2 (2002-2004) were assigned a value of 2, and sites with detections in both sample periods were assigned a value of 3. Rank values for occupancy rate and duration were summed across all six native species to create the site PI value. The site PI value can be used directly to prioritize sites for conservation, and it can be used indirectly to identify environmental characteristics correlated with increased persistence at sites. We used multiple regression to identify site characteristics associated with high PI values. The conservation value of sites was also evaluated for each native species based on their occupancy rate and duration ranks. Similarly, occupancy rates and duration were evaluated for the bullfrog to identify sites favorable to this species.

Species Habitat and Environmental Relationships

Maximum likelihood estimation was used to evaluate the association of environmental variables with species presence given that species were detected imperfectly. NLMIXED (SAS 9.1) was used to consider environmental variables as covariates in the assessment of species occurrence at sites. Ten environmental variables were included as covariates in the model for each species: size, elevation, precipitation, number of sites within 1 km (< 5 ha and ≥ 5ha), the proportion of the area within 200 m occupied by forest, meadow, shrub, and riparian, and the amount of the area within 50 that was developed (as per the development index).

Herp-Fish Interactions

We conducted chi-square contingency table analyses to examine relationships between the presence of fish and presence of each species. We conducted this analysis on 2004 data only because field methods in that year were the most rigorous relative to detecting fish presence. This question was addressed previously for the 1997 and 1998 sample data and is presented elsewhere (Manley and Schlesinger 2001).

Indicator Development

A herpetefaunal index of biological integrity (IBI) was developed for lentic sites based on five metrics: richness and abundance (adults and metamorphs) of amphibians, richness and abundance (adults and juveniles) of garter snakes, and presence of bullfrogs. The index was based on the status data set (148 sites sampled in 2003 or 2004). Abundance values used in the analysis were the highest number of individuals of any life stage (adult, subadult, or juvenile) recorded in either visit. Abundance values over 30 were rounded to the nearest 10, over 300 were rounded to the nearest 50, over 1000 rounded to the nearest 500, and all numbers over 10000 were represented by 10000.

For each metric, sites were arrayed in rank order based on the value of the metric, and then they were divided into three sequential intervals. The interval breaks were determined based on the distribution of observed values, ecological considerations, and ease of use for future applications. For species negatively associated with development, values were assigned to intervals as follows: sites in the lower interval were assigned a "0", sites in the middle interval were assigned a "5", and sites in the highest interval were assigned a "10". Specifically, species richness of native amphibians and garter snakes were assigned a value of "0" if no species were present, a "5" if 1 species was present, and a "10" if 2 or more species were present. Abundance can vary dramatically from year to year, so only very high abundance values (> 100 amphibians or > 10 garter snakes) were assigned a "10", and any lesser number greater than 0 was assigned a "5". For bullfrog which was positively associated with development, rank values are assigned in reverse: presence was assigned a "0", and absence was assigned a "10". The assigned values were summed across all metrics for each site to derive a total IBI value, where high values indicated good condition. The summed values were converted to a percent ("IBI site score") by dividing it by the theoretical maximum IBI value for any site in that ecotype as determined by the number of indicators (i.e., number of indicators * 10). Finally, the IBI site score was graphed against development (within 200 m) to define condition classes that indicated good, fair, and poor condition. The distribution of scores among sites with ≤ 10% development was provided as a potential basis for the desired proportion of sites in each condition class throughout the basin.

Monitoring Sample Size Analysis

We generally followed the approach of Manley et al. (2004) to assess the adequacy of sampling to detect a ≥ 20% relative change in the proportion of sample sites occupied between two time periods with a type I error rate of $\alpha \leq 0.2$, or 80% confidence, and a type II error rate of $\beta \leq 0.2$, or 80% statistical power. We used the estimated proportion of sites occupied, $\hat{P}$, across the 7 species of amphibians and garter snakes to inform the selection of three generic levels of P (50%, 20%, and 10% occupancy) for which we calculated sample size requirements. We could have calculated a specific sample size per species, but we chose to generate more generic sample size requirements to be consistent with the multiple-species approach that has thus far been taken to monitoring lentic ecosystems in the basin (see Roth et al. 2004).

We calculated sample sizes based on a change in the proportion of sites with observations, not the estimated proportion of sites occupied. The proportion of sites with observations, $\dot{P}$, is a function of the proportion of sites actually occupied, P, and the probability of detection with a given sampling protocol, p_d, as follows

$$\dot{P} = P * p_d \qquad (6)$$

where $p_d = (1-\hat{q}^t)$. We assumed two visits to all sites in this evaluation of sample size needs for monitoring. We calculated the 90% confidence interval (CI) for p_d for each species to determine the upper and lower bounds of N, the minimum number of sample sites needed to detect a relative change (increase or decrease) of $\geq$ 20%, for each of the three generic P values. The 90% CI was derived for each species using the standard error of q, $SE(q)$. The 90% confidence lower bound is given by

$$\text{Lower}\ (\text{CI}_{90\%}, p_d) = p_d - 1.644 * SE(q) \qquad (7)$$

Sample size requirements, N, were then determined by the proportion of sample sites with observations during the first sample period ($\dot{P}_1$), the effect size ($\delta = 0.2 * \dot{P}_1$), the prescribed error rates (α and $\beta = 0.2$), the direction of change desired to be detected (2-tailed), and site correlation ($\rho = 0.9$) between sample periods (Hoel et al. 1971a, Sokal and Rohlf 1995). A 2-tailed test was selected because it is a more rigorous test of the detection adequacy, and we always selected the larger of the two sample size estimates to increase the rigor of our evaluation. As in Manley et al. (2004), we assumed that sites would be remeasured with minimal error, so site correlation between sample periods was modeled as high (0.90), but not perfect (1.0). Thus, the N necessary to detect a $\geq$ 20% change between two sample periods for a given species was estimated using the normal approximation (Fleiss 1981):

$$N = \frac{\left[z_\alpha * \sigma_o + z_\beta * \sigma_a\right]^2}{(\delta * \dot{P}_1)^2} \qquad (8)$$

where z_α and z_β represent the 2-tailed critical values from a normal distribution, and σ_0 and σ_a represent standard deviations of the difference between $\dot{P}_1$ and $\dot{P}_2$ under the null and alternative hypothesis, respectively (Fleiss 1981).

Variance estimates were calculated based on a binomial distribution, and we assumed that $\dot{P}_t$ was approximately normally distributed (Hoel et al. 1971a,b). Variance associated with binomial distributions is greatest at the mid-point (0.50) and tapers toward 0 and 1 from the mid-point (Zar 1998): therefore, associated sample size requirements were asymmetrical, with the larger value associated with increases when $\dot{P}_1 \leq 0.5$ and declines when $\dot{P}_1 > 0.5$. The standard deviation of the difference between $\dot{P}_1$ and $\dot{P}_2$ was calculated using the standard formula:

$$\sigma_i / \sqrt{N} = \sqrt{\sigma^2_{1i} + \sigma^2_{2i} - 2\rho\sigma_{1i}\sigma_{2i}} / \sqrt{N} \quad (9)$$

where, for the null hypothesis of no change ($i = o$), σ^2_{1o} σ^2_{1o} and $\sigma^2_{2o} = \dot{P}_1(1 - \dot{P}_1)$, and for the alternative hypothesis of $\geq$20% change ($i = a$), $\sigma^2_{1a} = \dot{P}_1(1 - \dot{P}_1)$, $\sigma^2_{2o} = \dot{P}_2(1 - \dot{P}_2)$, $\dot{P}_2 = (1 - 0.20)\ \dot{P}_1$, and N = sample size.

Results

Status and Change of Site Conditions

General Representation

The sample sites representing current conditions consisted of 148 sites distributed around the basin and represented a wide range of sizes and elevations in the basin (Table 3). All sites were sampled in some categories resulting in sampling inequities among categories; specifically, almost all large lakes and low elevation lakes were sampled.

Table 3. Lake selections and their characteristics based on 4 gradients: orientation, elevation, size, and disturbance. Lakes were surveyed in 2003 and 2004 in the Lake Tahoe basin.

Orientation:	East						West						
Elevation*:	High			Low			High			Low			
Size**:	S	M	L	S	M	L	S	M	L	S	M	L	TOTAL
Disturb***:													
None	14	6	1	1	2	0	9	8	2	4	3	0	50
Low	4	6	7	4	5	2	6	7	9	9	9	13	81
Moderate	0	0	0	3	2	0	0	0	0	1	1	1	8
High	0	0	0	5	2	1	0	0	0	0	0	1	9
TOTAL	18	11	8	13	12	3	15	13	11	14	15	15	148

* Elevation: Low is < 2300 m, High is ≥ 2300
** Size: S is < 0.5 ha, M is 0.5 to < 5 ha, L is ≥ 5 ha
*** Disturbance within 200 m: Low is >0 to 10%, Moderate is > 10 to 30%, High is > 30%

Status of Site Conditions

Silt was by far the most common substrate at sample sites; it was present at 98% of the sites, and silt exceeded 75% of the substrate cover at over 60% of sites (Fig. 5). The remaining substrate types were only present at 40 to 60% of the sites, and few sites exceeded 25% cover of any of the remaining substrates. Of these, sand and cobble were the most prevalent, exceeding 25% cover at 10% and 17% of the sites, respectively, with a few sites exceeding 50% cover.

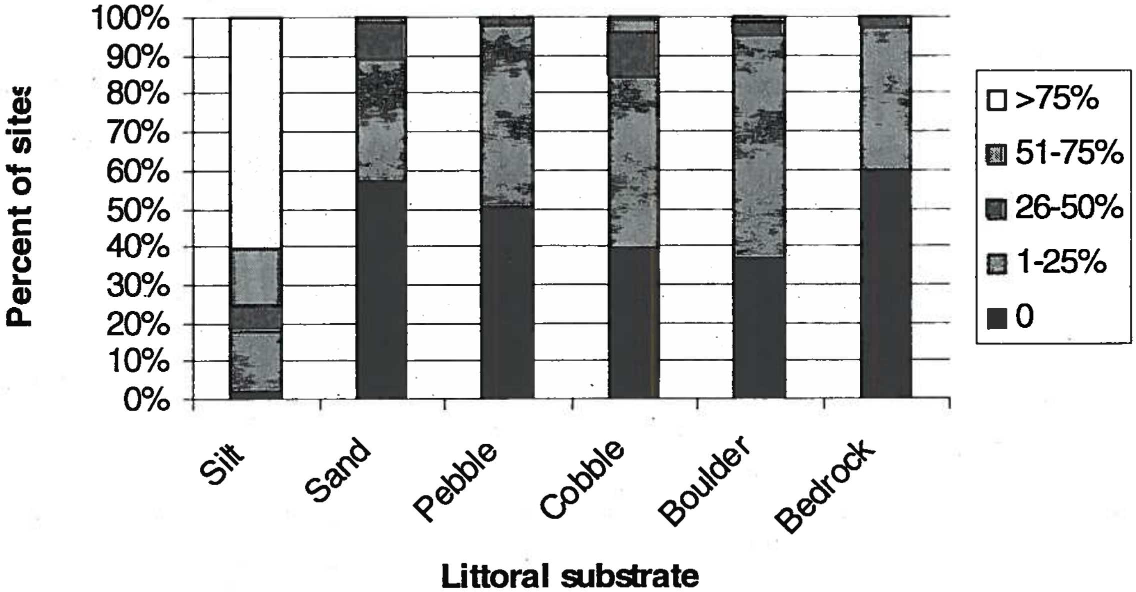


Figure 5. Littoral substrate average percent occurrence at 140 lentic habitat sites sampled in 2003 and 2004 in the Lake Tahoe basin.

Logs were prevalent in the littoral zone at most sites, with approximately 70% of all sites having one or more logs in the littoral zone (Fig. 6). However, logs were typically not abundant, with most sites having less than 25% of the littoral zone occupied by logs. Emergent plants were present at over 90% of all sites, and over 60% of sites had emergent plants occupying 25% or more of the littoral zone (Fig. 6). Comparisons of frequency of types of vegetation were based on dominance among transects, and based on these data emergent vegetation was also the most common vegetation life form at the lentic sites (Fig. 7). Over 45% of sites had emergent vegetation on at least 75% of littoral zone transects (Fig. 7b). Submergent vegetation was the next most common vegetation life form.

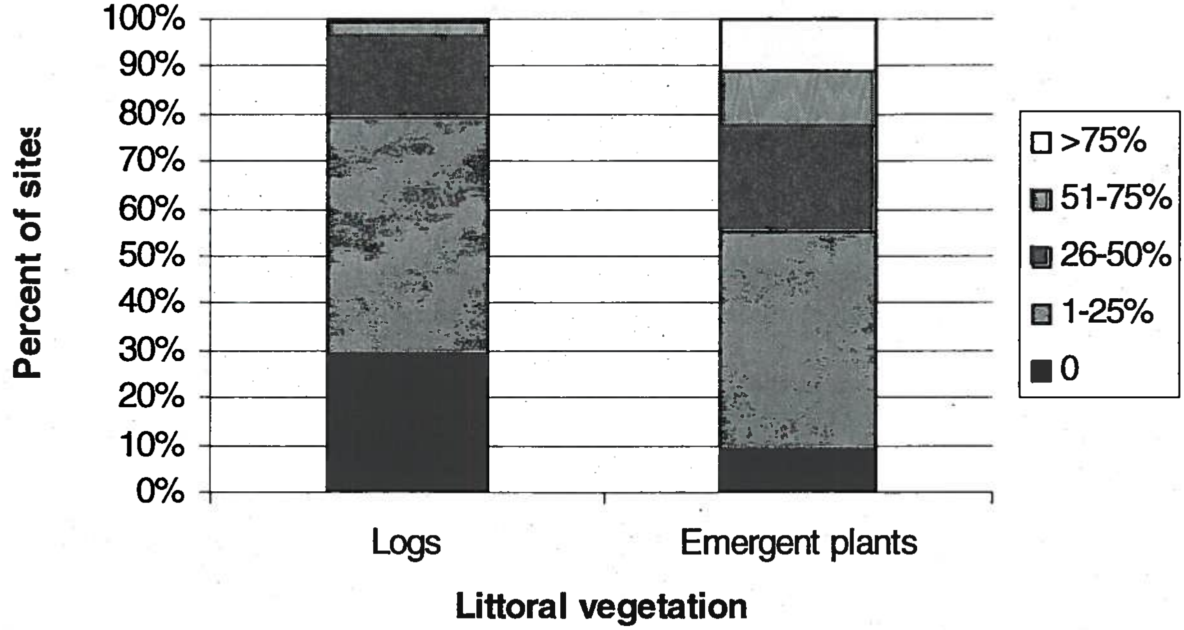


Figure 6. Littoral vegetation average percent occurrence at 143 lentic habitat sites sampled in 2003 and 2004 in the Lake Tahoe basin.

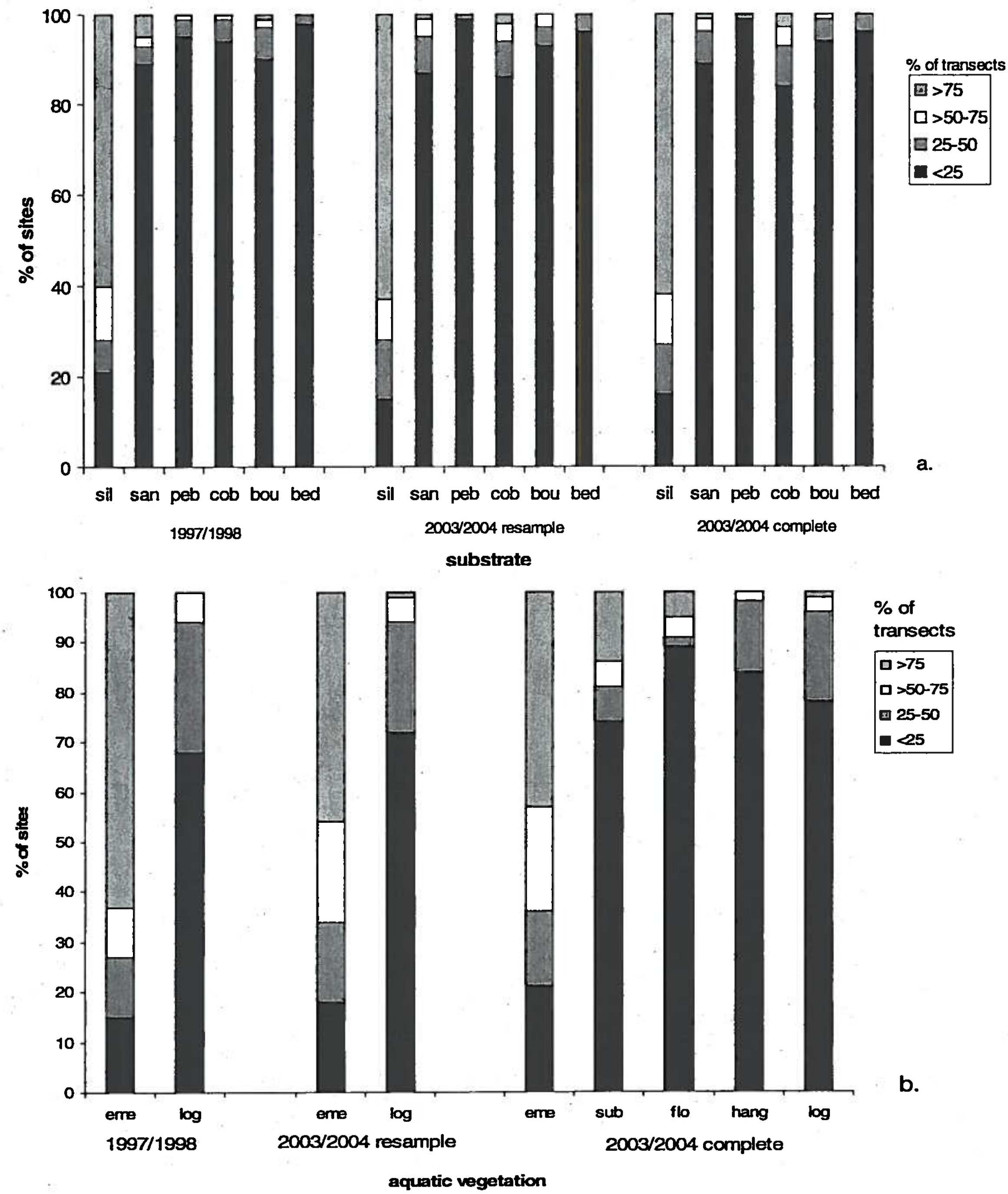


Figure 7. Frequency distribution of (a) dominant substrate and (b) vegetation (eme=emergent, sub=submergent, flo=floating, hang=overhanging, log=course woody debris) along aquatic transects at lentic sample sites in the Lake Tahoe Basin. Two groups of bars in each chart represent the first sample period (1997/1998) and the second sample period (2003/2004) of a common set of sites (n=84). The third group of bars (2003/2004 complete) includes the full set of sites sampled in 2003 and 2004 that are representative of the array of conditions occurring in the basin (n=148). However, missing data resulted in a sample size of n=137 for emergent substrate and logs and n=58 for the other vegetation variables.

Based on field data, only 4 sites (2.8%) had pavement within 10 m of the shoreline, and only 16 sites (11.2%) had pavement within 30 m of the shoreline. Approximately three times as many sites had compacted soil within 10 and 30 m of the shoreline: 21 sites (14.7%) within 10 m and 48 sites (33.6%) within 30 m of the shoreline. Based on the same set of sites, development in the larger landscape was also relatively low (Fig. 8). Within 50 m of each site, approximately 50% of the sites had no development, and only 8% were over 10% developed. Within 200 m of each site, development was encountered for a greater proportion of sites, bringing the percent with no development down to 33%, and a slightly greater proportion of sites (11.5%) had over 10% of the area developed.

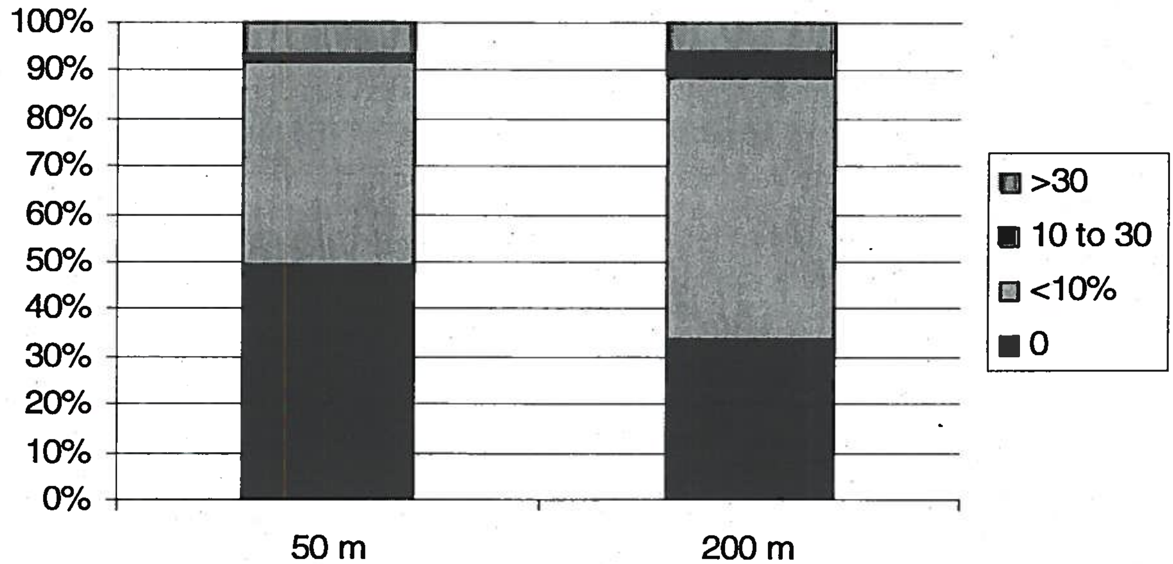


Figure 8. Percent of lentic sample sites with each of four categories of percent developed within two distances (50 and 200m) of the shoreline. Data were collected at 148 sites in 2003 and 2004 in the Lake Tahoe basin.

Vegetation within 200 m of sample sites showed a predominance of four vegetation classes (Fig. 9). Shrub dominated vegetation was the most frequently occurring vegetation class, followed by subalpine conifer, where they were present at 80% or more of the sites. Shrubs dominated (> 50% of the area) the vegetation at approximately 30% of the sites, but subalpine conifer dominated only just over 10% of the sites. Mixed conifer and lodgepole pine were also prevalent, occurring at over 40% of all sites, with mixed conifer being the dominant vegetation type at over 30% of the sites. Riparian vegetation was present at over 50% of the sites (at least to the extent that it was mapped), but it did not exceed 50% at any site. Meadow and aspen were present at approximately 80 and 90% of the sites, and rarely exceeded 25% at any site. Barren areas were present at over 30% of the sites, but only a few sites exceeded 25%.

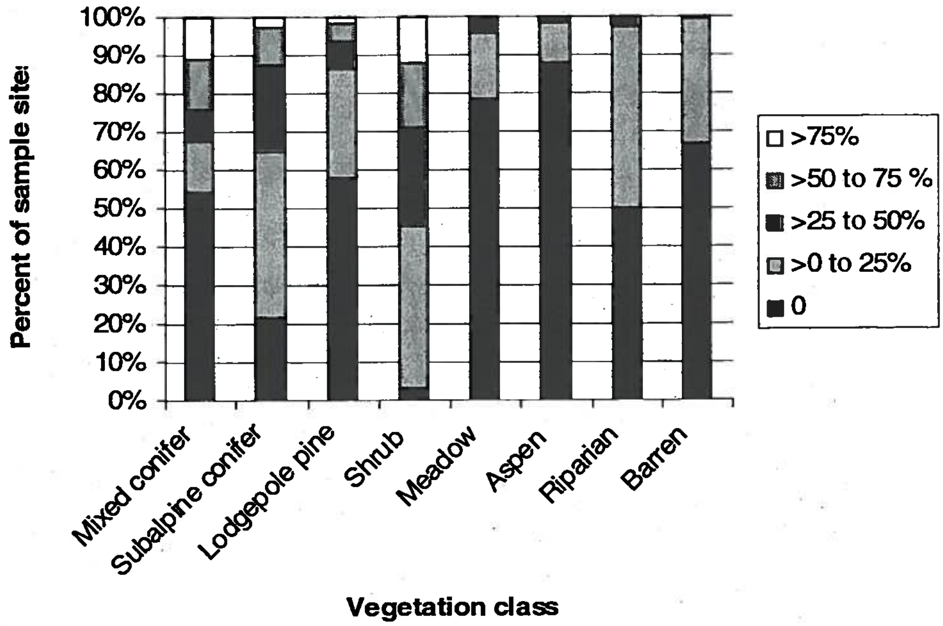


Figure 9. Percent of sample sites occupied by each of eight vegetation classes by percent of the area occupied within 200 m of the site based on IKONOS vegetation data for the Lake Tahoe basin for 148 lentic sites sampled in 2003 and 2004.

Development was coarsely represented by ROS classes in the process of site selection, but ROS classes generally followed elevational zones. Thus the distribution of sites relative to development can be evaluated within elevation zones. The development index was used to represent development and human disturbance for this analysis. The development index values within 50 and 200 m were highly correlated ($r = 0.951$), so index values within 50 m were used here because they represent conditions that are most likely to directly impact amphibians and snakes at the site. At lower elevations (< 2300 m), only 30% of the sites had no development within 50 m, and almost 15% of the sites had over 30% of the area developed, with an additional 3% of sites with 10 to 30% of the area developed, for a total of 16.7% with over 10% developed (Fig. 10). In contrast, 67% of high elevation sites had no development within 50 m and no sites had over 10% development. A t-test of development levels between the two elevation zones showed a significant difference ($t = 4.025$, $P < 0.001$).

Change in Site Conditions

We also evaluated change in status using a simple qualitative approach that tracked the continued the existence of lentic sites. Only one of the original 88 sites was drained in 2003, Divot Pond. However, in the course of searching for new sites in 2004 based on the waterbody map (circa 1990), we found that 10 (12.8%) of the 78 new sites that were field checked had been drained at some time over the past 15 years. Further, 7 of the 10 sites that were drained were at lower elevations (< 2300 m).

The more quantitative approach to assessing change in site condition consisted of comparing the values of field-based habitat data. Of the 9 habitat variables measured in the field in both sample periods, a few changes were observed (Table 4). We did not observe any significant differences in the frequency of occurrence of smaller substrates (e.g., silt, sand). We did observe a decrease in the frequency of occurrence of pebbles and boulders ($t = 2.43$, $p < 0.001$, $t = 3.06$, $p = 0.001$, respectively), and an increase in the frequency of cobbles ($t = -2.29$, $p = 0.012$) based on a two-tailed test. No change in emergent vegetation or logs was observed.

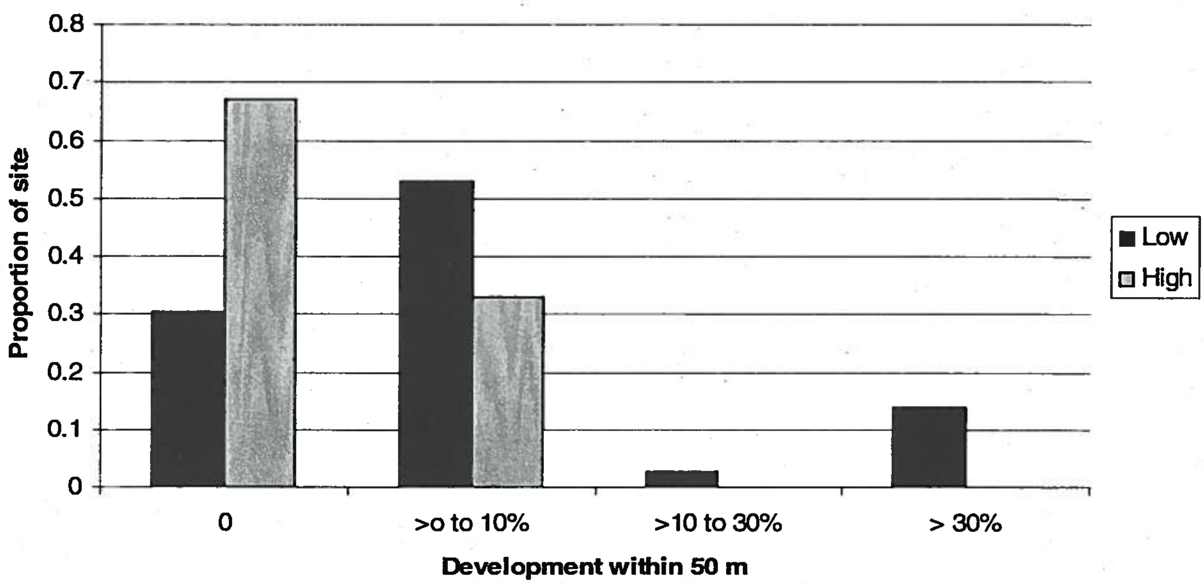


Figure 10. Proportion of lentic sites in each of two elevation zones (low < 2300 m, and high ≥ 2300 m) that had each of four levels of development within 50 meters.

Table 4. Mean and standard deviation for 9 habitat variables measured in the field in each of two sample periods: 1997/98 and 2003/04.

	Sample period 1		Sample period 2	
Habitat variable	**Mean**	**s.d.**	**Mean**	**s.d.**
Littoral substrates:				
Silt	68.9	37.16	71.8	35.42
Sand	10.3	22.38	8.3	17.69
Pebble	4.0	10.11	1.8	5.12
Cobble	6.2	11.1	9.3	18.94
Boulder	7.9	15.26	5.1	11.89
Bedrock	2.5	7.40	3.8	12.31
Other:				
Emergent vegetation	71.5	33.39	66.6	33.41
Logs	18.1	18.30	16.2	18.13
Maximum depth	7.3	15.71		

The distribution of amphibians (Fig. 13) and garter snakes (Fig. 14) varied among species, but many were restricted to the west and south sides of the basin. Pacific treefrog and western toad were distributed throughout the basin, as was the western terrestrial garter snake. Long-toed salamander was restricted to the west and south sides of the basin, and common garter snake had a similar distribution, with the exception of one detection on the north side of the basin. Sierra garter snake had the most restricted distribution of the three garter snakes, being detected only in the south and southwest sides of the basin. Bullfrog was only observed in the south side of the basin, and although it was primarily detected in proximity to Lake Tahoe, it was observed in the Upper Truckee drainage over 5 miles from the shore of Lake Tahoe. The long-toed salamander is the only species whose known geographic range would be predictive of its restricted pattern of occurrence primarily in the west and south sides of the basin. In 1997/98, it was detected in Edgewood Lake, but we have not been allowed access to reconfirm its status. All of the other species could potentially occur at all lentic sampling sites.

Status of Amphibian and Garter Snake Populations

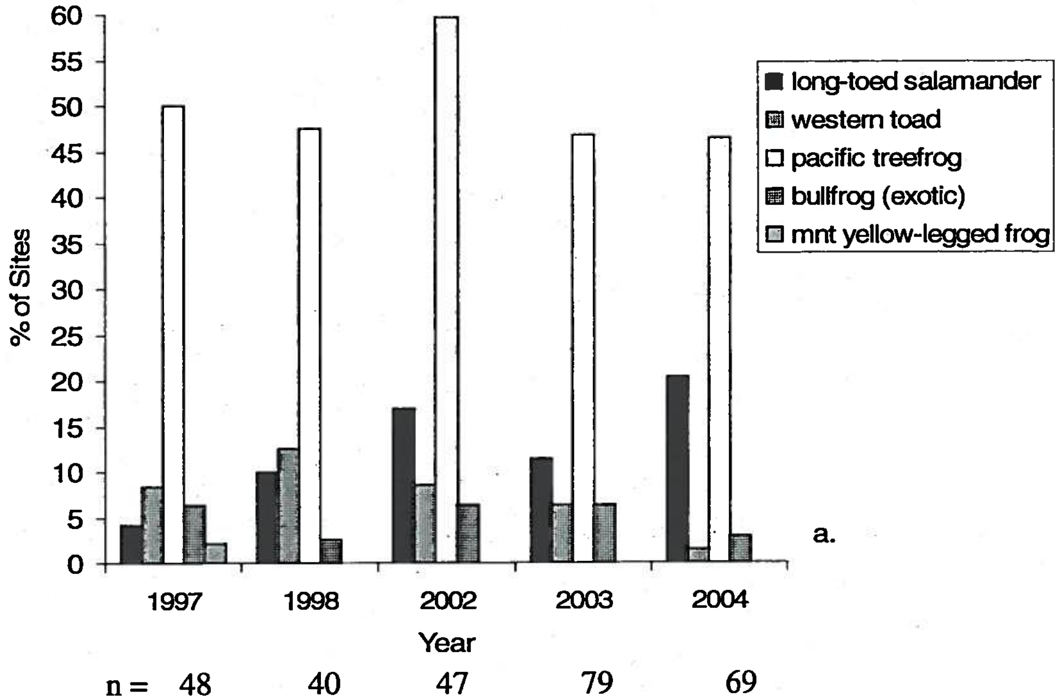
General Patterns

We detected all five species of amphibians and three species of garter snakes known to be extant in the Lake Tahoe basin (Table 5). We also detected three species of terrestrial lizards, which were not carried forward in our analysis because they are not primarily associated with aquatic systems studied here: western skink (*Eumeces skiltonianus*), western fence lizard (*Sceloporus occidentalis*), and alligator lizard (*Elgaria* sp.). The most commonly detected amphibian species was Pacific treefrog, which was detected at nearly 60% of the sample sites (Table 5). Long-toed salamander and western toad were the next most prevalent, detected at 21.1 % and 8.6 % of the sample sites, respectively. Bullfrog, an introduced exotic, was only detected at 5.3% of the sample sites. Mountain yellow-legged frogs were only found at one site. Garter snakes as a group were fairly common, with one or more species being detected at nearly half (n = 66, 43.4%) of the sample sites. Western terrestrial garter snake was detected at approximately 30% of the sites, while the common and Sierra garter snakes were not as well distributed, being detected at around 10% of the sample sites.

Table 5. Amphibian and reptile species detected at lentic sample sites in the Lake Tahoe basin (n = 152).

Common name	Scientific name	No. units	Frequency (%)
Amphibians:			
Pacific treefrog	*Hyla regilla*	87	57.2
Western toad	*Bufo boreas*	13	8.6
Long-toed salamander	*Ambystoma macrodactylum*	32	21.1
Bullfrog	*Rana catesbeiana*	8	5.3
Mountain yellow-legged frog	*Rana muscosa*	1	<1
Reptiles:			
Sierra garter snake	*Thamnophis couchii*	11	7.2
Western terrestrial garter snake	*Thamnophis elegans*	47	30.9
Common garter snake	*Thamnophis sirtalis*	17	11.2

The number and percent of sites with detections of each amphibian and garter snake species varied to a limited degree over sample years based on observations (Fig. 11). These "naïve" estimates do not take imperfect detectability into account, but nonetheless provide a coarse measure of relative frequency of occurrence over time. Pacific treefrog detections did not vary substantially over time, ranging from 46% of sites in 2004 to almost 60% in 2002. Western toad and bullfrog detections were low and moderately variable among years while long-toed salamander detections were greatest in the later years (Fig. 11a). Overall, detections of garter snakes appeared to increase from 1997 to 2004, though mainly due to increased detections of common and western terrestrial garter snakes (Fig. 11b) Species richness for amphibians and garter snakes was low across all years with most sample sites having only 1 or 2 species recorded in each taxonomic group (Fig. 12).



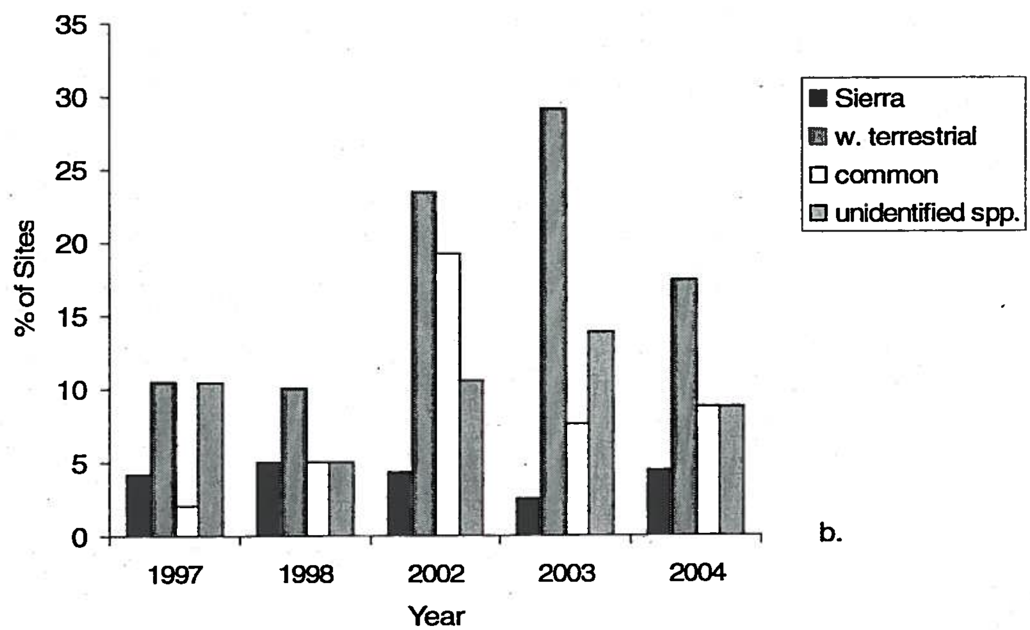
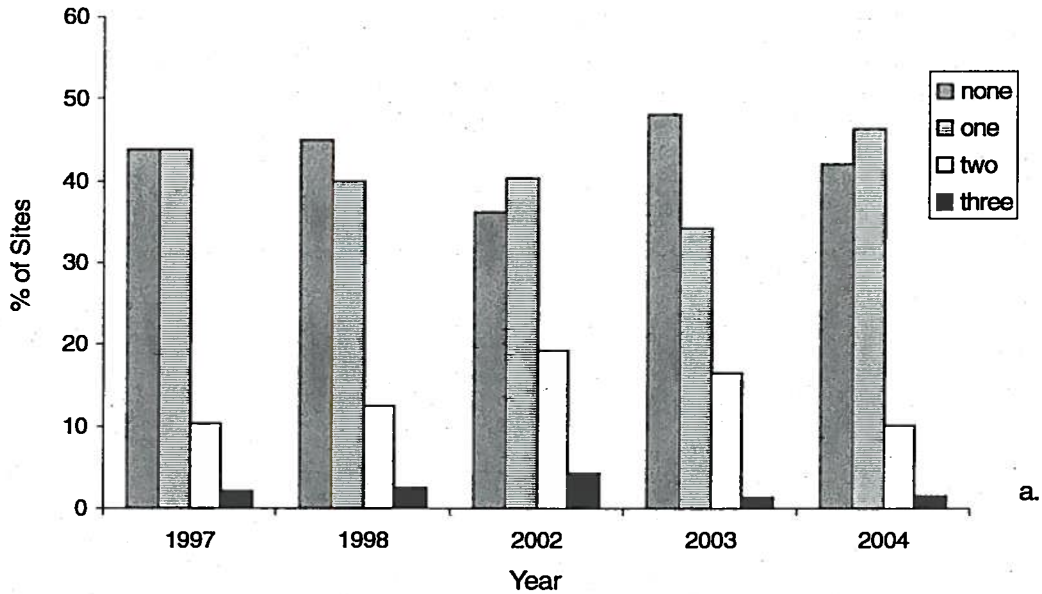


Figure 11. Percent of lentic sample sites with detections of each (a) amphibian and (b) garter snake species in each sample year. The total number of sites sampled in each year is indicated (n). Data were collected at 152 different sites in the Lake Tahoe basin, California and Nevada.



n = 48 40 47 79 69

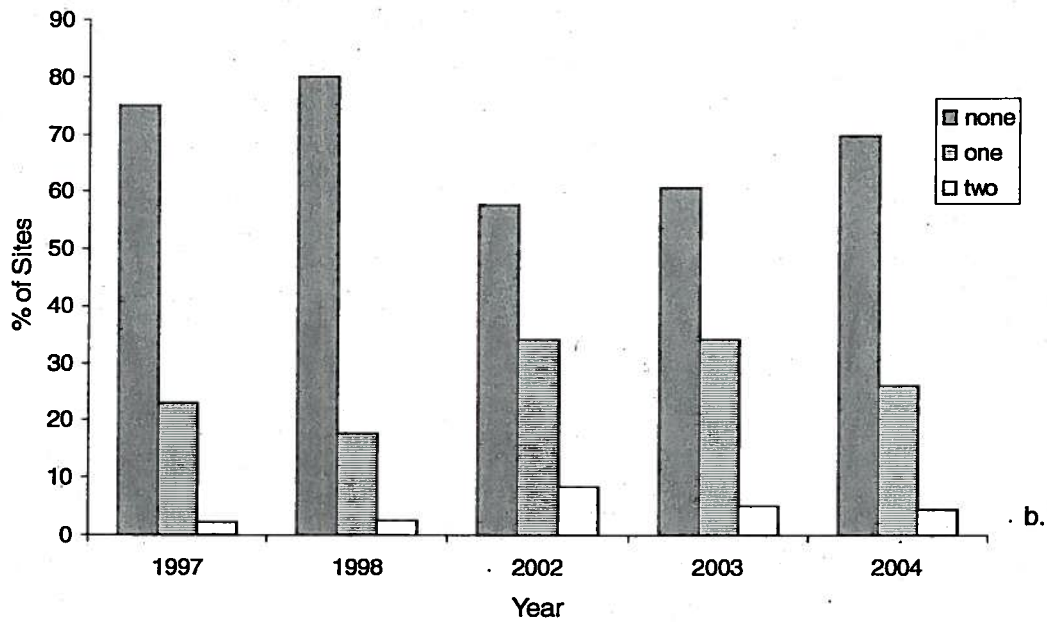


Figure 12. Percent of sample sites with increasing species richness for (a) amphibians and (b) garter snakes for each year. The total number of sites sampled in each year is indicated by n. Data were collected at a total of 152 different sites in the Lake Tahoe basin, California and Nevada.

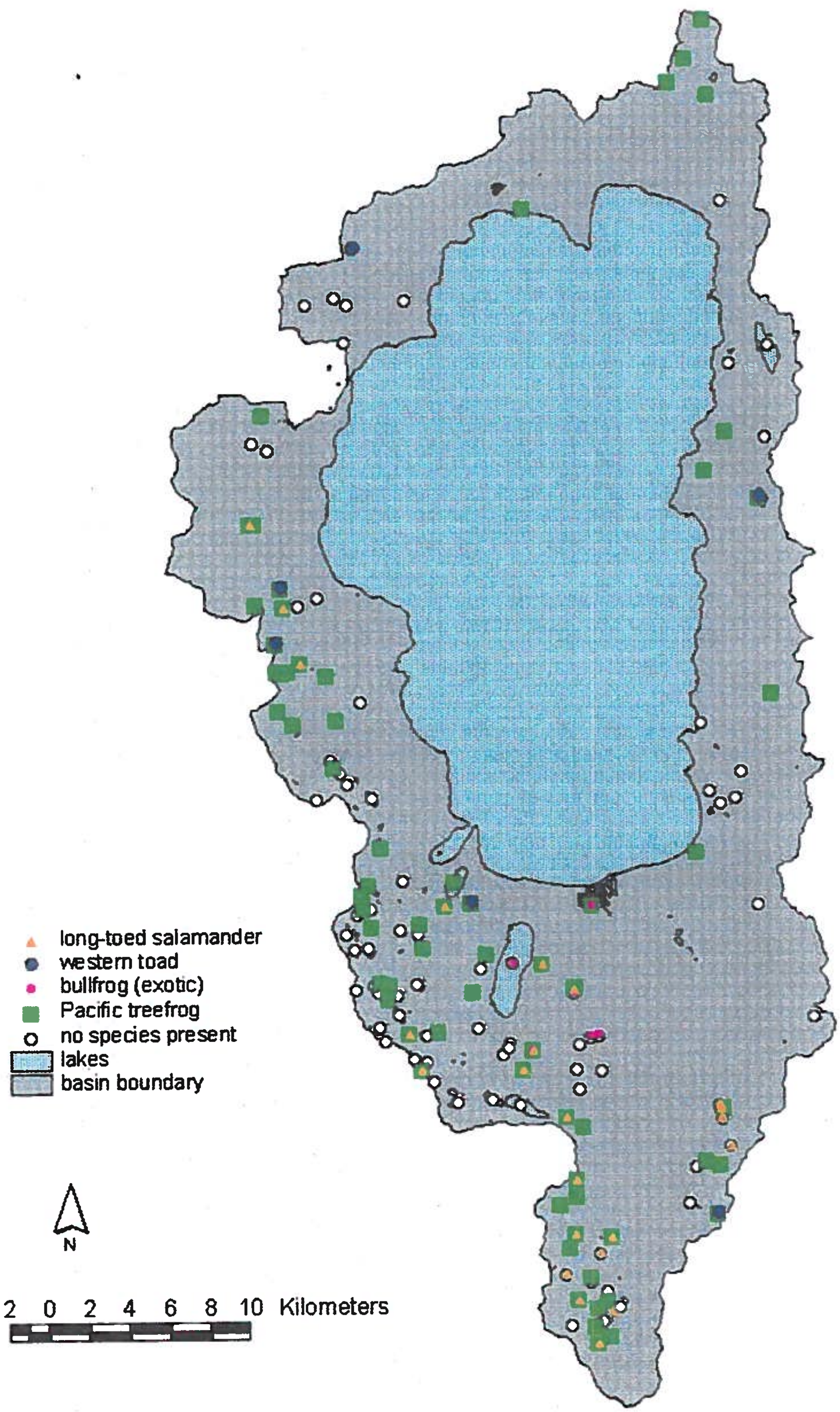


Figure13. Distribution (presence) of amphibian species in Lake Tahoe Basin for sites surveyed for status in 2003 and 2004.

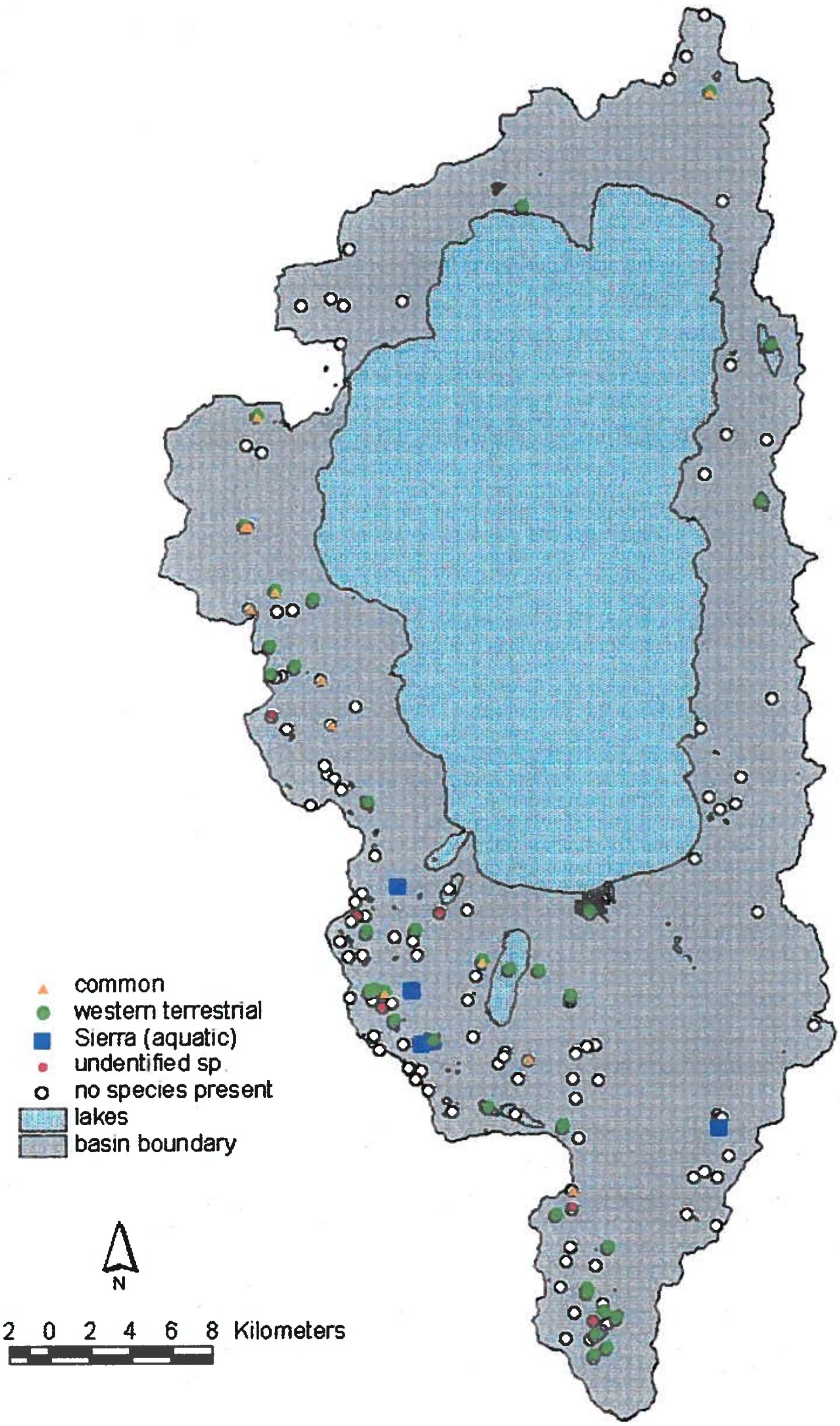


Figure 14. Distribution (presence) of garter snake species in Lake Tahoe Basin for sites surveyed for status in 2003 and 2004.

Species detections per site surveyed also varied by orientation based on sites representing current status (148 sites surveyed in 2003 or 2004) (Fig. 15). As noted, long-toed salamander was only detected on the south and west sides of the basin, and was detected at nearly four times more frequently per unit surveyed on the south side compared to the west side. Western toad occurred across all orientations, but was detected far less frequently on the south side of the basin. Pacific treefrog was detected least frequently on the east side and most frequently on the west side of the basin. Bullfrog was only detected in the south and east sides of the basin, basically in the south shore area of Lake Tahoe. The garter snakes also showed differences in their distribution. Common garter snake was not detected in the east, and was detected three or more times as often on the west side of the basin as the south or north, appearing to reflect the precipitation gradient around the basin. Western terrestrial garter snake did not show major differences in detections around the basin, but was detected slightly more frequently per unit surveyed in the south and west. Finally, the Sierra garter snake, like long-toed salamander, was only detected in the south and west sides of the basin, with minor differences in detection observed between these two orientations.

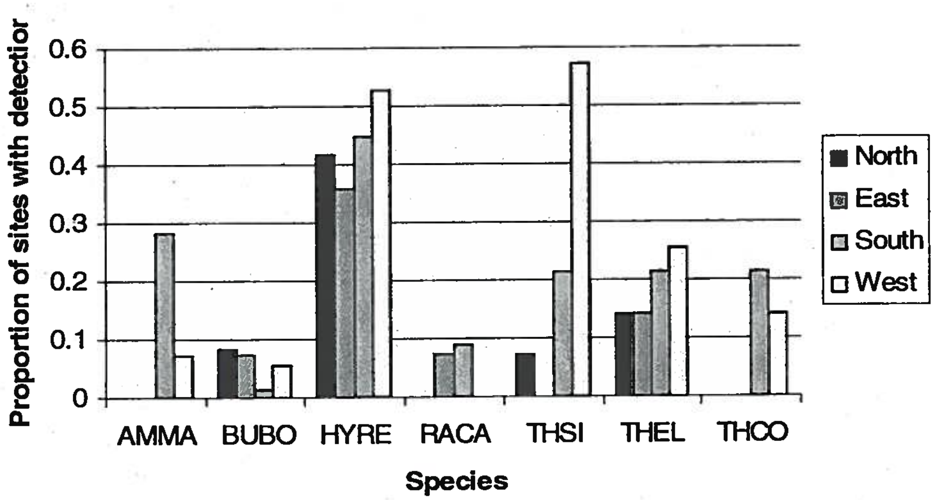


Figure 15. Proportion of sites with detections of each species of amphibian and garter snake for each of the four primary orientations around the Lake Tahoe basin. Data were collected in 2003 and 2004.

Proportion of Sites Occupied Estimates

The per-visit probability of detection estimates ($\hat{p} = 1 - \hat{q}$) for amphibians based on visual encounter surveys ranged from a low of 42% for long-toed salamander to a high of 76% for Pacific treefrog (Table 6). Bullfrog actually had the highest per-visit probability of detection of all species, but its frequency of detection was so low ($n = 4$ sites) that the per-visit probability of detection estimate, 95%, may not be entirely reliable. This is reinforced by the lack of rationale for bullfrog being significantly more detectable than western toad, which has similar body size and abundance patterns. Per-visit detectability was similar among the garter snake species, ranging from 37% and 58%, and in the same range of detectability of the amphibian species. This indicates that the survey methods used were reasonably effective for the majority of amphibian and reptile species at lentic sites.

Table 6. Estimated per-visit probability of non-detection ($\hat{q}$), probability of detection given two visits (p_d), and proportion of sites currently occupied ($\hat{P}$) for seven species of amphibians and garter snakes based on visual encounter surveys conducted at lentic sample sites in the Lake Tahoe basin. $\hat{q}$ based on all surveys (1997 to 2004) to the 152 sample sites; $\hat{P}$ based on surveys to the 148 sites sampled in 2003 an 2004.

	Detection estimates			Status	
Species[a]	$\hat{q}$	s.e. of $\hat{q}$	p_d	$\hat{P}$	s.e.
Long-toed salamander	0.575	0.0565	0.6694	0.165	0.070
Western toad	0.307	0.1025	0.9057	0.067	0.034
Pacific treefrog	0.259	0.0357	0.9331	0.555	0.077
Bullfrog	0.046	0.0459	0.9979	0.060	0.026
Sierra garter snake	0.419	0.1598	0.8244	0.044	-
W. terrestrial garter snake	0.632	0.0810	0.6008	0.472	0.176
Common garter snake	0.477	0.0930	0.7725	0.158	0.083

[a] One species, mountain yellow-legged frog (*Rana muscosa*), was only detected at one site on one visit, making it impossible to estimate q and P.

Standard error estimates for $\hat{q}$ (probability of non-detection) were variable among species (Table 6). Amphibians standard errors for $\hat{q}$ were low, and ranged from 0.036 to 0.057 with the exception of western toad, which had the highest standard error of 0.103. Variance estimates for the probability of non-detection for garter snakes were just below 0.10 for the two more commonly occurring species, and was higher at 0.160 for Sierra garter snake. Western toad and Sierra garter snake had standard errors that were 34% and 38% of q, respectively. The probability of detection across the two visits, ($p_d = 1 - \hat{q}^t$) ranged among species, from 60% and 100%, with species broadly distributed between these two detection values (Table 6). Long-toed salamander had the lowest probability of detection (67%) of all amphibians, with the other three species having over 90% probability of detection. Among the garter snakes, western terrestrial had the lowest detectability (60%), and Sierra garter snake had the highest (82%).

The estimated current (2003-2004) proportion of sites occupied ($\hat{P}$) was less than 20% for all but two species, Pacific treefrog and western terrestrial garter snake, which were estimated to have 56% and 47% of sites occupied, respectively (Table 6). $\hat{P}$ values could not be generated for mountain yellow-legged frog because it was only detected once. Standard errors were relatively low for amphibians, ranging from a low of 0.026 for bullfrog to 0.077 for Pacific treefrog. Standard errors were higher for garter snakes. The high standard error of $\hat{q}$ for Sierra garter snake made it impossible to calculate the standard error for $\hat{P}$. Standard error terms for the remaining two species ranged from 0.083 for common garter snake, and 0.176 for western terrestrial garter snake. The high probability of detection and low estimated proportion of sites occupied suggests a reliable representation of small population sizes in the basin for all but Pacific treefrog and western terrestrial garter snake. Common garter snake is associated with terrestrial and aquatic environments, and detections at aquatic sites may not be an accurate indication of the entire population of this species in the basin.

Changes in Amphibian and Garter Snake Populations

All but long-toed salamander and Pacific treefrog experienced over a 20% a relative change in the estimated proportion of sites occupied (Table 7). Long-toed salamander increased in the estimated proportion of sites occupied by 17.9%, and the western terrestrial and common garter snakes increased by 62.2% and 132.4%, respectively. Similarly, bullfrog increased by 20.0%. Conversely, Pacific treefrog declined by 13.6%, western toad declined by 45.0%, and Sierra garter snake declined by 46.3%. With only one detection in 1997-98 and no detections in 2003-04, the data are too sparse to make any conclusions about the mountain yellow-legged frog other than its population is extremely limited in the basin. The 90% confidence interval on the estimated proportion of sites occupied in sample period 1 indicated that, because of the high variance of the *P* estimates, none of the observed changes in estimated proportion of sites occupied were significantly different (Fig. 16). However, the decline in the proportion of sites occupied by western terrestrial garter snake was close to significant.

Table 7. Difference in the estimated proportion of sites occupied ($\hat{P}$) in sample period 1 (1997-1998) and sample period 2 (2003-2004), and 90% confidence interval (CI) on the proportion of sites occupied in the first sample period (1997-1998). Asterisk indicates observed change values indicate change greater than 20% relative change between 1997-1998 and 2003-2004.

	Sample period 1				Sample period 2		Observed change	
Species	$\hat{P}$	s.e.	90% CI	20% relative change	$\hat{P}$	s.e.	$\Delta\ \hat{P}$	Relative %
Long-toed salamander	0.140	0.063	0.104	0.028	0.165	0.070	0.025	17.9
Western toad	0.120	0.048	0.079	0.024	0.067	0.034	-0.054	45.0*
Pacific treefrog	0.642	0.080	0.131	0.129	0.555	0.077	-0.087	13.6
Bullfrog	0.050	0.024	0.039	0.010	0.060	0.026	0.010	20.0*
Sierra garter snake	0.082	-	-	0.016	0.044	-	-0.038	46.3*
W. terrestrial garter snake	0.291	0.126	0.207	0.058	0.472	0.176	0.181	62.2*
Common garter snake	0.068	0.040	0.066	0.014	0.158	0.083	0.090	132.4*
Mtn. yellow-legged frog	0.012	-	-	0.002	0	-	-0.012	100.0*

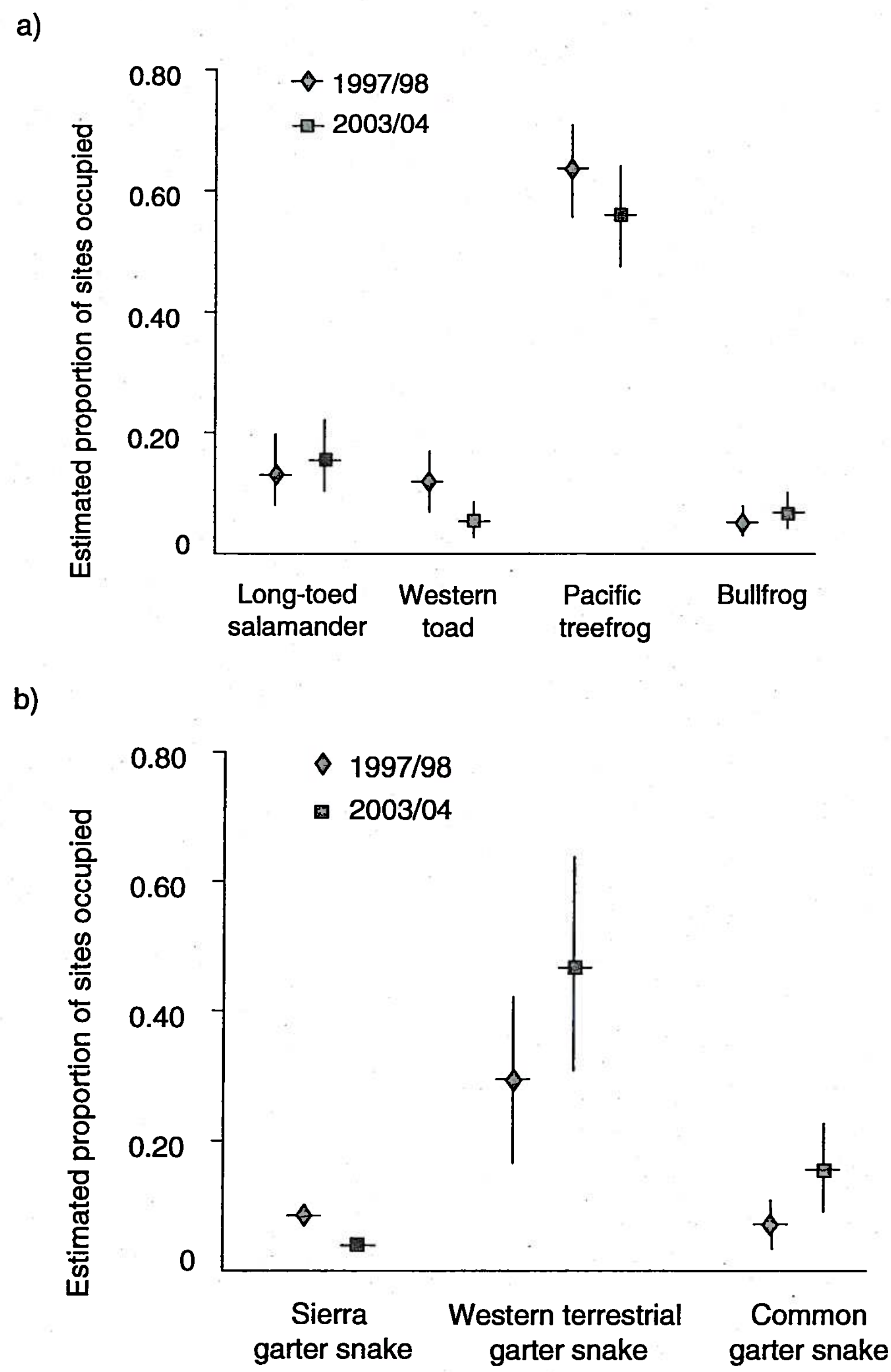


Figure 16. Estimated proportion of sites occupied (and their standard errors) in each of two sample periods for (a) 4 amphibian and (b) 3 garter snake species. The same 84 sites were sampled in each sample period (1997 to 1998 and 2003 to 2004), and sites were sampled in only of the two years spanned by each sample period. Data were collected in the Lake Tahoe basin.

We also looked at the change in the status of individual sites based on field observations (Table 8). We used the smaller of the number of sites changing (pres to abs or abs to pres) to represent the magnitude of change in site status unrelated to population increase or decrease. The greater the number and proportion of sites turning over, the less stable the populations per site. Three turnover rates were observed. Three species exhibited the high turnover rate of around 30%: long-toed salamander, western toad, and Sierra garter snake. The other three native species showed the moderate turnover rate of around 15%: Pacific treefrog, western terrestrial garter snake, and common garter snake. Bullfrog had no turnover in site occupancy.

Turnover in site occupancy based on the combination of both survey methods (visual encounter survey and pole seining) for the subset of 48 sites suggested that turnover was about half that estimated based on visual encounter surveys alone (Table 9). Long-toed salamander was observed at 28 of the sites, with both methods detecting the species during 19 of the surveys (68% of the time), with the remaining detections split between the two methods. This difference in detectability is consistent with the similar estimates of probability of detection, assuming two visits.

Table 8. Change in occupancy status at 84 sample sites for 4 species of amphibians and 3 species of garter snakes between 2 sample periods (1997-98 and 2003-04). Data were collected at lentic sample sites located throughout the Lake Tahoe basin and based on single or first visit to each site.

	No change					
Species	abs-abs	pres-pres	Gain (abs-pres)	Loss (pres-abs)	Total no. of sites with presence	% turnover
Long-toed salamander	70	1	4	9	14	28.6
Western toad	74	2	3	5	10	30.0
Pacific treefrog	34	31	10	9	55	18.0
Bullfrog	79	4	1	0	5	0
Sierra garter snake	78	1	2	3	6	33.3
W. terrestrial garter snake	64	6	11	3	20	15.0
Common garter snake	77	2	1	4	7	14.3

Table 9. Detection differences between visual encounter surveys and pole seining for long-toed salamander and western toad at 40 lentic sites sampled in 2003 and/or 2004 (7 sites sampled in both years) located throughout the Lake Tahoe basin.

	No change				Total no.	
Species	abs-abs	pres-pres	Gain (abs-pres)	Loss (pres-abs)	of sites with presence	% turnover
Long-toed salamander	20	19	4	5	28	14.3
Western toad	42	4	1	1	6	16.7

Environmental Relationships

Habitat Associations

The occurrence of species (based on field detections) showed patterns of association with the primary environmental factors: size and type of site, and elevation (Fig. 17). Two species, bullfrog and Sierra garter snake, showed differences in occurrence with lentic habitat type: they were only detected in lakes, as opposed to meadows. The other two garter snake species were detected more frequently at lakes (per site surveyed) than meadows (Fig. 17a). Smaller lakes were generally occupied more frequently by four of the seven species, namely long-toed salamander, Pacific treefrog, western terrestrial garter snake and Sierra garter snake, and the other three species did not show a strong pattern of occurrence in relation to size (Fig. 17b). Elevation did not appear to be a factor affecting the distribution of species in the basin, with the exception of bullfrog, which was restricted to lower elevations (Fig. 17c).

Environmental conditions associated with the persistence index (PI) were evaluated as a measure of site conditions associated with supporting the native amphibian and reptile communities. Multiple linear regression on the 75 sites with PI values (Appendix F) showed that four variables were significantly associated with PI values (adjusted $r^2 = 0.140$, $P = 0.005$): positive association with amount of forest within 200 m and precipitation, and negative association with elevation and development within 50 m. Variables not significantly associated with PI values were site area, number of sites within 1 km, and the amount of meadow, riparian, or shrub within 200 m.

The inclusion of environmental variables in maximum likelihood estimations of species occurrence for each species revealed that few contextual environmental variables were strong predictors of species occurrence (Table 10). Long-toad salamander and Pacific treefrog occurred more frequently at smaller-sized sites. Western toad occurred more frequently in drier environments with a greater abundance of riparian vegetation, and it had similar associations as the Sierra garter snake. Western terrestrial garter snake appeared to occur more frequently at larger-sized sites at lower elevations. Common garter snake was associated with low elevation and high precipitation, suggesting that it was most frequently occurring at lower elevations on the west side of the basin.

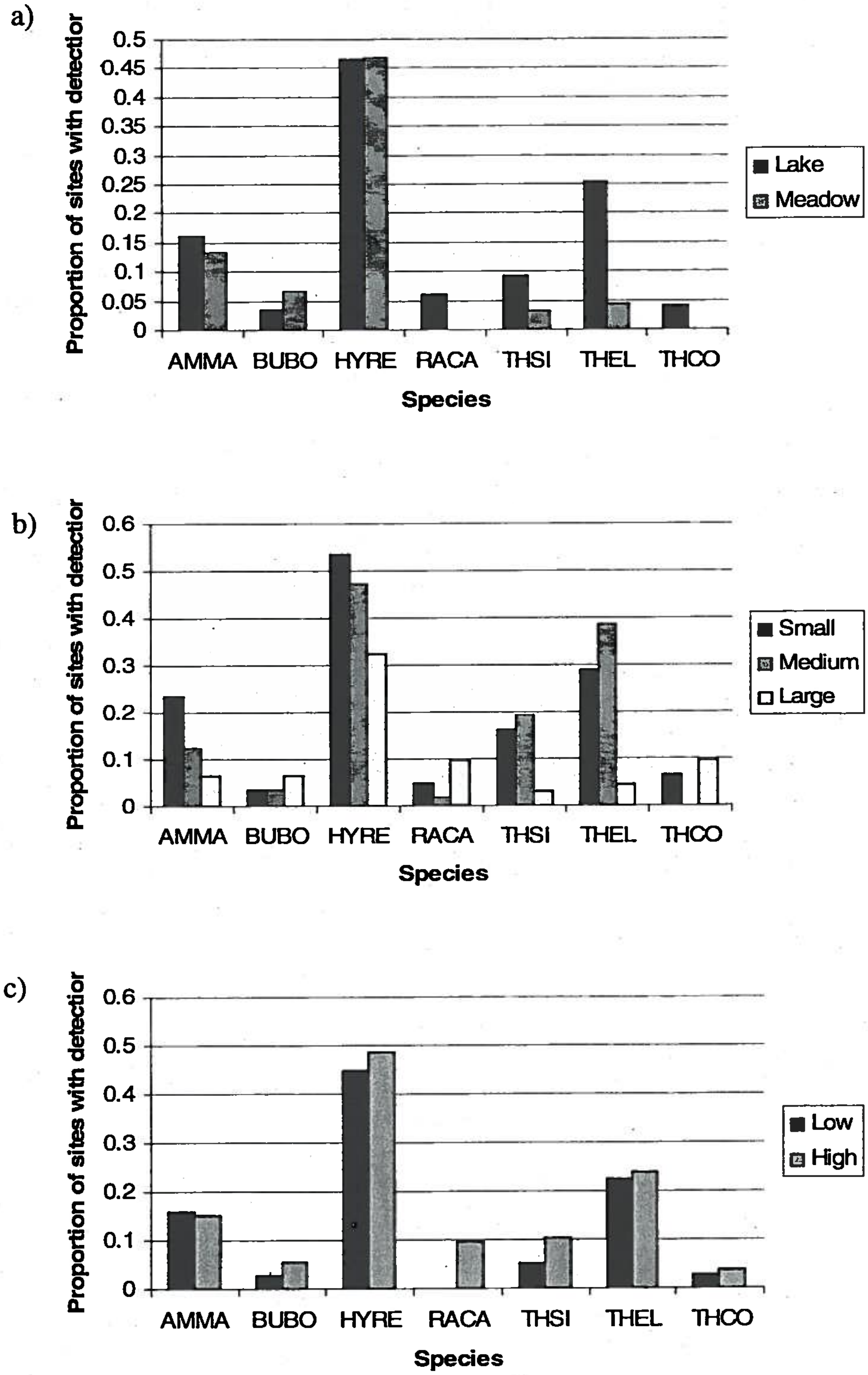


Figure 17. Proportion of sites with detections for each species of amphibian and garter snake detected in the Lake Tahoe Basin relative to three environmental factors: habitat type (lake or meadow; a), size (small < 0.5 ha, medium 0.5 to 5.0 ha, large > 5.0 ha; b), and elevation (low < 2300 m, high ≥ 2300 m; c). AMMA = Long-toed salamander, BUBO = Western toad, HYRE = Pacific treefrog, RACA = Bullfrog, THCO = Sierra garter snake, THEL = Western terrestrial garter snake, THSI = Common garter snake.

Table 10. Environmental variables that describe conditions within which lentic sites exist that were significantly associated with the presence of each of seven species of amphibians and garter snakes. All variables with P values < 0.15 were reported, along with AIC values for the model. Data were collected at 152 sites* within the Lake Tahoe basin in one or more years between 1997 and 2004. AMMA = Long-toed salamander, BUBO = Western toad, HYRE = Pacific treefrog, RACA = Bullfrog, THCO = Sierra garter snake, THEL = Western terrestrial garter snake, THSI = Common garter snake.

Environmental variable	AMMA	BUBO	HYRE	RACA	THEL	THCO	THSI
Size	negative $P =$ 0.067		negative $P =$ 0.106		positive $P =$ 0.032		
Elevation					negative $P =$ 0.023	negative $P =$ 0.029	negative $P =$ 0.033
Precipitation	negative $P =$ 0.097	negative $P =$ 0.019		negative $P =$ 0.099			positive $P =$ 0.027
Development					negative $P =$ 0.067	negative $P =$ 0.149	
Forest							
Shrub		positive $P =$ 0.128				positive $P =$ 0.103	
Meadow				positive $P =$ 0.126			
Riparian		positive $P =$ 0.067				positive $P =$ 0.057	
AIC	322	200	626	92	411	116	228

- AMMA model excluded sites on the eastside of the basin, for a total of only 142 sites.

Herp-Fish Interactions

Overall, fish (of any species) were detected at 72 of the 152 (47.4%) sample sites, and trout were detected at most (n = 58; 80.6%) sites with fish. Our preliminary analysis of biotic interactions indicated that fish, especially introduced non-native trout, may be having a negative influence on the distribution of both long-toed salamanders and Pacific treefrogs (Table 11). Long-toed salamander and Pacific treefrog were both less common at sites where fish were detected, though some co-occurrence of fish and amphibians was observed. Western toad was detected too infrequently to evaluate their co-occurrence relative to fish.

Table 11. Amphibian, garter snake, and trout interactions in the 105 Lake Tahoe Basin water bodies sampled in 2004. Cell contents are the number and overall percent of lentic units in each category.

		Trout Present					
		Present		Absent			
Species		**n**	%	**n**	%	**Chisquare**	***P***
Long-toed salamander						13.03***	0.001
	Present	**0**	0.0	**24**	22.9		
	Absent	**31**	29.5	**50**	47.6		
Western toad						na	
	Present	**1**	0.9	**2**	1.9		
	Absent	**30**	28.6	**72**	68.6		
Pacific treefrog						3.21*	0.073
	Present	**10**	9.5	**38**	36.2		
	Absent	**21**	20.0	**36**	34.3		
Garter snake species						0.043	0.835
	Present	**9**	8.6	**23**	21.9		
	Absent	**22**	20.9	**51**	48.6		

* Significant at $P < 0.10$
*** Significant at $P < 0.001$

Site Persistence Index Values

Site PI values were summarized by orientation (north, east, south, west), given that a number of species' ranges did not extend to the east side of the basin (Fig. 7 and 8). The north and east sides of the basin had relatively low percentage and number of sites with high PI values compared to the south and west sides of the basin (Appendix F). On the east side of the basin, nine sites were eligible for analysis (surveyed in two or more years and one or more species were detected), and 22.2% (n = 2) had high (> 10) PI values. On the north side of the basin, seven sites were eligible, and two 28.6% (n = 2) had high PI values. On the west side, 22 sites were eligible, and 72.7% (n = 16) had high PI values, seven of which had PI values > 15. On the south side of the basin, 37 sites were eligible, and 37.8% (n = 14) that had high PI values.

Sites with persistent populations of each species were also identified (Appendix F). Long-toad salamander had high occupancy or duration (i.e., rank of 3 for either metric) at seven sites, six on the south side and one on the west side of the basin. Western toad was detected at only 11 sites, and high occupancy or duration was observed at one site on the north and three sites on the west side of the basin. Pacific treefrog had high occupancy or duration at 31 sites around the basin: approximately 50% were on the west side of the basin (n = 15), 25% were on the south side, and the remainder were split between the north and the east sides of the basin. Bullfrog had high occupancy and duration at four of the six sites where it occurred.

Garter snakes were detected at relatively few sites and low occupancy and duration ranks relative to amphibians. On the east side of the basin, only two sites had high occupancy or duration for any species of garter snake, and both had high values for western terrestrial garter snake. No sites on the north side of the basin had high persistence. The south and west sides of the basin had the most sites with high occupancy or duration (5 and 7, respectively), with many of the sites on the west side having detections of > 1 species of garter snake. Western terrestrial garter snake had high occupancy or duration at a greater number of sites (n = 8) compared to Sierra garter snake (n = 1) or common garter snake (n = 4).

Indicators

Index of Biological Integrity

The IBI showed a sharp decline at sites with > 10% development, and again around 40% development. (Fig. 18) Of the 131 sites with ≤ 10% development, 27.5% (n = 36) had scores ≥ 60, and represented sites where all sites were occupied by one or more species of native amphibian and one or more species of garter snake. Sites with scores ≥ 60 were determined to represent good condition. The 43.5% (n = 57) sites with scores of < 40 were determined to be in poor condition, where generally sites had no native amphibians or garter snakes, and the majority of sites with bullfrogs scored (nearly 10% of the sites).

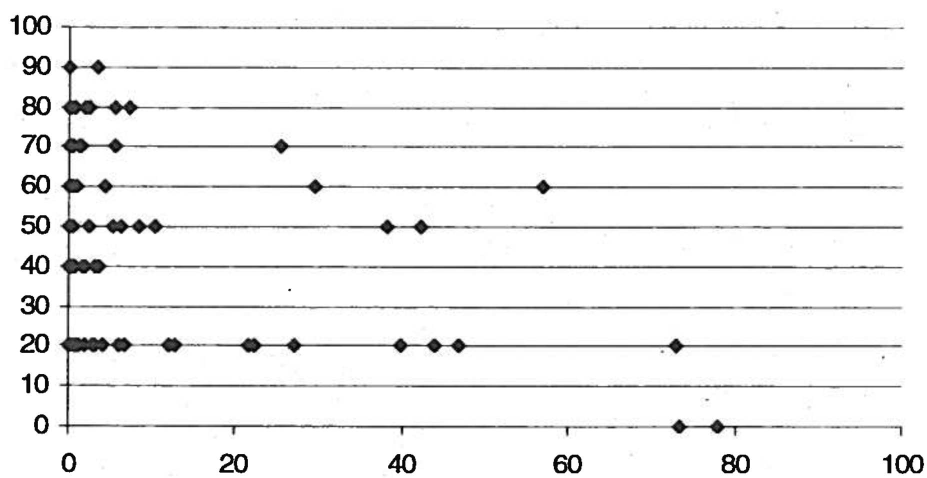


Figure 18. Herpetological index of biological integrity scores relative to development within 200 m for 148 small lakes and ponds in the Lake Tahoe basin. Data were gathered in 2003 and 2004.

Monitoring Sample Size Analysis

The estimated proportion of sites occupied by the seven species of amphibians and reptiles evaluated ranged from 5.5% to 59.9% (Table 12). Sample size requirements for these species based on our sample ranged from 10 to 28 sample sites for Pacific treefrog to 340 to 781 sample sites for bullfrog, which equate to a full census of lentic sites in the basin. The current number of sample sites (n = 152) appears to be minimally sufficient for three species without any adjustments: Pacific treefrog, common garter snake, and long-toed salamander. However, these estimates require interpretation, as opposed to taking them at face value (see Discussion). When we generalized the proportion of sites occupied, we see that at most 50 to 80 sites are required for species if they occupy 50% of all sites using this sampling methodology. When 25% of the sites are occupied, sample size requirements range from 70 to 180 sites, and when only 10% of the sites are occupied, sample size requirements rise to a minimum of 200 sites.

Table 12. Sample size estimates for detecting ≥ 20% relative change in occupancy (80% confidence and power) of each amphibian and garter snake species at lentic sites in the Lake Tahoe basin. Estimates were based on maximum likelihood estimates of the average proportion of sites occupied over the two sample periods ($\hat{P}$). Sample size estimates were calculated for $\hat{P}$ and for six scenarios: 50%, 25%, and 10% of sites occupied and the direction of change (increase or decrease).

		Estimated number of sample sites required							
		$\hat{P}$		50% of sites occupied		25% of sites occupied		10% of sites occupied	
Species	ave. $\hat{P}$	Min	max	min	max	min	max	min	max
Long-toed salamander	0.150	168	240	35	57	92	136	263	371
Western toad	0.094	227	292	22	33	66	88	197	254
Pacific treefrog	0.599	10	28	24	61	70	172	208	505
Bullfrog	0.055	340	781	22	51	66	152	198	455
Sierra garter snake	0.063	307	546	21	51	63	125	190	345
W. terrestrial garter snake	0.382	56	116	36	80	93	183	266	490
Common garter snake	0.113	196	297	26	49	74	119	219	332

[a] One species, mountain yellow-legged frog, was only detected at one site on one visit, making it impossible to estimate P and same size requirements.

Pole seining was used to improve detections of long-toed salamander and western toad. Estimated probability of non-detection estimate was only slightly higher for visual encounter surveys (two visits) compared to pole seining (Table 13). Based on a 90% confidence interval, pole seining did not have a significantly lower probability of non-detection ($q = 0.291 \pm 0.151$) compared to visual encounter survey ($q^2 = 0.331 \pm 0.093$). Western toad had a probability of non-detection of < 10% ($q^2 = 0.094$) with visual encounter surveys, but probability of non-detection with pole seining was practically zero. The number of sites with detections of western toad precluded a reliable estimate of standard error for the probability of non-detection, so no statistical comparison was made between the two sample methods.

Table 13. Comparison of probability of non-detection (q) for two sample methods, visual encounter survey and pole seine, for long-toed salamander and western toad. Visual encounter surveys were conducted in 2002-2004 at 149 sites, and pole seining was conducted in 2003-2004 at 45 sites, in the Lake Tahoe basin. $1 - p_d$ = probability of non-detection with two visits.

	Visual encounter survey			Pole seine	
Species	$\hat{q}$	s.e. of $\hat{q}$	$1 - p_d$	$\hat{q}$	s.e. of $\hat{q}$
Long-toed salamander	0.575	0.0565	0.331	0.291	0.0920
Western toad	0.307	0.1025	0.094	<0.001	0.8018

Discussion

Lentic Site Conditions

Aspects of site condition that have the greatest potential to change over short time periods include aquatic vegetation, logs, surrounding vegetation, local ground disturbance, and surrounding disturbance. Variables common to both sample periods were limited to littoral zone features and GIS variables (few of which were specific to the year in which the surveys were conducted). Habitat conditions in the littoral zone did not change substantially between sample periods. Local disturbance was only collected in the second sample period.

Wholesale loss of sites through draining is another potential source of change in habitat condition. Our field reconnaissance suggests that the basin may have lost 10% of its lentic sites in the past 15 or so years. This represents a high rate of loss, particularly because it was concentrated in the lower elevations.

Amphibian and Garter Snake Populations

The basin supports relatively few native species of amphibian and aquatic reptile species. Historically, there were other species of amphibians, it is likely there were larger populations of many species, particularly mountain yellow-legged frog, based on historical populations throughout the Sierra Nevada (Fellers et al. 2002). Given the probability of detection estimates, it is not likely that we missed detecting any species. Mountain yellow-legged frog is the rarest and likely the most endangered amphibian species in the basin. Only one detection was obtained, and it was during the 1997-98 sample period. One population of mountain yellow-legged frogs is known to occur in a fen not randomly selected as part of the 152 sample sites.

All species of amphibian and garter snake species, with the exception of Pacific treefrog, had low occupancy. Previous surveys in the basin (Manley 2000, Manley and Schlesinger 2001) suggested that amphibian species primarily exist in lentic habitat types, thus these survey data should provide a reliable representation of the size of the populations of these species in the basin. Given the small proportion and number of sites occupied in the basin, our results indicate that long-toed salamander, western toad, and mountain yellow-legged frog have very small populations that are vulnerable to extinction. Manley and Schlesinger (2001) found that garter snake species used both lentic and lotic habitats, but that all three species were frequently detected in lentic habitats. Thus, although lotic habitats provide habitat for these species, lentic habitats may provide higher quality habitat and support the majority of the population of the two aquatic-associated species, Sierra garter snake and western terrestrial garter snake.

Pacific treefrog has been observed at approximately 50% of surveyed sites every year, with the exception of 2002, when it dropped to near 40%. Based on estimates of the proportion of sites occupied, Pacific treefrog occupies 77% of all sites, nearly 15% more sites than it did in 1997-98. Therefore, the Pacific treefrog population in the basin appears to be robust and viable. Pacific treefrog may provide a valuable point of comparison to help identify factors that may be affecting amphibian populations that are declining, namely western toad.

Long-toed salamander populations appear stable over the 6 year period sampled, at an estimated 15% of sites occupied. Although apparently stable, population sizes in the basin are small and vulnerable to a variety of threats, including predation from bullfrog and trout, mortality from fungus infections, loss of key breeding areas, and a myriad of stochastic factors. The long-term viability of this species will depend on understanding population limitations and increasing the proportion of sites occupied to the extent possible. An analysis of the distribution of long-toed salamanders and the evaluation of genetic diversity will greatly help us understand what is limiting the population and how best to maintain a viable population in the basin.

Western toad was detected at 4.8% of the sites surveyed, and was estimated to currently occur at 5.6% of sites. Based on USGS maps, the basin has approximately 335 lakes and ponds, and perhaps an additional 60 wet meadows. This translates to an approximation of only 20 populations of western toad in the basin. Western toads can occupy stream habitats, but Manley (2000) and subsequent surveys by local staff (J. Reiner pers. com.) encountered western toads infrequently in stream habitats. Further, population declines indicated by the change data are alarming. Based on both field observations and estimates of proportion of sites occupied, western toad occupies 25% fewer sites than it did 5 to 6 years ago. It does not appear that trout interactions are a significant factor in determining the occupancy of sites, so it is not clear why the species is declining and what are the most effective actions to increase the size and extent of the population in the basin.

Bullfrog still occupies a small proportion, 7.2%, of lentic sites in the basin. However, the number of occupied sites increased by almost 50%. Further, the fact that bullfrogs are limited to the lower elevation sites means that a much greater proportion of lower elevation sites are occupied and therefore impacted by bullfrog. Given the high vulnerability of amphibian populations in the basin, the impact that bullfrogs have on native amphibians, and the greater anthropogenic stressors affecting populations at lower elevations, efforts to control, reduce, and eradicate bullfrog from the basin could be an effective means to improve occupancy and persistence of amphibian populations at critical lower elevation sites.

Common garter snake is associated with terrestrial and aquatic environments, and detections at aquatic sites may not be an accurate indication of the population size of this species. Therefore, we focus on the other two species here. In general, Sierra garter snake is more of habitat specialist than western terrestrial garter snake. The frequency of detection and estimated occurrence are consistent with this premise. Sierra garter snake was detected at only 7.2% of the sites, but western terrestrial was not much higher at

11.2%. Sierra and western terrestrial garter snakes can be difficult to differentiate in the field unless they are captured. This factor may affect decrease detectability estimates among these two species because of the added lack of detections resulting from incorrect identifications or the inability to determine species, supported by the fact that *Thamnophis* sp. was recorded for 8% of surveys, a greater proportion of surveys than Sierra garter snake recorded. Both of these species appear to have small population sizes in lentic habitats, but lotic habitats provide additional habitat. Manley and Schlesinger (2001) found approximately the same proportion of sites occupied in lentic and lotic habitat types, approximately 5% for Sierra garter snake and 10% for western terrestrial garter snake. However, Manley (2000) did not sample lotic habitat types in proportion to their occurrence, but rather sampled mouth to headwaters in equivalently. This resulted in the larger, slower moving reaches being a greater proportion of the sample than the population of reaches in the basin. Garter snakes need slow moving water for foraging, and so it is likely that they occupy a much smaller proportion of all stream reaches than indicated above. Therefore, both of these garter snake species are likely to have small populations in the basin, and observed declines in the Sierra garter snake indicate the need to install some measures to ensure that these two snake species maintain viable populations in the basin.

Indicators and Monitoring

Clearly, high variance estimates pose a challenge to monitoring change over time. Factors that affect variance are consistent detectability, accurate identification, and frequency of occurrence. Two visits using the visual encounter survey seems to provide sufficient detectability to continue to serve as the primary survey technique for all species. Pacific treefrog vocalizes and can be quite common where it occurs, as can western toad, characteristics that are likely to be responsible for these species being more readily detected. Visual encounter surveys could be augmented with automated data collection devices ("frog loggers"), which are becoming refined and available enough for use in standardized monitoring programs such as is being contemplated in the basin.

Three species were estimated to be adequately sampled with the existing set of 148 sites to monitor population change, including long-toed salamander, a species of particular interest in the basin. Species requiring more than the current number of 148 sample sites are not likely to be adequately sampled regardless of the effort without some adjustments to sampling design and/or detection methods. Simple measures can be taken to improve the proportion of sites occupied simply by being selective in the sites included in the analyses of population change for each species.

Three primary factors need to be considered in designing an effective monitoring program for amphibians and garter snakes in the basin: detection methods, species distributions, and true occupancy of the species. Probability of detection values were fairly high, ranging from 60% to almost 100%, so it is not recommended to increase the number of visits per season. Pole seining could be used to increase detectability, but this method is highly labor intensive and using it at every site would greatly reduce the number of sites sampled, decreasing representativeness of the sample and the precision of estimates of habitat condition and change (see Future Work section for inquiries into relative probability of detection with visual encounter surveys and pole seining).

The most efficient approach to reducing sample size requirements is likely to be through careful consideration of species distributions and habitat associations. The distribution of most species among lentic sites is not random. Individual species will have specific habitat associations that are predictable to some extent. The greater the proportion of sites occupied, the lower the sample size required to detect changes over time. Thus, habitat associations can be used to eliminate sites that are intrinsically unsuitable (e.g., elevation, size, or orientation outside of ecological tolerances) for occupancy from calculations of population change, and to improve the precision of estimates of proportion of sites occupied by using habitat conditions as covariates (MacKenzie et al. 2002).

Recommendations

The recommendations provided here are simply a listing of ideas that have the potential to benefit conservation and restoration efforts for lentic sites and associated species throughout the basin. They are an extension of the findings presented in this report, but as such they represent interpretation, not facts. They are provided as a point of departure for ideas and discussion.

Population Conservation

- Eradicate bullfrogs where they are known to occur, with highest priority areas being those further from Lake Tahoe, assuming that these populations have the greatest potential to move through streams to effect a more systemic invasion of this species.

Habitat Integrity

- Institute a no-net-loss policy for wetlands throughout the basin and on the east side in particular.
- Preclude siphoning at sites that have a high PI index or characteristics of high PI sites, and those that have high occupancy or duration for one or more native species of amphibian or garter snake.
- Based on the IBI, development above 10% within 50 or 200 m of a site will begin to impact the presence and abundance of native amphibians and snakes, and development above 40% appears to substantially impact these species. Lower elevation sites are at greatest risk of development (with the exception of ski areas), and the current proportion of lower elevation sites with over 10% development is just over 15%.
    - It is recommended that the level of development around all lentic sites in the basin be determined, and summarized by orientation, and then use this information to set targets for managing development around lentic sites.
    - It is recommended that no more than 20% of sites have more than 10% of the area within 200 m developed, and that management strives for no more than 10% of the sites on the east side, since they are so limited in number

- It is recommended that no more than 10% of sites have more than 10% of the area within 50 m developed

Indicators

- Based on sites with ≤ 10% development, a reasonable target for IBI values within the basin are that no less than 20% of sites should be in good condition (IBI > 60) and no more than 30% of sites should be in poor condition (IBI < 40).
- Although the contextual environmental variables were generally weak indicators of species occurrence, it is still recommended that the level of development within 30 to 50 m of sites is recorded as a key indicator of site condition.
- Continue to characterize littoral zone logs, vegetation, and substrates.

Monitoring

- Given the low proportion of sites occupied by most species, it is important to sample a large number of sites – annual resamples would reduce the total number of sites needed to be sampled, given a fixed budget per year. It is not necessary for the same number of sites to be sampled each year of the sample period, but the more equitable the better in case a given year is unique in some manner.
- Sample all sites or at least all sites in the less abundant elevation-size-orientation categories such that the sample size is as strong as possible.
- Sample periods should be as short as possible – ideally one or two years – and be relatively consistent in their duration over time. This will enable the sample period to characterize occupancy relative to fairly consistent large-scale environmental conditions so that differences among sites within a sample period can be reliably attributed to site conditions.
- If resources are available to sample additional sites beyond the current 150 monitoring sites in, they should be directed at specific types of sites (objectively selected based on basin-wide habitat models) to improve the proportion of sites with detections for specific species.
- Only sites within species geographic ranges should be included in primary monitoring data set (i.e., those used to quantify change): only include sites on the south and west sides of the basin in the analysis of long-toed salamander, and potentially common garter snake and bullfrog (depends if lentic data are indicative of the distribution of these two latter species).
- More equivalent representation of sites in each elevation-size-orientation category could be considered, but it is most likely that shortfalls in equivalency are primarily a function of occurrence and access.
- Investigate the potential of using frog-loggers to enable monitoring at a greater number of sites and perhaps increase the probability of detection for some species.

Future Work

Data collected over the past 7 years lends itself to in-depth analysis of habitat relationships and population distribution, and for long-toed salamander and western toad we can generate estimates of population dynamics and persistence using field observations and measurements and genetic data. These endeavors are beyond the original scope of the project, but additional funding from the U.S. Forest Service made it possible to gather additional data in the field on these two species of amphibians because management may have the potential to improve the status of their populations in the basin if we had a better understanding of the factors limiting their populations. Insights gained from this work would provide the foundation needed to develop conservation strategies for aquatic vertebrates, lentic ecosystems, or in combination with other factors, a comprehensive aquatic management strategy for the basin. In particular, the information generated by the analyses described below will provide a strong foundation for identifying conservation and restoration opportunities and strategies. A brief description of specific endeavors is provided below.

Population Status

- Finish analysis of genetic diversity for long-toed salamander and western toad
- Use genetics data (see Appendix C) combined with population distribution and abundance data and habitat relationships to describe the dynamics and viability of long-toed salamander and western toad populations and identify specific locations in the basin that have high conservation value for these species
- Evaluate waterbird population status and change (see Appendix D)

Habitat Relationships

- More in-depth multivariate habitat relationships modeling to develop predictive models of occurrence and persistence
- Interpretation of the habitat value and probability of occupancy of all lentic habitat sites in the basin
- Identification of limiting factors for population expansion and site occupancy
- Conduct an aquatic conservation assessment that takes the full suite of population and habitat factors into consideration

Monitoring

- Evaluate the value of including plant species identification, invertebrate sampling, and site temperature measurements in monitoring protocols

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Literature Cited

Anderson, J.D. 1967. A comparison of the life histories of coastal and montane populations of Ambystoma macrodactylum in California. American Midland Naturalist 77(2): 323-355

Basey, H. E., and D. A. Sinclear. 1980. Long-toed salamander. Page 20 *in* J. Verner, and A. S. Boss, technical coordinators. California wildlife and their habitats: western Sierra Nevada. USDA Forest Service Gen. Tech. Rep. PSW-37. Pacific Southwest Research Station, Berkeley, CA, USA.

Bishop, Y. M., S. E. Fienberg, and P. W. Holland. 1975. *Discrete Multivariate Analysis: Theory and Practice*. MIT Press, Cambridge, MA, USA.

California Department of Fish and Game. 2004. California Natural Diversity Database Special Animals. http://www.dfg.ca.gov/whdab/html/animals.html. (August).

Corkran, C.C. and C. Thoms. 1996. Amphibians of Oregon, Washington, and B.C. A field I.D. Guide. Lone Pine Publishing, Edmonton, Alberta, Canada.

Davidson, C. 2004. Declining downwind: Amphibian population declines in California and historical pesticide use. Ecological Applications 14(6):1892-1902.

Daly, C., G. Taylor, T. Kittel, D. Schimel, and A. McNab. 2002. Development of a 103-year high-resolution climate data set for the conterminous United States. Comprehensive Final Report for 9/1/97-5/31/02. Submitted to NOAA Climate Change Data and Detection Program. July. Available at: http://www1.ncdc.noaa.gov/pub/data/prism100.

Drost, C. A. and G. M. Fellers. 1996. Collapse of a regional frog fauna in the Yosemite area of the California Sierra Nevada, USA. Conservation Biology 10(2):414-425.

Elliott-Fisk, D. L, R. A. Rowntree, T. A. Cahill, C. R. Goldman, G. Gruell, R. Harris, D. Leisz, S. Lindstrom, R. Kattelmann, D. Machida, R. Lacy, P Rucks, D. a. Sharkey, and D. S. Ziegler. 1997. Lake Tahoe case study. Pages 217–276 *in* Sierra Nevada Ecosystem Project, Final Report to Congress, Addendum. Univ. of California Centers for Water and Wildland Resources Rept. No. 40, Davis, CA, USA.

Fellers, G. M., and K. L. Freel. 1995. A standardized protocol for surveying aquatic amphibians. U.S. Department of Interior Technical Report NPS/WRUC/NRTR-95-01.

Fellers, G. M., R. N. Fisher, and C. R. Schwalbe. 2002. Status of Amphibians in California and Arizona. U.S. Geological Survey, Biological Resources Division, Western Ecological Research Center, Sacramento, CA, USA.

Fisher, R. N. and H. B. Shaffer. 1996. The decline of amphibians in California's Great Central Valley. Conservation Biology 10(5): 1387-1397.

Fitch, H. S. 1941. The feeding habits of California garter snakes. California Fish and Game 27:1-32.

Fleiss J. L. 1981. Statistical methods for rates and proportions. 2nd edition. John Wiley & Sons, New York, NY, USA.

Hoel, G. H., S. C. Port, and C. J. Stone. 1971a. Introduction to Statistical Theory. Houghton Mifflin Company, Boston, MA, USA.

Hoel, G. H., S. C. Port, and C. J. Stone. 1971b. Introduction to Probability Theory. Houghton Mifflin Company, Boston, MA, USA.

Jennings, M. R. 1996. Status of amphibians. Pages 921-944 *in* Sierra Nevada Ecosystem Project: Final Report to Congress, vol. II, Assessments and scientific basis for management options. University of California, Centers for Water and Wildland Resources, Davis, CA, USA.

Jennings, M. R. and M. P. Hayes. 1994. Amphibian and reptile species of special concern in California. Final Report, submitted to the California Department of Fish and Game, Rancho Cordova, CA, USA.

Jennings, W. B., D. F. Bradford, and D. F. Johnson. 1992. Dependence of the garter snake *Thamnophis elegans* on amphibians in the Sierra Nevada of California. Journal of Herpetology 26:503-505.

Kezer, J. and D. S. Farner. 1955. Life history patterns of the salamander Ambystoma macrodactylum in the high Cascade Mountains of southern Oregon. Copeia 1955: 127-131.

Knapp, R. A. and K. R. Matthews. 2000. Nonnative fish introductions and the decline of mountain yellow-legged frogs from within protected areas. Conservation Biology 14:1-12.

Knapp, R. A., K. R. Matthews, and O. Sarnelle. 2001. Resistance and resilience of alpine lake fauna to fish introductions. Ecological Monographs 71(3):401-421.

Lindstrom, S. A. 2000. A contextual overview of human land use and environmental conditions. Pages 23-122 *in* D. D. Murphy and C. M. Knopp, editors. Lake Tahoe Basin Watershed Assessment, Volume. I. USDA Forest Service, General Technical Report PSW-GTR-175. Pacific Southwest Research Station, Albany, CA, USA.

Manley, P. N. 2000. Biological diversity and its measure: an assessment of lotic riparian ecosystems in the Lake Tahoe Basin. Ph.D. Dissertation. University of California, Berkeley, CA, USA.

Manley, P. N., and M. D. Schlesinger. 2001. Riparian biological diversity in the Lake Tahoe basin. Unpublished report to the California Tahoe Conservancy and U.S. Forest Service, South Lake Tahoe, CA, USA.

Manley, P. N., W. J. Zielinski, M. D. Schlesinger, and S. R. Mori. 2004. Evaluation of a multiple-species approach to monitoring species and ecosystem conditions at the ecoregional scale. Ecological Applications 14(1):296-310.

Manley, P. N., J. A. Fites-Kaufman, M. G. Barbour, M. D. Schlesinger, and D. M. Rizzo. 2000. Biological integrity. Pages 403—600 *in* D. D. Murphy and C. M. Knopp, editors. Lake Tahoe Basin Watershed Assessment, Volume. I. USDA Forest Service, General Technical Report PSW-GTR-175. Pacific Southwest Research Station, Albany, CA, USA.

Marsh, D. M. and P. C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. Conservation Biology 15 (1):40-49.

Matthews, K. R., R. A. Knapp, and K. L. Pope. 2002. Garter snake distributions in high elevation aquatic ecosystems: Is there a link with declining amphibian populations and non-native trout introductions.? J. Herpetology 36(1):16-22.

Matthews, K. R., K. L. Pope, H. K. Preisler, and R. A. Knapp. 2001. Effects of non-native trout on Pacific treefrogs (*Hyla regilla*) in the Sierra Nevada. Copeia 2001(4):1130-1137.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255.

Mayer, K. E., and W. F. Laudenslayer, Jr. 1988. A guide to wildlife habitats of California. California Department of Fish and Game, Rancho Cordova, California, USA.

Morey, S. 1988. Western toad. Pages 64-65 *in* D. C. Zeiner, W.F. Laudenslayer, Jr., and K.E. Mayer, editors. California's wildlife, volume I: amphibians and reptiles. California Department of Fish and Game, Sacramento, CA, USA.

Moyle, P.B. 1973. Effects of introduced bullfrogs, Rana catesbeiana, on the native frogs on the San Joaquin Valley, California. Copeia 1973: 18-22.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley, CA, USA.

Murphy, D. D. and C. M. Knopp, editors. 2000. Lake Tahoe watershed assessment. USDA For. Serv. Gen. Tech. Rept. PSW-GTR-175. Pacific Southwest Research Station, Berkeley, CA, USA.

Pawitan, Y. 2001. In all likelihood: statistical modeling and inference using likelihood. Oxford University Press, New York, New York, USA.

Philliod, D. S. and C. R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4:322-333.

Roth, J. R., P. N. Manley, M. M. McKenzie, and M. D. Schlesinger. 2004. Multiple Species Inventory and Monitoring 2002 Monitoring Report. Unpublished report, U.S. Department of Agriculture, Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, CA, USA.

Schaffer, J. P. 1998. The Tahoe Sierra. 4th ed. Wilderness Press, Berkeley, CA, USA.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research, 3rd ed. W. H. Freeman and Company, New York, NY, USA.

Stebbins, R.C. 2003. A Field Guide to Western Reptiles and Amphibians (Peterson Field Guide Series) 3rd Edition. Houghon-Mifflin Company, Boston, MA, USA.

Tyler, T., W. J. Liss, L. M. Ganio, G. L. Larson, R. Hoffman, E. Deimling, and G. Lomnicky. 1998. Interaction between introduced trout and larval salamanders (Ambystoma macrodactylum) in high-elevation lakes. Conservation Biology 12(1): 94-105.

USDA. 1988. Land and resource management plan: Lake Tahoe Basin Management Unit. USDA Forest Service, Pacific Southwest Region, South Lake Tahoe, CA. USA..

U.S. Fish and Wildlife Service. 2004. Endangered and threatened wildlife and plants; review of species that are candidates or proposed for listing as endangered or threatened; annual notice of findings on resubmitted petitions; annual description of progress on listing actions. Federal Register 69(86): 25876-24904.

Zar, J. H. 1998. Biostatistical analysis, 2nd ed. Prentice-Hall Inc., Englewood Cliffs, NJ, USA.

Zeiner, D. C., W. F. Laudenslayer, Jr., and K. E. Mayer, editors. 1988. California's wildlife, Volume I: amphibians and reptiles. California Department of Fish and Game, Sacramento, CA, USA.

Appendix A – Site sets defined by year(s) sampled and basis of selection for sampling. Bolded = samples used in change or status analyses where sites were only represented in one year per sample period.

Site Sets	Analysis	**#**	**Sample Year** 1997	1998	2002	2003	2004
Monitoring Sites:							
Set 1: 97/98 only	None	3	0	3	0	0	0
Set 2: 2002 remeasure	None	1	0	1	1	0	0
Set 3: 2003 remeasure	Change	29	**13**	**16**	0	**29**	0
Set 4: 2002/03 remeasure	Change	9	**6**	**3**	9	**9**	0
Set 5: 2003/04 remeasure, no hab in 2004 (intentional remeasure in 2004 = 8)	Change and status	9	**6**	**3**	0	**9**	9
Set 6: 2002/3/4 remeasure with habitat in 2004 (intentional remeasure in 2004 = 2)	Change and status	19	**11**	**8**	19	19 **(2)**	19 **(17)**
Set 7: 2002/3/4 remeasure w/o habitat in 2004 (intentional remeasure in 2004 = 7)	Change and status	18	**12**	**6**	18	**18**	18
Set 8: 2003/04 new (8.5 = no hab in 2004 = 5)	Status	7	0	0	0	**7**	7
Set 9: 2003 only new	Status	5	0	0	0	**5**	0
Set 10: 2004 only new	Status	52	0	0	0	0	**52**
Total		152	48	40	47	96	105
Total for change			48	36		67	17
Total for status						79	69
Other Sites:							
Set 11: Recon only	Loss	28	0	0	0	0	28
Set 12: AMMA watershed	Metapop	10	0	0	0	0	10
Set 13: misc non-randomly selected sites	Genetics	4	0	0	(2 in 2001)	1	1

*** Clarification on data used for which summaries/analyses:

- Data sets used to characterize sample period 1 for change = 3, 4, 5, 5.5, 6, 6.5, 7, 7.5 (n = 84 sites)
- Data sets used to represent 2003 in sample period 2 for change = 3, 4, 5, 5.5, 6.5, 7, 7.5 (n = 67 sites)
- Data sets used to represent 2004 in sample period 2 for change = 6 (n = 17 sites)
- Data sets used to represent 2003 in sample period 2 for status = change plus 8, 8.5, 9 (n = 79 sites)
- Data sets used to represent 2004 in sample period 2 for status = change plus 10 (n = 69 sites)

Appendix B – History of data collection methods for lentic sample units.

* Number in parentheses is the a tally of units that were dry or otherwise not sampled.

Survey	1997	1998	2001	2002	2003	2004
	Sample Year					
***Herptefauna*:**						
Original monitoring sites	48 1 visit: all	40 1 visit: all	6 (0) / 1 visit: all	51 (4) / 1 visit: 31 2 visits: 20	87 (3) / 1 visit: 3 2+ visits: 84	47 (1) / 1 visit: 21 2+ visits: 26
New monitoring sites			6 (0) / 1 visit: all	51 (4) / 1 visit: 31 2 visits: 20	99 (3) / 1 visit: 3 2+ visits: 96	130 (25) / 1 visit: 48 2+ visits: 82
Fish:						
# individuals	none/few/many	none/few/many		none/few/many	none/few/many	none/few/many
species ID	basic*	basic*		basic*	basic*	basic*
visual and snorkel	yes			yes	yes	yes
Net	no			no	no	yes
Habitat measures:						
# littoral transects (lt)	≥ 50	≥ 50		≥ 30	≥ 30	≥ 50
lt depth						yes
lt substrate	dominant	dominant		%	%	% and dominant
lt wood	pres float and submerged	pres float and submerged		indiv character float and submerged	indiv character float and submerged	indiv character float and submerged
lt veg	species pres, overhang pres	species pres, overhang pres		none	none	life form pres, overhang pres
upland transect	none	none		None	none	≥ 50
# outlets	no	no		no	no	yes
depths < 30m	yes	yes		yes	yes	yes
Disturbance	no	no		no	within 30 m	within 30 m
Invertebrates	dip net samples	dip net samples		no	no	no

Appendix C – Amphibian Genetic Sampling and Analysis

Sampling

The methods used were standard for collecting individuals/tissue for genetic analysis and habitat suitability modeling. Tissue samples were collected from a sample of long-toed salamanders (*Ambystoma macrodactylum*) and western toads (*Bufo boreas*) at all the sample units where they are present. Tissue collections entail toe clipping for adults and sub-adults or large metamorphs, and tail clipping or whole larvae collection for larval stages of the two species. No more than 10% of the larval population at any given location was sacrificed for a sample. The target number of individuals sampled for tissue at each lentic unit with detections was 50 individuals. If fewer than 10 larvae existed at a site, only toe/tail clipping was conducted, and no whole larval collection took place. At locations with 20 or fewer individuals, all individuals were sampled. At locations with between 20 and 40 individuals, only 20 total individuals were sampled. At sites with greater than 40 individuals, 50% of the total population was sampled with a maximum of 50 individuals sampled. Adults of either species were toe clipped regardless of the population size, but care was taken to minimize handling time of individuals and to avoid sampling of thumbs. Sampling of adults at sites with very few individuals, especially of *A. macrodactylum*, was critical for documentation of possible range expansions (e.g., detections of *A. macrodactylum* in Nevada). Toe/tail clipping and whole larval collection procedures followed Leyse et al. 2003. Tadpoles/metamorphs were rarely euthanized and subadults/adults were not euthanized.

Analysis

Laboratory work and genetic data analyses are currently being conducted in the H.B. Shaffer Laboratory at the University of California, Davis (W.K. Savage, pers. comm..) and in the Conservation Genetics Center at the University of Nevada, Reno (M. Peacock, pers. comm.). Standard laboratory techniques are being used to isolate and amplify genetic material (DNA). Analysis is currently focused on microsatellite markers, which are short repeating sections (e.g., CTACTACTACTA) of nuclear DNA. These markers represent relatively rapidly evolving regions of DNA (time scale of 100's to 1,000's of years) and are useful for characterizing genetic variability and gene flow from population to population (i.e. lentic unit to lentic unit) (Avise 2004). Estimates of within and among population (lentic unit) variation and gene flow are being derived using standard software (e.g. *Arlequin*, *Genpop*, etc.). Estimates of migration rates may require additional software and use of "super computer" time (M. Peacock, pers. comm.).

Preliminary Results

Genetic samples for long-toed salamanders and western toads were collected at a total of 36 sites in 2003 and 2004; 31 sites were sampled for long-toed salamanders, 3 for western toads, and 2 had both species. In 2003, a total of 257 long-toed salamander samples were collected from 15 sites with 3-31 individuals per site. In that same year, a total of 141 western toad samples were collected from 5 sites with 7-54 individuals per site. In 2004, 729 long-toed salamander samples were collected at 23 sites, included repeat visits to 5 sites from 2003 (3-50/individuals per site). Fifty western toad samples were collected from one site in 2004.

Preliminary results for the long-toed salamander are based on 15 microsatellite loci that have been developed for most of the individuals in the 2003 sample. In general, preliminary analysis of population genetic variation indicates a correlation between geographic and genetic distances. I.e. lentic units that are geographically closer are more genetically similar than those that are farther (W.K. Savage, pers. comm.). Details on genetic variation and structure across natural dispersal barriers and within and among watersheds will not be available until completion of data analysis for all samples from 2003 and 2004. Laboratory work on western toads is just beginning and so no preliminary results are available.

Literature Cited

Avise, J.C. 2004. Molecular Markers, Natural History, and Evolution. 2nd Edition. Sinauer Associates, Inc. Publishers. Sunderland, MA.

Leyse, K.E., A.J. Lind, .K. Savage, H.B. Shaffer, and M.R. Stephens. 2003. Tissue Collection Protocol for Genetic Research. Unpublished Technical Manual. University of California, Davis

Appendix D - Waterbird Survey Methods

We conducted point count surveys to describe the species composition and abundance of birds at all sample units. Bird survey techniques have varied to a limited degree within and between the two sample periods. Given the open environment associated with many lentic units, we established count stations 500 m apart around the perimeter of each sample unit to ensure point counts were independent. If visibility was limited at the designated count location, the observer moved to the closest point with good visibility. The primary objective in establishing point count stations was to achieve complete coverage of sites, minimize overlap between count stations, and spend at least 40 minutes counting birds. Count stations at sample units with multiple counts were located by conducting the first count and then pacing the distance along the perimeter until the straight-line distance between points was approximately 500 m. The GPS location of point count stations was noted on the datasheet and the location mapped so the same count stations could be used for the second visit. For resample sites from 2003, observers attempted to conduct counts at the same locations. At resample sites with one point count station, an additional site was established.

Point counts were performed between 0530 and 0930 hrs, beginning no sooner than 15 min after sunrise. Each point count lasted exactly 20 min, with data separated into the first 3, 5, 10 and 20 minutes. Observers recorded every bird seen or heard at any distance (including birds flying overhead). Pacific treefrog and Douglas squirrel vocalizations were always recorded if detected during point counts. Observers used binoculars to aid in identifying birds seen at a distance. If more than 1 observer surveyed a sample unit at the same time (primarily at larger sample units), observers were located at different stations and counts occurred simultaneously. An absolute number of birds present at the sample unit for all counts combined was derived by comparing all individual counts and omitting individual birds counted more than once.

Appendix E – Environmental variables generated for each lentic sample unit. Core field variables were measured on site in both sample periods (1997-98 and 2002-04) and were the basis of the habitat change evaluation. Additional field variables were recorded on site and only in one or more years in the second sample period (2003-2004). GIS-based data variables were developed from the latest GIS coverage available, with the exception of vegetation and disturbance. Variables were developed primarily from coverages from 2000.

CORE FIELD (all years)	ADDITIONAL FIELD (subset of years)	GIS-BASED
	Physical Site Characteristics	
Area (ha) – digitized from USGS maps (1997/98) or calculated as the area of an ellipse (2001-2004)	2004 - connectivity: number of permanent and ephemeral inlets and outlets	Connectivity: number of lentic sites by area category within 50, 200, and 500 m and 1 and 2 km buffers around each lentic site.
Maximum depth (m)		Slope: within 50 and 200m
Perimeter (1997/98 and 2004)		Aspect: within 50 and 200m
		Elevation (m)
		Orientation: east or west side of Lake Tahoe
	Environmental Setting	
		Precipitation (cm): derived from PRISM modeled precipitation data (Daly et al. 2002) – 44 year average – 1960-2004.
		Vegetation: area of CWHR vegetation types (from 2002 IKONOS); area of CALVEG types, canopy closure, and tree dbh (from Basin vegetation coverages 1997 and 2002) in 50, 200, 500 m and 1 and 2 km buffers around each lentic site.
	Littoral Zone and Shoreline Characteristics	
% of aquatic transects dominated by: silt, sand, pebbles, cobbles, boulders, bedrock.	2003-04 - % of each transect covered by: silt, sand, pebbles, cobbles, boulders, bedrock.	
% of aquatic transects with presence of: logs, emergent vegetation	2002-04 - % of each transect covered by: logs, emergent vegetation 2004 - % of each transect covered by: floating, submergent and overhanging vegetation	
	2004 - coarse woody debris: sizes of logs and log aggregations	
	2004 - % of aquatic and upland transects with presence of: rush, sedge, grass, lily, other herbs, willow, alder, shrub, aspen, cottonwood, lodgepole, other pine, conifer and deciduous trees	

Appendix E cont.

CORE FIELD (all years)	ADDITIONAL FIELD (subset of years)	GIS-BASED
Disturbance and Administrative Boundaries		
	2003-04 - % of area disturbed within 10 and 30 m buffers: highway, paved road , dirt road, trail, other	Development index based on land use classification and modeling by Sean Parks (PSW).
		Impervious surfaces from IKONOS 2002 data: area in 50, 200, 500 m and 1 and 2 km buffers around each lentic site.

Appendix F – Persistence index (PI) values for the 75 sites that were sampled in two or more years (n = 91 sites) and had one or more species of amphibian or garter snake detected. Asterisk = presence one or more years. X = occupancy or duration had a value of 3; XX = occupancy and duration had a value of 3. AMMA = Long-toed salamander, BUBO = Western toad, HYRE = Pacific treefrog, RACA = Bullfrog, THCO = Sierra garter snake, THEL = Western terrestrial garter snake, THIS = Common garter snake.

Site code	Site name	Type	Orient	Years surveyed	Species richness	PI value	AMMA	BUBO	HYRE	RACA	THCO	THEL	THSI
SPO	Spooner Lake	L	E	3	3	13		*	XX	*		*	
MAR	Marlette Lake	L	E	4	3	11		*				X	*
BKM	Bended Knee Meadow (Rabe Meadow)	M	E	2	2	6		*	*				
MEL	A Mellow One (Bliss Pond)	L	E	2	1	6			XX				
ZEP	Zephyr Meadow	M	E	4	1	6			XX				
FOL	Folsom Spring Pond	P	E	4	1	6						XX	
LOG	Log Monument Pond (Wildwood Basin)	P	E	3	1	5			X				
HOR	Horsehead Meadow	M	E	2	1	3			*				
SKY	Sky Meadows Pond (ST-01)	P	E	4	1	2	*						
WAT	Watson Lake	L	N	4	4	18		XX	X			*	*
REC	Recline Pond	P	N	4	3	13			XX			*	*
SCM	Snow Creek Meadow	M	N	4	2	9			XX			*	
SWE	Sweetwater Sewage Pond	P	N	2	2	6		*	*				
MUD	Mud Lake	P	N	4	1	6			XX				
GIN	Ginny Lake	P	N	2	1	4			*				
BUR	Burton Pond	P	N	4	1	3							*
SUM	Summit View Lake (EB-02)	P	S	4	4	20	*		XX			XX	X
LUM	Lumberg Pond	L	S	2	4	19	X		X			*	X
FRO	Frog Pond (EL-45)	L	S	3	4	16	*		XX			*	*
LUT	Luther Meadow	M	S	3	4	15	*	*	XX			*	
SEN	Seneca Pond	P	S	4	3	15	X		XX	XX			*
NOR	Norbert Lake	P	S	4	3	14	X		XX			*	
SMA	Smallmill Pond	P	S	3	3	14	*		XX			*	

Site code	Site name	Type	Orient	Years surveyed	Species richness	PI value	AMMA	BUBO	HYRE	RACA	THCO	THEL	THSI
LIL	Lily Lake	L	S	4	3	12			*		*	*	
FAL	Fallen Leaf Lake	L	S	3	3	12			*	XX		XX	*
OLE	Oleo Pond (EL-22)	P	S	4	2	12	XX		XX				
LIM	Limbo Pond (FP-02)	P	S	4	3	11	*		*		*		
MEI	Meiss Lake	L	S	2	2	10			XX			*	
POL	Polygon Pond	P	S	2	2	10			XX			*	
FOO	Footprint pond	P	S	2	2	10	X		X				
OVE	Overlook Meadow	M	S	4	2	9	*		XX				
FIR	First Lake	P	S	2	2	9			X			*	
RND	Round Lake	L	S	3	2	9			*			XX	
BEN	Benwood Pond	P	S	4	2	8	*		X				
DAR	Dardanelles Lake	L	S	4	2	8			X			*	
TAL	Tallac Lagoon (EB-27)	L	S	2	2	8			*	XX		*	
UBM	Upper Benwood Meadow	M	S	2	2	8			*			*	
ELB	Elbert Lake	L	S	3	2	7			X			*	
GRS	Grass Lake, Glen Alpine	L	S	4	1	6					X		
FRE	Freel Meadows	M	S	4	1	6			XX				
PEW	Pew Pond	P	S	4	1	6			XX				
PIG	Pigeon Pond	P	S	2	1	5	X						
CEL	Celio Ranch Pond	P	S	2	1	4			*				
PUR	Purgatory Pond (FP-04)	P	S	2	1	4			*				
SOD	Soda Pond (CL-06)	P	S	2	1	4			*				
GRA	Grass Lake, Luther Pass	F	S	4	1	3			*				
FLO	Floating Island Lake	P	S	2	1	3			*				
FOU	Four Lakes # 2	P	S	4	1	3			*				
ECH	Lower Echo Lake	L	S	4	1	3						*	
LAL	Little Angora Lake (EL-10)	P	S	3	1	2			*				

Site code	Site name	Type	Orient	Years surveyed	Species richness	PI value	AMMA	BUBO	HYRE	RACA	THCO	THEL	THSI
POW	Pond of the Woods	P	S	3	1	2			*				
BIR	Birdie Pond	P	S	4	0	0				XX			
BAR	Lake Baron	L	S	3	1	2			*				
LPM	Lily Pond Meadow	M	W	4	4	20	XX		XX			*	X
LOU	Lake Louise	L	W	4	4	19		XX	XX			*	*
BLA	Blackwood Pond	L	W	4	4	19	*		XX			*	XX
PAG	Page Meadows Pond	M	W	4	4	17	*		XX			*	X
HOM	Homey Meadow	M	W	4	3	17	X	XX	XX				
ELL	Ellis Lake	P	W	4	3	16	XX		XX				*
SKI	Skinny Whale Pond	P	W	3	4	15	*		XX		*	*	
BUC	Buck Lake	L	W	4	3	14		X	X			*	
MCK	Mckinney lake	L	W	2	3	14	*		X			XX	
BOR	Border Pond (RB-28)	P	W	2	3	12						*	*
STO	Stony Ridge Lake	L	W	2	3	10		*			*	*	
SNA	Snazure Pond	P	W	2	2	10			XX			*	
SUS	Susie Lake	L	W	4	2	9					*	XX	
BEA	Beaver pond meadow	M	W	2	2	9		*	X	*			
LOS	Lost Lake	L	W	4	2	8			X			*	
VAN	Van Gogh Lake	L	W	3	2	7			X		*		
FND	Found Pond (HW-13)	P	W	3	1	6			XX				
GRO	Lower Grouse Lake	P	W	3	1	6			XX				
QUA	Quail Lake	L	W	2	1	6						XX	
GIL	Gilmore Lake	L	W	2	1	4					*		
HIG	High Life Pond	P	W	2	1	4			*				
CAS	Cascade Lake	L	W	3	1	3			*				