BIOGEOGRAPHY OF INVERTEBRATES IN HANGING GARDENS OF THE COLORADO PLATEAU

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♦ INTRODUCTION

Research on plant and invertebrate communities of hanging gardens in five parks on the Colorado Plateau is at the half way point. Many interesting and somewhat unanticipated biological and geological questions have arisen, and we are progressing toward our initial research objectives. Plant diversity and community survey work is on schedule and providing insight into biogeographic and community patterns. Insect survey work is slightly behind due to the high abundance and diversity of taxa.

Our research objectives for the 1992 field season were to (1) complete the survey of plant and invertebrate animal communities of hanging gardens in Zion National Park (ZION) and Glen Canyon National Recreation Area (GLCA), and to begin a community survey of communities in Capitol Reef National Park (CARE), (2) map the geographic distribution of the endemics identified and determine levels of endemism within and among parks and (3) determine levels of similarity between each sampled hanging garden plant and insect community.

FIELD METHODS

Most of the hanging gardens we sampled in 1992 were chosen during a closeout session at Zion National Park (ZION) and Glen Canyon National Recreation Area (GLCA) at the end of the 1991 field season. The Capitol Reef National Park (CARE) sites were chosen during a work trip in May, 1992. The return trip to ZION had two main objectives: 1) to complete the work on the Canyon Overlook hanging gardens due to their discovery on the last day of the 1991 field season, and 2) to verify our plant species lists compiled in 1991 since there were discrepancies with Welsh (1989).

Field sampling techniques were the same as in summer 1991 (Stanton et al. 1992) with the exception of the following. All hanging gardens in ZION were re-sampled for plant species diversity since our 1991 species lists were not in total agreement with Welsh's (1989) report. We made a more concerted effort to search each subsequent hanging garden for all plant species present.

Each hanging garden was visually separated into the following microhabitats: wet walls, ledges, ledge-soil complex, and seeplines. Wet walls were obviously vertical but also included some slopes and floors that were covered with thin sheet flow of water and were dominated by ferns, prokaryotic and protistan communities. Ledges were of sufficient width and length to support linear plant communities in cracks and narrow strips of wet soils. Most of the vascular plant communities were found on ledge-soil complexes with wet colluvial soils just down slope of ledges or underneath an alcove. Seeplines are drier, linear communities that develop at a fracture in the sandstone or at impervious bedding planes on canyon walls and at the back of dryer alcoves. These microhabitat definitions are generally the same as in 1991 but now substitute seepline for backwall and drier ledges. The ledge microhabitat is now reserved for wet transitions between wet walls and wet colluvial soils of the ledge-soil complex. Data collection on the physical parameters of each hanging garden were increased to include aspect and length of tributary drainage above hanging gardens.

♦ RESULTS

Over 600 plant specimens were collected as vouchers for distribution and community data. These above specimens are presently being identified by Dr. Hartman at the Rocky Mountain Herbarium at the University of Wyoming. Once identification is complete, analysis of community and biogeographic data on 1992 hanging gardens will begin.

Topographic surveys for all hanging gardens sampled have been completed to determine hanging garden size (Tables 1, 2). Plant species richness for each hanging garden was determined from 1991 data (Tables 1, 2) to allow preliminary calculation of area-species relationships (MacArthur and Wilson, 1967) for ZION and GLCA. The slopes of the two regression lines are significantly different ($t_{(.05)2,25}$ = 2.58, p = .02) which indicates different area-plant species relationships for the two parks. ZION's slope (0.15) is within the range MacArthur and Wilson (1967) give for continental biota (0.12-0.17) while GLCA's slope (0.25) is in a more island-like range (0.20-0.35). This trend may continue with the addition of hanging garden plant richness data collected in 1992; if so, it may influence management recommendations.

A cluster analysis of hanging garden vascular plant communities has been initiated for ZION. This is based on community similarity coefficients and will allow the development of a plant community classification system. We will continue cluster analysis on vegetation data from GLCA and the other parks as species identification is completed.

While sampling the ledge-soil complex microhabitat at Weeping Rock Hanging Garden in ZION last summer we were assisted by Resource Management staff. They requested advice on how to best protect the hanging garden plant resource in light of trampling and "social trails". Our judgement was that the most fragile resource was the wet, unstable soils and that a boardwalk should be constructed.

We have begun a preliminary analysis on the distribution and community importance of characteristic hanging garden plants, endemics, disjunct populations of more widespread species, and possible endangered species (Table 3). Federal and state status was taken from Atwood et al. (1991). Zion daisy, *Erigeron sionis*, has been found on only two hanging gardens in ZION (although the second one has yet to be verified by Dr. Hartman) and has a very small part of the community canopy coverage. There are, however, many individual plants on the wet wall at Canyon Overlook II hanging garden not two feet from the trail on which thousands of tourists walk each year. Alcove bog-orchid, *Habenaria zothecina*, has been found on wet rock and wet soils on three hanging gardens in GLCA (although the two from 1992 have yet to be verified by Dr. Hartman) where it occupies 2-5% of the canopy. All three hanging gardens have a north aspect (Table 2): Rattlesnake-356°, Swallow-7°, and Camp-5°. These are isolated locations in Pictograph, Ribbon, and Knowles Canyons respectively which show little, if any, sign of visitation. While each of the stands have many individual plants of this species and appear to be in good vigor, there is a finite number of north facing hanging gardens on the Colorado Plateau. If next season's work in CANY verifies this pattern, the C2 status may need to be upgraded. Disjunct populations of American spikenard, *Aralia racemosa*, and cliff jamesia, *Jamesia americana*, are found on the same two ZION hanging gardens; Falling Water and Grotto. American spikenard has an 8% average canopy cover on wet, ledge microhabitats as well as several individual plants on both hanging gardens. Cliff jamesia has much fewer numbers of individuals and did not show up in community samples. Both hanging gardens have or have had water diversion projects to supply Zion Lodge. The other plants shown in Table 3 were chosen as characteristic hanging garden plants not found in surrounding habitats. Most of them appear to be widespread and to form a significant portion of the canopy cover of vascular plant communities.

Insect collections are currently being processed and identified to Family prior to shipment

Table 1. Plant species richness and physical parameters of hanging gardens in Zion National Park: size in m^2, aspect in degrees, elevation in feet. Plant species numbers are best current estimates and may change slightly as taxonomic work is completed.

Hanging Garden	Size	Richness	Aspect	Elevation
Pine Creek	72	4	344°	4200
Upper Emerald	1170	19	120°	4700
Lower Emerald	131	11	158°	4300
Grotto	628	18	16°	4600
Menu Falls	190	19	218°	4500
Fall	274	11	31°	4500
Falling Water	420	18	318°	4600
Narrows Trail	383	19	259°	4500
Trail's End	226	10	303°	4500
Canyon Overlook I	4	10	238°	5250
Canyon Overlook II	70	17	124-242°	5250
Court Patriarchs	99	13	177°	4750
Snail	61	11	270°	4500
Kaye's	124	25	192°	4600
Weeping Rock	812	22	196°	4500
Hailstone	28	13	100°	4700

to the USDA Bee Laboratory at Utah State University and the systematic Entomology Laboratory at Oregon State for species identification. Most of the sweep netted, hand, and flower pollinator/feeder collections have been processed and shipped for identification.

We have begun a biogeographic analysis of the distribution of bumblebees (*Bombus*) from 1991 collections. All of the five species collected are found in boreal and montane forest biomes (Table 4) and three, *Bombus centralis*, *B. melanopygus*, and *B. occidentalis* have their highest abundance in the boreal/montane forest biome (Table 4) (Milliron 1971, 1973, Stephan 1957, Thorpe et al 1983). These data support the hypothesis that hanging garden fauna are ice age relicts. Bumblebees tend to be generalized floral feeders, but our records match only two previously documented bumblebee species-plant genus associations: *B. morrisoni* on *Cirsium* in GLCA, and *B. huntii* on *Dodecatheon* in ZION. Both of these bumblebees are widespread in the Great Basin (Table 4). Our floral visitation records for *B. centralis*, *B. melanopygus*, and *B. occidentalis* (Table 4) appear to be previously undocumented.

In GLCA and ZION, many hanging gardens appear to be located on the contact between the Navajo sandstone and the Kayenta formation (Tables 5, 6) at an approximate elevation of 3800-4200 (Table 2) and 4100-5300 feet (Table 1) respectively. These gardens straddle the contact and have distinct geomorphic microhabitats. The wet backwall (and hanging wall under an alcove) are in the cliff forming Navajo sandstone, while the ledges and colluvial soil slopes develop in the siltstone and mudstone layers of the Kayenta. Most of the remaining hanging gardens

Table 2. Plant species richness and physical parameters of hanging gardens in Glen Canyon National Recreation Area: size in m^2, aspect in degrees, elevation in feet. Plant species richness is currently being determined for hanging gardens worked in summer 1992.

Hanging Garden	Size	Richness	Aspect	Elevation
Dune	173	18	90°	4000
Crossbed	115	22	201°	4040
Rattlesnake	836	19	356°	3800
Hardwood	1177	29	155°	3840
Pedestal	269	15	160°	3800
Zephyr	81	15	174°	3800
Graffiti	44	7	175°	3800
Upper Three	825	15	230°	4100
Lower Three	162	6	230°	3840
Surprise	150	9	120°	3880
Ivy	70	7	233°	3840
Baby	35	10	263°	3760
Baby Too	38	10	205°	3920
Zigy	1215		186°	3880
Hook	351		212°	4160
Hawk	193		243°	4160
Swallow	52		7°	3880
Ice	893		238°	4050
Corner	249		112°	4050
Channel	714			3920
Camp	341		5°	3800
Pyro	37		202°	3800
Boondoggle	17		195°	3800

are within the Navajo sandstone with seeps associated with synclinal crossbedding. Almost all hanging gardens sampled have been associated with or located below surface drainage pouroff points. We have found Welsh's (1972) classification of hanging gardens into alcove, windowblind, and terrace types to be only somewhat descriptive. For example, with his system, only type IV classic alcoves are associated with surface drainage tributaries. We plan to measure surface drainage area and length above each hanging garden then combine that data with hanging garden size, structure of primary seep, and

Table 3. Canopy coverage values for hanging garden vascular plants with narrow distribution; () = coverage range, T = trace, [] = sample size. Microhabitat symbols: ww = wet wall, l = ledge, ls = ledge/soil, seep = seepline.

Species	Status		Microhabit			
	Fed	St	ww	l	ls	seep
Jamesia americana	C2	G5T1/ S1		T [2]		
Habenaria zothecina	C2	G1 /S1	.05 [1]		.025 (.02-.03) [2]	
Erigeron sionis	C2	G2 /S2	.01 [2]			
Aralia racemosa	-	-	-	.08 (T-.15) [3]	.04 [1]	
Aquilegia chrysantha	-	-	.13 (.12-.15) [2]	.03 (T-.06) [4]	.04 (T-.22) [9]	
Dodecatheon pulchellum zionense	-	-	.03 (.03-.04) [3]	.11 (.08-.13) [3]	.20 (.06-.35) [8]	
Mimulus cardinalis	-	-	.40 (.18-.63) [2]	.06 (.01-.17) [3]	.03 (T-.06) [2]	
Cirsium rydbergii	-	-	.04 (.01-.13) [6]	.05 [1]	.29 (.01-.79) [13]	.02 [1]
Cladium californicum	-	-		.037 [1]	.063 [1]	
Primula specuicola	-	-	.01 (T-.02) [2]	.02 (T-.04) [2]	.02 (.02-.03) [4]	
Mimulus eastwoodiae	-	-	.08 (T-.20) [5]	T	T	
Aquilegia micrantha	-	-	.10 (.01-.20) [4]		.03 (T-.06) [9]	

Table 4. Biogeographic analysis of the distribution of bumblebees, *Bombus* as floral visitors on hanging gardens in ZION and GLCA during 1991. Distribution is by state or province abbreviation; floral records by plant genus.

Species	Distribution	Center of abundance	Biome affinity	New floral records
Bombus centralis	AK,BC,AL,WA,OR, CA,ID,UT,NM,AZ	BC,WA,ID,CA	Montane & boreal forest; Upper Sonoran	*Aralia* in ZION
Bombus huntii	BC,AL,SA,WA, OR,ID,MT,WY, CA,NV,UT,AZ,NM, MEX	UT,NV	Boreal & montane forest; sonoran & great basin desert	*Aralia* in ZION
Bombus melanopygus	AK,BC,WA,OR,ID, CA	BC,WA,OR	Montane & boreal forest	*Dodecatheon* in ZION
Bombus morrisoni	BC,WA,OR,ID, WY,CA,NV,UT, CO,NM,AZ	CA,AZ	Montane forest surrounding Great Basin desert	none
Bombus occidentalis	AK,BC,AL,SA,WA, OR,ID,MT,WY,CA, NV,UT,AZ,NM	BC	Montane & boreal forest	*Aralia*, *Aquilegia*, *Mimulus*, *Dodecatheon* in ZION

microhabitat complexity (Tables 5, 6) to develop a more explanatory classification system for hanging gardens of the Colorado Plateau.

♦ DISCUSSION

No significant problems have been encountered. Field work for summer 1992 was hampered early in the season by rainy weather and later by logistical support problems at GLCA. Inadequate lab facilities at GLCA prevented efficient use of down time for specimen preparation and sorting. The vast number of insects collected demand a lot of preparation time which has put us behind our planned schedule. This is also the case for species identification at the Oregon State Systematic Lab (SEL). Identification of Apoid bees at the USDA Bee Lab in Utah State is up to date, and we plan to shift preparation emphasis to that group. A potential problem may exist in getting most specimens identified to species within the proposed three year time frame for project funding. This will be especially true if a significant number of specimens prove to be endemic to hanging gardens or new to science. In order to relieve some of the workload on the SEL at Oregon State, we plan to send insects collected from DINO next summer to Borris Kondratieff for identification at the Colorado State University Entomology Museum. This was suggested by Steve Petersberg, Resource Management Specialist at DINO since Dr. Kondratieff is currently working on a general insect survey at DINO.

The first priority for the remainder of the reporting period is to identify the pressed plant specimens and to process the pitfall and malaise trap

Table 5. Geomorphic characteristics of ZION hanging gardens. Geologic formation characteristics as follows: Spbd = bedding planes within Springdale member, Kbd = bedding planes within Kayenta Formation, K/N = Kayenta-Navajo contact, Nxbd = Navajo crossbeds. Microhabitats: seep = seepline, ww = wet wall, l = ledge, ls = ledge/soil.

Hanging Garden	Size (m^2)	Structure of primary seep	Microhabitats present
Pine Creek	72	Spbd	seep,ww,ls
Upper Emerald	1170	K/N	seep,ww,l,ls
Lower Emerald	131	Kbd	seep,ww,ls
Grotto	628	K/N	seep,ww,l,ls
Menu Falls	190	Kbd, K/N	seep,ww,ls
Fall	274	Kbd, K/N	seep,ww,l,ls
Falling Water	420	K/N	seep,ww,l,ls
Narrows Trail	383	K/N	seep,ww,l,ls
Trail's End	226	Nxbd	seep,ww,ls
Canyon Overlook I	4	Nxbd	seep
Canyon Overlook II	70	Nxbd	seep,ww,l
Court Patriarchs	99	Kbd	seep,ww,ls
Snail	61	K/N	seep,ww,ls
Kaye's	124	K/N	seep,ww,l,ls
Weeping Rock	812	K/N	ww,ls
Hailstone	28	Nxbd	seep

insect collections. Analysis of vegetation ecology data and plant and insect biogeographic distribution patterns will follow. A literature search for both plant and insect species distribution maps and biogeographic affinities will continue.

We contacted Jayne Belnap at CANY and Steve Petersberg at DINO last summer to make tentative plans for summer 1993 field season. Our reconnaissance work at CANY in 1991 located large hanging gardens at CANY and ARCH. We have reconnaissance trips scheduled for late May and mid-June for DINO and have read Naumann's (1990) DINO flora report for locations of hanging gardens. We plan to finalize the field season plans next spring.

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Table 6. Geomorphic characteristics of GLCA hanging gardens. Symbols as in Table 4.

Hanging Garden	Size (m^2)	Structure of primary seep	Microhabitats present
Dune	173	Nxbd	seep,ww,ls
Crossbed	115	Nxbd	seep,l,ls
Rattlesnake	836	Nxbd	seep,ww,l,ls
Hardwood	1177	K/N	seep,l,ls
Pedestal	269	K/N	seep,ww,ls
Zephyr	81	K/N	seep,ww.ls
Graffiti	44	K/N	seep
Upper Three	825	K/N	seep,ww,ls
Lower Three	162	Nxbd	seep,ls
Surprise	150	K/N	ls
Ivy	70	K/N	seep,ls
Baby	35	Kbd	seep
Baby Too	38	Nxbd	seep
Zigy	1215	Nxbd	seep,ww,l,ls
Hook	351	Nxbd	seep,ww,l,ls
Hawk	193	Nxbd	seep,ww,ls
Swallow	52	Nxbd	seep,ww,ls
Ice	893	Nxbd	seep,ww,ls
Corner	249	Nxbd	seep,ww,ls
Channel	714	Nxbd	ww
Camp	341	K/N	seep,ww,ls
Pyro	37	K/N	seep,ww,ls
Boondoggle	17	K/N	seep,ls

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