SPIDER DIVERSITY PATTERNS ON THE ISLAND OF MOOREA

April Yang

Molecular and Environmental Biology / Division of Organisms and Environment, University of California, Berkeley, California 94720, USA

Abstract. The island of Moorea, Society Islands (French Polynesia) provides a unique opportunity to examine patterns of spider diversity on a small high volcanic island. I collected spiders at a range of elevations (0~900m) and habitats (disturbed coastal, streamside, mid-elevation ridges and high mountains). This allowed me to map distributions and look at differences in spider assemblages. Specimens were identified to family level. I found a total of 30 different morphospecies. A total of 1738 spiders were collected (using sweep netting and active searching) represented by 12 families, 16 determined genera and 12 determined species. My survey revealed that streamside and coastal communities had the greatest overall biodiversity while having the lowest native diversity. Mid-elevation ridges and high mountains had lower overall diversity but higher native biodiversity. Differences in overall diversity may be due to variation in structural diversity of these habitats. In the future more extensive surveys of the spider fauna need to be done to determine whether structural diversity, elevation or vegetation type is most responsible for different distributions of biodiversity. The spider fauna of Moorea is dominated by nonnative species. As anthropomorphic disturbances on the environment increase more efforts should be directed towards conservation of mid-elevation ridge and high mountain sites which possess more native species.

Key words: arthropods; spider; diversity; habitat; Moorea, French Polynesia

Introduction

The dynamics of island ecosystems are intricately tied with human activity. When Polynesians arrived approximately 1500 years ago they brought with them plants, animals, and a lifestyle that sculpted the landscape of French Polynesia (Lepofsky et al. 1996). The isolated nature of islands makes them unique and ideal "natural laboratories" for studying community structure and ecological processes (MacArthur & Wilson 1967).

Presently, the biodiversity of these island ecosystems is under threat from loss of habitat due to an intensification of agricultural practices, habitat fragmentation, and encroaching invasive species (e.g. Meyer and Florence 1996). As invasions by nonnative species increases, it is unclear how native biodiversity will fair (Gillespie 2008). This makes it important to estimate the existing biodiversity for conservation purposes (Gillespie 1999).

Abundant and highly diverse, spiders are found on every continent except Antarctica. These top-level predators, may also serve as valuable bioindicators of ecosystem health (Noss 1990). Despite this, very little is known about the natural histories and distributions of many species. Knowledge of the spider fauna of the Pacific has been largely limited to publications made by Lucius Berland in the 1920's and 1930's. Berland (1934b) stated that the fauna of the Society Islands was poorly known and that further exploration was necessary in order to access the true diversity of spiders.

Moorea is the second tallest island of the Society Islands chain. Formed from a volcanic hotspot approximately 1.25 mya, it supports an assemblage of plants and animals found no where else. More than

1600 people (2007 census) live within 100m along the coastline. As the population begins to grow, there is an increased need to start conservation efforts.

One of the first steps in developing a conservation plan is to learn the distribution, abundance and status of the organisms in order to develop appropriate management techniques. This survey attempts to add to our growing knowledge of terrestrial arthropods found on Moorea.

METHODS

Site Selection

All spiders were collected at eight sites in a range of habitats and elevations on the island of Moorea, French Polynesia (149º50'W, 17º32'S) on 20 collection expeditions between September and November of 2008. To make analysis of the distribution of spider populations easier, collection sites have been divided into coastal, streamside, mid-elevation ridge and high mountain sites (Figure 1).

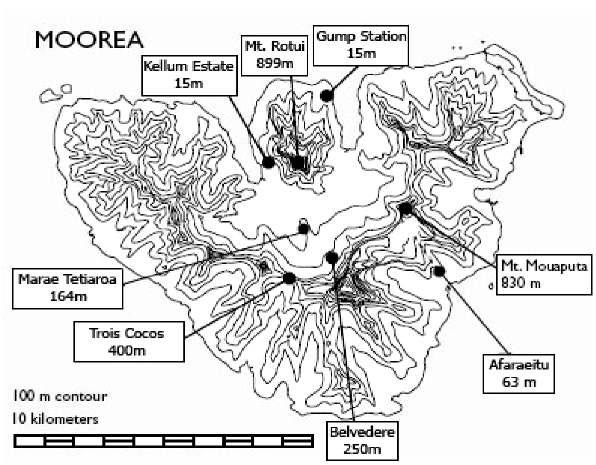

FIG. 1. Topographical map of Moorea showing collection sites and their elevations.
Geographic coordinates of collection sites:

Coast		
Gump House	149°49.60'W 17°29.44'S	15 m
Kellum Estate	149°50.90'W 17°30.87'S	15 m
Streamside:		
Afaraeitu	149°48.4'W 17º32.8'S	63 m
Marae Tetiaroa	149°49.78'W 17º32.193'S	164m
Mid-Elevation		
Belvedere	149°49.59'W 17°32.44'S	250 m
Trois Cocos	149º50.52'W 17º32.83'S	400 m
High		
Mt. Mouaputa	149°48.20'W 17º31.58'S	830 m
Mt. Rotui	149°49.70'W 17º30.75'S	899 m

Vegetation Types

Habitats were characterized by dominant vegetation types. These dominant vegetation types were noted and are listed in Table 1.

	Dominant Vegetation
Coastal	*Cocos nucifera* (I)
Gump Station	*Hibiscus tiliaceous* (N)
Kellum	*Inga feuillei* (I)
	Inocarpus fagifer (I)
	Mangifera indica (I)
	Miconia calvascens (I)
	Chrysophyllum cainito (I)
	Spathodea campanulata (I)
Streamside	*Davallia denticulate* (I)
Afaraeitu	*Angiopteris evecta* (I)
Marae Tetiaroa	*Inocarpus fagifera* (I)
	Syzigium malaccense (I)
	Hibiscis tiliaceus (N)
	Cordyline fruticosa (I)
Mid-elevation	*Freycinetia impavida*(N)
Belvedere	*Hibiscus tiliaceus* (N)
Trois Cocos	*Metrosideros collina* (N)
	Miconia calvascens (I)
High Mountain	*Pandanus tectorius* (N)
Mt. Mouaputa	Unknown (N)
Mt. Rotui	*Syzygium malaccense* (I)

Table 1: Dominant plant types seen in habitats. Plants are listed with their status as Introduced (I) or Native (N)

Spider Collection

At selected sites on the island of Moorea, I sampled once during the day and once at night using a modified Coddington sampling protocol (Coddington et al. 1996).

Ground sampling targeted spiders which live on litter, logs, rocks and plant surfaces this targets the areas between the knee and the ground. Aerial sampling involved searching leaf foliage, branches, tree, trunks, and the spaces in between, from knee height up to one's maximum overhead arm's reach. Sweeping is done to dislodge spiders by striking vegetation with a sweep net.

All spiders were aspirated into vials containing 80% ethanol. One sample unit equals one hour of uninterrupted effort using one of these three methods. During this time, I attempted to collect every spider encountered. I spent a total of four sample hours at each site, excluding high elevation sites where I was only able to collect for one sample hour each.

Spiders were identified to family level when possible using a key by Ubick et al. (2005) and the assistance of Rosemary Gillespie (pers. comm.). Both known and unknown species were assigned a unique identification number. Specimens were deposited at the Essig Museum of Entomology at the University of California, Berkeley. The status of spider: native, introduced, invasive, was also established when possible (Gillespie, pers. comm.).

Analysis

Spider assemblages were analyzed using both Excel 2002 and JMP 8.0 (SAS Institute 2008). The Shannon-Weiner (Shannon and Weiner 1953) diversity index, species richness, and species evenness were calculated for spider populations in different habitats: coastal, stream, mid-elevation ridge, and high mountain. The data set was also analyzed using Tukey's test to check if means for sites are significantly different from one another.

RESULTS

Spider Collection

I collected 30 morphospecies in the following families: Araneidae, Dysderidae, Pholcidae, Salticidae, Scytodidae, Sparassidae, Tetragnathidae, Thomisidae, and Uloboridae. I was able to identify 12 to species: *Araneas nigropunctatus* (L. Koch, 1871); *Gasteracantha cancriformis* (Linnaeus, 1758); *Dysdera crocota* C.L. Koch, 1838; *Pholcus ancoralis* L. Koch, 1865; *Thorelliola ensifera* (Thorell, 1877); *Heteropoda venatoria* (Linnaeus, 1767); *Leucauge granulata* (Walckenaer, 1842); *Tetragnatha tuamoaa* Gillespie, 2003; *Tetragnatha macilenta* L. Koch, 1872; *Rhomphaea cometes* L. Koch, 1872; *Tangaroa tahitiensis* (Berland, 1934) and *Misumenops melloleitaoi* Berland, 1942. Refer to Appendix A for more detailed notes on distributions. Of the species identified, three are considered to be native: *Tangaroa tahitiensis* (Berland, 1934); *Tetragnatha tuamoaa* Gillespie, 2003 and *Misumenops melloleitaoi* Berland, 1942.

A few species of spiders were widespread and highly abundant in a majority of the sites. These species included the native Uloboridae: *Tangaroa tahitiensis*;

Habitat	Number of sampling hours	Number of spiders collected	Overall Species Richness	Native Species Richness	Number of native spiders collected*
Coastal	8	514	15	1	6
Streamside	8	776	19	1	1
Mid-Elevation Ridge	8	407	20	2	15
High Mountain	2	40	8	1	20

Table 2: Summary table of spiders collected in Moorea. High Mountain site is included for qualitative purposes. *The widely distributed native *Tangaroa tahitiensis* (Berland 1934) excluded from this table

the introduced Salticidae: *Thorelliola ensifera*; and the Pholcidae: *Pholcus ancoralis*. Numbers of individuals are summarized in Table 3. *T. tahitiensis* was found in great abundance in coastal, streamside, and mid-elevation ridges. Their numbers often comprised 30% of all specimens collected from a site. *T. ensifera* and *P. ancoralis* were found in greatest abundance in streamside habitats followed by coastal and mid-elevation ridge habitats.

Habitat	*Tangaroa tahitiensis*	*Thorelliola ensifera*	*Pholcus ancoralis*
Coastal	312	39	37
Streamside	229	164	172
Mid-Elevation Ridge	298	24	14

Table 3: Summary of abundant spider populations

Spider Diversity

The Shannon-Weiner index for each habitat was calculated. Figure 2 compares the index across the different habitats and sampling times. The streamside habitat showed the highest overall spider diversity followed by the coastal, high-mountain and finally mid-elevation habitats.

The Tukey test showed that the streamside communities were significantly different from coastal and mid-elevation ridge habitats (Figure 2). The biodiversity index for coastal and mid-elevation site was not significantly different.

Source	**DF**	**Sum of Squares**	**F Ratio**	**Prob>F**
Day vs. Night	1	0.1507	2.3545	0.1398
Habitat	3	2.0775	10.8199	0.0002

Table 4: Summary of the Effects tests performed on the data. Habitat had a significant effect on biodiversity while time of sampling did not. High-elevation sites were not included due to a small number of replicates.

The significance of time of sampling (Day vs. Night) and habitat on the biodiversity of index was also calculated (Table 4). The time of sampling did not have an affect on biodiversity; whereas, habitat was shown to be significant in driving the biodiversity index.

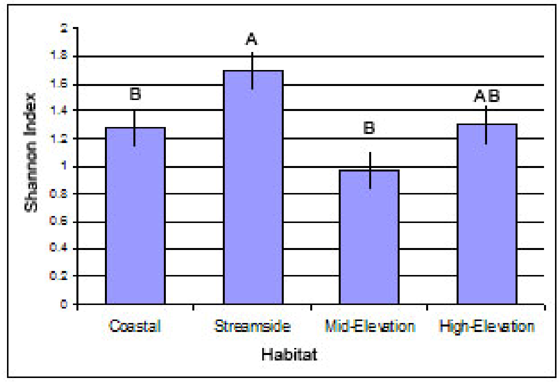

Figure 2: Average biodiversity of each habitat. Error bars represent standard error. Bars that do not share the same letter are significantly different. High elevation habitats were included for qualitative purposes.

The species richness of the four sites is recorded in table 2. This table also includes the number of known native species. The mid-elevation ridges possessed both the greatest number of species followed by streamside, coastal and high mountain communities. The mid-elevation ridge had the most native species (Table 2). Detailed biodiversity indices are included in Appendix B.

Discussion

Spider collection

During my collections, a few species were collected in great numbers in coastal, stream and mid-elevation ridge habitats. *T. tahitiensis* was by far the most abundant. Based upon their abundance and their wide distribution on the island it would appear this species was an introduction. However, *T. tahitiensis* is almost certainly native based upon molecular work done by Rosemary

Gillespie of UC Berkeley. The high density may also be a product of the spiders' natural history. I have collected as many as eight individuals off of the same plant. The abundance of this native species suggests that this spider, along with other introduced species, prefers disturbed habitats.

Spider Diversity

The Shannon-Weiner index showed that diversity in spiders in streamside habitats was highest. While this may be an accurate reflection of the spider assemblage in the area, it is also likely the product of the increased structural diversity resulting from the large number of microhabitats present by the stream (Mühlenberg M, L. et al). Streamside areas possess the added habitat of vegetation growing above and next to water. Many families of spiders, such as Tetragnathidae, seem to prefer this habitat. Consequently, this family was more found in higher abundance than in other sites. The disturbed coastal habitats also possessed a high biodiversity index. The more native mid-elevation ridge sites had the lowest overall biodiversity.

Despite the lower biodiversity index, I was able to collect the most native species in mid-elevation ridge sites. I was also able to collect them in higher abundance compared with the coastal and streamside sites. Aside from *Tangaroa tahitiensis* (Berland, 1934), I found two native spiders: *Tetragnatha tuamoaa* and *Misumenops melloleitaoi*.

The high elevation sites were not sampled as extensively. I was only able to sample for two hours as opposed to eight in the other sites. Despite this, high elevation sites possessed the native *M. melloleitaoi* in great number. With more time spent collecting in these areas at night and on repeated occasions more native and nonnative species would be found. The presence of a greater population of native spiders at mid-elevation ridges and high mountain sites suggests that these areas possess more native species.

A far greater number of nonnative species were found in coastal and streamside disturbance areas. This may be the result of synergistic effects between introduced species. However, not enough sampling was done in order to determine whether these large numbers were the result of invasive meltdown (Simberloff &Von Holle 1999) or if they were the result of the increased structural diversity resulting from more diverse microhabitats.

This survey of the spiders found on the island of Moorea revealed that while overall species diversity was higher in the more disturbed coastal and streamside communities the native species diversity was low. Native species diversity was highest in the relatively more intact mid-elevation ridges and high mountain communities. The species richness appears to increase with elevation.

Island ecosystems provide the opportunity to examine the impacts of habitat and anthropomorphic disturbance on spider populations. Disturbance alters community structure through the introduction of foreign plant and animal species. The degree to which this affects the composition of spider communities is unclear and requires further study. As more of the island becomes developed it becomes increasingly important to understand these processes for conservation purposes.

ACKNOWLEDGMENTS

I thank professors, graduate student instructors and fellow students for their helpful suggestions and support. Special thanks to Mari Mari Kellum for use of her property. George Roderick provided helpful review of the paper. Verification of species and useful background information was provided by Rosemary Gillespie. I am grateful to University of California, Berkeley and the Richard P. Gump Station, without which this project would not have been possible.

LITERATURE CITED

Berland, L. 1926. Remarques sur la repartition et les affinites des araignees du Pacifique. Proc Third Pan Pacific Set Congress Tokyo 1:1044-1054.

Berland, L. 1942. Polynesian spiders. Bernice P Bishop Mus Occas Papers 17:1-24.

Clausen, I. H. S. 1986. The use of spiders (Araneae) as ecological indicators. Bulletin of the British Arachnological Society 7(3):83-86.

Coddington, J.A., L.H. Young, & F.A. Coyle. 1996. Estimating spider species richness in southern Appalachian cove hardwood forest. J. Arachnol., 24:11-28.

Gillepie RG (1999). Naivete and novel perturbation: Conservation of native spiders on an oceanic island system. Journal of Insect Conservation 3: 263-272

Gillespie RG (2003) Spiders of the genus Tetragnatha in the Society Islands. *Journal of Arachnology*, Vol. 31, No. 2 (2003), pp. 157-172

Gillespie RG, Claridge EM, Roderick GK (2007). Biodiversity dynamics in isolated island communities: interaction between natural and human-mediated processes. *Molecular Ecology*, 17, 45–57

Institut Statistique de Polynésie Française (ISPF) (2007). "TABLEAU II Population des communes et communes associées de Polynésie française" (PDF).

Kirch P.V., 1996. Late Holocene Human-Induced Modifications to a Central Polynesian Island Ecosystem. Proceedings of the National Academy of Sciences of the United States of America, Vol. 93, No. 11 (May 28, 1996), pp. 5296-5300

Lepofsky D. Kirch PV. Lertzman KP (1996). Stratigraphic and paleobotanical evidence for prehistoric human-induced environmental disturbance on Mo'orea, French Polynesia. Pacific Science 50: 253-273.

MacArthur RH, Wilson EO (1967) *The Theory of Island Biogeography*. Princeton University Press, Princeton, NJ.

Mayfield, M. M., Maciej B.F., Daily D.C., Ackerly D.., 2005. Species and Functional Diversity of Native and Human- Dominated Plant Communities. Ecology, 86(9), 2005, pp. 2365–2372

Meyer J., Florence J., 1996. Tahiti's native flora endangered by the invasion of Miconia calvescens DC. (Melastomataceae). Journal of Biogeography, 23. 775-781

M¨uhlenberg M, Leipold D, Mader HJ, Steinhauer B. 1977. Island ecology of arthropods. I. Diversity, niches, and resources on some Seychelles Islands. *Oecologia* 29:117–34

Nishida G.M., Version 2008 September 5, 2008. French Polynesia Checklists. Essig Museum of Entomology Collections. http://essigdb.berkeley.edu/checklists/. Accessed September 25, 2008

Noss, R.F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conserv. Biol., 4(4):355-364.

Platnick NI. 2005. The World Spider Catalog. Version 7.5. New York: American Museum of Natural History. (1 February 2007; *http://research.amnh.org/entomology/spiders/catalog/index.html).*

Spiders of North America: An Identification Manual. Darrell Ubick, Pierre Paquin, Paula E. Cushing, and Vince Roth, eds.; Nadine Dupérré, illus. American Arachnological Society (*www.americanarachnology.org*), 2005. 377 pp., illus.

Wilcove D.S., D. Rothstein, J. Dubow, A. Philips, E. Losos. 1998. Quantifying threats to imperiled species in the United States. Bioscience 48 8: 607-615

Woods, M., and P. V. Moriarty. 2001. Strangers in a strange land: The problem of exotic species. *Environmental Values*, 10:163-91

APPENDIX A

Family	Genus	Species ID	Coastal	Stream	Mid	High	Status
Araneidae	*Araneas*	*nigropunctatus* (L. Koch, 1871)	0	0	1	0	Introduced
Araneidae	*Cyclosa*	MS016	0	0	6	0	Unknown
Araneidae	*Gasteracantha*	*cancriformis* (Linnaeus, 1758)	0	0	1	0	Introduced
Araneidae	*Neoscona*	MS002	8	4	0	0	Introduced
Dysderidae	*Dysdera*	*crocota* C. L. Koch, 1838	13	9	12	0	Introduced
Linyphiidae	---	MS013	0	1	1	0	Introduced
Nesticidae	*Eidmanella*	MS019	7	8	0	1	Introduced
Pholcidae	*Pholcus*	*ancoralis* L. Koch, 1865	37	172	14	0	Introduced
Salticidae	*Thorelliola*	*ensifera* (Thorell, 1877)	39	164	24	1	Introduced
Salticidae	---	MS009B	0	1	2	0	Unknown
Salticidae	---	MS009C	3	8	0	4	Unknown
Scytodidae	---	MS015	0	14	0	1	Introduced
Sparassidae	*Heteropoda*	*venatoria* (Linnaeus, 1767)	7	15	1	0	Introduced
Tetragnathidae	*Leucauge*	*granulata* (Walckenaer, 1842)	28	96	8	0	Unknown
Tetragnathidae	***Tetragnatha***	***tuamoaa* Gillespie, 2003**	**6**	**1**	**14**	**0**	**Native**
Tetragnathidae	*Tetragnatha*	MS006B	4	1	0	0	Unknown
Tetragnathidae	*Tetragnatha*	*macilenta* L. Koch, 1872	28	23	2	0	Unknown
Theridiidae	---	MS025	0	0	12	0	Unknown
Theridiidae	*Argyrodes*	MS017	0	1	1	0	Unknown
Theridiidae	*Rhomphaea*	*cometes* L. Koch, 1872	4	14	1	0	Introduced
Theridiidae	*Theridion*	MS003	15	12	5	0	Unknown
Theridiidae	*Theridion*	MS004A	1	0	1	1	Unknown
Theridiidae	*Theridion*	MS004B	2	1	0	0	Unknown
Theridiidae	*Theridion*	MS004C	0	2	1	0	Unknown
Theridiidae	*Theridion*	MS004D	0	0	0	2	Unknown
Theridiidae	*Theridion*	MS004E	0	0	0	4	Unknown
Theridiidae	*Theridion*	MS021	0	0	1	0	Unknown
Thomisidae	***Misumenops***	***melloleitaoi* Berland, 1942**	**0**	**0**	**1**	**20**	**Native**
Uloboridae	***Tangaroa***	***tahitiensis* (Berland, 1934)**	**312**	**229**	**298**	**6**	**Native**

Appendix A: Spiders were collected at eight locations on Moorea. If possible, spiders were identified to species. Unknowns are grouped into morphospecies and are assigned unique identifiers. In some cases, the status of each species is shown. The status is based on their known distributions and some molecular data.

APPENDIX B

Date	Site	Shannon-weiner Index	Species richness	Species evenness
3-Nov	Kellum Day	0.941626	8	0.117703
3-Nov	Kellum Day	1.089059	5	0.217812
9-Nov	Kellum Night	1.376281	8	0.172035
9-Nov	Kellum Night	1.716374	8	0.214547
5-Oct	Gump Day	1.330405	7	0.190058
25-Sep	Gump Day	1.383163	6	0.230527
6-Oct	Gump Night	1.135258	11	0.103205
24-Sep	Gump Night	1.298731	9	0.144303
16-Oct	Afaraeitu Day	1.517685	9	0.168632
8-Nov	Afaraeitu Day	1.637974	7	0.233996
16-Oct	Afaraeitu Night	1.902419	9	0.21138
8-Nov	Afaraeitu Night	1.627797	9	0.180866
7-Oct	Marae Day	1.417653	6	0.236275
5-Nov	Marae Day	1.757225	9	0.195247
9-Oct	Marae Night	2.115166	13	0.162705
8-Nov	Marae Night	1.555507	14	0.111108
9-Oct	Belvedere Day	1.466673	8	0.183334
5-Nov	Belvedere Day	0.933484	6	0.155581
13-Oct	Belvedere Night	1.170488	6	0.195081
31-Oct	Belvedere Night	0.772791	5	0.154558
13-Oct	Trois Cocos Day	1.017137	7	0.145305
31-Oct	Trois Cocos Day	0.354599	3	0.1182
13-Oct	Trois Cocos Night	1.019166	9	0.113241
29-Oct	Trois cocos Night	1.058501	12	0.088208
11-Oct	Mouaputa Day	1.427061	5	0.285412
18-Oct	Rotui Day	1.171344	6	0.195224

Appendix B: Calculated Shannon-Weiner index for each individual site sampled in. Spiders were collected at eight locations on Moorea. Each site was sampled four times, twice during the day and twice during the night. High-elevation sites were only sampled once during the day.