A Survey of Macrolepidopteran Moths on Moorea, French Polynesia with a Preliminary Examination of Their Role as Pollinators

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ABSTRACT. Despite the unique biological opportunities presented by the island chains of French Polynesia, the biology of the area is poorly understood. Moths are among the many taxa with undocumented biodiversity. There is biological interest in documenting which moth species are present and how they interact with the plant community. I collected 161 macrolepidopteran moths at a range of elevations on the island of Moorea, French Polynesia to explore their diversity and study their role as pollinators. I assembled a pollen library of 27 common plant species and attempted to match these pollens with pollen grains that were removed from moths. Although identification to species was not possible with all of the moths that were collected, I grouped them into morphospecies by wing pattern; 35 morphospecies were found. There were more species found at higher elevations. The abundance of some species changed with elevation. The most abundant morphospecies at all sites were non-endemics that are widely distributed throughout the South Pacific. Many moths were found to feed on the invasive *Lantana camara* and some fed on plants in the Myrtaceae. This study suggests that the moth fauna on Moorea is dominated by non-endemics, but that there may be some relictual endemics, especially at the higher elevations. It also suggests that invasive plants have a considerable impact on the moth fauna. Future research on Moorean moths should focus on accomplishing a more comprehensive survey of moth biodiversity and examining the interaction of the moth fauna with native and introduced plants.

Introduction

Humans have drastically transformed the biology of French Polynesian islands in the last two millennia. The first major impact was the arrival of Polynesians more than 1400 years ago (Lepofsky et al. 1996). The second great impact was European colonization during the twentieth century. The transformation of the islands continues today as they become more developed and biological invasions alter the landscape (e.g. Meyer and Florence 1996).

Despite the unique biological opportunities presented by the island chains of French Polynesia, the biology of the area is poorly known. Moths are among the scores of large taxonomic groups that we know little about. Comprehensive surveys of moth diversity have been done in Hawaii (Zimmerman 1948) and on larger continental islands such as Australia (Common 1990), New Zealand (Hudson 1928), and Borneo (Holloway 1976). There have also been a few studies on smaller islands (e.g. Holloway 1977, Holloway 1990), but for most islands in French Polynesia, there is little more than a superficial examination (e.g. Paulian 1998) of the moth fauna since the Bishop Museum's entomological expeditions in the 1930's (Adamson 1939).

From Darwin forward, biologists have used islands as natural laboratories to tease apart the intricacies of evolution. Each chance to explore undocumented biodiversity such as Moorea's moth fauna can lead to new evolutionary insights (e.g. Fleischer et al. 1998; Chown 1994). However, because human impact on the island is likely to result in the extinction of arthropod taxa (Hambler and Speight 1996; Dunlop 1989), it is imperative that we learn what we can from these organisms soon.

Furthermore, there is little in the way of conservation efforts in French Polynesia. As shown in Hawaii, a similar setting, documenting diversity is the first step to developing conservation goals for arthropods (Gillespie 1999). As an added benefit for studying moth diversity, Holloway (1984) suggests the use of moths as bioindicators on tropical islands. Kitching et al. (2000) effectively use moths as bioindicators in Australian rainforests. A better understanding of moth diversity in French Polynesia may allow moths to be used there to assess ecosystem health.

Beyond discovering what moth taxa are present on these islands, we need information on the moths' role in the ecosystem to apply our knowledge in an evolutionary or conservation context. Moths play important roles as herbivores during their larval stage, as pollinators during their adult stage, and as food for predators and parasitoids throughout their life cycle (Scoble

1992). There is no information on how moths play these ecological roles on French Polynesian islands.

This study takes preliminary steps toward filling these gaps in our knowledge for the island of Moorea. Moorea is a high (1207 m) volcanic island in the Society Islands chain. It is 17 kilometers across and has 12,000 residents, most of whom live on the coast (French Polynesia Government Presidency 2001). Originally a conical volcano, the center of Moorea has collapsed and eroded out toward two bays leaving two connected central valleys surrounded by a ridge of high mountains rising up from the coast (Howel 1933). I surveyed macrolepidopteran moths at sites on the coast, in the valleys, and in the mountains to assess their diversity. (Macrolepidopterans are a traditional classification of moth families that include larger, easily-studied moths; this study focuses on them because little is known about their counterparts, microlepidopterans). On high volcanic islands, much of the insect diversity is found at the higher elevations (Peck 1999). This study compares the moth diversity of three regions of the island based on elevation—coast, valleys, and mountains—to see if moths in Moorea are consistent with this trend.

This study also includes an examination of the moths' capacity as angiosperm pollinators. Adult lepidopterans feed almost exclusively on angiosperm nectar and, with coleopterans, dipterans, and hymenopterans, are responsible for most angiosperm pollination. Moths often pollinate plants with pale, fragrant flowers (Kevan and Baker 1999). The extinction of moth species due to habitat loss or competition with invasive moths could negatively impact plant diversity on Moorea, especially for rare plants (Spira 2001). To discover which plants moths were feeding on in Moorea, I compared pollen grains that were taken from the mouthparts of collected moths to pollen grains taken from local plants. Like the moths, published pollen libraries are available for floras in Hawaii and larger continental islands (e.g. Selling 1946; Moar 1993), but none is available for islands in French Polynesia. Thus, this study includes a small pollen library created with plants collected in Moorea.

Methods

Study Location

All moths and plants were collected at nine sites at a range of elevations on the island of Moorea, French Polynesia (149º50'W, 17º32'S) during 19 collection expeditions between 28 September and 15 November 2001. To aid in the analysis of distributional data for the moths, I divided these collection sites into three regions: those in the coastal areas of Moorea, those in the mid-elevation valleys, and those on mountain ridges and peaks (Figure 1).

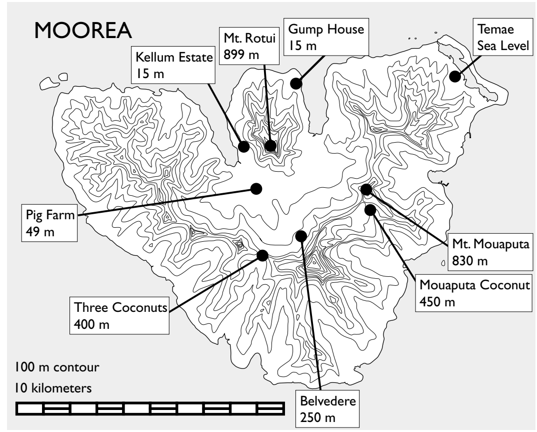

Figure 1. Topographical map of Moorea showing collection sites and their elevations. Geographic coordinates of collection sites:

Coast			
Temae	149º46.34'W	17º28.48'S	0 m
Gump House	149°49.60'W	17°29.44'S	15 m
Kellum Estate	149°50.90'W	17°30.87'S	15 m
Valleys			
Pig Farm	149°50.12'W	17°32.24'S	49 m
Belvedere	149°49.59'W	17°32.44'S	250 m
Mountains			
Three Coconuts	149º50.52'W	17º32.83'S	400 m
Mouaputa Coconut	149º48.21'W	17º31.85'S	480 m
Mt. Mouaputa	149º48.20'W	17º31.58'S	830 m
Mt. Rotui	149º49.70'W	17º30.75'S	899 m

Moth and Flower Collections

Moths were collected after dark (1900-2300) with a blacklight. A white sheet, ~2 x 3 m, was suspended between two supports with a rope, the blacklight hanging in the upper center. I caught as many different species as possible. Moths were usually caught on the sheet, but occasionally with a net. All moths were frozen overnight and pinned for storage. One moth of each macrolepidopteran species had its wings spread for identification.

Moths were identified to superfamily, and family if possible (Borror et al. 1992; Mandy Heddle, personal communication). Also, if possible, moths were identified to species using Paulian (1998). The remaining unknown moths

Location	Morphospecies	(Super)Family	# Collected	Known Range
Coast:	Chasmina tibialis	Noctuoidea	15	Unknown
	Gnathothlibus erotus	Sphingidae	4	India, South Pacific, Australia
(Tamae: Sea Level	Unknown # 71	Noctuoidea	4	Unknown
Gump House: 15 m	Unknown # 8	Noctuoidea	3	Unknown
Kellam Estate: 15 m)	Macroglossum hirundo	Sphingidae	2	Southeast Asia, South Pacific, Australia
	Unknown # 7	Noctuoidea	2	Unknown
	Agrius convolvuli	Sphingidae	1	Europe, Asia, Australia
	Mocis trifasciata	Noctuoidea	1	Indonesia to Fiji, Northern Australia
	Simplicia caeneusalis	Noctuoidea	1	India to Australia
	Spodoptera mauritia	Noctuoidea	1	International agricultural pest
	Thalassodes pilaria	Geometridae	1	Unknown
	Unknown # 39	Noctuoidea	1	Unknown
	Unknown # 72	Noctuoidea	1	Unknown
Valleys:	Thalassodes pilaria	Geometridae	7	Unknown
	Simplicia caeneusalis	Noctuoidea	5	India to Australia
(Pig Farm: 49 m	Chasmina tibialis	Noctuoidea	5	Unknown
Belvedere: 250 m)	Chrysodeixis chalcites	Noctuoidea	4	International agricultural pest
	Gnathothlibus erotus	Sphingidae	2	India, South Pacific, Australia
	Unknown # 19	Noctuoidea	2	Unknown
	Unknown # 53	Noctuoidea	2	Unknown
	Unknown # 60	Noctuoidea	2	Unknown
	Macroglossum hirundo	Sphingidae	1	Southeast Asia, South Pacific, Australia
	Unknown # 1	Noctuoidea	1	Unknown
	Unknown # 3	Geometridae	1	Unknown
	Unknown # 4	Noctuoidea	1	Unknown
	Unknown # 22	Geometridae	1	Unknown
	Unknown # 26	Geometridae	1	Unknown
	Unknown # 41	Noctuoidea	1	Unknown
	Unknown # 52	Noctuoidea	1	Unknown
Mountains:	Chrysodeixis chalcites	Noctuoidea	17	International agricultural pest
	Chasmina tibialis	Noctuoidea	11	Unknown
(Three	Cleora sp.	Geometridae	8	Unknown, but native to French Polynesia
Coconuts: 400 m	Simplicia caeneusalis	Noctuoidea	8	India to Australia
Mouaputa	Gnathothlibus erotus	Sphingidae	7	India, South Pacific, Australia
Coconut: 480 m	Thalassodes pilaria	Geometridae	7	Unknown
Mt. Mouaputa: 830 m	Macroglossum hirundo	Sphingidae	4	Southeast Asia, South Pacific, Australia
Mt. Rotui: 899 m)	Unknown # 19	Noctuoidea	4	Unknown
	Unknown # 21	Noctuoidea	3	Unknown
	Agrius convolvuli	Sphingidae	2	Europe, Asia, Australia
	Unknown # 20	Noctuoidea	2	Unknown
	Unknown # 53	Noctuoidea	2	Unknown
	Hippotion celerio	Sphingidae	1	Worldwide
	Ophiusa coronta	Noctuoidea	1	India, Pacific Islands, Australia
	Unknown # 1	Noctuoidea	1	Unknown
	Unknown # 22	Geometridae	1	Unknown
	Unknown # 26	Geometridae	1	Unknown
	Unknown # 29	Geometridae	1	Unknown
	Unknown # 42	Noctuoidea	1	Unknown
	Unknown # 44	Noctuoidea	1	Unknown
	Unknown # 45	Noctuoidea	1	Unknown
	Unknown # 52	Noctuoidea	1	Unknown
	Unknown # 69	Noctuoidea	1	Unknown
	Unknown # 70	Noctuoidea	1	Unknown

Table 1. Macrolepidopteran moths were collected at nine locations on Moorea. Some species were identified using Paulian (1998); unknown species were grouped into morphospecies by wing pattern and their identification numbers follow the labels in the actual collection. The moths are grouped according to what region of the island they were collected at: the coast, the valleys or the mountains. The collection locations that were in each region are listed with their elevations. The number collected of each species is shown because it roughly corresponds to the abundance of each species. If possible, the known range of each species is shown.

were grouped into morphospecies by wing pattern and given identification numbers; they are labelled this way in the collection which is in the Essig Museum of Entomology at the University of California, Berkeley. For species that were identified, their global ranges were determined if possible (Common 1990; Nielsen et al. 1996; Swamiappan and Balasubramanian 1979; Mandy Heddle, personal communication).

Flowers, especially common flowers that were likely to be moth-pollinated, were collected on several expeditions. Flowers from 10 plant species were collected in the field at several sites:

Fagraea berteriana: Mouaputa Coconut
Gardenia tahitensis: Gump Station
Lantana camara: Belvedere
Leucaena leucocephala: Belvedere
Merremia sp.: Three Coconuts
Rubus rosifolia: Three Coconuts
Spathodea campanulada: Mouaputa Coconut
Spathoglottis pacifica: Three Coconuts
Stachytarpheta urticifolia: Belvedere
Tecoma stans: Belvedere

For 17 additional plant species, pollen was obtained from mounted herbarium specimens from a collection of common plants on Moorea established in 1992-1993. This collection is kept at the Gump Research Station on Moorea.

During all moth collections, I made casual observations of nearby flowers to see if moths could be seen to feed at them.

Pollen Preparation and Analysis

Pollen was removed from moths and mounted in glycerine jelly (10 g gelatin, 70 ml glycerine, 60 ml water). I dipped a pin in warm glycerine jelly on a microscope slide then dabbed the proboscises and other mouthparts of the moths. I repeated this several times. The slides were then covered, left to dry overnight and sealed with nail polish if pollen grains were found on them.

Pollen from plants was treated by acetolysis before being mounted on slides. Anthers or pollen masses were first separated from other plant material. They were then hydrated for 10 min in 3 ml water using a few drops of detergent if they were dry specimens from the herbarium collection. The pollen was washed in glacial acetic acid before acetolysis. 1 ml of acetolysis fluid (90% acetic anhydride, 10% sulfuric acid) was added to the decanted pollen mass. The pollen was shaken in test tubes and placed in boiling water for 10 min. It was then centrifuged and washed in glacial acetic acid and then water. Finally, a concentrated solution of pollen was mixed with glycerine jelly on a slide. The slides were allowed to dry overnight and then ringed with nail polish.

To match pollens with each other, digital pictures were taken of all unique pollen grains at as many angles as possible on all plant and moth pollen slides. The pictures were then placed into a single computer graphics file to compare pollen shape and sizes. The microscope slides from which the pictures are taken are at the Jepson Herbarium at the University of California, Berkeley. I examined how many different kinds of pollen were found on individual moths, on each species, and at each collection site. I then looked at the pollen from the moths to discern which plant families the pollens were from, and if possible, matches to specific local plant species for which I had pollen grains.

Results

Moth Collections

I collected 161 macrolepidopteran moths in Moorea. I divided them into 35 morphospecies: 25 noctuoids, 6 geometroids, and 4 sphingids. I identified 12 species by wing pattern using Paulian (1998); the remaining species were grouped into unknown morphospecies. Table 1 (previous page) shows the moth assemblages found at each of the regions on the island: coast, valleys and mountains. Table 2 shows how many expeditions were within each region and shows how many moth individuals, morphospecies, and unknown morphospecies were found in each.

Region	Number of collection expeditions	Number of moths collected	Number of morphospecies found	Number of unknown morphospecies found
Coast	5	37	13	5
Valleys	3	37	16	10
Mountains	6	87	24	14

Table 2. Summary of moths collected in three regions of Moorea.

Plant	Moth species	Location and elevation
Unknown species in Myrtaceae	*Gnathothlibus erotus*	Kellum Estate (15 m)
	Unknown 53	Belvedere (250 m)
Lantana camara	*Macroglossum hirundo*	Gump Station (15 m)
	Chrysodeixis chalcites	Belvedere (250 m)
	Thalassodes pilaria	Mt. Rotui (899 m)
	Unknown 69	Belvedere (250 m)

Table 3. Plant-pollinator associations in Moorea.

At all sites, the most abundant moths, most of which I was able to identify with Paulian (1998), were non-endemic species that are widely distributed across the South Pacific and often much of the southern hemisphere. Some are international agricultural pests (Table 1). There are several species that are abundant at all elevations. *Chasmina tibialis*, a white noctuid, was the most frequent visitor to the blacklight during the collections and may have been the most numerous macrolepidopteran on the island. *Gnathothlibus erotus* was the most abundant sphingid and was found at all elevations; *Macroglossum hirundo* was also abundant at all elevations. At the valley and mountain sites—not the coastal sites—*Chrysodeixis chalcites*, *Thalassodes pilaria*, and *Simplicia caenseualis* were abundant.

Plant-Pollinator Associations

Pollen was found on 51 of 161 moths (32%). Two associations between moths and plants were found (Table 2). The pollen library I created to identify the pollen found on moths is in Appendix 1.

Pollen from *Lantana camara* (Verbenaceae), a common introduced flower at all elevations, was identified on four moth species (Table 2). Except for an unidentified noctuid moth, all of these species were observed to feed on *L. camara* in the field at the Belvedere. *L. camara* pollen was taken off of moths from all three regions of the island. Two moths had pollen from a plant that is a member of the Myrtaceae. This might be *Metrosideros collina* or *Syzigium malaccense* on Moorea.

Multiple kinds of pollen—some unidentified—were found on all of the moth species in which pollen was found on more than one individual. This indicates generalist feeding habits. The exact numbers of plant species these moths were feeding on is unclear. The moths determined to be generalist feeders were *Thalassodes pilaria*, *Chrysodeixis chalcites*, *Chasmina tibialis*, *Macroglossum hirundo*, *Simplicia caenseualis*, and two unknown noctuids (60 and 19).

Discussion

Moth Diversity on Moorea

Although 35 macrolepidopteran morphospecies were found, there are doubtless more on Moorea. Even the final collection expeditions yielded unseen species. Furthermore, the validity of the morphospecies based on wing pattern is questionable (Holloway et al. 1987), and I suspect that some of the species identified using Paulian (1998) are incorrect. While this study has done much to elucidate a fauna that was previously unknown, it is a small step toward a complete taxonomic understanding of moths on Moorea.

The numbers of morphospecies and unknown morphospecies that were found increased from coast to valleys to mountains (Table 2). This may be because I had more successful collection expeditions in the mountains: twice as many macrolepidopterans were caught there. However, there was only one more expedition in the mountains than on the coast, and more than twice as many moths were caught. Also, although three expeditions were taken in the valleys and five on the coast, the same number of moths was caught. This suggests that the moth fauna at the higher elevations on Moorea is more diverse and likely to contain biologically interesting endemic species.

I did not rigorously sample for moth abundance, but the number of moths of each species that were collected at each site roughly corresponds to their abundance at that site. The numerical dominance of non-endemic moth species that are widespread or cosmopolitan—many of which are probably introduced—is an indication of the strong effect humans have had on the biology of Moorea.

Although some species appear at all elevations, the data suggest a disparity between the coastal sites and the valley and mountain sites.

The valley and mountain sites have more species in common than either has with the coastal sites. None of the unknown species from the coastal sites are found in the valley or mountains and vice versa. And some species found at all elevations demonstrate the disparity through abundance. It would be interesting to examine whether this is because of the natural differences associated with elevation or because of the more intense human impact on the coast.

Moth-Plant Interactions

The number of moths that feed on *Lantana camara* is evidence of the impact that invasive species have had on Moorea. *L. camara* is an international weed with an international effort to control it. It is a popular subject of biocontrol research (Broughton 2000). Its attractiveness to pollinators no doubt helps make it a successful invader. Also, these moths may be successful because they take advantage of *L. camara* as a food source. The introduction and spread of *L. camara* and other invasive plant species may have indirect negative effects on the native flora by competing for their pollinators.

The moths that feed on the Myrtaceae have unknown significance. Of the two most likely candidates, *Metrosideros collina* is a charismatic native tree, important to insects throughout the Pacific and *Syzigium malaccense* is a Polynesian introduction (Whistler 1991). It would be useful and interesting to discover the rest of the plant-pollinator relationships among the moths on Moorea. The web of relationships is no doubt complex and will be difficult to uncover. This study shows that there are many generalists, and some of the most interesting links to uncover are those between rare plants and their pollinators where the chances of discovery are slim.

Future Research

This project's value would increase with more labwork that was not possible due to time constraints. I could identify all of the moth species collected, possibly including even the microlepidopterans and determine, if possible, their origins and status on the island: native, recent introductions, or long-established introductions. Because the pollen taken from the moths was not treated by acetolysis, matches with the plant pollen grains were not possible for most of the 51 moths on which pollen was found. The cytoplasm in the pollen grains—usually removed by acetolysis—hid the features necessary for identification. With proper pollen preparation procedures and comparisons to existing pollen libraries, possibly supplemented by more collections on Moorea, the pollen found on moths could be identified. To better understand the moth fauna on Moorea, more extensive collections should be done to collect uncollected species and get abundance data.

The level of human impact on Moorea has made most if not all taxa a mixture of native and introduced species. Understanding the interaction between introduced and native moths with introduced and native plants through pollination is an excellent way to gauge how human impact via species introductions has affected Moorea's biology. This should be a goal for moth and plant research on the island. It would paint a picture of how intact—or how shattered—the ecology of the island is and how it compares to what may have been before European and before any human impact. This will help shape conservation policies in the future.

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