CHARACTERIZING RIPARIAN ECOSYSTEMS (PLANTS, SOIL, AND WATER) OF WAIPĀ, KAUA'I OF THE HAWAIIAN ISLANDS

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAI'I IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

NATURAL RESOURCES AND ENVIRONMENTAL MANAGEMENT

MAY 2006

By
Guy A. Ragosta

Thesis Committee:
Carl Evensen, Chairperson
Ali Fares
Roger Fujioka
Tamara Ticktin

We certify that we have read this thesis, and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Natural Resources and Environmental Management

Thesis Committee:

Carl Evensen

Chairperson

for Tamara Ticktin

Fujioka

ACKNOWLEDGEMENTS:

Thanks to all who've helped out in the positive direction of this research, especially the University of Hawai'i at Mānoa Department of Natural Resources and Environmental Management, The Waipā Foundation, Hanalei Watershed Hui, Dr. Adam Asquith from UH Sea Grant, Dr. Mark Walker from University of Nevada at Reno, Dr. Kenneth Tate and Dr. Rob Atwill from UC Davis, U.S. Environmental Protection Agency Region IX Water Quality Group, U.S. Department of Agriculture, Kaua'i Youth Conservation Corps, Waipā Thursday *poi* crew, Sashamon, Richard Irving (aka Bobo Richie), Sabra Kauka, Summer Austin, my family, and my committee members for their strong guidance and support.

TABLE OF CONTENTS:

CHAPTER 2. A GRAPHICAL ANALYSIS OF WAIPĀ STREAM TEMPERATURE: A TROPICAL ISLAND RURAL WATERSHED SCALE CASE STUDY:

CHAPTER 3. CHARACTERIZING VEGETATION OF WAIPĀ STREAM AND TRIBUTARIES OF THE HAWAIIAN ISLAND OF KAUA'I:

3.5 RESULTS

CHAPTER 4. MICROBIAL AND CHEMICAL SURFACE SOIL AND WATER ANALYSIS OF WAIPĀ RIPARIAN ZONE AND TRIBUTARIES OF KAUA'I OF THE HAWAIIAN ISLAND:

TABLES:

FIGURES:

Chapter 1:

Introduction:

Hawaiian watersheds differ between valleys and islands. It is likely that different forms and levels of land use management (ie, urbanization, deforestation, grazing, conservation, agriculture, military occupation, etc.) within each watershed relates to varying degrees of change in riparian ecosystems and water quality. In the present era of the human-dominated biosphere, co-evolution now takes place at a much more rapid and unpredictable pace than previously in human history (Folke et al., 2002). Changes in watershed management and policy in Hawai'i are an instructive case study on the evolution of resource management from a traditional vertically integrated system, to a segmented central government-based system, and now towards a community and watershed focus (Derrickson et al., 2002). The location of this study, Waipā watershed, is on the north shore of Kaua'i of the Hawaiian island chain (Figure 1.1), and covers approximately 650 hectares from 1141 m above mean sea level at Mamalahoa peak down rugged vegetated terrain to the stream mouth flowing into Hanalei Bay of the Pacific Ocean at mean sea level (Figure 1.2). The larger Hanalei watershed of approximately 23.7 miles (HHRP, 2002) encompasses sub-watersheds of Waipā, Wai'oli, Wainini, and Waikoko.

Waipā was an *ahupua'a*: the basic land units in Hawai'i (Derrickson et al., 2002) that varied amongst valleys and islands. Morgan (1948:17) cited in Derrickson et al (2002) defines the *ahupua'a* as "a complete estate, running from the sea to the mountains and hence providing a share of all the different products of the soil and sea; fish from the seashore; taro, yams, sugarcane, breadfruit, and bananas in the fertile area of the lowlands; and further up in the forest belt, firewood, poles for houses, logs for canoes, bark for tapa cloth, olona and other plant fibers for cords and rope, and feathers". The term *ahupua'a* comes from the alter (*ahu*) marking the seaward boundary of the area on which the sculptured head of a pig (*pua'a*) was placed at the time of the collection of tribute to the god Lono and his earthly representative the high chief (*ali'i nui*) during the Makahiki or annual harvest festival (Kamehameha Schools, 1994). But, alteration of the Hawaiian island chain from an independent nation to a territory and then State of the U.S.A. drastically changed the *ahupua'a* system. This system, which traditionally gave native Hawaiian residents of an *ahupua'a* control and responsibility for sea waters past mean high-tide lines, changed to the present system in which all ocean past mean high-tide lines now fall under U.S. government jurisdiction. This created what Hardin (1968) refers to as 'The Tragedy of the Commons', opening once privately managed ocean resources to public use for recreation and industry.

The Submerged Land Act of 1953 recognizes state authority over submerged lands extending out to three geographical miles into the Atlantic and Pacific Oceans and three marine leagues into the Gulf of Mexico from the coastline (EHC, 2000). The lands beneath navigable waters are defined as (1) lands within state boundaries that were navigable when the state became a member of the Union, (2) lands periodically or permanently covered by tidal waters, or (3) lands that were filled in or reclaimed lands that were formerly beneath navigable waters. The federal government retains certain rights to use the submerged lands for commerce, navigation, defense, and international affairs, but not the rights of ownership or management that were specifically granted in the act.

The outer continental shelf (OCS) is an undersea land lying seaward and generally beyond the three-mile seaward boundaries of the states (EHC, 2000). This area sometimes contains oil and gas reserves. The federal government, which administers control through the Department of the Interior's Minerals Management Service (MMS), has exclusive jurisdiction of this subsoil and seabed, which it leases to private companies for exploration, drilling, and production. In March 1983, the U.S. declared its 200-mile exclusive economic zone by presidential proclamation, thereby asserting sovereign rights over the resources in the 200 miles extending beyond its coastline, including fishing and mineral resources, and jurisdiction to protect the marine environment (EHC, 2000) probing the question of how far seaward did the original *ahupua'a* of Waipā extend prior to U.S. occupation of Hawai'i? And is it possible for residents of Waipā and other Hawaiians to regain rights to their original *ahupua'a* boundaries with current U.S. jurisdiction over seaward areas past mean high tide lines?

In 1990, Congress passed the Coastal Zone Reauthorization Amendments, adding a section designed to reduce nonpoint source pollution of coastal waters (EHC, 2000). Section 6217 requires states that have a coastal zone management program to develop and implement coastal nonpoint pollution control programs. In Hawai'i the lack of a well planned and implemented management system to control nonpoint source pollution furthers the concerns of watershed communities feeling the pressures of increasing population and development. The difficulties to manage and track nonpoint source contaminants is confounded by poor interaction and cooperation among various groups and agencies regulating and managing what is now a non-functioning *ahupua'a* at Waipā, owned, regulated, and managed by the state and federal government seaward of mean high tide line, and owned by the Bishop Estate landward of mean high tide line.

Today, the land within Waipā's borders lies under the management of the Waipā Foundation, a non-profit group dedicated to the perpetuation of Hawaiian cultural values and environmental preservation and restoration of their watershed. Terrain of Waipā varies extremely across the landscape, abruptly changing from 0 to 180 degree slopes at many locations with confounding natural and artificial hydrological systems. Kapalikea peak at approximately 300 m above mean sea level on the southeastern ridge of Waipā flanks Wai'oli watershed running southeast to north above Kapalikea tributary which intersects upper Waipā stream. Kolopua peak borders smaller Waikoko and larger Lumaha'i watersheds at the southwest ridge of Waipā approximately 300 m above mean sea level with vast areas of *Dicranopteris linearis* covering the hillsides disturbed by Hurricane Iniki along a winding tributary that flows into upper Waipā stream. Upon reaching higher elevations of the watershed, numerous tributaries branch in different directions over highly varying slopes via surface and subsurface flow, compounded by dike complexes starting at the formidable aspect of Mamalahoa peak at 1141 m above mean sea level until intersecting a main channel of Waipā stream. The main channel of Waipā stream significantly changes in riparian vegetation composition with increasing elevation (Figure 1.3). Substrate size significantly increases with elevation up Waipā stream.

Streamflow varies at monitoring locations across the watershed dependent upon rainfall and flashflood events. Heavy rains in Waipā often cause turbidity of streams and associated impairment of water quality to increase in the watershed.

The introduction of grazing livestock had severe negative impacts on land and water resources (Derrickson et al., 2002) not only in Hawai‘i, but tropical island watersheds around the globe. Extensive and ongoing resource degradation was caused by goats, cattle, pigs, and sheep introduced into Hawai‘i by visiting sea captains before the end of the 18th century (Derrickson et al., 2002). Livestock damage to native forests and to watersheds through overgrazing and erosion of steep slopes was recognized as a severe problem throughout the 19th century (Cox, 1992) and remains a problem today. It is common for a significant amount of runoff to be generated from pastures during flood irrigation (Tate et al., 2005), which at Waipā excessively exits into the coastal zone especially after intense rain events. Excessive irrigation diversion can reduce in-stream flow levels, which in turn can result in the reduction of available aquatic habitat, elevated stream temperatures and increased pollutant concentrations (Tate et al., 2005). Consequently, land use changes and associated river discharges in coastal tropical regions present a global threat to coral reef environments (West et al., 2001).

The impact of grazing cattle on water quality has been the subject of considerable interest as water quality standards become more restrictive (Sherer et al., 1992). Islands not heavily damaged by direct human habitat modification and without introduced hooved mammals such as goats and pigs have been found to be relatively resistant to plant invasion (Merlin and Juvik, 1993). Waipā introduced free-grazing cattle into their watershed over 30 years ago. Now, approximately 50 rodeo cattle graze a confined area of the lower floodplain near Waipā stream mouth. Feral pigs run wild at different densities in space and time in the watershed, the extent of which has not been researched, but their presence is evident in the majority of the uplands via direct observation, erosion of land, tracks, and their mauling of *Psidium cattleianum* (common name strawberry guava) fruits across the landscape.

Grazed pastures, cesspools, urban runoff and infiltration, population sprawl, native and non-native wildlife, and unsustainable agricultural practices represent potential sources of non-point source microbial pollution in many tropical island watersheds, including Waipā. As microbial water quality declines in rural tropical stream ecosystems due to land degradation and introduction of fecal sources of bacteria, research lags on using *riparian buffer zones* to decrease microbial contamination to ambient water. There are a number of zoonotic (diseases transferred from animals to humans) diseases of concern to humans if ambient waters are contaminated with fecal material from non-human animal species (USEPA, 2003). Ambient water is defined as "any fresh, marine or estuarine surface water used for recreation, propagation of fish, shellfish, or wildlife; agriculture; industry; navigation; or as source water for drinking water facilities (USEPA, 2003)."

Microbial recreational water quality standards were developed by the United States Environmental Protection Agency (USEPA) based on scientific principles verified by field data and application of some assumptions (Fujioka, 1999). In 1986, the U.S. EPA mandated that all US states and territories change the traditional recreational water quality standard of 200 fecal coliform/100 ml to 35 enterococci/100 ml for marine waters and to 126 *E. coli*/100 ml or 33 enterococci/100 ml for fresh waters (USEPA, 1986). Studies conducted in the continental USA indicated that the only significant sources of fecal indicator bacteria such as *E. coli* and enterococci are feces of man and other warm-blooded animals (Fujioka, 2001). But, very little research exists on tracking point and non-point sources of fecal indicator bacteria and correlating illness rates of rural and urban tropical island ecosystem communities.

A lack of water for washing and bathing contributes to diseases that affect the eye and skin, including infectious conjunctivitis and trachoma, as well as to diarrheal illnesses, which are a major cause of infant mortality and morbidity in developing countries (Gerba, 1996). Other waterborne diseases are transmitted through the fecal-oral route, from human to human or animal to human, so that drinking water and recreational water are two of several possibilities of infection (Gerba, 1996). In many tropical islands, urban sprawl and unsustainable land practices have led to a lack of sanitary ambient water systems. But, tracking and calculating the source and movement of non-point source microorganisms that cause waterborne diseases can be a costly and time consuming process, perhaps too costly for many tropical island communities in developed and developing nations.

As investigations continue on methods to curb improper land management, *riparian buffer zones* are being advocated by agencies such as the U.S. Department of Agriculture as a practical method to reduce waterborne transport of zoonotic microbial pathogens from animal agricultural operations to nearby surface water supplies (Rosen et al., 2000). Buffers are strips of vegetation adjacent to agroforestry or agricultural production, typically either managed buffer zones or natural riparian vegetation, proposed to improve or maintain downslope water quality (Barling and Moore, 1994). Creating sustainable agroforestry buffer zones to decrease microbial contamination to ambient water systems in tropical island watersheds could greatly improve coastal and riparian water quality, public health, and international image for tourism.

Buffer zones are intended to intercept and remove waterborne contaminants before they reach a specified down-slope site (Atwill et al., 2002), and to intercept polluted surface runoff and groundwater flow to reduce pesticide, nutrient and other organic pollutants before they enter the stream (Lin et al., 2002). The importance of buffer zone creation lies in the fact that waters that receive non-point source contaminants can contain unacceptably high concentrations of indicator organisms such as enterococci that signal the possible presence of pathogenic microorganisms (Lim et al., 1998). Ideally, buffer zones will include plants relevant to the cultural uses of the watershed community of concern while providing economic and environmental sustainability.

To the author's knowledge, no one has scientifically and methodically researched a full-length Hawaiian riparian zone for vegetation, hydrology, or chemical and microbial (*E. coli*, enterococci, total coliform) soil constituents. In order to create effective riparian buffer zones for decreasing non-point source microbial contaminants in a tropical island watershed, it helps to understand spatial and temporal components of riparian hydrology, riparian vegetation composition and function, movement of microorganisms of concern thru the riparian zone, riparian soil properties (physical, chemical, and microbial), stream geomorphology, geology, surrounding land use history, and other metrics of interest. This thesis focuses on characterizing vegetation of Waipā stream and tributaries, monitoring stream temperature and associated variables across Waipā watershed, and testing water quality and microbial and chemical surface soil parameters along Waipā stream and tributaries. Long-term objectives of this study include creating sustainable agroforestry buffer zones to decrease microbial contamination to ambient water of Waipā watershed and ultimately Hanalei Bay.

References:

Atwill, E.R., L. Hou, B.M. Karle, T. Harter, K.W. Tate, R.A. Dahlgren. 2002. Transport of *Cryptosporidium parvum* Oocysts through Vegetated Buffer Strips and Estimated Filtration Efficiency. Appl. and Environ. Microb. 68: 5517-5527.

Barling, R.D., and I.D. Moore. 1994. Role of buffer strips in management of waterway pollution - a review. Environ. Manage. 18: 543-558.

Cox, T.R. 1992. The Birth of Hawaiian Forestry: The Web of Influences. Pacific Hist. Rev. 61(2): 169-192.

Derrickson S.A.K., M.P. Robotham, S.G. Olive, and C.I. Evensen. 2002. Watershed Management and Policy in Hawai`i: Coming Full Circle. Journal of the American Water Resources Association. 38(2): 563-576.

Environmental Health Center. 2000. Coastal Challenges: A Guide to Coastal and Marine Issues. Environmental Health Center, 1025 Connecticut Avenue, NW, Suite 1200, Washington, DC, 20036. www.nsc.org/ehc.htm. 178 pp.

Folke, C., Colding, J, Berkes, F. 2002. Synthesis: building resilience and adaptive capacity in social-ecological systems. Chapter 14 in Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press. pp. 352-387.

Fujioka, R., Sian-Denton, C., Borja, M., Castro, J., Morphew, K. 1999. Soil: the environmental source of *Escherichia coli* and enterococci in Guam's stream. *Journal of Applied Microbiology Symposium Supplement.* 85, 83S-89S.

Fujioka, R.S. 2001. Monitoring coastal marine waters for spore-forming bacteria of fecal and soil origin to determine point from non-point source pollution. Water Science and Technology. 44:181-188.

Gerba, C.P. 1996. Pathogens in the Environment. Pollution Science: Chapter 19, pp. 279-299.

Hanalei Heritage River Program. November 2002. Environmental Protection Agency Watershed Initiative Grant Proposal. P.O. Box 1285. Hanalei, HI, 96714. (808) 826-1985. hanaleiriver@hawaiian.net

Hardin, G. 1968. The Tragedy of the Commons. Science 162: 1243-1248.

Kamehameha Schools. 1994. About Ahupua`a. In: Life in Early Hawai`i: The Ahupua`a (Third Edition). Kamehameha Schools Press, Honolulu, Hawai`i, pp. vi-vii.

Lim, T.T., Edwards, D.R., S.R. Workman, B.T. Larson, L. Dunn. 1998. Vegetated Filter Strip Removal of Cattle Manure Constituents in Runoff. *American Society of Agricultural Engineers.* 41(5): 1375-1381

Lin, C.Y., W.C. Chou, and W.T. Lin. 2002. Modeling the width and placement of riparian vegetated buffer strips: a case study on the Chi-Jia-Wang Stream, Taiwan. Journal of Environmental Management. 66: 269-280.

Merlin, M.D., Juvik, J.O. 1993. Relationships among native and alien plants on Pacific Islands with and without significant human disturbance. Pages 597-624 *in* C.P. Stone, C.W. Smith, and J.T. Tunison, editors. Alien plant invasions in native ecosystems of Hawai`i: management and research. University of Hawai`i Cooperative National Park Resources Studies Unit, Honolulu.

Morgan, T. 1948. Hawai`i: A Century of Economic Change. Harvard University Press, Cambridge, Massachusetts.

Rosen, B.H., R. Croft, E.R. Atwill, S. Wade, and S. Stehman. 2000. Waterborne pathogens in agricultural watersheds. Technical note 2, p. 1-64. Watershed Science Institute, University of Vermont, Burlington, VT.

Tate, K., Lancaster, D., Morrison, J., Lile D., Sado, Y., Huang, B. 2005. Monitoring helps reduce water-quality impacts in flood-irrigated pasture. California Agriculture, Volume 59, Number 3. pp 168-175.

U.S. Environmental Protection Agency. 1986. Ambient Water Quality Criteria for Bacteria: 1986 (EPA/440/5-84-002). Washington DC, USEPA Press.

U.S. Environmental Protection Agency. 2003. Guidelines Establishing Test Procedures for the Analysis of Pollutants; Analytical Methods for Biological Pollutants in Ambient Water; Final Rule. U.S. Federal Register- 40 CFR Part 136 Vol. 68, No. 139.

West K., Van Woesik, R. 2001. Spatial and Temporal Variance of River Discharge on Okinawa (Japan): Inferring the Temporal Impact on Adjacent Coral Reefs. Marine Pollution Bulletin. 42(10): 864-872.

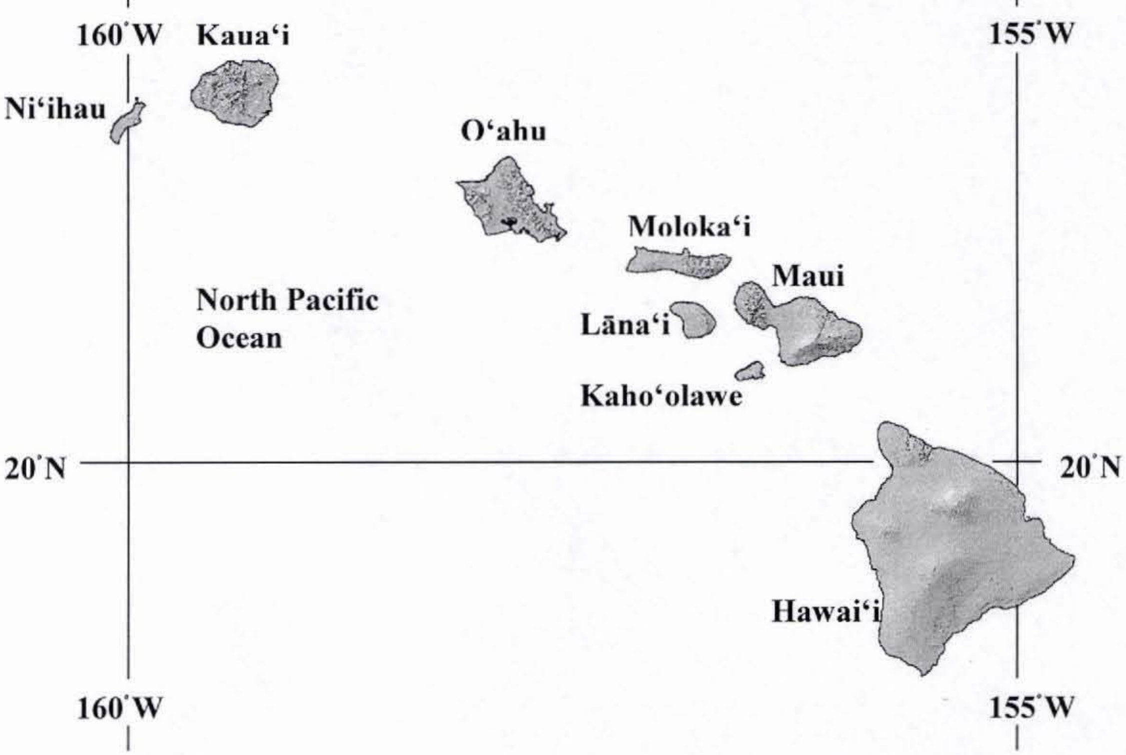

160°W
Kaua'i
155°W
Ni'ihau
O'ahu
Moloka'i
Maui
North Pacific
Ocean
Lāna'i
Kaho'olawe
20°N
20°N
Hawai'i
160°W
155°W

Figure 1.1

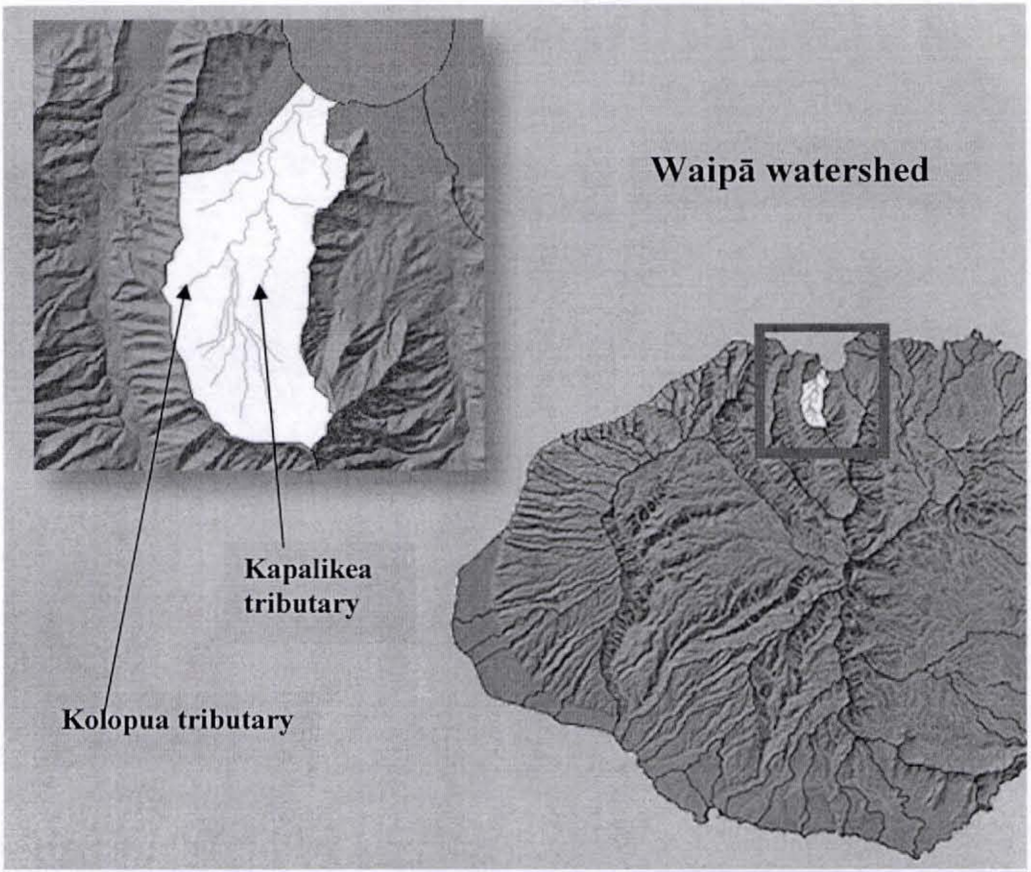


Figure 1.2: Island of Kaua'i and closeup of Waipā watershed

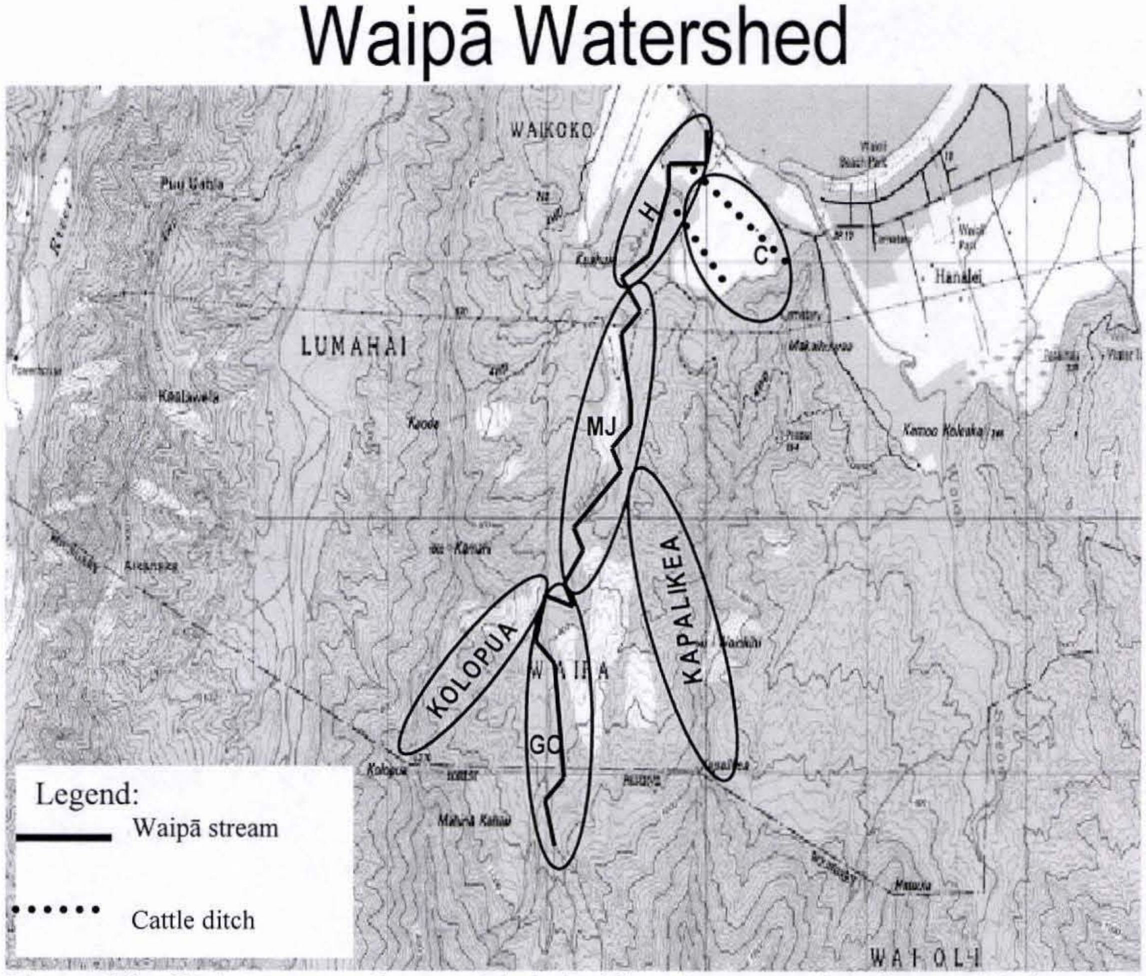


Figure 1.3: Waipā topography map labeled with major areas of study: stratified dominant riparian canopy communities, two major tributaries, and cattle pasture. Stream temperature and water quality monitoring sites were placed at the beginning and end of each riparian vegetation community, at the confluence of two tributaries, and at the end of a cattle pasture drainage ditch.
C= Cattle pasture drainage ditch (300 meters long)
H= *Hibiscus tiliaceus* section (1000 meters long)
MJ= *Mangifera indica* and *Syzigium cumini* section (2000 meters long)
GO = *Psidium guajava*, *Psidium cattleianum*, and *Metrosideros polymorpha* section (1100 meters long)
Kapalikea tributary (2000 meters long)
Kolopua tributary (1000 meters long)

CHAPTER 2:

"A Graphical analysis of Waipā stream temperature: a tropical island rural watershed scale case study"

Ragosta, G., Asquith, A., Fares, A., Evensen, C., Ticktin, T.

2.1 Abstract:

A lack of data exists on spatial and temporal variations in stream temperature for rural and urban tropical island watersheds across the globe. This paper analyzes approximately one year of stream temperature data across an elevation gradient of the rural tropical island watershed of Waipā, Kaua'i in the Hawaiian island chain (Figure 2.1). Preliminary data collection and analysis is also presented on riparian canopy cover, solar radiation, precipitation, air temperature, and streamflow. Stream temperature was recorded in the middle of the water column every hour for approximately one year using commercially available digital stream temperature gauges at the following locations: at the start and finish of dominant vegetation overstory communities along Waipā stream, and at the confluence of two tributaries (Kapalikea and Kolopua) that enter into upper elevations of Waipā stream (Figure 2.2). A major change in stream temperature does not occur along Waipā stream from highest to lowest elevation monitoring sites except for between End H and Waipā bridge monitoring sites. Kapalikea tributary has a higher average daily water temperature versus Kolopua tributary. Total relative canopy cover is about 60 percent higher in Kolopua versus Kapalikea tributary.

2.2 Background:

Watershed groups, individuals, land managers, and regulatory agencies are collecting considerable amounts of stream temperature data in order to understand, protect and enhance cold-water fisheries (Tate et al., 2005), and study how land use effects stream temperature and associated decline in water quality. Approximately one year of stream temperature data was collected in the Waipā watershed on Kaua'i between June 2004 to July 2005 at 6 different locations, but questions remain as to successful identification of temperature sources and sinks. Specific concerns on causes of stream temperature increases on Waipā watershed focus on the elevation of summer stream temperatures because of activities such as streamflow diversion for irrigation of pastures and crops, return of warm irrigation runoff to streams from agricultural practices, reduction in riparian canopy cover due to fire and grazing, modification of stream channel width and depth due to a number of activities including grazing, road construction, invasive species, increased flood peaks, and surface compaction. There is often significant disagreement about the relative impacts of land use activities and natural watershed characteristics on stream temperature (Tate et al., 2005). Many Hawaiian communities such as Waipā are concerned as to whether human induced stream temperature changes significantly alter survival and reproduction of the native O'opu fish and cause associated changes in water quality. Fish response to temperature is dependent upon species (rainbow trout, coho salmon, etc.) and life stage (larval, fry, juvenile, etc.) (Bestcha et al., 1987). As a result, stream temperature criteria or objectives to safeguard cold-water fisheries habitat are often dependent upon the species occupying a given stream reach, and the life stage at which the species is present in the stream reach (Tate et al., 2005) or estuary.

While the availability of inexpensive, automatic temperature recorders has facilitated data collection, the sheer volume of data gathered often overwhelms individuals, watershed groups, and agencies (Tate et al., 2005). As a result, the data is often not analyzed. We have also observed that when groups collect stream-temperature data, they often neglect to collect data on associated factors (such as air temperature, precipitation, solar radiation, streamflow, stream canopy cover, and stream reach length) that are required to fully interpret the stream temperature data, in order to reach defensible conclusions for management, restoration, and regulatory decisions (Tate et al., 2005).

While great quantities of data are being generated, its analysis and interpretation are often not adequate to identify stream reaches that are gaining or losing temperature, or to correlate temperature changes with factors such as vegetative canopy cover or stream-flow levels (Tate et al., 2005). The objective of our study was to demonstrate methods for the graphical display and analysis of stream-temperature data collected in Waipā watershed. We illustrate presentation formats and nonstatistical approaches to facilitate the synthesis and interpretation of data for the purposes of evaluating the impacts of land-use activities (Tate et al., 2005) and comparing water temperature variation across Waipā watershed, and other metrics of interest. This chapter of the thesis was modeled after a study by Tate and colleagues (2005).

2.3 Waipā watershed:

Waipā is located on the north shore of the Hawaiian island of Kaua'i (Figure 2.1). Topography highly varies across the north shore, and due south nearby Mt. Wai'ale'ale receives one of the highest recorded annual rainfalls in the world, at a 32 year average of over 1168 cm per year (www.infoplease.com/ipa/A0001631.html). Throughout Waipā's 650 hectare landscape, which varies from mean sea level to approximately 1141 m above mean sea level at Mamalahoa peak, heavy subsurface infiltration enters the main stream channel and increasing numbers of tributary systems wind around large boulders and natural dike complexes in the upper part of the watershed. Waipā watershed has many tributaries, but two of the largest are Kolopua and Kapalikea. A forest fire in the late 1960's changed the upper eastern portion of Waipā around Kapalikea tributary, now covered in invasive grasses and scattered trees and shrubs, including many *M. quinquenervia* planted by the U.S. Forest Service after the fire (personal communication with Dr. Adam Asquith, 2005). The western portion of the watershed across Waipā stream avoided the fire, and consists of highly variable slopes and plant species along Kolopua tributary. Both Kapalikea and Kolopua tributaries flow into upper Waipā stream, which meanders through changing riparian plant systems into a lower floodplain where the main stream flows thru the beach and into the Pacific Ocean of Hanalei Bay.

Streamflow in the tributaries and main stream reach peak flow after heavy rains and flashfloods. Perennial flow in the tributaries and main stream begin at different elevations dependent upon rainfall levels. Kolopua tributary is approximately 1000 m long, and Kapalikea tributary is approximately 2000 m long. Many smaller tributaries exist as perennial and intermittent systems up and down Waipā landscape and stream, which provides habitat for a number bird, amphibian, and fish species.

2.4 Objectives:

Stream temperature monitoring initiated in June 2004 and stream temperature data collected through July 2005 across Waipā watershed are presented in this paper. The locations monitored across Waipā were selected to: 1.) systematically track changes in stream temperature from the upper to lower extent of Waipā stream; 2.) dissect Waipā stream into discrete reaches based upon changes in dominant riparian overstory community; 3.) account for the confluence of two major tributaries (Kapalikea and Kolopua) that enter into upper elevations of Waipā stream; 4.) to allow future calculation of correlations using linear mixed effects modeling (Pinheiro and Bates, 2000) (Tate et al., 2005) among riparian canopy cover, solar radiation, rainfall, and streamflow within designated sections (Figure 2.2) to stream temperature at monitoring locations (Table 2.2).

2.5 Methods and Materials:

2.5.1 Measurement of stream temperature:

At each monitoring location, stream temperature was recorded every hour using commercially available HOBO digital automatic temperature recorders submerged in the middle of the water column in areas of thorough stream mixing and held in place with rock anchors. Data collection at the 1-hour time step allows for capture of daily maximum and minimum temperatures, as well as calculation of daily average temperature (24 readings per day), 7-day running average of daily average and maximum temperature (Table 2.1) (Tate et al., 2005). For the purposes of this paper we report the daily average stream temperature, the daily maximum and minimum stream temperature, and the 7-day running average of daily maximum and daily average temperature. This allows assessment of the potential to modify stream temperature via biocontrol techniques to increase riparian habitat for native fish and wildlife while improving ambient water quality.

2.5.2 Measurement of streamflow, rainfall, air temperature, solar radiation, and riparian streambank canopy cover:

Streamflow was periodically measured at each monitoring location using a Marsh-McBirney Flo-Mate Model 2000 flow meter via the area velocity method [stream width (ft) x average stream depth (ft) x average stream velocity (ft per sec)]. Streamflow was measured two times in mid-July 2004, mid-March 2005, and mid-May 2005 at every monitoring location except Waipā bridge. Air temperature (2.5

m), solar radiation (1 m), and precipitation (1.5 m) were recorded every hour (above the ground surface), in direct sunlight via weather stations in areas of adequate air mixing at upper (about 300 m above mean sea level) and lower (mean sea level) weather stations of Waipā watershed (Figure 2.2).

Percent streambank canopy cover was measured in June and July 2004 at 4 randomly located plots within each of three stratified riparian vegetation canopy cover communities, Kapalikea and Kolopua tributaries. Plot sizes were 10 x 10 m in all plots except for the tributaries, where highly variable and in some cases steeply sloped banks which are not traversable and are covered in *Dicranopteris linearis*. So we decreased our plot sizes in the tributaries to 5 x 5 m. Stream canopy cover, or the amount (percent) of sky blocked by vegetation (CDF & G, 1998), was measured with a densitometer placed at eye level within each plot every 50 cm along three transects. Transects were located within each plot at designated sections (Figure 2.3).

2.6 Surface water temperature in Waipā stream and tributaries:

Land managers at Waipā would like to identify and prioritize points of concern for fisheries (such as areas exceeding temperature range for native O'opu fish to thrive), restoration opportunities (such as riparian planting to increase canopy cover) or land-use activities that should be mitigated (such as excessive warm irrigation-water returns) within their watershed. Interest could focus on a specific reach (ie, Kolopua tributary vs. Kapalikea tributary), or along a longitudinal profile from upper to lower stream reach locations (ie, WB vs. H vs. MJ vs. GO) (Figure 2.2).

One way to display and analyze data from monitoring locations along a stream system is to plot temperature at multiple locations over time on the same graph (Tate et al., 2005). Figures 2.4 to 2.7 plot average daily stream and tributary temperature, and the 7-day running average of daily average stream and tributary temperature beginning in June 2004 and into 2005 at monitoring sites in Waipā watershed. Figures 2.4 to 2.7 provide valuable baseline data on the current condition of the stream and tributaries. They present a synthesis of a large raw dataset, which reveals seasonal trends (ie, peak stream temperatures in June through July 2004 and 2005 in the tributaries, rapid stream temperature reduction during heavy rainfall events) which would be lost in monthly, seasonal or annual statistics. Figures 2.4 to 2.7 provide a simple means of illustrating which section of the stream and tributary confluences are warmer or colder, how stream temperature changes throughout the summer and winter, and an initial examination of how stream temperature changed across a given riparian vegetation community, elevation, or tributary.

Figures 2.4 and 2.6 also show the influence of the proximity of Waipā Bridge monitoring site to the Pacific ocean which mixes with freshwater entering from surrounding agricultural and urban activities. Waipā bridge has a much higher average daily and 7-day running average of daily stream temperature compared to the other monitoring sites. Figures 2.4 to 2.7 provide a simple means for us to determine if stream temperature differences exist along Waipā stream or between two major tributaries of the watershed.

Figures 2.6 and 2.7 illustrate the benefits of simplicity and clarity in plotting the 7-day running average compared to the daily average, resulting in a smoother plot that facilitates comparisons among multiple locations (Tate et al., 2005). Daily mean stream temperature from the upper to the lower part of Waipā stream does not change substantially until Waipā bridge (Figure 2.6). The 7-day running average of daily average water temperature is clearly higher in Kapalikea versus Kolopua tributary during June through July 2004 and 2005 (Figure 2.7).

If the concern is acute affects of daily temperature variations, then plotting the daily average or maximum for only one or two sites is more clear and informative (Tate et al., 2005). Daily average Waipā stream temperature between the highest (End GO) and lowest (Waipā bridge) elevation monitoring sites can range from 16.2° C to 27.8°C (Figure 2.8). Waipā stream at any given day can be 1.24 °C warmer at End GO to 7.11°C warmer at Waipā bridge in comparison to other sites (Figure 2.9 and 2.10). The minor differences in stream temperature between sites End H to End GO along Waipā stream can probably be attributed to increase in elevation because the upper part of the watershed is naturally cooler. In June through July 2004 and 2005 the daily maximum and minimum water temperature of Kapalikea is consistently higher than Kolopua tributary (Figures 2.11 and 2.12). The 7-day running average of daily maximum water temperature during June through July 2004 and 2005 is approximately 2°C warmer on average per week in Kapalikea versus Kolopua tributary (Figure 2.13). From November 2004 to April 2005 the daily maximum, minimum, and 7-day running average of daily maximum water temperature in Waipā tributaries decreases in range compared to June and July 2004 and 2005 (Figures 2.11 to 2.13). From November 2004 to April 2005 declines in stream temperature in all monitoring locations are probably due to increased levels of rainfall and streamflow, decreases in solar radiation and air temperature, and increases in elevation.

2.7 Comparing changes in temperature between stream reaches:

While graphics such as Figures 2.4 to 2.13 allow for efficient display and initial interpretation of large raw datasets, additional data reduction and graphical analysis is required to appropriately compare the change in stream temperature occurring between reaches (Tate et al., 2005). Monitoring locations were selected to evaluate stream temperature variation between dominant riparian vegetation canopy communities, and at the confluence of two major tributaries that enter into Waipā stream. As a result, the distance between monitoring sites varies (Figure 2.2). It would be inappropriate to directly compare the change in stream temperature across reaches as illustrated in Figures 2.4 to 2.13 because perhaps no changes occur due to the flashy short nature of Waipā stream. The direct interpretation of change in stream temperature across reaches reported in Figures 2.4 to 2.13 is confounded by the fact that each of the reaches is of different length, slope, hydrologic systems, vegetation community, and land use history.

An efficient and simple approach to account for reach length is to divide the change in temperature through each reach by the length (Tate et al., 2005). The resulting unit is *change in temperature per section length.* To illustrate this approach we examined the change in average daily Waipā stream temperature between monitoring sites from November 2004 to July 2005. We calculated the data illustrated in Figures 2.14 and 2.15 by taking the average of the differences in daily average temperature between 4 monitoring locations (ie,. End GO, End MJ, End H, Waipā bridge) along Waipā stream.

Depending upon the specific interest of the group conducting the monitoring, similar calculations could be generated and graphed on a daily, weekly, or monthly basis, using average, maximum or minimum temperatures (Tate et al., 2005). For the purposes of demonstration and interest we selected a simple daily average comparison of change between reaches.

Figures 2.14 and 2.15 provide a significant amount of directly interpretable information to watershed managers and other interested parties working in or around Waipā. For example, these figures clearly tell us that a major change in stream temperature does not occur along Waipā stream from highest to lowest elevation monitoring sites except for between End H and Waipā bridge monitoring sites. On Waipā stream, the rate of warming is far greater in the reaches between End H and Waipā bridge than between any other monitoring sites along the main stream channel. The rate of temperature increase was consistently highest in the reach between End H and Waipā bridge. All monitoring sites upstream from Waipā bridge do not see major changes in daily average temperature. It is conceivable that the background, or natural temperature of Waipā bridge is greater than that of upper Waipā stream considering only the entrance of seawater from the Pacific Ocean into and out of the Waipā bridge monitoring site. But, consideration should also be given to surrounding land uses (ie, urban and agriculture runoff and infiltration) at the Waipā bridge monitoring sites and their effect on daily average stream temperature. Relative surrounding land use history and management significantly differ from the Waipā bridge monitoring site and all other upstream monitoring locales which are uninhabited and heavily vegetated.

Stream temperature gains at Waipā bridge could also be associated with irrigation water diversion and irrigation water return. This does not imply that irrigation management influences stream temperature near Waipā bridge, simply that in order to determine stream temperature sources and sinks, studies on subsurface and surface hydrology of Waipā stream and surrounding land impacts on stream temperature should continue. These graphs do not establish cause and effect; rather, they facilitate understanding of watershed-scale temperature dynamics and serve as an effective assessment tool (Tate et al., 2005).

2.8 Evaluating the relationship between stream temperature and factors such as streamflow, riparian canopy cover, air temperature, rainfall, and solar radiation:

The results reported in Figures 2.4 through 2.15 inevitably lead to speculation about the factors or reasons causing differences in temperature change across Waipā stream and tributaries. The collection of data on factors that may effect stream temperature is the first step in translating speculation into defensible conclusions (Tate et al., 2005). It is difficult to evaluate the simultaneous and interacting relationships which might exist between factors such as air temperature, streamflow, riparian canopy, rainfall, solar radiation and stream temperature using graphical analysis.

However, graphical analysis of stream temperature and associate factors can provide useful insight for improving local monitoring schemes and more thoroughly quantifying statistical relationships (Tate et al., 2005). To illustrate this point and to demonstrate the need for statistical approaches when addressing complex monitoring objectives (Tate et al., 2005) we display data on the change in streamflow and riparian canopy cover between monitoring sites. Rainfall, air temperature, and solar radiation data for the upper and lower parts of Waipā watershed are also presented.

Figure 2.16 shows average streamflow along Waipā stream at monitoring sites. Average streamflow for Figure 2.16 were calculated by taking the average streamflow at each monitoring site over all monitoring dates. Comparison of Figure 2.16 with figures for daily average stream temperature show that decreases or increases in Waipā streamflow do not necessarily correlate to changes in stream temperature. We do see a major decrease in streamflow from section MJ to section H. This decrease in streamflow could be related to the fact that the dominant canopy cover of the entire H section is *H. tiliaceus*, which when overgrown along Waipā stream virtually stops streamflow and clogs the channel with its roots and soil deposition. Recent attempts by a local community group, the Waipā Foundation to remove *H. tiliaceus* from the streambank have improved streamflow in this section from near 0 to the current average streamflow at the End H monitoring site. This removal was done to increase stream flow and allow movement of water in and out of the stream mouth and subsequent entry of sea faring creatures. But, Waipā stream mouth frequently clogs behind a beach sandberm creating a pond-like environment where water sits relatively stagnant near Waipā bridge until a heavy rain, flashflood, appropriate tidal situation, human modification, or large ocean swell bursts open the blockage and the stream flows into Hanalei Bay.

Figure 2.16 also shows that Waipā stream gains flow from section GO to section MJ, two of the highest elevation and most undisturbed sections monitored in this study. Figure 2.17 shows that no difference exists in average streamflow (calculated the same as Figure 2.16) between Kapalikea and Kolopua tributaries-which makes analyzing associate data to determine the reason for the major differences between daily average and daily maximum water temperature of the two tributary sites all the more important.

In Figures 2.18 and 2.19, data for riparian canopy cover are presented as relative canopy cover percentage per section as a percentage of the total canopy cover present along Waipā stream and Kapalikea and Kolopua tributaries. The tributary and stream canopy cover data are presented as separate graphs to compare differences along the stream and between the tributaries. Relative canopy cover of Kolopua tributary is about 60 percent greater than Kapalikea tributary (Figure 2.18). Increases in relative canopy cover occur between sections along Waipā stream with increasing elevation.

Following this graphical, univariate approach one might conclude that streambank canopy cover is the main factor influencing the direction and rate of temperature change between Kapalikea and Kolopua tributaries, and that further analysis on streamflow data might help determine correlations between streamflow and stream temperature. Perhaps the increase in canopy cover in Kolopua tributary results in an associate reduction in solar radiation to this reach relative to Kapalikea tributary and would logically lead to lower rates of temperature increase.

There were distinct trends in increases in daily average air temperature and solar radiation during the same time periods in which daily average water temperature peaks in the tributaries and in Waipā stream (Figures 2.20 and 2.21). Analysis of daily average rainfall at upper and lower elevations in Waipā watershed may be related to daily average changes in Waipā stream and tributary water temperature fluctuations (Figure 2.22), and daily average rainfall at about 300 m above mean sea level (1.1 cm/day) and at mean sea level (1.04 cm/day) are almost equal.

Following a graphical approach that only considers a single associated variable (univariate) of stream temperature change, streamflow, riparian canopy, air temperature, solar radiation, and rainfall, one might conclude that there are probably strong relationships between these factors. However, it is inappropriate and likely misleading to use a univariate, graphical analysis approach to (1) fully explore and quantify these relationships, (2) to determine if streamflow and canopy interact to influence stream temperature, or (3) to determine if the influence of canopy or streamflow is different between stream reaches or sections (Tate et al., 2005). Answering these complex monitoring questions requires a multivariate statistical analysis of the dataset containing stream temperature and factors of interest such as streamflow, air temperature, rainfall, solar radiation, and canopy cover (Tate et al., 2005). Fortunately, relatively simply collected datasets can be subjected to graphical and statistical analysis (Tate et al., 2005).

2.9 Discussion:

We have demonstrated some display and graphical analysis approaches by which data collected in typical stream temperature monitoring projects can be interpreted by and presented to land managers, watershed groups, and other interested parties following the approach of Tate and colleagues (2005). This approach allows for evaluation of stream temperature across Waipā watershed for comparison to temperature criteria, and identification of watershed areas with high or low rates of stream temperature gain, such as differences found between Kapalikea and Kolopua tributaries. This level of analysis allowed us to translate a large raw dataset into information for the Waipā Foundation and associated groups to identify and prioritize allocation of limited resources for native plant restoration and improvement of management practices relative to stream temperature reduction. While graphical display and analysis of Waipā stream temperature and associated data on factors such as streambank canopy cover, streamflow, rainfall, air temperature, and solar radiation provide initial insight about the influence these factors have on stream temperature, it does not allow for quantification of these relationships or the examination of interactions between these factors. Often there are several factors acting simultaneously, and interacting, to determine stream temperature across a stream system. Situations such as this require a multivariate statistical approach which simultaneously evaluates these relationships (Tate et al., 2005). Regardless of the analysis approach used, the potential effect introduced by repeatedly measuring stream temperature at each monitoring location must be considered (Tate et al., 2005). The codependence introduced by repeated measurements of a single location through time can be addressed using a linear mixed-effects regression analysis (Pinheiro and Bates, 2000). Tate and colleagues used the linear mixed-effects regression analysis after collecting over three years worth of stream temperature data and other metrics of interest across different stream systems and watersheds in California. It is recommended that as the raw dataset for stream temperature, streamflow, air temperature, rainfall, solar radiation, canopy cover, and other variables increase over time at Waipā, and perhaps a neighboring or paired watershed and stream, that linear mixed-effects regression analysis be used to simultaneously evaluate relationships of all concurrent factors in Waipā watershed and their influence on stream temperature.

2.10 References:

Asquith, A. 2005. Conversation about land use history at Waipā watershed. Unpublished.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperatures and aquatic habitat: fisheries and forestry interactions. In: Salo, E.O. and T.W. Cundy, eds., Proc. Symposium Streamside Management: Forestry and Fishery Interactions. Held. Feb 12-14 1986. University of Washington, Seattle, WA.: 191-232.

California Department of Fish and Game (CDF & G). 1998. California salmonid stream habitat restoration handbook. Appendix M.

Infoplease website. Mt. Wai'ale'ale rainfall data, from island of Kaua'i. (www.infoplease.com/ipa/A0001631.html). Accessed on February 2006.

Pinheiro, J.C., Bates, D.M. 2000. *Mixed Effects Models in S and S-plus*. New York: Springer. 528 p.

Tate, K., Lile, D., Lancaster, D., Porath, M., Morrison, J., Sado, Y. 2005. Graphical analysis facilitates evaluation of stream-temperature monitoring data. California Agriculture, Volume 59, Number 3: 153-160.

Tate, K., Lile, D., Lancaster, D., Porath, M., Morrison, J., Sado, Y. 2005. Statistical analysis of monitoring data aids in prediction of stream temperature. California Agriculture, Volume 59, Number 3: 161-167.

Tate, K., Lancaster, D., Morrison, J., Lile D., Sado, Y., Huang, B. 2005. Monitoring helps reduce water-quality impacts in flood-irrigated pasture. California Agriculture, Volume 59, Number 3: 168-175.

Table 2.1: Stream-temperature metrics (Tate et al., 2005):

Daily maximum temperature: Maximum of 24 observations collected every hour during each 24-hour day.

Daily minimum temperature: Minimum of 24 observations collected every hour during each 24-hour day.

Daily average temperature: Average of 24 temperature observations collected every hour during each 24-hour day.

7-day running average of daily maximum temperature: Calculated for each day as average of daily maximum temperature observed for that day and for 6 consecutive prior days.

7-day running average of daily average temperature: Calculated for each day as average of daily average temperature observed for that day and for 6 consecutive prior days.

Table 2.2: GPS coordinates for stream temperature and water quality monitoring sites using Geo Trimble Explorer:

Monitoring Location:	GPS Coordinates Latitude	GPS Coordinates Longitude
1) Waipā bridge (WB)	2455482.80 m N	447035.56 m E
2) End section C	2455356.06 m N	447049.89 m E
3) End section H	2455026.50 m N	446546.95 m E
4) End section MJ	2453756.36 m N	446151.45 m E
5) End section GO	2452717.85 m N	446044.24 m E
6) Confluence of Kapalikea tributary	2454123.34 m N	446418.72 m E
7) Confluence of Kolopua tributary	2453624.69 m N	445946.03 m E

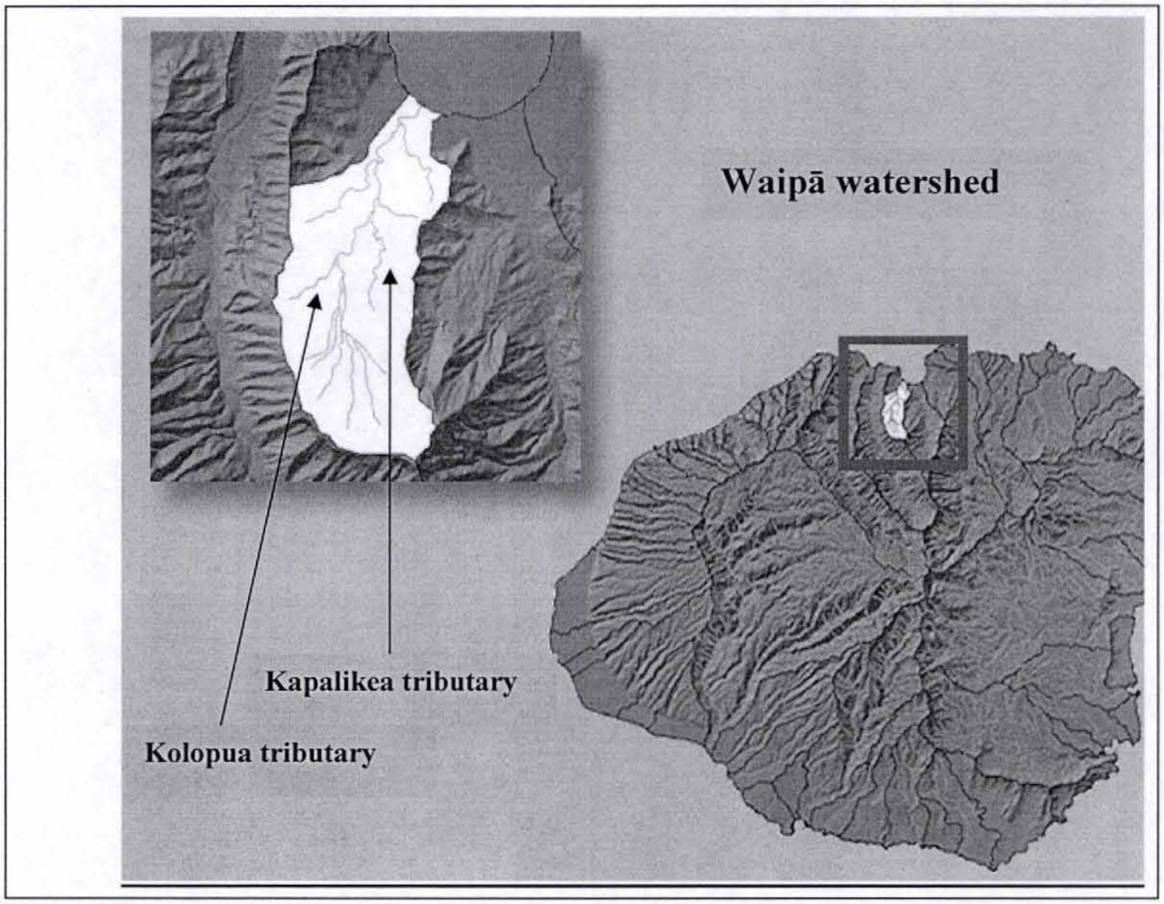


Figure 2.1: Island of Kaua`i and closeup of Waipā watershed (Image courtesy of Luisa Castro, UH Mānoa College of Tropical Agriculture and Human Resources)

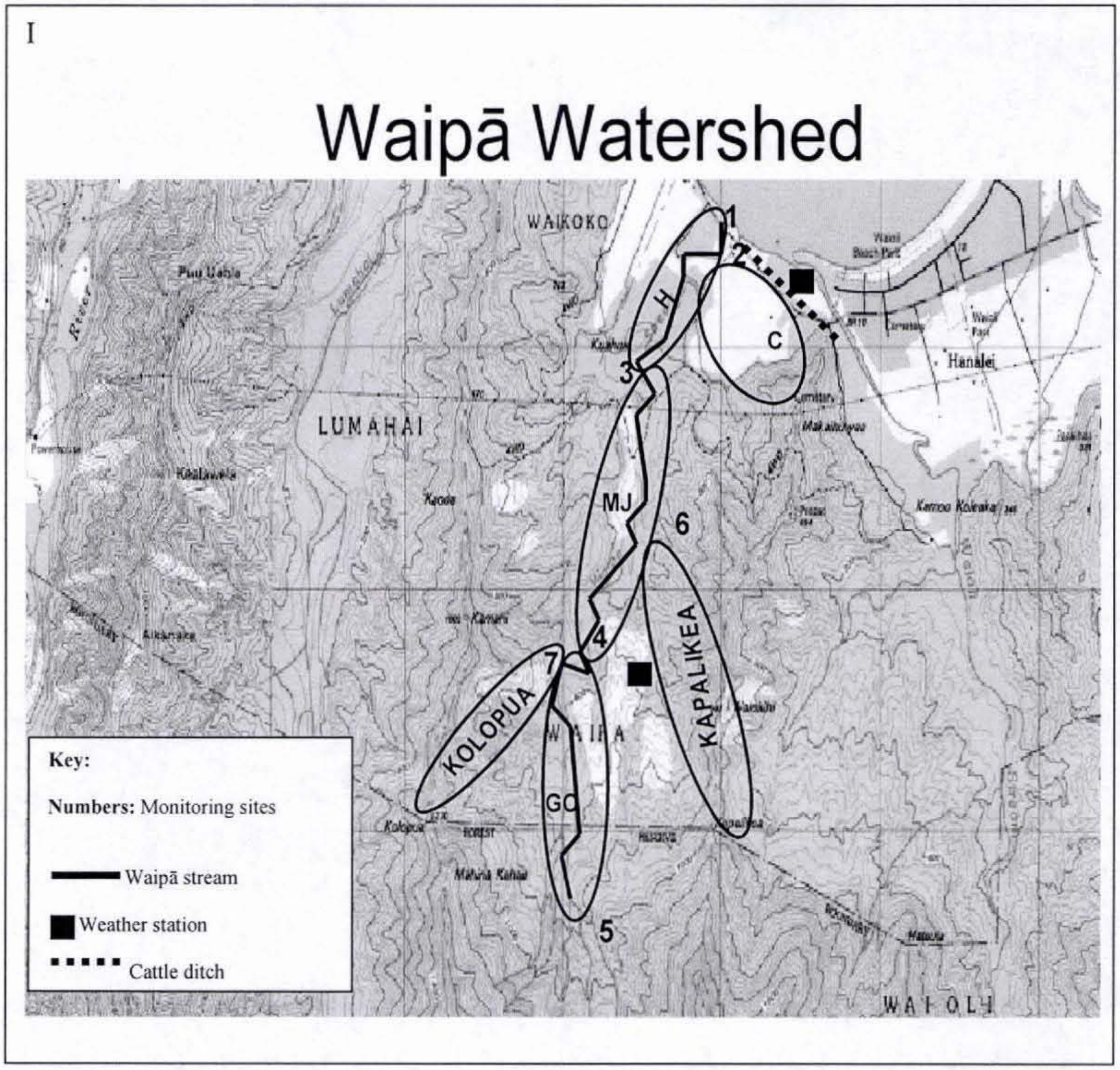


Figure 2.2: USGS topography map of Waipā watershed labeled with major sections of study: stratified dominant riparian canopy communities, two major tributaries, and cattle pasture. Stream temperature and water quality monitoring sites were placed at the beginning and end of each riparian vegetation community, at the confluence of two tributaries, and at the end of a cattle pasture drainage ditch.

Site 1.) Waipā bridge
Site 2.) End C= Cattle pasture drainage ditch (300 meters long)
Site 3.) End H= *H. tiliaceus* section (1000 meters long)
Site 4.) End MJ= *M. indica* and *S. cumini* section (2000 meters long)
Site 5.) End GO = *P. guajava*, *P. cattleianum*, and *M. polymorpha* section (1100 meters long)
Site 6.) Kapalikea tributary (2000 meters long)
Site 7.) Kolopua tributary (1000 meters long)

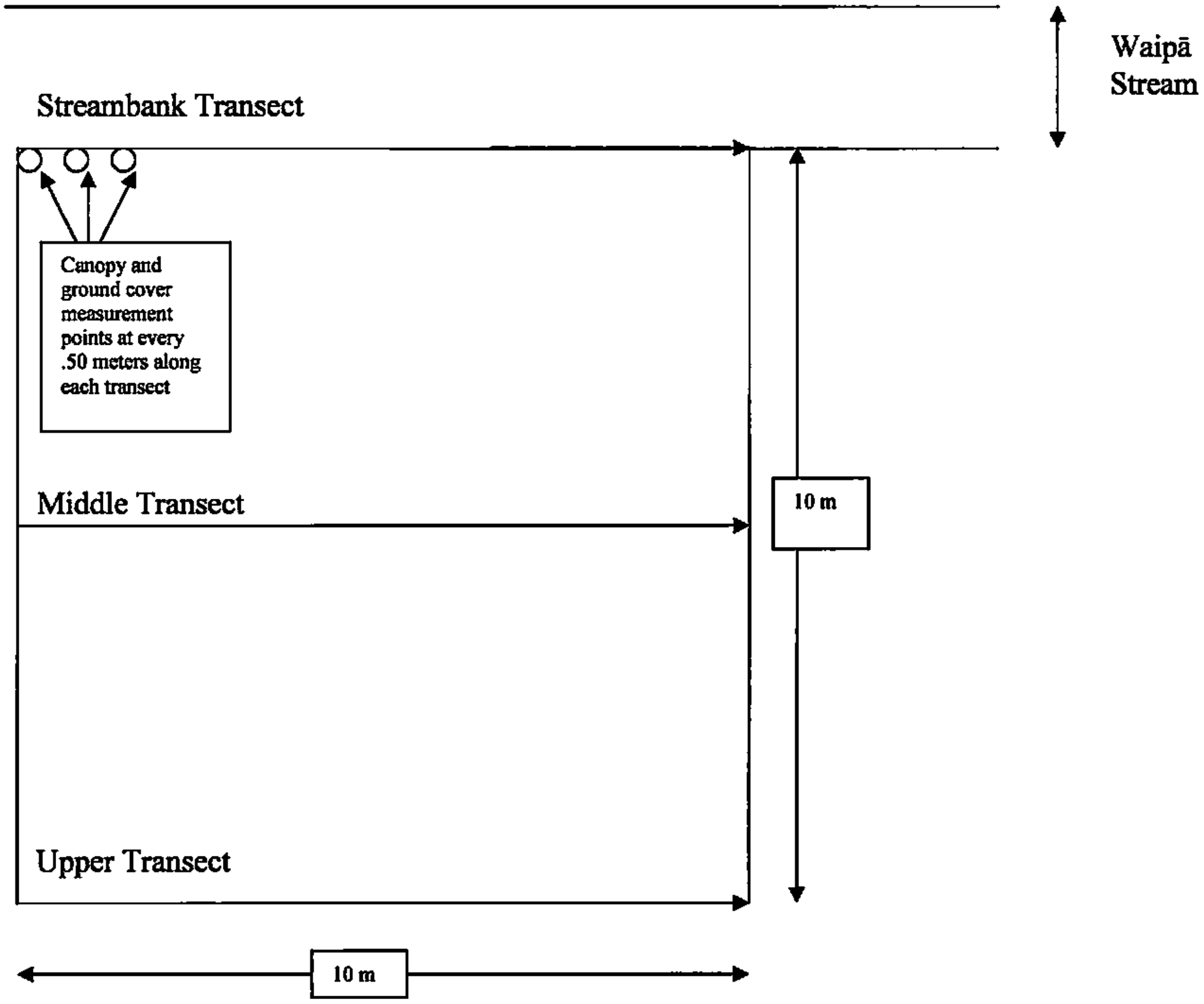


Figure 2.3: Plot and transect layout for characterizing riparian ground and canopy cover

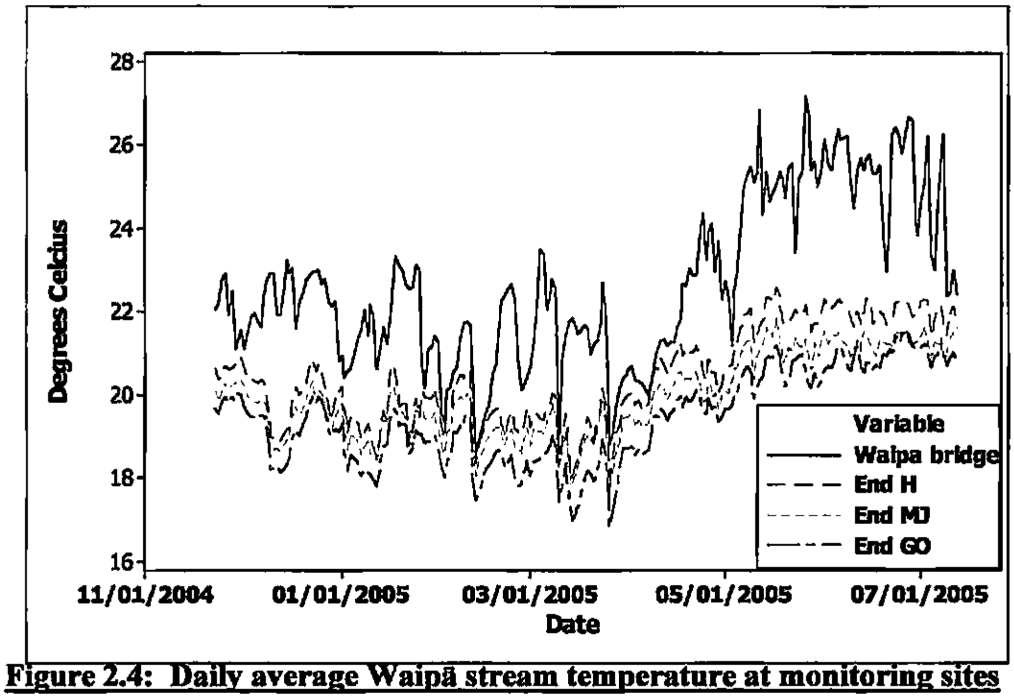


Figure 2.4: Daily average Waipā stream temperature at monitoring sites

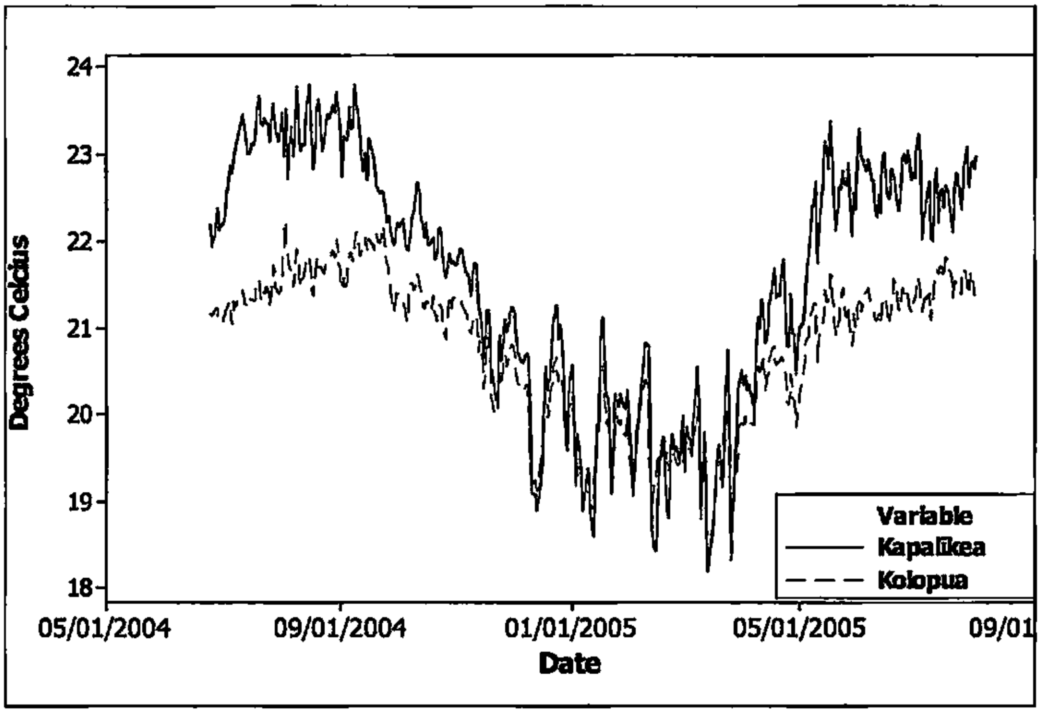


Figure 2.5: Daily average water temperature of Waipā tributary monitoring sites

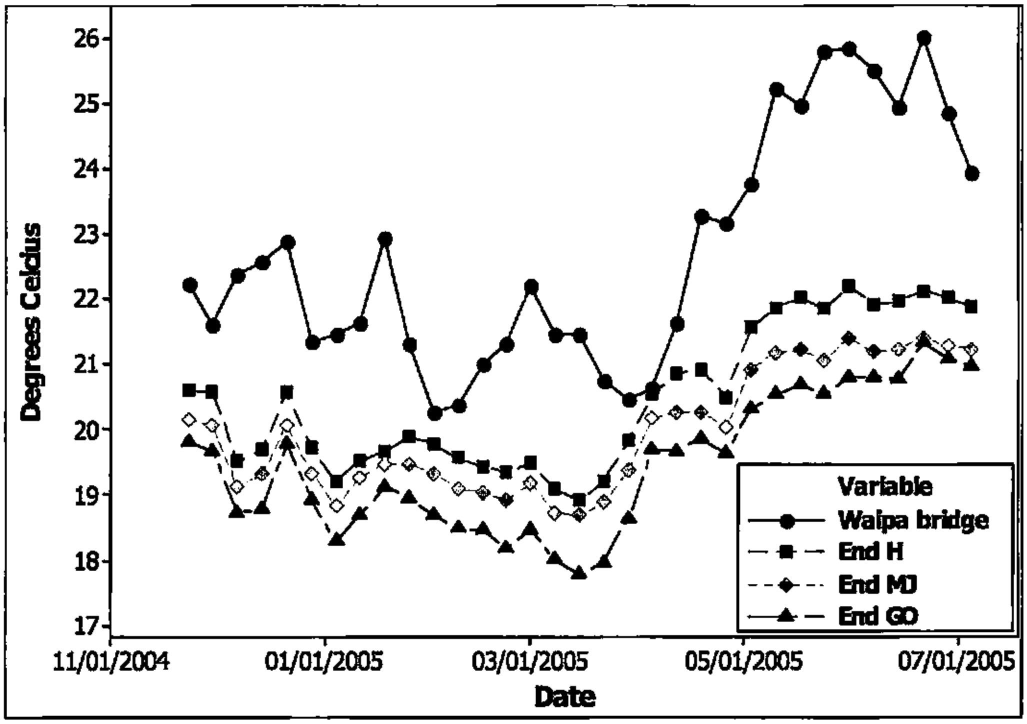


Figure 2.6: 7-day running average of daily average Waipā stream temperature

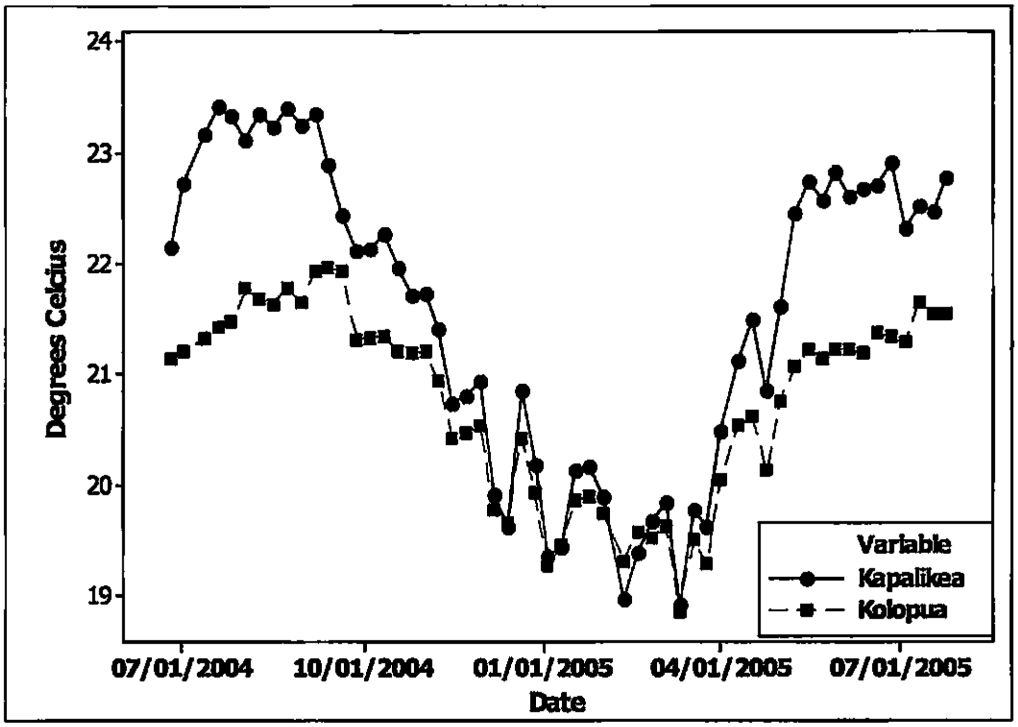


Figure 2.7: 7-day running average of daily average water temperature of Waipā tributaries

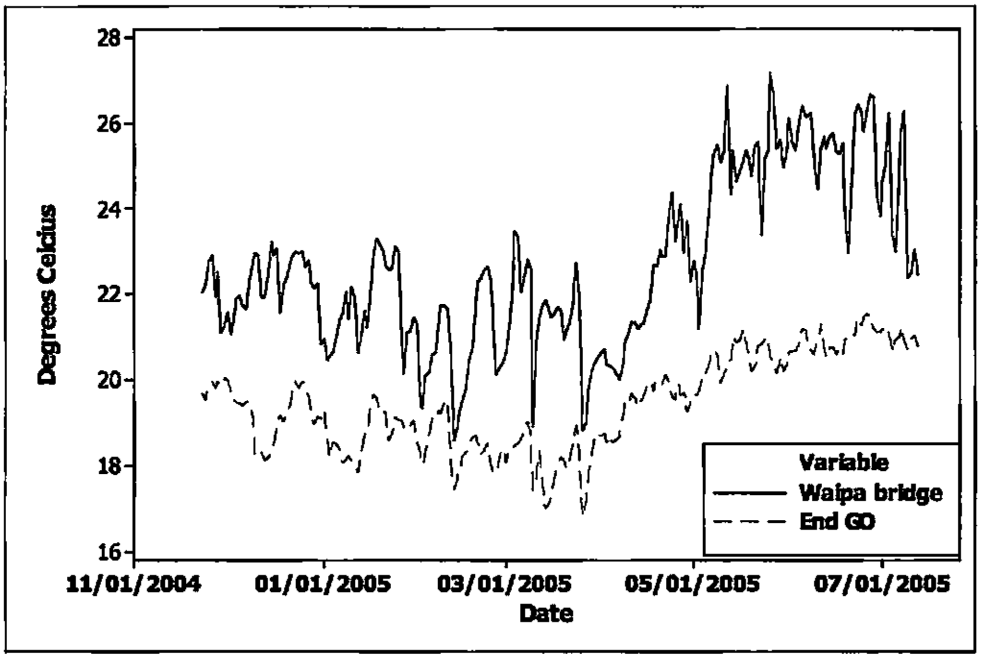


Figure 2.8: Daily average Waipā stream temperature of highest versus lowest elevation sites

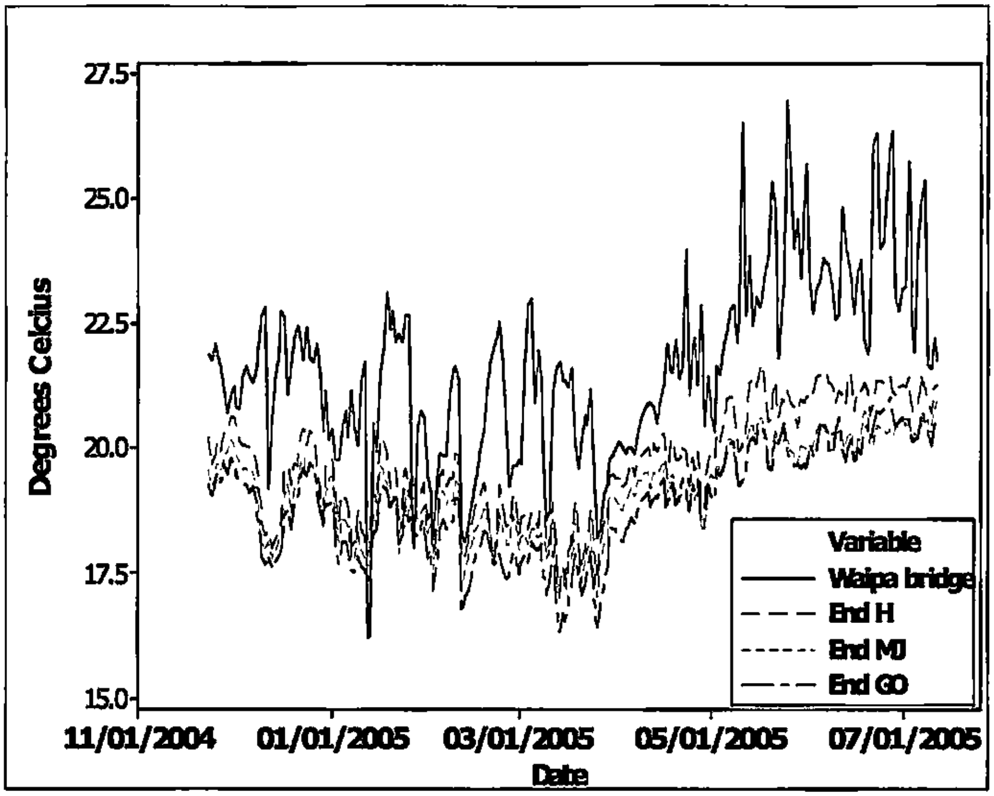


Figure 2.9: Daily minimum Waipā stream temperature at monitoring sites

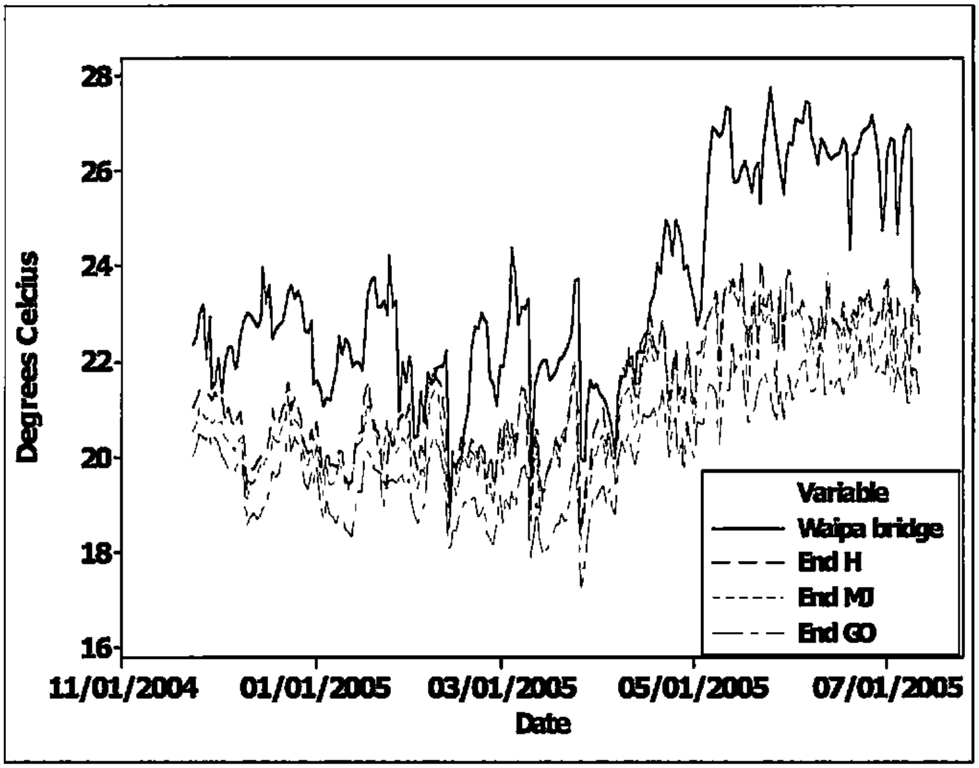


Figure 2.10: Daily maximum Waipā stream temperature at monitoring sites

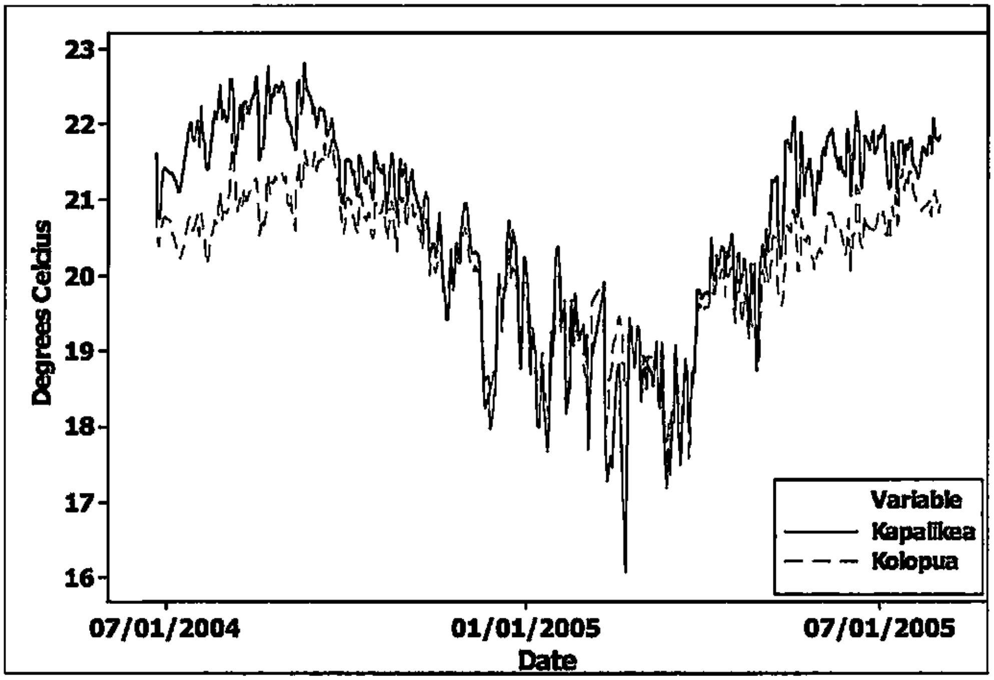


Figure 2.11: Daily minimum water temperature of Waipā tributaries

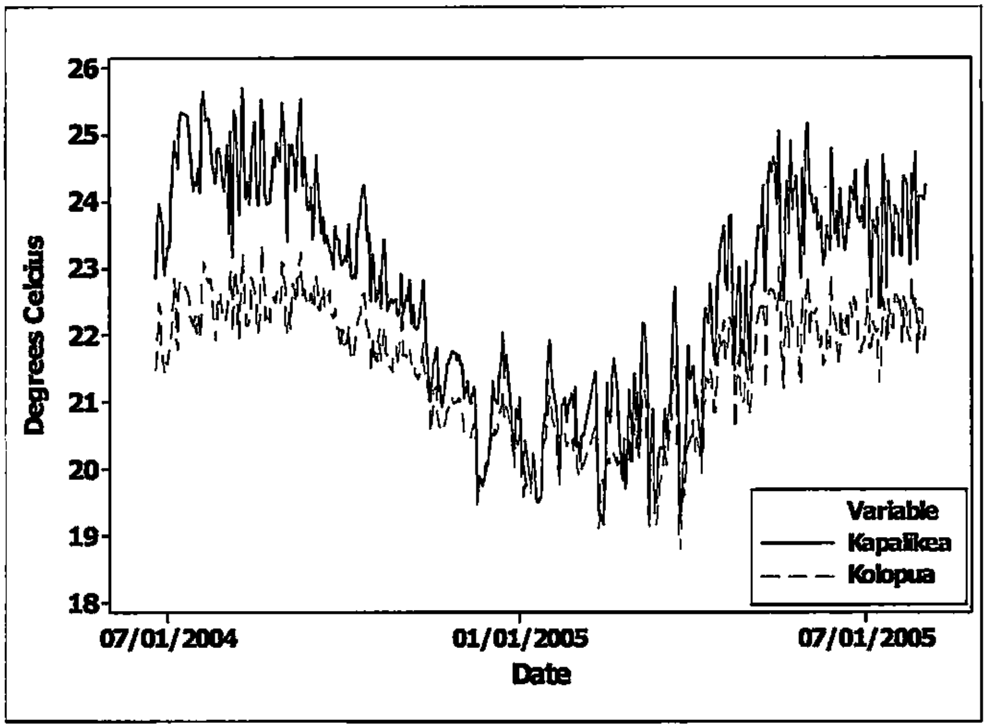


Figure 2.12: Daily maximum water temperature of Waipā tributaries

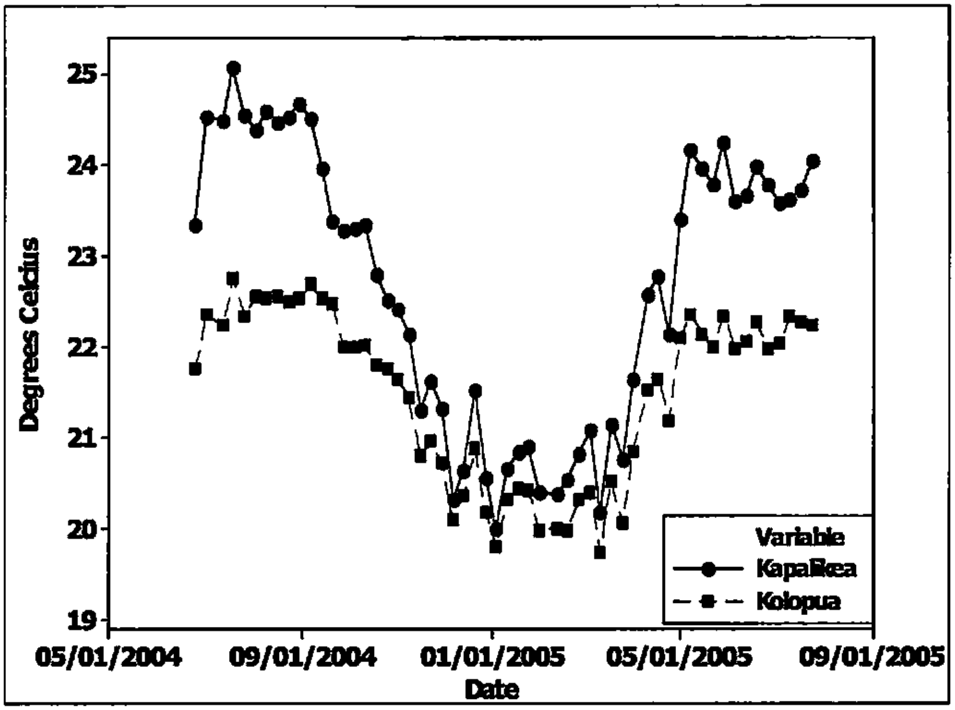


Figure 2.13: 7-day running average of daily maximum water temperature of Waipā tributaries

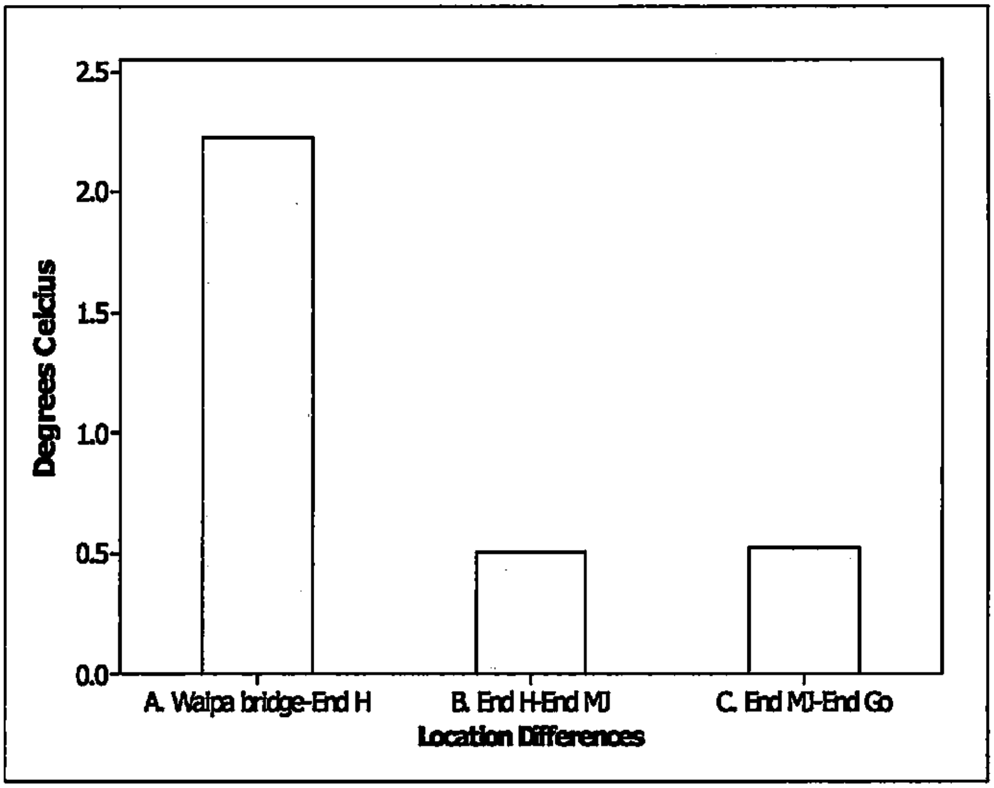


Figure 2.14: Average Waipā stream temperature change per section calculated as difference of total average of daily averages of monitoring sites

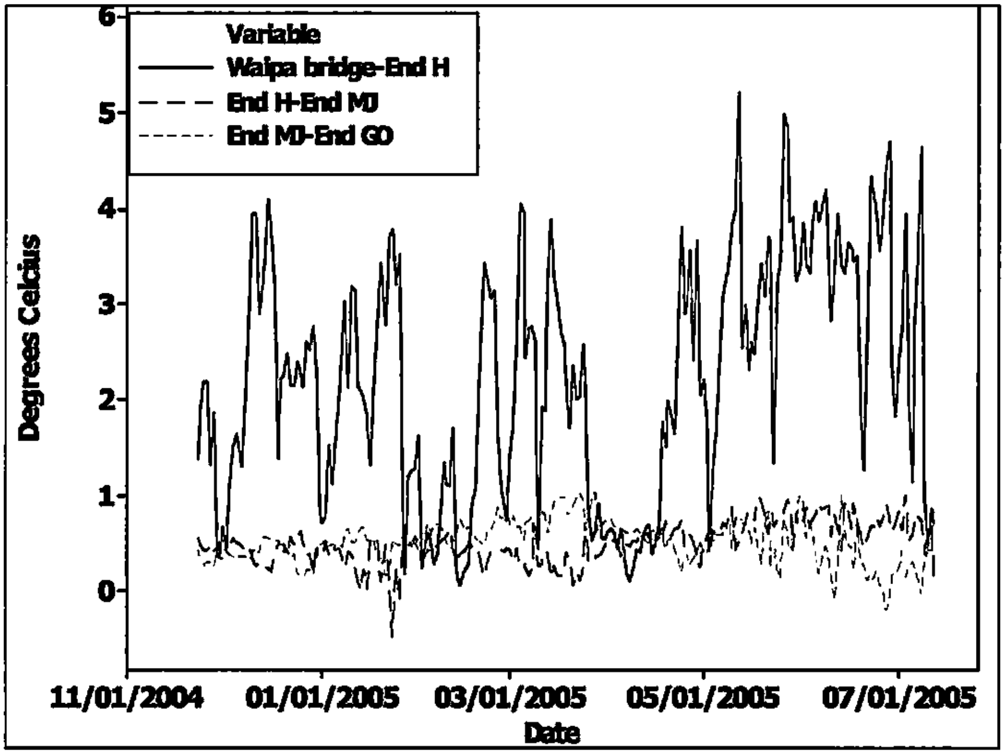


Figure 2.15: Average daily Waipā stream temperature change between monitoring sites

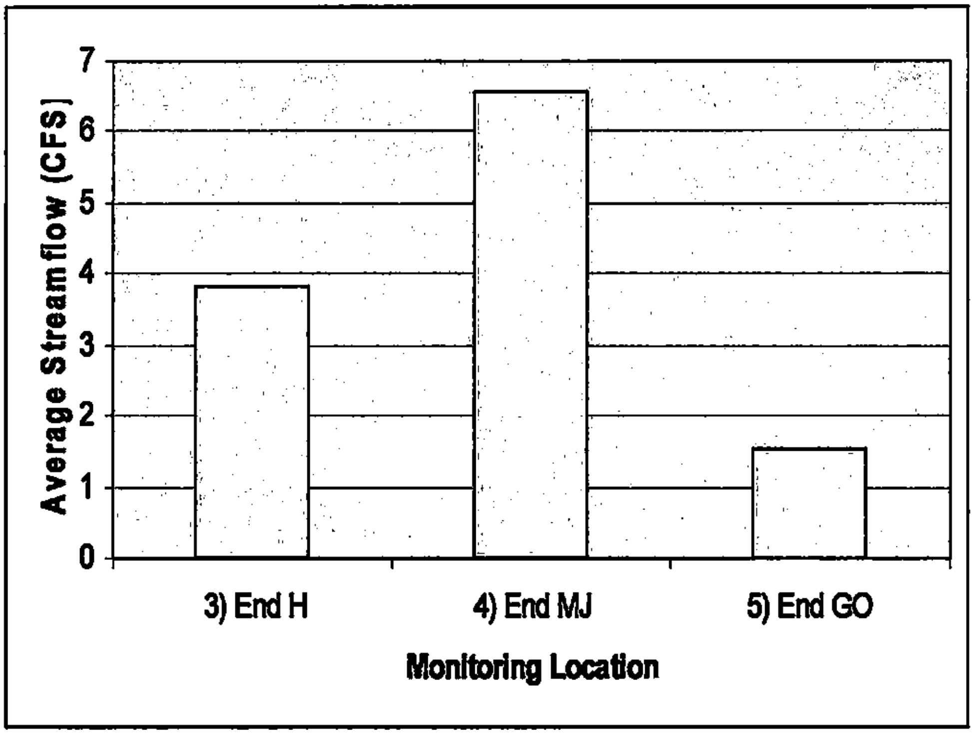


Figure 2.16: Average Waipā streamflow at monitoring sites

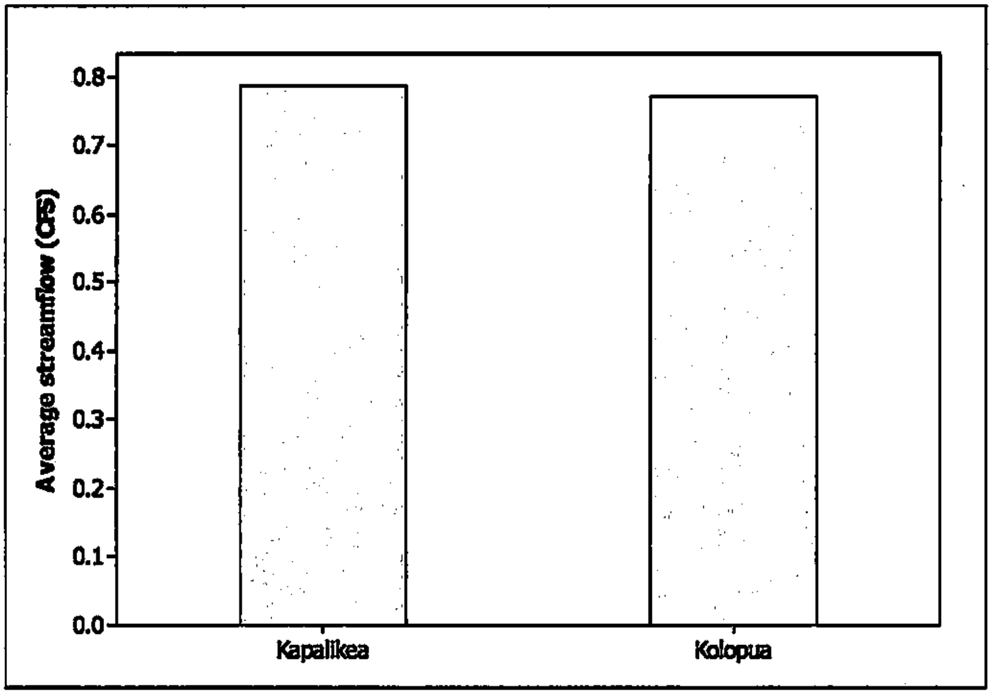


Figure 2.17: Average streamflow at confluence of Waipā tributaries

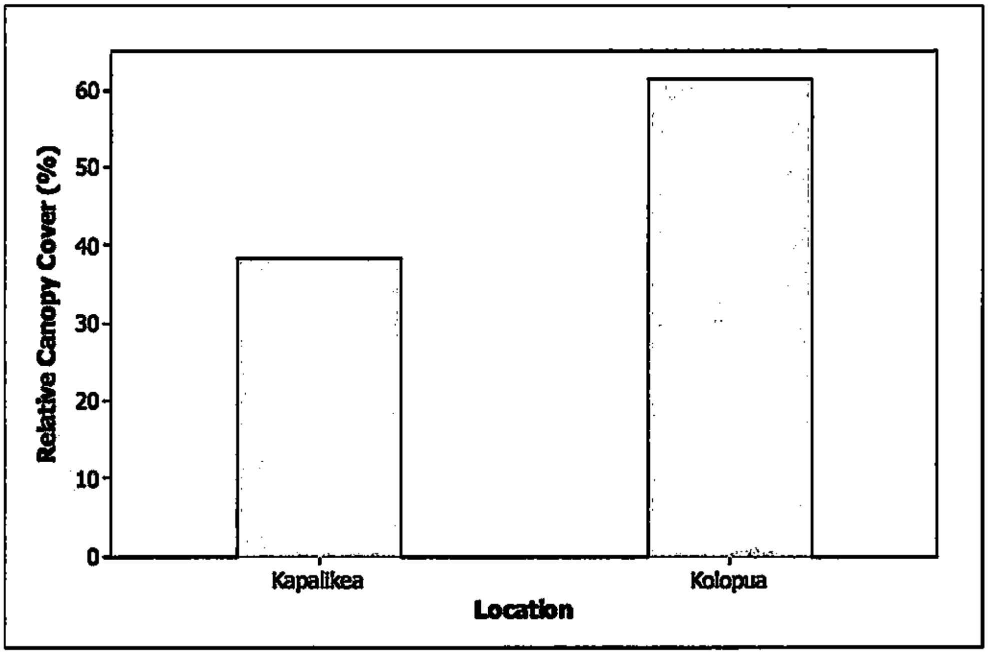


Figure 2.18: Relative canopy cover of Waipā tributaries

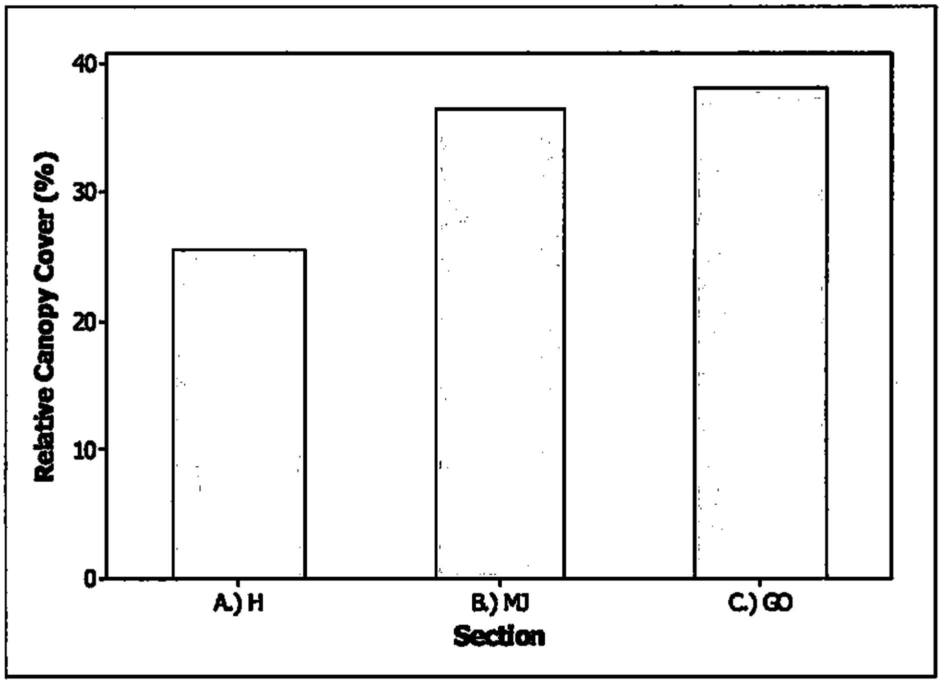


Figure 2.19: Relative canopy cover per section along Waipā stream

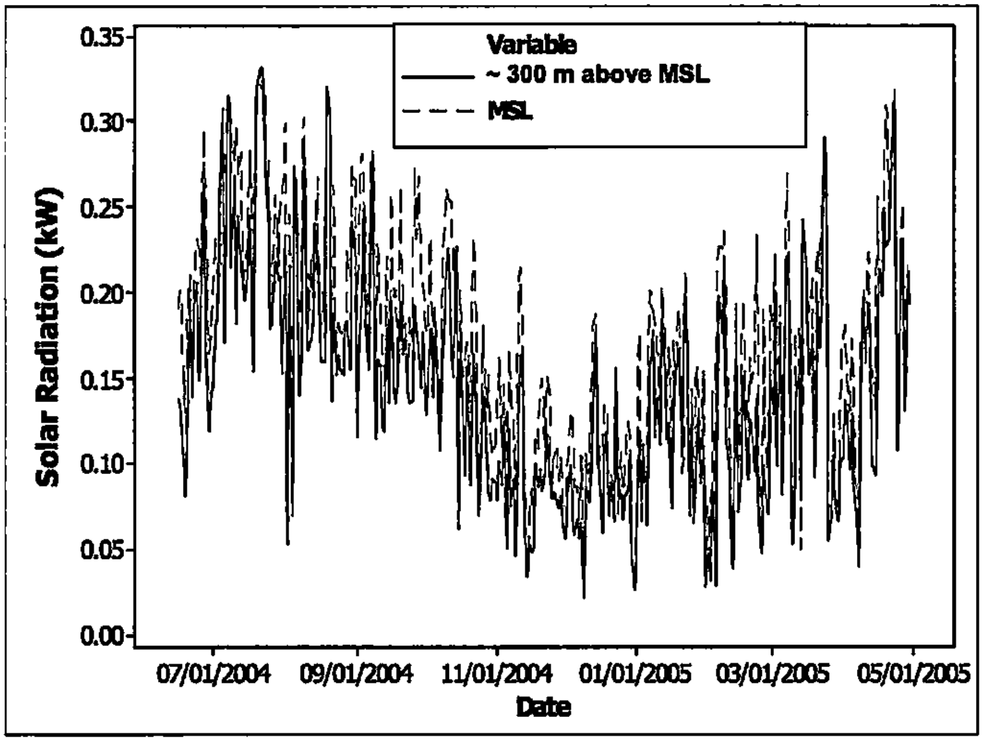


Figure 2.20: Average daily solar radiation at mean sea level (MSL) and about 300 m above MSL at Waipā watershed

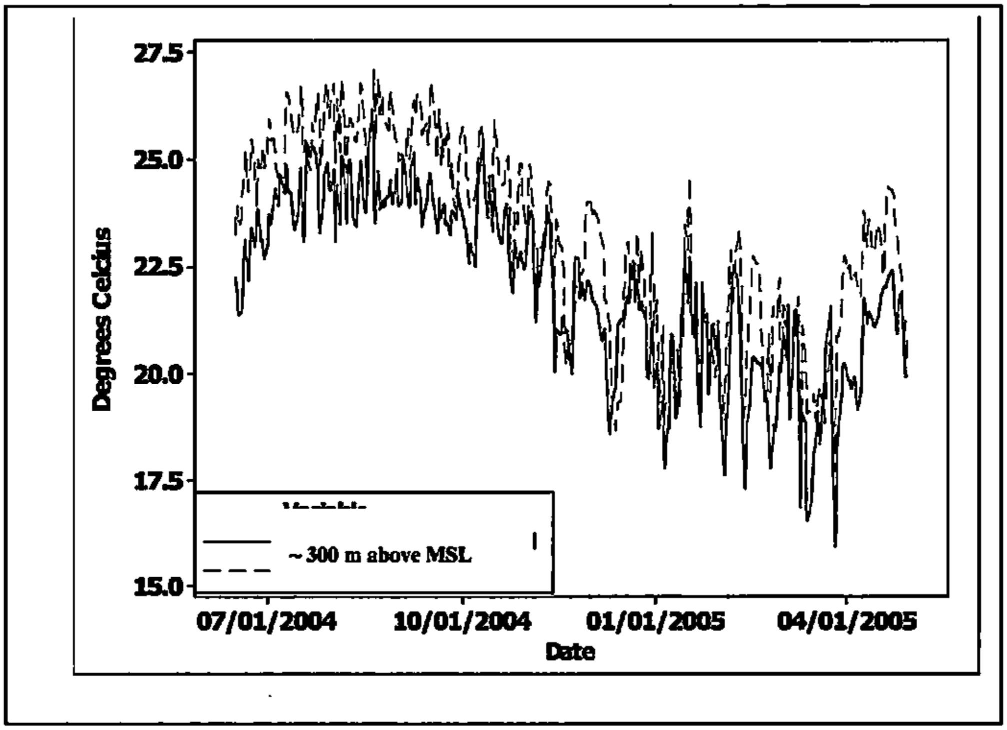


Figure 2.21: Daily average air temperature at mean sea level and ~ 300 m above MSL for Waipā watershed

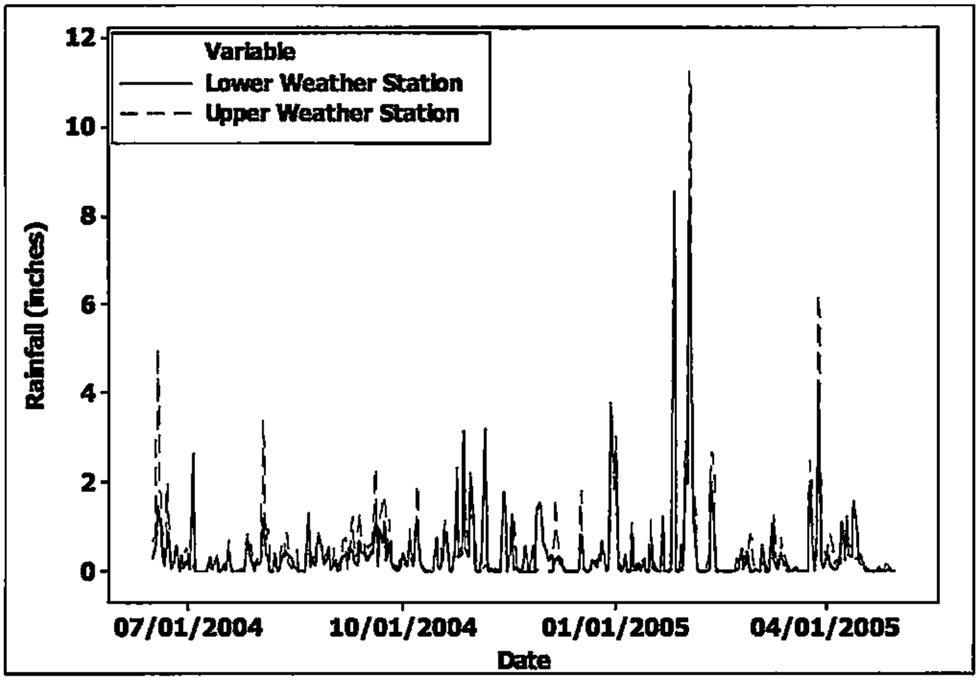


Figure 2.22: Average daily rainfall for mean sea level and about ~300 m above mean sea level (MSL) at Waipā watershed

CHAPTER 3:

"Characterizing canopy and ground cover of Waipā stream and tributaries of the Hawaiian island of Kaua'i"

Ragosta, G., Ticktin, T., Evensen, C.

3.1 ABSTRACT:

Vegetation was scientifically and methodically characterized along Waipā stream and tributaries on the Hawaiian island of Kaua'i (Figure 3.1 and 3.2) to improve understanding of the function of these areas as pollution buffers. Waipā watershed covers about 650 hectares from mean high tide up to Mamalahoa peak at approximately 1141 m above mean sea level. *Hibiscus tiliaceus* significantly dominates canopy cover of the lower half-mile of Waipā stream up to approximately 60 m above mean sea level. Draping multidirectional numerous individuals of *H. tiliaceus* create monotypic canopy communities and decrease streamflow with increasing growth rates while soil deposits around a maze of roots. Principal Component Analysis (PCA) for canopy cover showed that when *H. tiliaceus* canopy cover was low, *Psidium cattleianum* was high along Waipā stream and tributaries. *H. tiliaceus* transitions upstream into a mixed riparian canopy system of *Mangifera indica*, *Syzigium cumini*, and *P. cattleianum* invading upper elevations of *Psidium guajava*, *Aleurites moluccana*, and remnant native species such as *Metrosideros polymorpha*. A paired t-test shows that average *Zingiber zerumbet* ground cover per plot is significantly higher in summer 2004 than winter 2005 at P = .020, and average *Christella dentata* ground cover per plot is significantly higher in winter 2005 than summer 2004 at P = .011. A Kruskal-Wallis test showed that the average number of bare ground contacts per plot are significantly higher at P = .005 in the cattle pasture (section C) and Kapalikea tributary (section KA) versus upper elevations of Waipā stream (section GO). Average rock contacts per plot significantly increases upslope from sections H and C along Waipā stream. By characterizing canopy and ground cover of Waipā riparian zone, tributaries, and cattle pasture, we can better understand plant distribution, composition, and function at varying locations. Land managers can use the data for future native plant restoration projects and educational curriculum.

3.2 Introduction:

This thesis initiates long-term goals of better understanding the use of specific riparian plant species in stream rehabilitation projects and as buffer zones to decrease microbial contamination to ambient waters, increase streamflow and wildlife habitat, decrease stream temperature, and improve recreational water quality within Waipā watershed and ultimately Hanalei Bay. Scientific and methodical classification of riparian plant systems for ground and canopy cover of *any* Hawaiian stream is unknown to the authors.

Riparian vegetation has different impacts on stream processes depending upon its position in a catchment (Abernethy et al., 1998). A close association between vegetation cover and geomorphology has been reported in studies of streamside vegetation in other regions of the US (Bell, 1974; Bell et al., 1977; Dollar et al., 1992), signifying that local topographic gradients reflect stream valley cross-sectional form and determines the local moisture regime and soil development (Mitsch et al., 1993). Widespread disturbance of riparian zones has compromised the genetic and ecological integrity of many species and communities of riparian vegetation (Howell et al., 1994). Many riparian areas in the United States have been mismanaged and degraded by improper livestock grazing; however proper management practices can minimize the effects of grazing (Mosley et al., 1998). Sovell et al (2000) found that fecal coliform and turbidity were consistently higher in continuously grazed riparian areas than in rotationally grazed and buffered riparian zones. Waters that receive pasture runoff can also contain unacceptably high concentrations of indicator organisms such as fecal coliform that signal the possible presence of pathogenic microorganisms, and it is better for manure to be deposited farther away from water than nearer (Lim et al., 1998). Because riparian vegetation is vital for maintaining ecosystem health and yet so easily degraded by cattle, one of the primary goals of national riverine conservation approaches and policies must be the protection and restoration of riparian corridors especially on private and public agricultural lands where riparian areas are likely to be mismanaged (Doppelt et al., 1993). But managers should locate revegetation schemes where they will most effectively achieve ecological, geomorphological, or other project goals (Abernethy et al., 1998).

As native riparian plants disappear due to mismanagement, the importance of collecting data on these systems accordingly increases. Native plants are of two kinds: those that arrived and formed successful populations without changing their morphological characteristics (*indigenous*), and those that evolved into different taxa after they became established (*endemic*) (Mueller-Dombois et al., 1998). The most effective method of selecting native riparian vegetation species is to conduct a vegetation survey (Walker et al., 1990) in a remnant stand of riparian vegetation (Carr et al., 1999). River managers *must* determine if such remnant sites can provide a suitably representative template of conditions at the site to be rehabilitated (Webb and Erskine, 2003). If this is the case then the surveys conducted should at the very least measure features such as the relative abundance and density of species present and interrelationships with changes in micro-topography, soils, aspect, flood frequency and disturbance regimes (McLoughlin, 1997).

To complement the information gathered from remnant vegetation surveys, historical records such as diary entries, portion (early land survey) plans (Jeans, 1978) and photographs may be of some use in the species selection process (Webb and Erskine, 2003). Caution, however, should be exercised in their use, as historical accounts are often qualitative, incomplete or inexact (Webb and Erskine, 2003).

Given that vast amounts of money and resources are spent on riparian vegetation rehabilitation programs, it would seem irresponsible not to trial various species under different conditions in order to make a statistically robust assessment of their appropriateness (Webb and Erskine, 2003). Remnant surveys and historical records may identify indigenous species and their natural distributions, however such species may not be suited to planting at the site to be rehabilitated due to post-European settlement river metamorphosis (Schumm, 1969; Webb and Erskine, 2003), increased soil salinity (Webb and Erskine, 2003), or a multitude of other factors. Rather, it is suggested that plantings should be monitored on a regular basis and decisions made regarding appropriate species as results are collected, analyzed and interpreted over a longer time period. But, prior to plantings it helps to understand riparian vegetation composition and function as a means to estimate abundances of particular species (ie, native vs. invasive), and to plan for future eradication and restoration projects.

In order to understand how streamside vegetation affects the distribution and abundance of animal populations and communities, it would be helpful to know something about how the vegetation varies from one location to another, and if this variation is inherently continuous or discrete (ie, whether riparian vegetation can be classified into discrete types or not) (McGarigal et al., 2000). Principal component analysis (PCA) provides us with a means to identify and quantitatively describe the existence of dominant gradients in streamside vegetation, and to qualitatively determine whether that variation is inherently continuous or discrete (McGarigal et al., 2000). Very little scientific data exists on underlying gradients of *any* Hawaiian riparian and tributary vegetation communities.

3.3 Objectives:

Scientifically and methodically characterizing Waipā canopy and ground cover can aid abundance and diversity estimates of riparian plant species. After calculating types and amount of plants in Waipā riparian zones, we can test for significant differences and gradients of vegetation communities between sections. Perhaps a particular plant species invades so extensively, thereby making quantification and subsequent eradication an essential component prior to successful native plant restoration. Calculating the abundance and diversity of ground and canopy cover in riparian zones of Waipā can aid in the design of buffer zones to decrease microbial contamination to down-slope ambient waters. Future research could include planting a variety of species along riparian zones, drainage ditches, and tributaries to test the ability of plants to intercept fecal indicator bacteria and waterborne contaminants.

3.4 Methods and Materials:

3.4.1 Site Selection:

A stratified random design allows the field-worker to subdivide the survey area, or any given stand, into several homogeneous regions, then to locate the stands or samples randomly within each homogeneous region (Barbour, 1999). This design ensures that samples will be dispersed throughout the entire survey area and throughout each stand, and it does not compromise the concept of random sampling (Avery, 1964). Initial assessments of riparian canopy and ground cover using aerial photos, insight from local land managers, site visits, and analysis of a USGS topography map allowed us to stratify drainage ecosystems within Waipā watershed into the following sections:

1. Lower floodplain: Cattle pasture drainage ditch (300 meters) (Section C)
2. Lowest elevation along Waipā stream: dominated by *H. tiliaceus* (1000 meters) (Section H)
3. Middle elevation along Waipā stream: dominated by *M. indica and S. cumini*

(2000 meters) (Section MJ)
4. Upper elevation along Waipā stream: dominated by *P. guajava, P. cattleianum, and M. polymorpha* (1100 meters) (Section GO)
5. Kapalikea tributary (2000 meters) (Section KA)
6. Kolopua tributary (1000 meters) (Section KO)

The following variables were measured in 4 randomly located plots per section (Figure 3.2 and 3.3): diameter at breast height (dbh) for all tree species > 5 cm^2, canopy cover, and ground cover. In Waipā, cattle graze in an open meadow sparsely covered in trees and relatively monotypic in ground cover. Two drainage ditches run east to west in the pasture and connect with Waipā stream mouth. The cattle often drink and traverse in and around the same water systems in which they often defecate and urinate. The tributaries and stream sections of this study diversify in canopy and ground cover upslope from the pasture.

At each randomly selected location within each section, a 10 x 10 m plot parallel to channel flow and perpendicular to the streambank was created to characterize the vegetation communities (Figure 3.3). Plot sizes decrease to 5 x 5 m in the tributaries due to varying bank slopes, making it extremely difficult to create plots in many tributary locales. We excluded vertical banks mostly covered in *D. linearis* from data collection and analysis. Calculations were adjusted for the tributaries to coincide with data in 10 x 10 m plots.

Within each plot, three 10 m long transects were oriented parallel to channel-flow at the bank edge, halfway and at the uppermost edge of the plots (Figure 3.3). Every 50 cm along each transect, ground cover was recorded using a modified-pin drop method (Barbour, 1999), and canopy cover using a densitometer. Diameter at breast height (dbh) was measured for all tree species > 5 cm^2 within each plot. Basal area was calculated using the formula, basal area $=\prod r^{2}$. r in this calculation equals half the value of the dbh for each species.

3.4.2 Statistical design and analysis:

Normality tests for differences in total vegetation between sections showed that basal area, canopy cover, and ground cover did not meet the standards for normality (Appendix 3.29 through Appendix 3.46). After log-transforming the data, only ground cover during winter 2005 contained a normal distribution. So, a nonparametric test (Kruskal-Wallis) was used to evaluate differences in basal area, canopy cover, and ground cover for summer 2004 (Appendix 3.32, 3.43, and 3.46). A one-way ANOVA was used to test for significant differences of total vegetated ground cover between sections during winter 2005 (Appendix 3.37).

Principal Component Analysis (PCA) was used to determine gradients of basal area, ground and canopy cover between individual species and sections. Because we sought to give equal emphasis to all species regardless of their absolute variances, we used the correlation matrix (McGarigal et al., 2000) to derive the principal components. The two most dominant species per plot were included in the PCA. In many instances, the researcher is forced to analyze a set of variables with only a 2:1 ratio of samples to variables (McGarigal et al., 2000). In our case, sections (ie, GO) were the samples and species (ie, *Z. zerumbet*) were the variables.

Initial analysis of descriptive statistics, stem-and-leaf, and box plots for the principal component scores show that no outliers exist in the dataset (Appendix 3.1 to 3.14), and our diagnostics indicate that the multivariate normality assumption is not met well. A few points noticeably deviated with respect to the variables of concern, which we considered meaningful variation in Waipā riparian vegetation. Rigorous concern over multivariate normality and sample size is not warranted here, since we are using PCA solely as a means to explore and describe the gradients of variation in the data set, and not to generate statistical inference concerning the underlying population (McGarigal et al., 2000).

A first step in PCA analysis involves making scree plots (Appendix 3.15 to 3.20), and generating a correlation matrix (Appendix 3.21 to 3.24). There are obvious break points in the principal components for each scree plot. But we retained all components for further analysis as a means to explore and describe vegetation gradients of Waipā stream and tributaries. For the purposes of this paper, we only describe the first three components of each variable. For the correlation matrix, we based our interpretation of each component on those variables with loadings greater than .40 or less than -.40, and placed most emphasis on those with loadings greater than .60 or less than -.60 (McGarigal et al., 2000).

We excluded statistical analysis for canopy cover data along the cattle pasture drainage ditch as our main interest was in comparing canopy differences among the tributaries and stream. All statistical analysis for comparing basal area did not include section C or H. Basal area was not measured in section H because *H. tiliaceus* species contain no distinct trunk, and roots wind in and out of ground and air making identification and measurement of individual species difficult.

3.5 Results:

3.5.1 Basal area and density of stream and tributaries (section MJ, GO, KA, and KO):

Average basal area per plot over all sections was: *P. cattleianum* at 1072 cm^2 with a Standard Error Interval (SEI) of 719 to 1424 cm^2, *M. indica* at 782 cm^2 with a SEI of 248 to 1317 cm^2, and *P. guajava* at 589 cm^2 with a SEI of 430 to 783 cm^2 (Figure 3.4). *M. indica* dominated average basal area per plot of section MJ at 3129 cm^2 with a SEI of 1321 to 4939 cm^2 (Figure 3.5). *P. guajava* dominated average basal area per plot of section GO at 1049 cm^2 with a SEI of 744 to 1353 cm^2 ,and *M. polymorpha* at 946 cm^2 per plot with a SEI of 617 to 1274 cm^2 (Figure 3.6). *P. guajava* dominated average basal area per plot of Kapalikea tributary at 707 cm^2 with a SEI of 294 to 1119 cm^2 (Figure 3.7). *Psychotria* spp. dominated average basal area per plot of Kolopua tributary at 1129 cm^2 with a SEI of 0 to 2257 cm^2 (Figure 3.8). While *P. cattleianum* did not dominate basal area for any particular section, its overall total basal area made it the most dominant species for all areas studied at 17,144 cm^2.

P. cattleianum had a relatively low average density of 97 cm^2 per stem, but the dominance of total individual stems of *P. cattleianum* (Figure 3.9) gave it the highest average basal area per plot (Figure 3.4). The average number of stems per plot was significantly higher in all upstream plots versus lower sections C and H (Figure 3.10). The average density (total basal area/total number of stems) is dominated by: *M. indica* at 1015 cm^2 (SEI of 0 to 2086 cm^2), and *M. polymorpha* at 221 cm^2 (SEI of 40 to 402 cm^2) (Figure 3.11). Section MJ had the highest average density per plot because of the dense stands of *M. indica*, not present in other areas studied (Figure 3.12).

Normal probability plots for total basal area were log-transformed and the data were abnormally distributed between sections (Appendix 3.25 and 3.26). A Kruskal-Wallis test indicated that basal area of section KA is significantly lower than section MJ at P = .09 probably because a forest fire disturbed the mid-section of Kapalikea tributary in the late 1960's and did not directly alter other sections studied, and section MJ contains the most dense stands of *M. indica*, not found in other sections studied at Waipā (Appendix 3.27).

The eigenvalues that explain 68 percent of the cumulative variation are PC1 = 2.5, PC2 = 2.2, PC3 = 1.5, and PC4 = 1.2 (Appendix 3.24). PC1 reflects an inverse gradient that when *M. polymorpha* and A. *moluccana* are low, *M. indica* is high. PC2 reflects a gradient that when *M. quinquenervia* is low, *C. obtusifolia* is also low. PC3 reflects a gradient that when *C. fruticosa* and *A. moluccana* are high, *P. guajava* is low. PC4 reflects a gradient that when *M. polymorpha* is high, *Psychotria* spp. are low.

PC1 vs. PC2 explains the most variation along PC1 for section GO vs. section MJ via the negative values for section GO plots versus the positive values for section MJ plots, probably because of the high density of *M. indica* in section MJ versus thinner more diverse stands of section GO (Figure 3.13). PC1 vs. PC3 and PC2 vs. PC3 show no linear trend explaining the variation of PC2 or PC3 between sections (Figure 3.14 and 3.15).

3.5.2 Canopy cover of stream and tributaries:

There are major differences between average number of canopy cover contacts per plot along Waipā stream and tributaries (Figure 3.16). *P. cattleianum* averaged about 50 contacts per plot (SEI from 37.3 to 67.5 individuals). The next closest average of canopy cover contacts per plot was *P. guajava* at 19.4 (SEI from 14.6 to 24.1). *H. tiliaceus* dominated canopy cover for section H (Figure 3.17). *P. cattleianum* dominated canopy cover of section MJ, Kapalikea and Kolopua tributaries (Figure 3.18, 3.20, and 3.21). *P. guajava* and *P. cattleianum* equally dominated section GO for a combined total of > 60 percent of the total canopy cover contacts (Figure 3.19).

Normal probability plots for total canopy cover individuals were log-transformed and the residuals were abnormally distributed between sections (Appendix 3.28 through 3.30). A Kruskal-Wallis test showed a significant difference exists between section H and Kolopua tributary at P = .021 because *H. tiliaceus* dominates canopy cover of section H and section KO is dominated by more numerous canopy layers and stems of *P. cattleianum* (Appendix 3.31). If not effectively managed, *H. tiliaceus* clogs Waipā streamflow. But, intense rain events spark Hortonian sheet flow movement across areas of *H. tiliaceus*, carrying with it surface water, leaf litter, woody debris, soil, and potential microbial contaminants towards Waipā stream mouth.

The eigenvalues that explain 67 percent of the cumulative variation are PC1 = 3.1, PC2 = 1.8, PC3 = 1.6, and PC4 = 1.4 (Appendix 3.23). In PC1, when *C. hirta* is low, *P. guajava* and *A. moluccana* are also low. Maybe Koster's curse (*C. hirta*) values increase when *P. guajava* and *A. moluccana* values are high. PC2 reflects a gradient that when *C. obtusifolia* is low, *C. jamaicense* is also low. In PC3, when *H. tiliaceus* and *C. fruticosa* are low, *P. cattleianum* is high. After section H ends about 1000 m distance up from Waipā stream mouth, PC3 shows that all other upper elevation sections have a high canopy cover of *vivi* (*P. cattleianum)* in the tributaries and main channel (except for those with sparsely distributed canopy cover of *ti* [*C. fruticosa*]), reflecting the heavy invasiveness of *P. cattleianum* at Waipā.

PC1 vs. PC2 explains the most variation along PC1 as all plots for sections MJ and H are < 0 for PC1, while all other sections are >1 for PC1 (Figure 3.22). PC2 separates out Kapalikea tributary as the only section in which 0 canopy cover contacts (Figure 3.23) occur in some plots. PC3 separates out *H. tiliaceus* dominated section H from all other sections except fire-stricken Kapalikea tributary (Figure 3.24).

3.5.3 Vegetated ground cover for all plots (summer 2004):

Of all plant species found, the average number of individual species per plot was: *Paspalum* spp. at 39 (SEI of 10 to 67), *Nephrolepis multiflora* at 33 (SEI of 25 to 41), and *Z. zerumbet* at 18 (SEI of 11 to 26) (Figure 3.25). Most dominant ground cover individuals per section were: *P. conjugatum* for section C (Figure 3.26), *Oplismenus hirtellus* for section H (Figure 3.27), *Paspalum* spp. for section KA (Figure 3.30), and *N. multiflora* for section MJ, GO, and KO (Figures 3.28, 3.29, and 3.31).

Normal probability plots for vegetated ground cover individuals were log-transformed and the residuals were abnormally distributed between sections (Appendix 3.32 through Appendix 3.34). A Kruskal-Wallis test showed that significant differences exist at P = .001 between section H and Kapalikea tributary, probably because of the more monotypic *Paspalum* spp. and *D. linearis* ground cover in section KA versus relatively low ground cover in section H (Appendix 3.35).

The eigenvalues that explain 68 percent of the cumulative variation are PC1 = 2.5, PC2 = 2.2, PC3 = 1.5, and PC4 = 1.2 (Appendix 3.22). PC1 reflects a gradient that when *P. conjugatum* is low, *P. polystachyos* and a category of *Unknown* species are also low. The majority of unknown species were not identified because cattle modified vegetation to such an extent that identification was difficult in the lower floodplain pasture. Of particular importance in PC2 is the separation of sites with low levels of *H. tiliaceus* ground cover versus all other plant species. PC3 reflects an inverse gradient indicating that low values of *Z. zerumbet* and *P. cattleianum* are associated with high values of *Freycinetia arborea* and *O. hirtellus.* . Perhaps the overwhelming dominance of *P. cattleianum* canopy and basal area correlates to low levels of *F. arborea*, a native Hawaiian crawling vine also known as *`ie `ie*. Maybe a competitive relationship exists in which high values of *P. cattleianum* and *Z. zerumbet* excludes growth of native plants such as *F. arborea.*

A scatterplot of PC1 vs. PC2 shows a linear increase of separation explaining the variance in vegetated ground cover with increasing elevation along Waipā stream (Figure 3.32). PC1 reflects the major difference between section C and all other sections. PC2 reflects the separation of *H. tiliaceus* dominated section H with all other sections (Figure 3.33). PC3 separates the differences between low ground cover in section MJ, C, and H from Kapalikea tributary, probably due to the dense ground cover of *Paspalum* spp. in section KA (Figure 3.34).

3.5.4 Vegetated ground cover for all plots (winter 2005):

Of all plant species found, the average number of individual species per plot was: *Paspalum* spp. at 42 (SEI of 11 to 72), *C. dentata* at 38 (SEI of 27 to 49), and *D. linearis* at 14 (SEI of 1 to 27) (Figure 3.35). Most dominant ground cover individuals per section were: *P. conjugatum* for section C (Figure 3.36), *H. tiliaceus* for section H (Figure 3.37), *Paspalum* spp. for section KA (Figure 3.38), and *C. dentata* for section MJ, GO, and KO (Figures 3.38, 3.39, and 3.41).

Normal probability plots for vegetated ground cover individuals were logarithmically transformed and the data was normally distributed between sections (Appendix 3.36 through Appendix 3.39). A one-way ANOVA of the log-transformed data followed by Tukey's comparison test showed highly significant differences of total vegetated ground cover between sections at P = 0.0001 (Appendix 3.40). Section C significantly differed from section KA, perhaps due to the homogeneous and sparse *P. conjugatum* coverage in section C versus the dense ground coverage of *Paspalum* spp. and *D. linearis* in a previously burned area of Kapalikea tributary. Average ground cover per plot of section H is significantly lower than section MJ, GO, KA, and KO. *H. tiliaceus* dominates canopy cover of section H, and prohibits the more abundant ground coverage present in sections MJ, GO, KA, and KO. Significant differences exist in average ground cover for section MJ versus KA and KO, reflecting the higher average ground cover in the tributaries versus section MJ along the main stream channel.

The eigenvalues that explain 79 percent of the cumulative variation are PC1 = 2.4, PC2 = 1.7, PC3 = 1.5, and PC4 = 1.4 (Appendix 3.21). PC1 reflects an inverse gradient that when *C. dentata* and *O. hirtellus* are low, *P. polystachyos* and *P. conjugatum* are high. PC2 reflects an inverse gradient that when *D. linearis* and *O. hirtellus* are low, *N. multiflora* and *Paspalum* spp. are high. PC3 reflects a gradient that when *P. cattleianum* ground cover is high, *C. dentata* is also high. PC4 separates sites with low values of *H. tiliaceus* from all other species.

A scatterplot of PC1 vs. PC2 shows a linear increase along PC1 in vegetative ground cover of Waipā stream with increasing elevation (Figure 3.42). PC1 also separates out section C and H versus all other sections. PC2 separates out Kapalikea tributary from all other sections, reflecting the dense ground cover per plot in section KA (Figure 3.43). PC3 shows no linear trend, but it separates section KA from other sections (Figure 3.44).

3.5.5 Comparing vegetated ground cover results between seasons:

The high density of *Paspalum* spp. in Kapalikea tributary reflects the ability of this species to invade the fire-stricken ground (personal communication with Dr. Asquith, 2005). *Paspalum* spp. are sparsely present in all other areas studied at Waipā during summer 2004 and winter 2005. The average of *C. dentata* individuals per plot is significantly higher in winter 2005 than in summer 2004 at P = .011 (Appendix 3.41). The average of *Z. zerumbet* individuals per plot is significantly higher in summer 2004 than in winter 2005 at P = .020 (Appendix 3.28). *C. dentata* occupies 3 percent of the ground cover of section GO during summer 2004, and 41 percent during winter 2005 (Figure 3.45). *Z. zerumbet* occupies 19.2 percent of the ground cover of section GO during summer 2004, and 0 percent during winter 2005 (Figure 3.46). Perhaps an unknown relationship exists between a particular tree species (ie, *P. cattleianum*) and seasonal fluctuations in growth rates of *C. dentata* and *Z. zerumbet*.

H. tiliaceus dominates ground cover of section H during winter 2005. *O. hirtellus* dominates ground cover of section H during summer 2004. Maybe the flushing rains and scattered hortonian sheet flow systems going through section H during winter 2005 versus the relatively dry summer 2004 caused changes in the ground cover composition by unearthing soil and moving plant parts and species.

3.5.6 Vegetated ground and canopy cover differences among transects within plots:

The ability of a buffer zone to remove contaminants depends on a variety of factors (ie, hydrology, land use, plant community, soil type, slope, and aspect) acting simultaneously. Calculating differences in total vegetated ground and canopy cover along transects at different distances upslope (Figure 3.3) from channel flow allows comparison of average vegetation cover among transects within plots. Eventually, we can evaluate the ability of different plant communities at different distances (0, 5 m, 10 m) upslope from the streambank to remove contaminants. In order to decrease conflict among land users, we can create models which calculate appropriate size of buffer zones in order to promote conservation and public health. Results showed that no significant differences exist for vegetated ground or canopy cover differences among transects within plots at P = .05 (Appendix 3.43 through Appendix 3.45).

3.5.7 Non-vegetated ground cover:

An important aspect of the creation of riparian buffer zones includes identifying and quantifying non-vegetative ground cover. As microbial contaminants move through a tropical island stream ecosystem, it is hypothesized that varying degrees of leaf litter, bare ground, rock, and woody debris will alter the buffer zone's ability to improve down-slope ambient water quality.

3.5.8 Non-vegetated ground cover (summer 2004):

At Waipā, the average number of non-vegetative ground cover contacts per plot for summer 2004 were approximately: 51 contacts of leaf litter (SE interval of 41 to 60 contacts), 34 contacts of bare ground (SE interval of 28 to 41 contacts), 7 contacts of rock (SE interval of 5 to 9 contacts), and 4 contacts of woody debris (SE interval of 3 to 5 contacts) (Figure 3.47). Bare ground dominated Section C at >200 total contacts (Figure 3.48). Leaf litter dominated for all other sections (Figure 3.49 through Figure 3.53).

Non-vegetative ground cover data for summer 2004 is not normally distributed (Appendix 3.46). A log-transformation of the non-vegetative ground cover data still shows a non-normal distribution (Appendix 3.47 and 3.48). A Kruskal-Wallis test for all non-vegetative ground cover variables showed that the number of bare ground contacts in sections C and KA are significantly higher than section GO at P = .001, probably due to higher land use degradation in sections C (grazing density) and KA (fire) versus upper elevations of Waipā stream in section GO (Appendix 3.49). Rock contacts are significantly higher in all sections at P = .01 versus sections C and H, reflecting the increase in substrate size with increasing elevation upstream (Appendix 3.50). Woody debris values are significantly higher at P = .03 in Kolopua tributary and section H versus section C and MJ (Appendix 3.51). Section C is significantly lower at P = .005 in leaf litter than Kapalikea tributary probably because of *Paspalum* spp. which might contribute more leaf litter to the ground cover system (Appendix 3.52).

3.5.9 Non-vegetated ground cover (winter 2005):

At Waipā, the average number of non-vegetative ground cover contacts per plot for winter 2005 were approximately: 37 contacts of leaf litter (SE interval of 33 to 42 contacts), 30 contacts of bare ground (SE interval of 25 to 34 contacts), 7 contacts of rock (SE interval of 5 to 9 contacts), and 4 contacts of woody debris (SE interval of 4 to 5) (Figure 3.54). Bare ground dominated Section C at >200 total contacts (Figure 3.55). Leaf litter dominated for all other sections (Figure 3.56 through Figure 3.60).

Non-vegetative ground cover data for winter 2005 is not normally distributed (Appendix 3.53). A log-transformation of the non-vegetative ground cover data still shows a non-normal distribution (Appendix 3.54). A Kruskal-Wallis test was done for all non-vegetative ground cover variables and it showed that the average number of bare ground contacts in sections C and KA are significantly higher than section MJ at P = .005, probably due to higher land use degradation in sections C (grazing density) and KA (fire) versus upper elevations of Waipā stream in section MJ (Appendix 3.55). Average rock contacts per plot are significantly higher in sections MJ, GO, and KA at P = .03 versus sections C and H, reflecting the increase in substrate size with increasing elevation up drainage systems (Appendix 3.56). Average woody debris contacts are significantly higher at P = .06 in Kolopua tributary versus section C (Appendix 3.57). Section C is significantly lower in leaf litter at P = .03 than Kolopua tributary (Appendix 3.58).

3.5.10 Non-vegetated ground cover differences among transects within plots:

Significant differences were found at $P < .05$ for bare ground and leaf litter values during summer 2004 among transects within plots during summer 2004 (Appendix 3.59 and 3.60). Average contacts per transect per plot for leaf litter were: 13 for the lower transect for leaf litter (SE mean of 3.8), and 19 for upper (SE mean of 4) and middle transects (SE mean of 2.8) for leaf litter. No other significant differences were found among transects within plots during summer 2004 or winter 2005 (Appendix 3.61 through Appendix 3.66).

3.6 Discussion:

The riparian zone canopies of Waipā stream and tributaries are heavily dominated by *hau* (*H. tiliaceus*) up to approximately 60 m above mean sea level and *vivi* (*P. cattleianum*) in the upper watershed. Prior to the introduction of natural gas onto Kaua'i, many Hawaiians used *H. tiliaceus* for firewood, fencing, and canoes, among other uses, but now a lack of extraction has led to an overgrowth in lower parts of Waipā stream (Personal communication with Dr. Adam Asquith, 2006). It is believed that feral pigs spread many of the *P. cattleianum* across Waipā watershed, coupled with past land use history of cattle and horses in sectored areas. As a total of all areas studied, '*vivi*' (*P. cattleianum*) exists as the dominant species comprising the riparian vegetation canopy and basal area of Waipā stream and tributaries. There are also seasonal changes in ground cover of *Z. zerumbet* (having the common name of shampoo ginger, and Hawaiian name *awapui*), which goes dormant most of the year until reappearing in July and August. Bare ground is significantly higher in the cattle pasture and Kapalikea tributary versus other sections measured at Waipā. The presence of cattle for over 25 years in the lower floodplain cattle pasture has probably caused the higher prevalence of bare ground in this section versus other locations studied. Fire stricken and erosion prone Kapalikea tributary contains more monotypic invasive grass and fern species than the diverse canopy and ground cover of Kolopua tributary. *D. linearis* ground cover data was underestimated because it grows on many steeply sloped (ie, channel walls 10 m high with 180°slopes) not traversable streambanks. Most likely, *D. linearis* has the highest vegetative ground cover in Waipā watershed.

While *P. cattleianum* dominates canopy cover of the MJ section, *M. indica* dominates basal area of this section at approximately 12,500 cm^2 with *P. cattleianum* at approximately 8,600 cm^2. A mixed canopy system exists with smaller diameter *P. cattleianum* tree species hovering under and over larger diameter *M. indica* species within section MJ. In all tributary and stream sections measured for basal area, *P. cattleianum* dominated at 17,144 cm^2, with *M. indica* second at 12,518 cm^2, and *P. guajava* third with 9,705 cm^2. *P. cattleianum* total basal area was underestimated because many individuals exist for dbh < 5 cm^2 which were not measured.

Combining the total basal area of common guava (*P. guajava*) and strawberry guava (*P. cattleianum*) shows that guava more than doubles the total basal area of any other species in riparian and tributary areas studied at Waipā. As seen in the Principal Component Analysis (PCA) for canopy cover, all areas low in hau bush (*H. tiliaceus*) and *ti* (*C. fruticosa*) are high in *P. cattleianum*. Hau bush only grows up to about 60 m above sea level and about 1000 m length up from Waipā stream mouth. *Ti* is not very prevalent along Waipā stream, yet scattered in Kapalikea tributary. Basically, *P. cattleianum* poses a threat to completely dominate vegetation systems of Waipā riparian zone and tributaries if management decisions to control its menacing spread and growth are not made within the near future. Could eradication of guava be achieved by increasing knowledge on the fruiting phenology and biological control methods of *P. cattleianum*?

Knowledge of other drainage ecosystems of Waipā could improve management of riparian buffer zones. Concurrent studies on chemical and microbial levels of Waipā soils and waters, and stream temperature analysis can be applied to creating riparian buffer zones in line with data on tropical island riparian vegetation systems. As water quality declines in many riparian ecosystems, understanding the structure and function of vegetation systems is critical to protecting and maintaining healthy sustainable ambient water supplies for tropical island communities.

3.7 References:

Abernethy, Bruce, Ian D. Rutherford. 1998. Where along a river's length will vegetation most effectively stabilize stream banks? Geomorphology. 23(1): 55-75.

Avery, T.E. 1964. To stratify or not to stratify. J. Forestry 62:106-108.

Barbour, M., Burk, J., Pitts, W., Gilliam, F., Schwartz, M. 1999. Terrestrial Plant Ecology: Third Edition. Benjamin Cummings Publishing, 2725 Sand Hill Road, Menlo Park, CA, 94025.

Bell, D.T. 1974. Tree stratum composition and distribution in the streamside forest. Am. Midl. Nat. 92, 35-46.

Bell, D.T., Del Moral, R. 1977. Vegetation gradients in the streamside forest of Hickory Creek Will County, Illinois. Bull. Torrey Bot. Club 104, 127-135.

Carr, G., Lord, R., Seymour, S., 1999. Rehabilitation of disturbed stream frontages using natural vegetation templates-a case study on the Yarra River, Victoria. IN: Rutherfurd, I.D., Bartley, R. (Eds.), Proceedings of First National Conference on Stream Management in Australia, pp. 247-251, Merrijig.

Dollar, K.E., Pallardy, S.G., Garrett, H.G., 1992. Composition and environment of floodplain forests of northern Missouri. Can. J. For. Res. 22: 1343-1350.

Doppelt, B., M. Surlock, C. Frissell, and J. Karr. 1993. *Entering the Watershed: A New Approach to Save America's River Ecosystems.* Island Press, Washington, D.C.

Howell, J., Benson, D., McDougall, L. 1994. Developing a strategy for rehabilitating riparian vegetation of the Hawkesbury-Nepean River. Pacific Conservation Biology. 1: 257-271.

Jeans, D.N. 1978. Use of historical evidence for vegetation mapping in New South Wales. Australian Geographer. 14: 93-97.

Lim, T.T., Edwards, D.R., S.R. Workman, B.T. Larson, L. Dunn. 1998. Vegetated Filter Strip Removal of Cattle Manure Constituents in Runoff. *American Society of Agricultural Engineers.* 41(5): 1375-1381

McGarigal, K., Cushman, S., Stafford, S. 2000. Multivariate Statistics for Wildlife and Ecology Research. New York: Springer-Verlag Inc.

McLoughlin, L. 1997. The impact of planting for restoration of remnant bushland on its scientific and educational values: implications for conservation planning. Pacific Conservation Biology 3, 27-38.

Mitsch, W., and Gosselink, J., 1993. Wetlands, Second Edition. Van Nostrand Reinhold, 115 Fifth Avenue, New York, NY, 10003.

Mosley, J.C., Cook, P.S., Giffis, A.J. 1997. Guidelines for managing cattle grazing in riparian areas to protect water quality: Review of research and Best Management Practices policy. Idaho Forest, Wildlife and Range Policy Analysis Group no. 15. University of Idaho, Moscow, Idaho.

Mueller-Dombois, D. 1998. Vegetation and ecosystem research for biodiversity conservation in the Pacific islands. Pacific Science Association Information Bulletin 50 (1-2): 1-10.

Schumm, S.A. 1969. River metamorphosis. Journal of the Hydraulics Division. Proceedings of the American Society of Civil Engineers. 95: 255-273.

Sovell, L.A., Vondracek, B., Frost, J.A., Mumford, K.G. 2000. Impacts of rotational grazing and riparian buffers on physicochemical and biological characteristics of southeastern Minnesota, USA, Streams. Environmental Management 26: 629-641.

Walker, J., Hopkins, M.S. 1990. Vegetation. In: McDonald, R.C., Isbell, R.F., Specht, J.C., (Eds.), Australian Soil and Land Survey Field Handbook, Australian Collaborative Land Evaluation Program, Commonwealth Scientific and Industrial Research Organisation, Land and Water, Canberra, pp. 58-86.

Webb. A.A., W.D. Erskine. 2003. A practical scientific approach to riparian vegetation rehabilitation in Australia. *Journal of Environmental Management*. 68: 329-341.

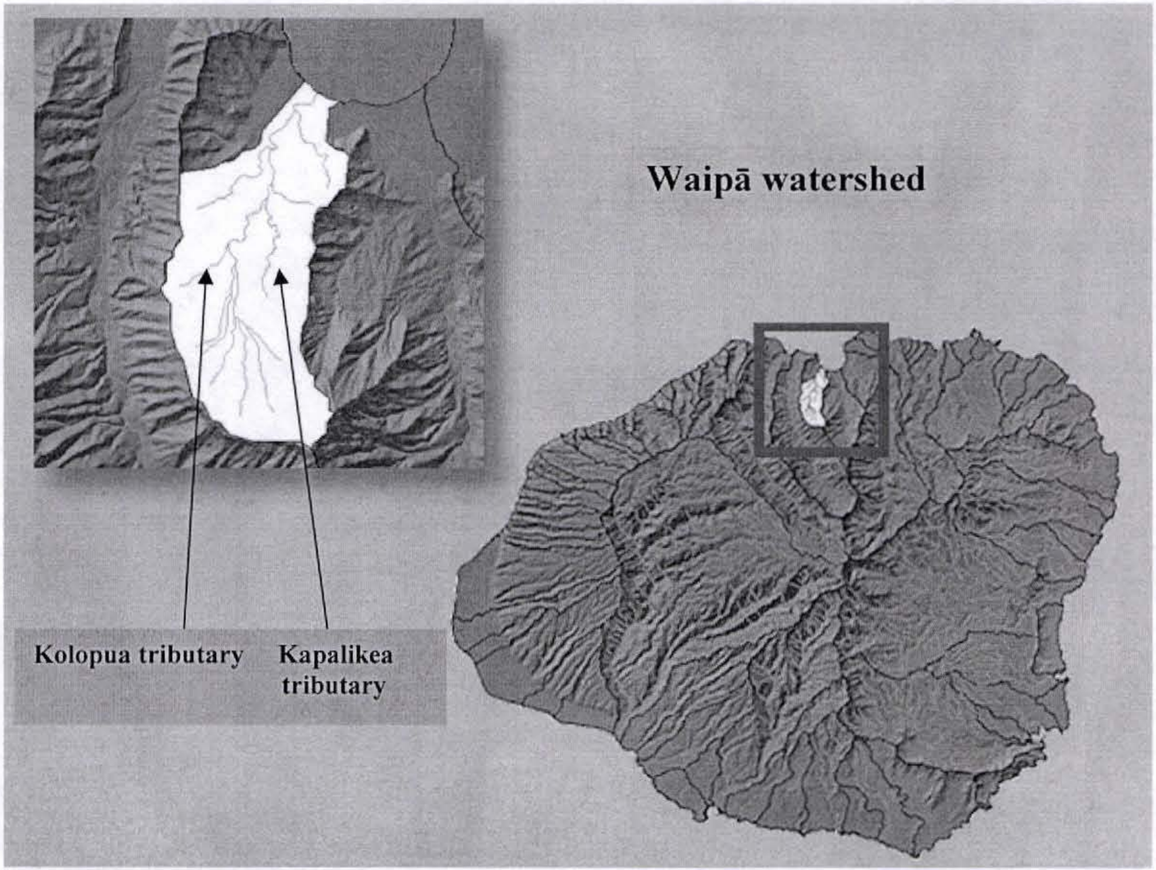


Figure 3.1: Island of Kaua`i and closeup of Waipā watershed

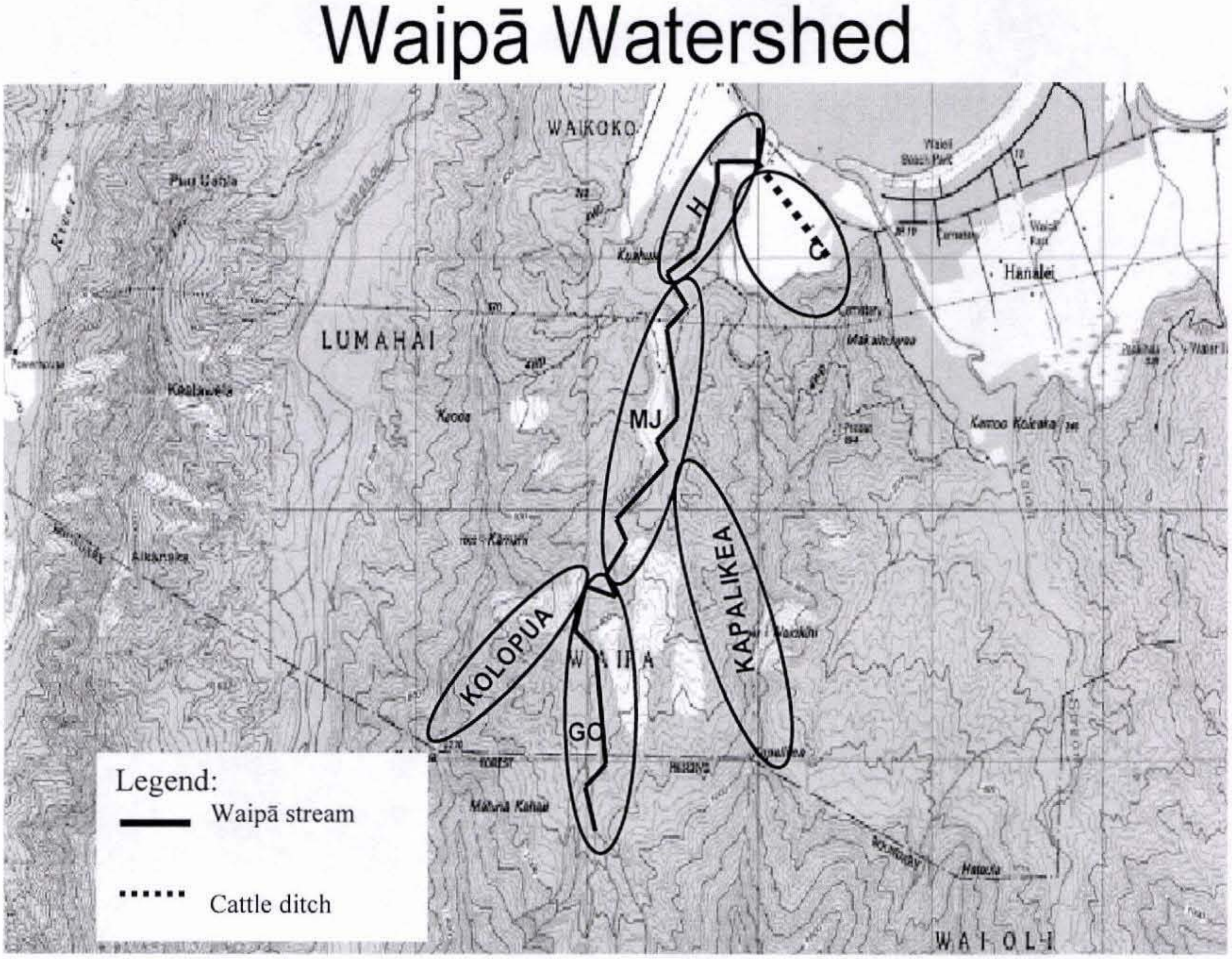


Figure 3.2: Waipā topography map labeled with major areas of study: stratified dominant riparian canopy communities, two major tributaries, and cattle pasture. Stream temperature and water quality monitoring sites were placed at the beginning and end of each riparian vegetation community, at the confluence of two tributaries, and at the end of a cattle pasture drainage ditch.

C= Cattle pasture drainage ditch (300 meters long)
H= *H. tiliaceus* section (1000 meters long)
MJ= *M. indica* and *S. cumini* section (2000 meters long)
GO = *P. guajava*, *P. cattleianum*, and *M. polymorpha* section (1100 meters long)
KA= Kapalikea tributary (2000 meters long)
KO= Kolopua tributary (1000 meters long)

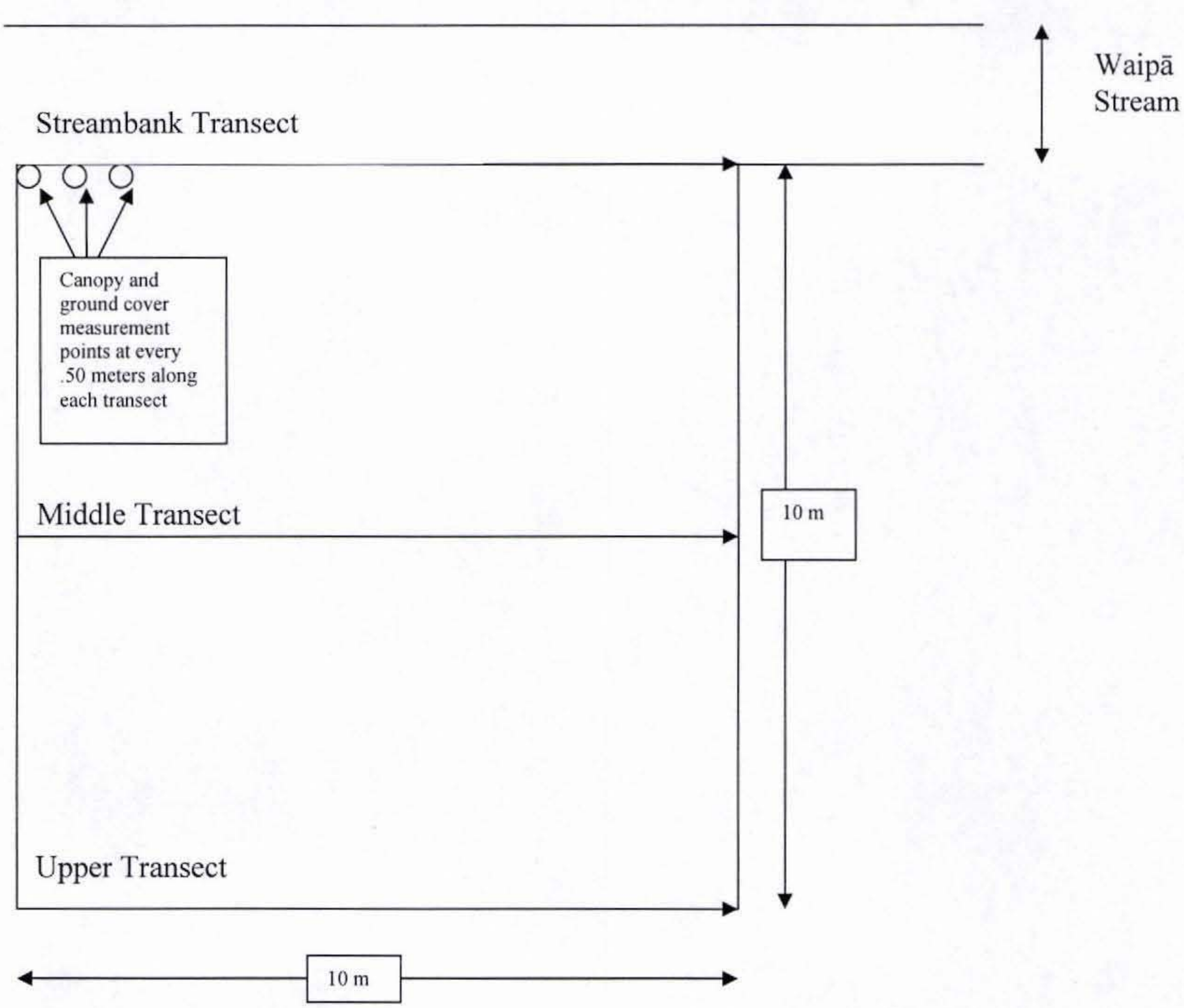


Figure 3.3: Plot and transect layout for characterizing riparian ground and canopy cover

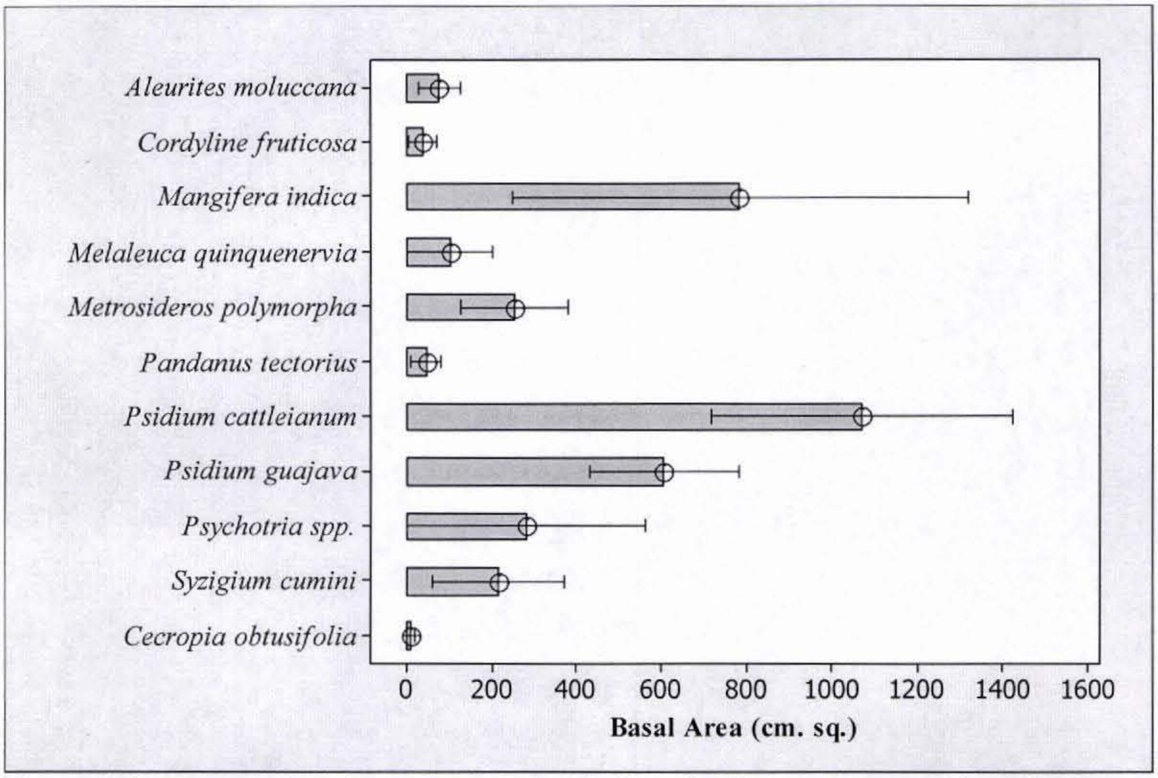


Figure 3.4: Average basal area per plot with Standard Error Interval bars (SEI bars)

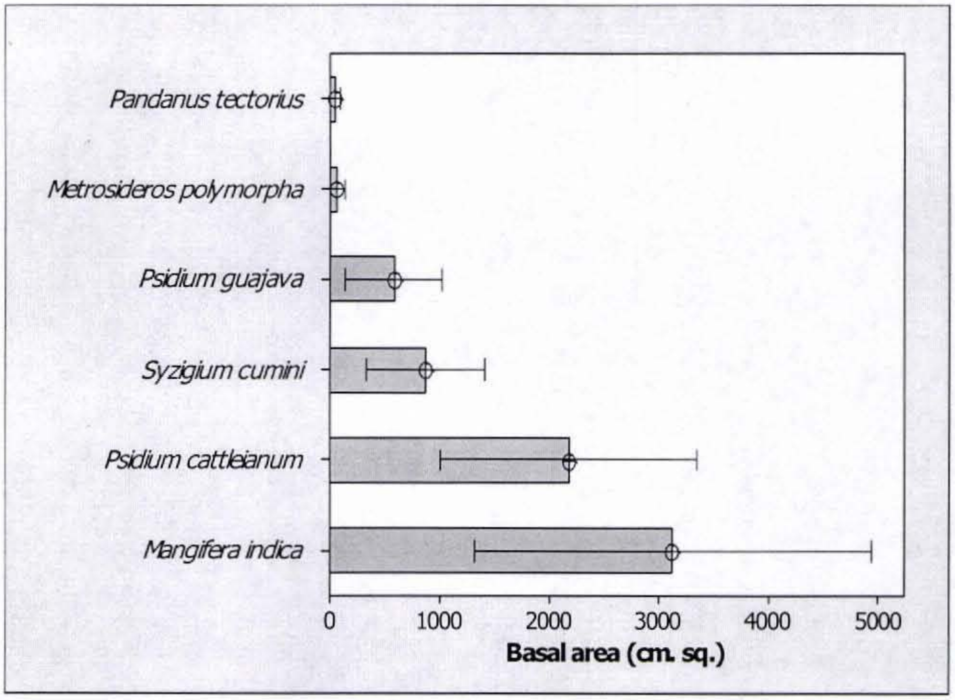


Figure 3.5: Average basal area per plot for section MJ with SEI bars

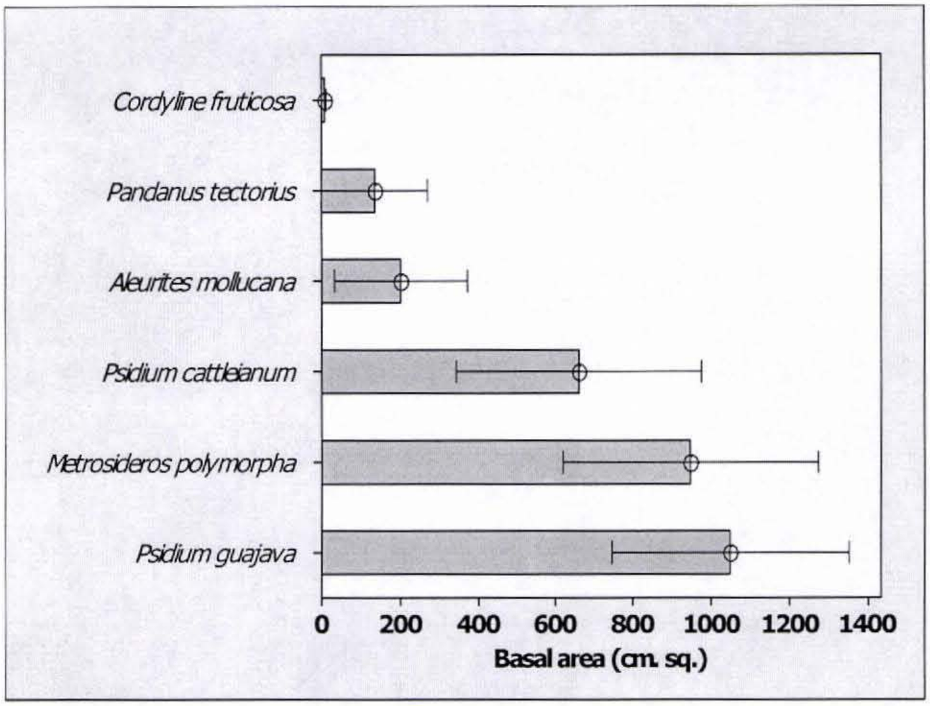


Figure 3.6: Average basal area per plot for section GO with SEI bars

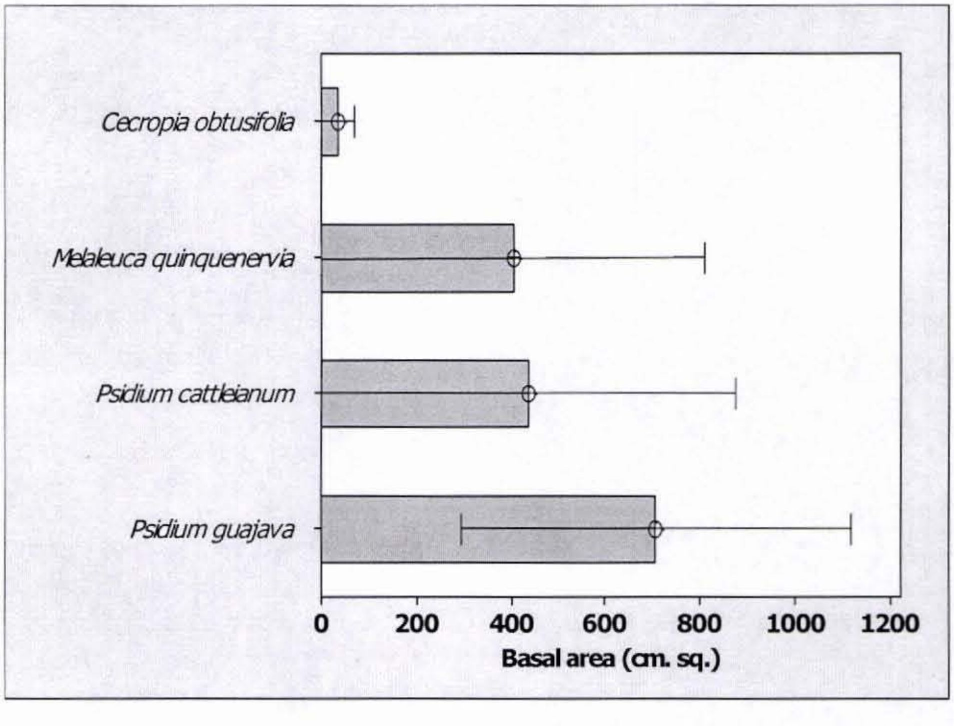


Figure 3.7: Average basal area per plot for Kapalikea tributary with SEI bars

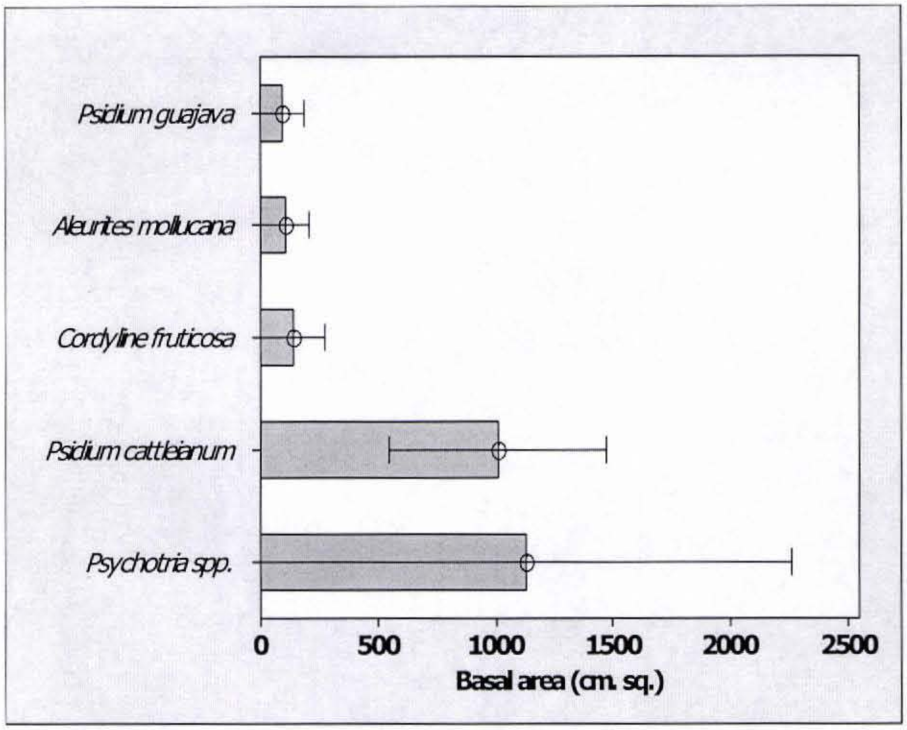


Figure 3.8: Average basal area per plot for Kolopua tributary with SEI bars

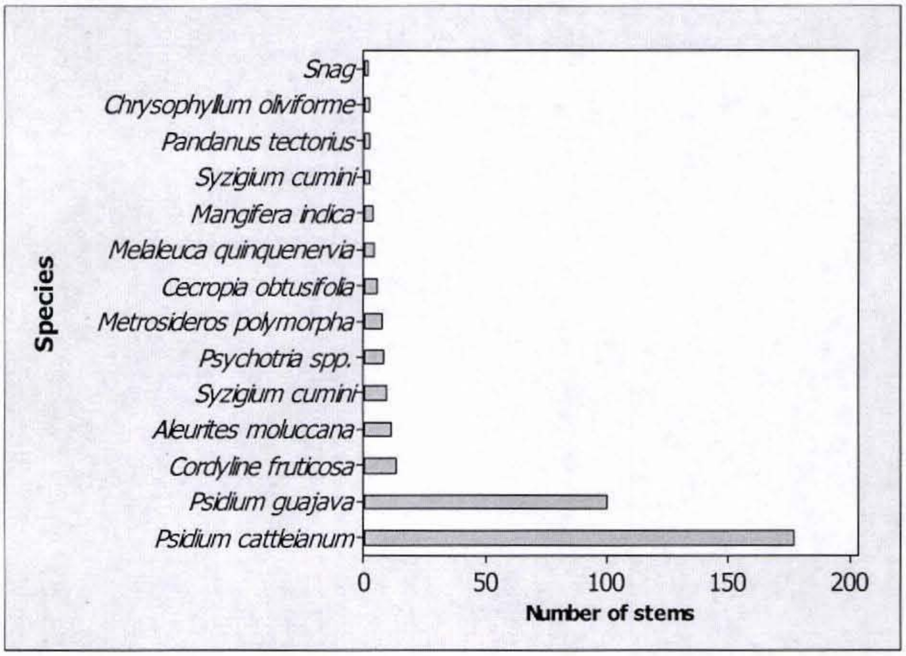


Figure 3.9: Total number of stems (> 5 dbh) in all plots along Waipā stream and tributaries

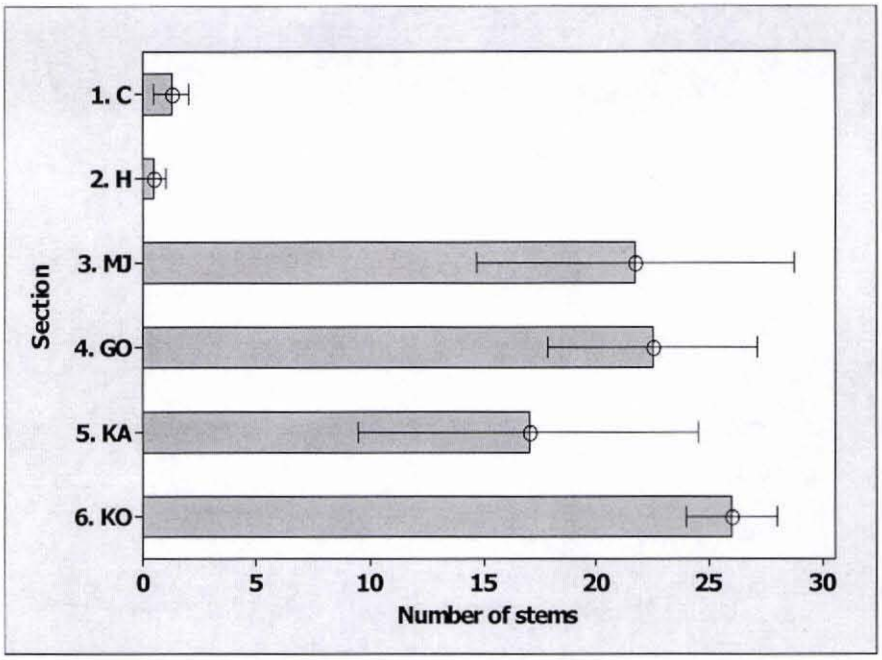


Figure 3.10: Average number of stems (> 5 dbh) per plot with SEI bars

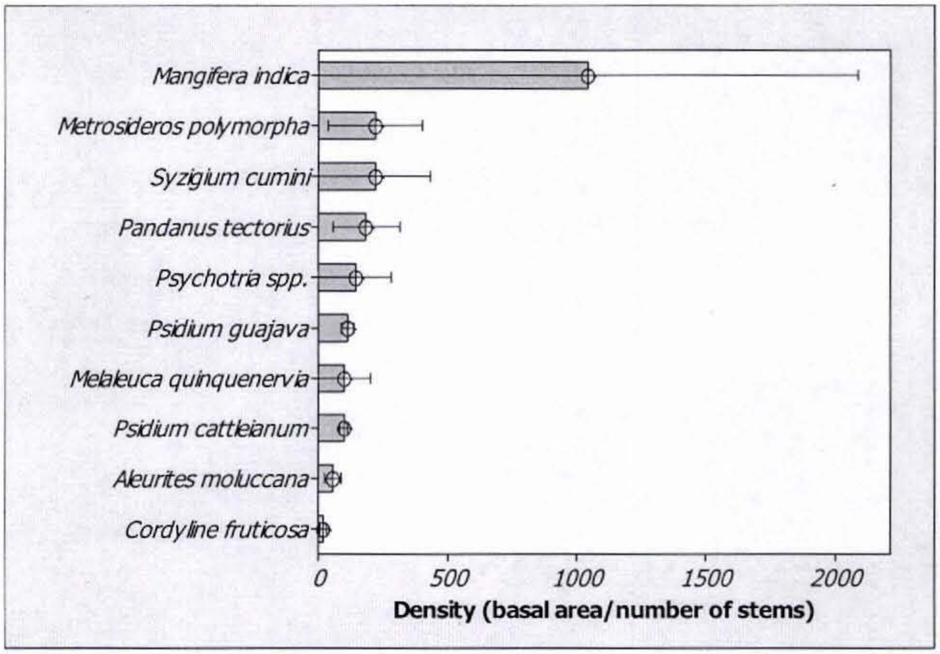


Figure 3.11: Average density per species over all sections (MJ, GO, KA, KO) (SEI bars)

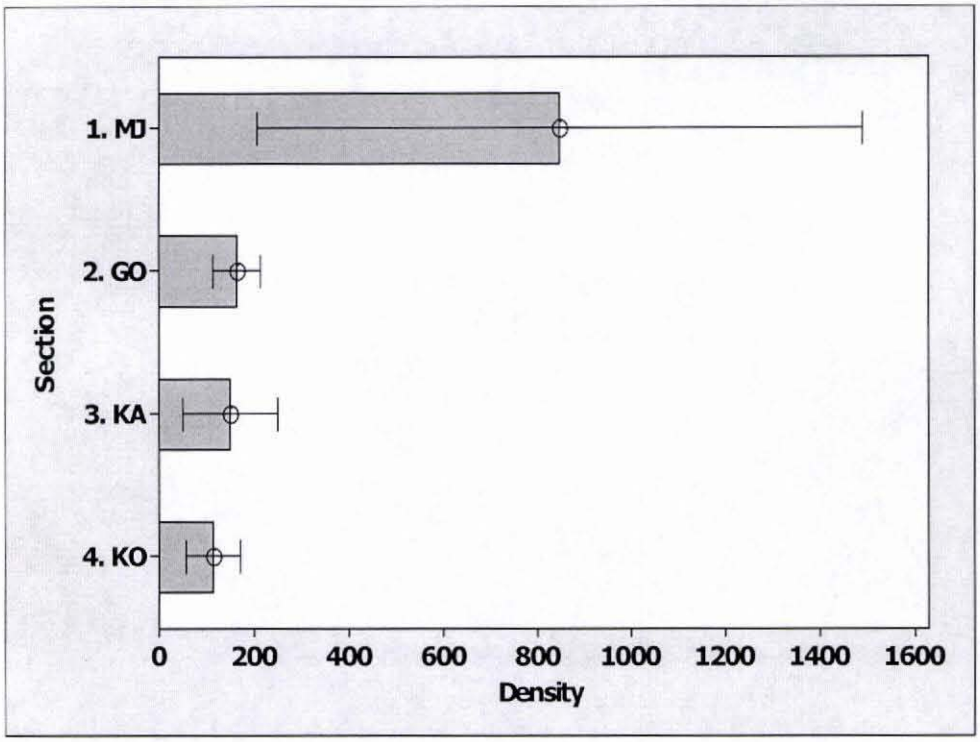


Figure 3.12: Average density (basal area/number of stems) per plot with SEI bars

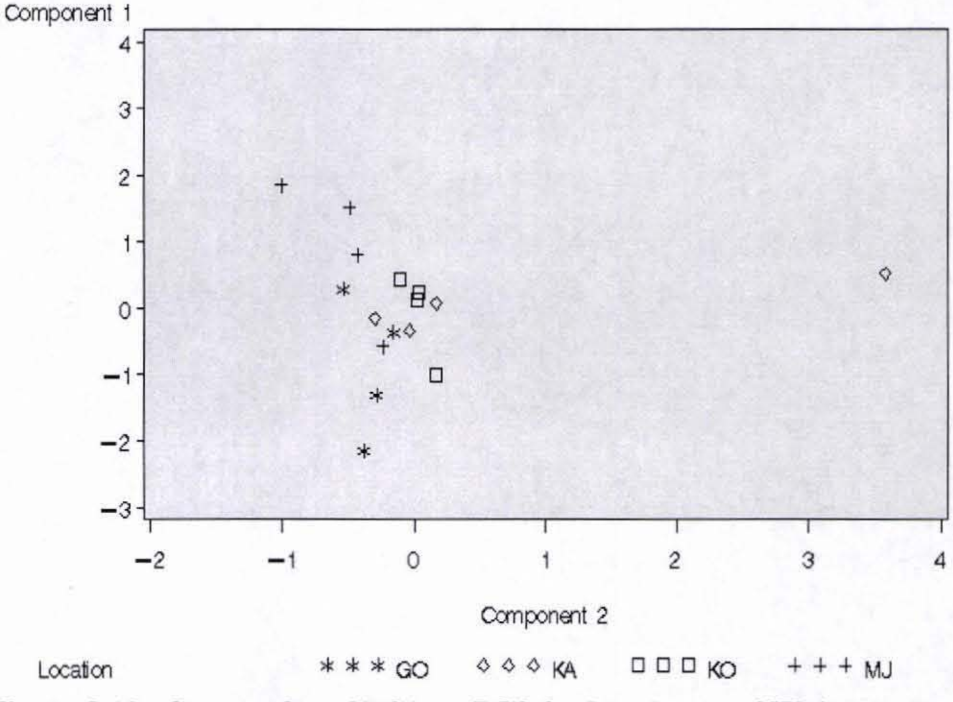


Figure 3.13: Scatterplot of PC1 vs. PC2 for basal area of Waipā stream and tributaries

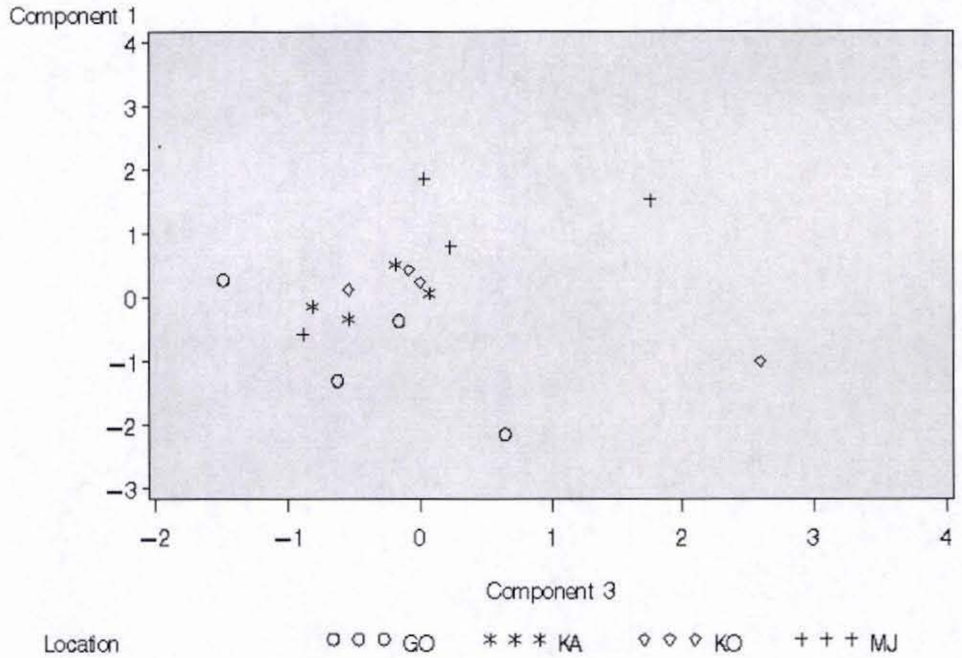


Figure 3.14: Scatterplot of PC1 vs. PC3 for basal area of Waipā stream and tributaries

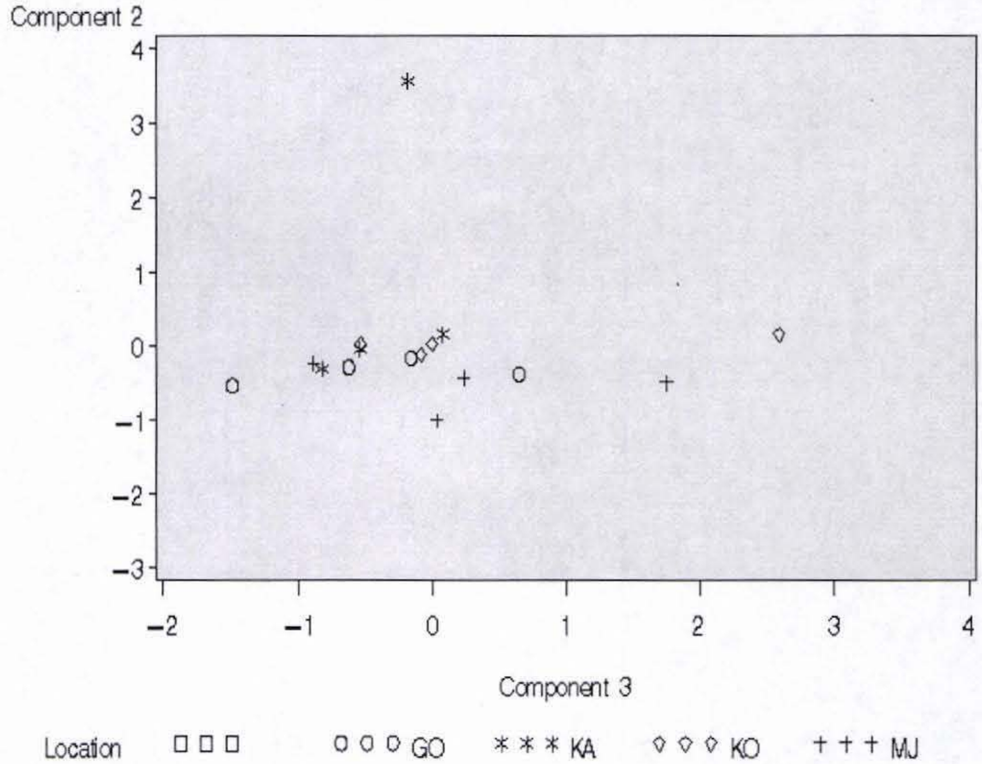


Figure 3.15: Scatterplot of PC2 vs. PC3 for basal area of Waipā stream and tributaries

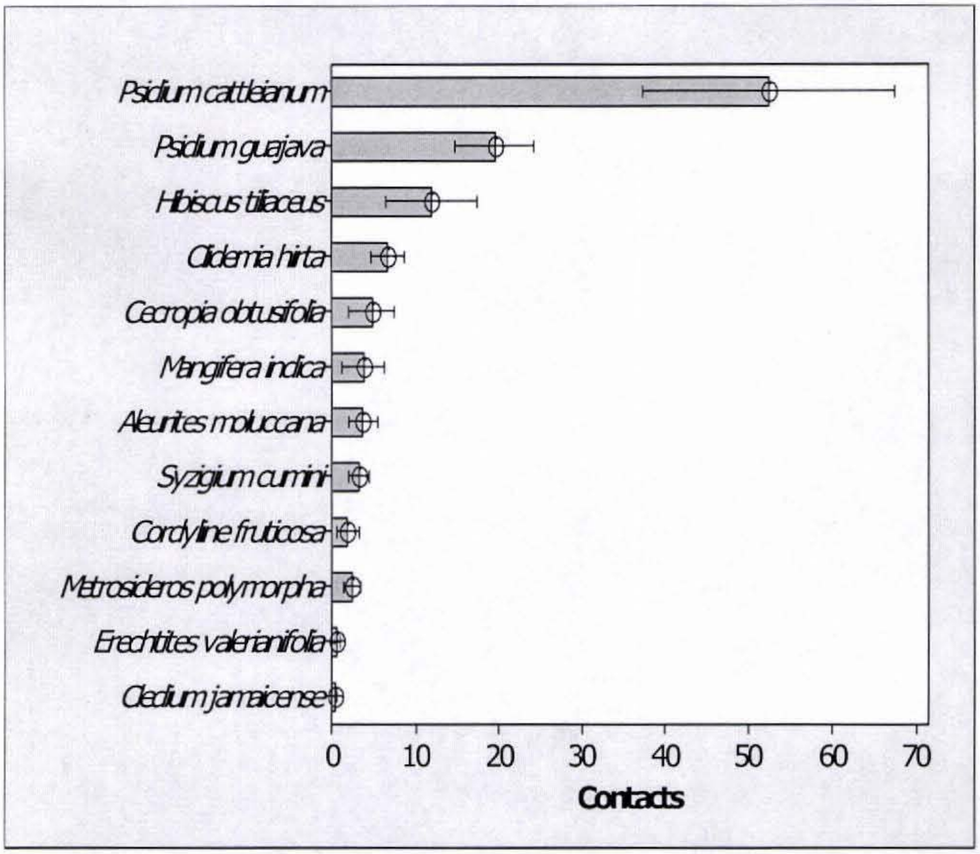


Figure 3.16: Average canopy cover contacts per plot with SEI bars

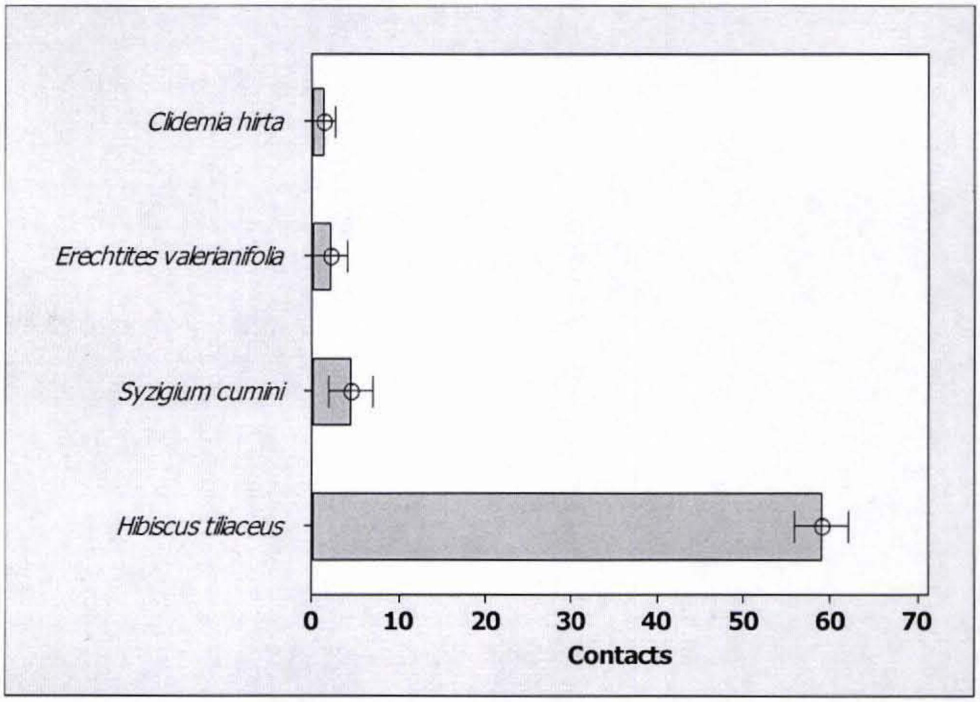


Figure 3.17: Average canopy cover contacts per plot in section H with SEI bars

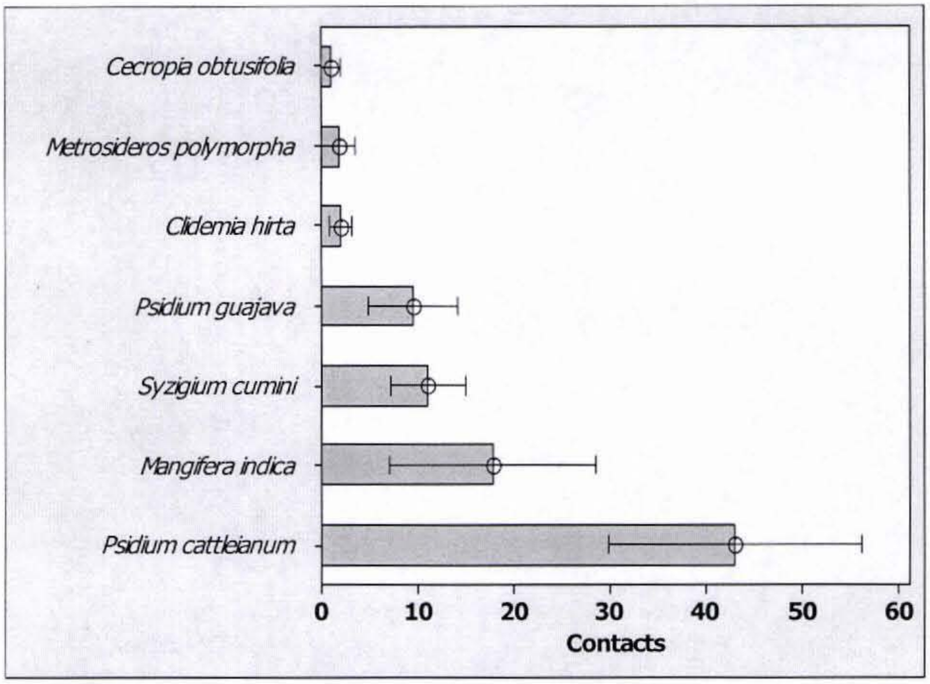


Figure 3.18: Average canopy cover contacts per plot in section MJ with SEI bars

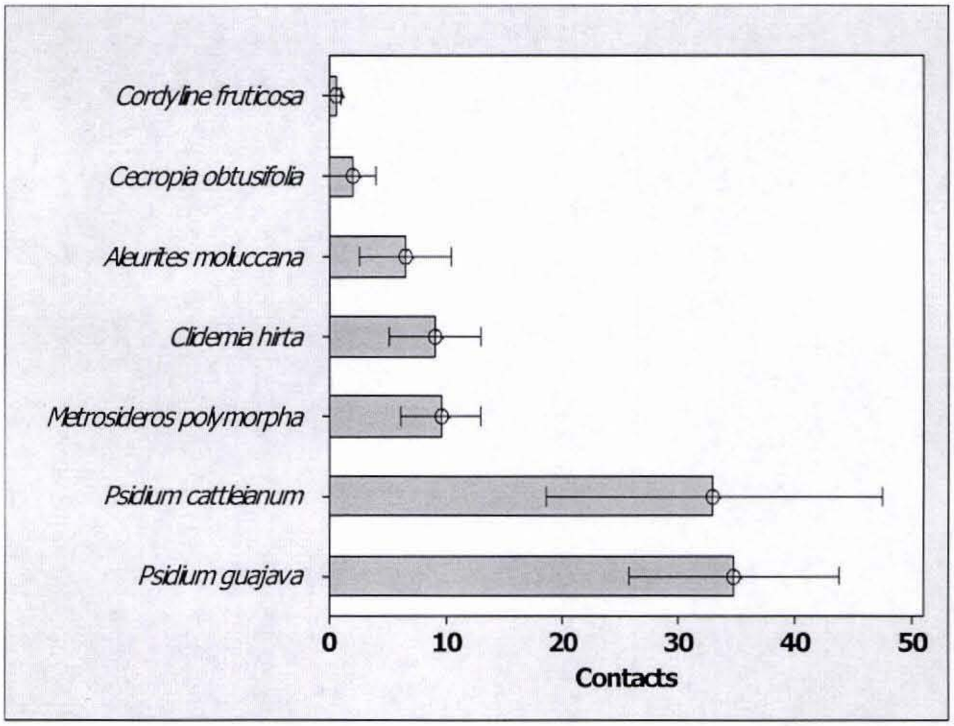


Figure 3.19: Average canopy cover contacts per plot in section GO with SEI bars

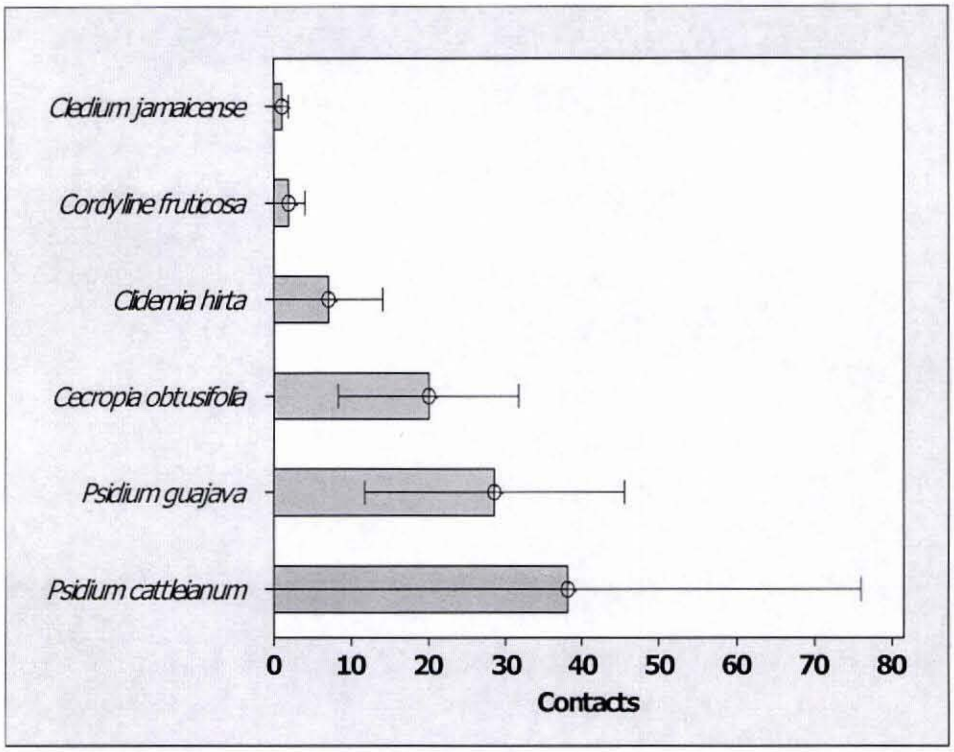


Figure 3.20: Average canopy cover contacts per plot in Kapalikea tributary with SEI bars

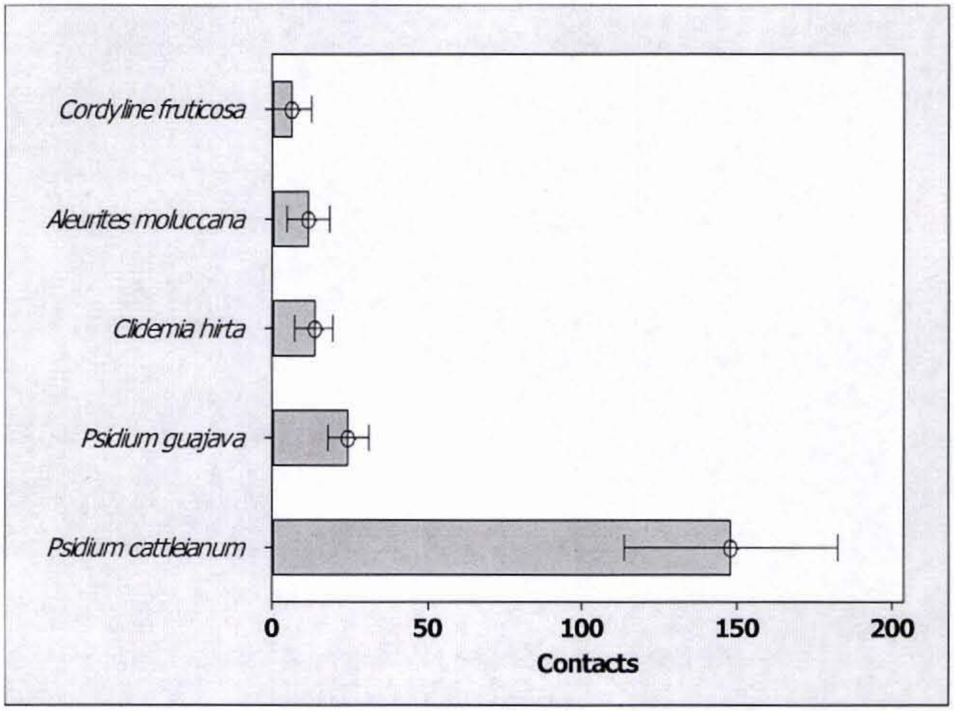


Figure 3.21: Average canopy cover contacts per plot for Kolopua tributary with SEI bars

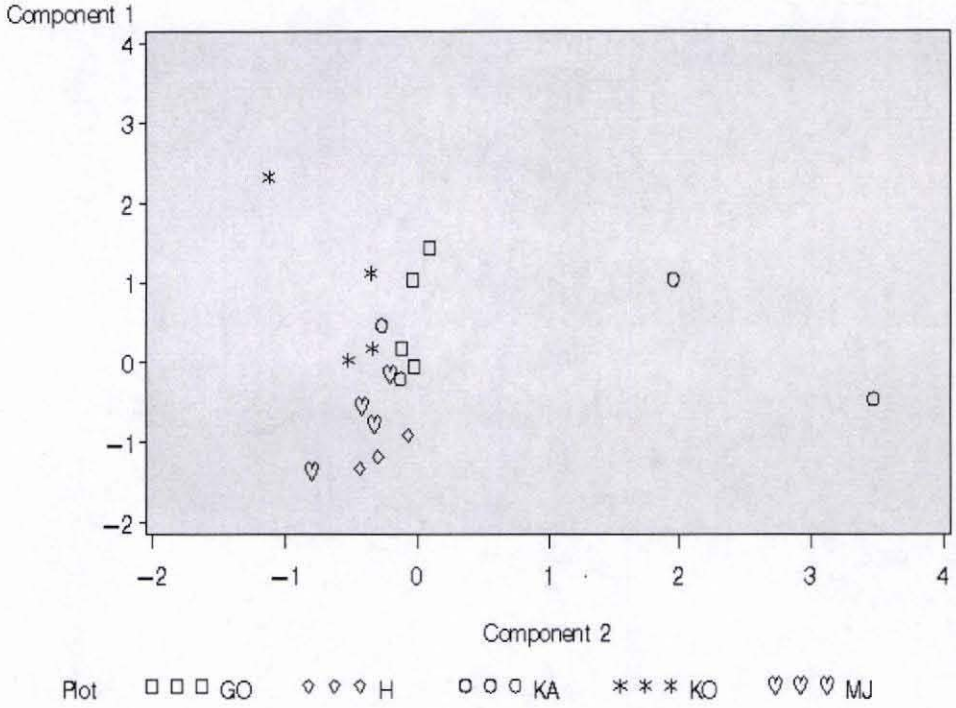


Figure 3.22: Scatterplot of PC1 vs. PC2 for canopy cover of Waipā stream and tributaries

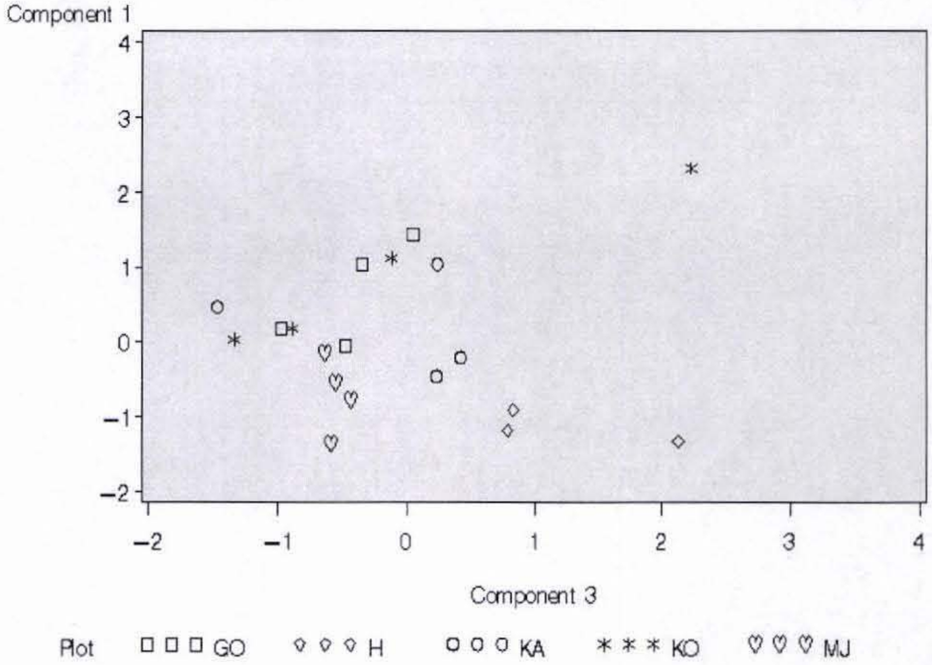


Figure 3.23: Scatterplot of PC1 vs. PC3 for canopy cover of Waipā stream and tributaries

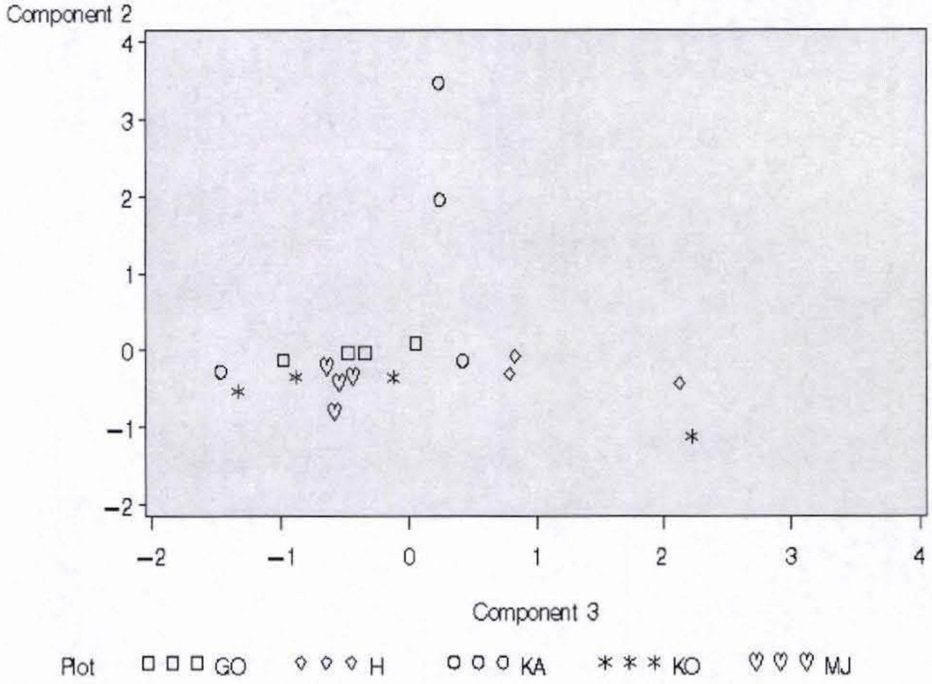


Figure 3.24: Scatterplot of PC2 vs. PC3 for canopy cover of Waipā stream and tributaries

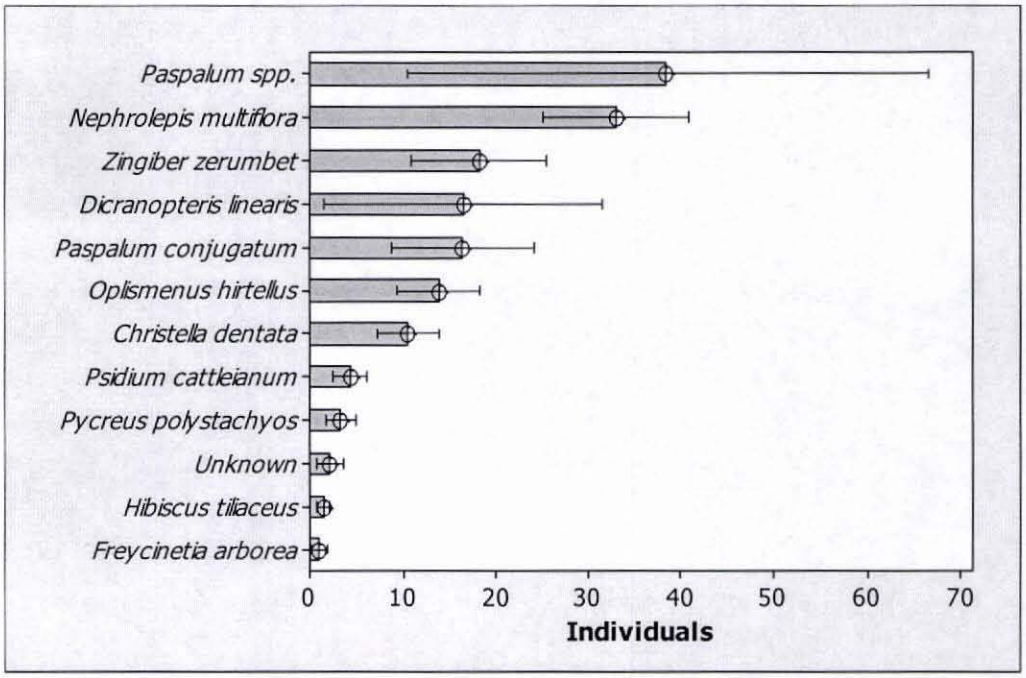


Figure 3.25: Average ground cover per plot (summer 2004) with SEI bars

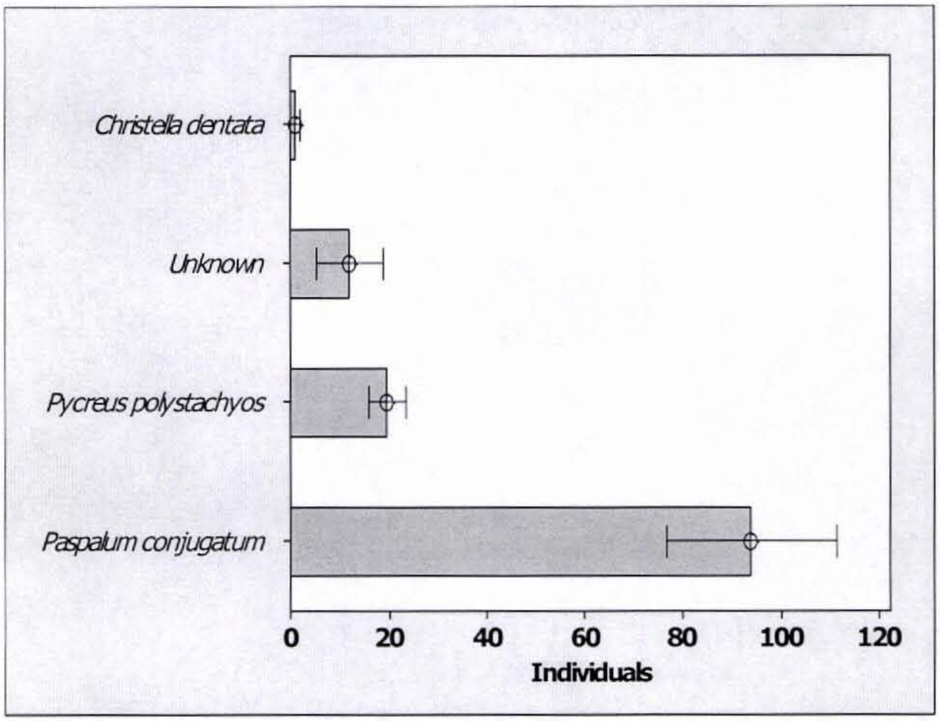


Figure 3.26: Average ground cover per plot in section C (summer 2004) with SEI bars

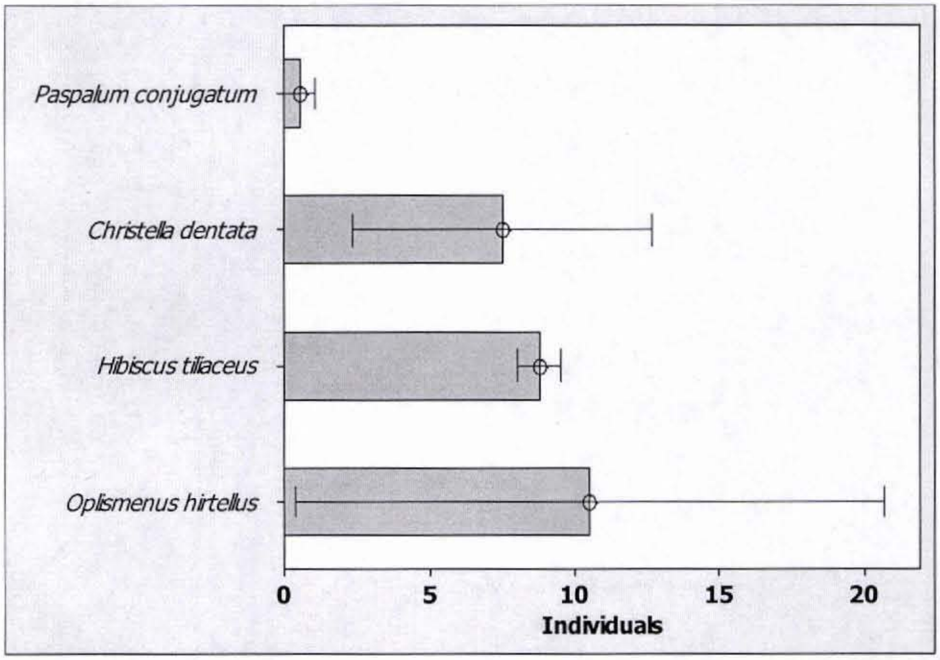


Figure 3.27: Average ground cover per plot in section H (summer 2004) with SEI bars

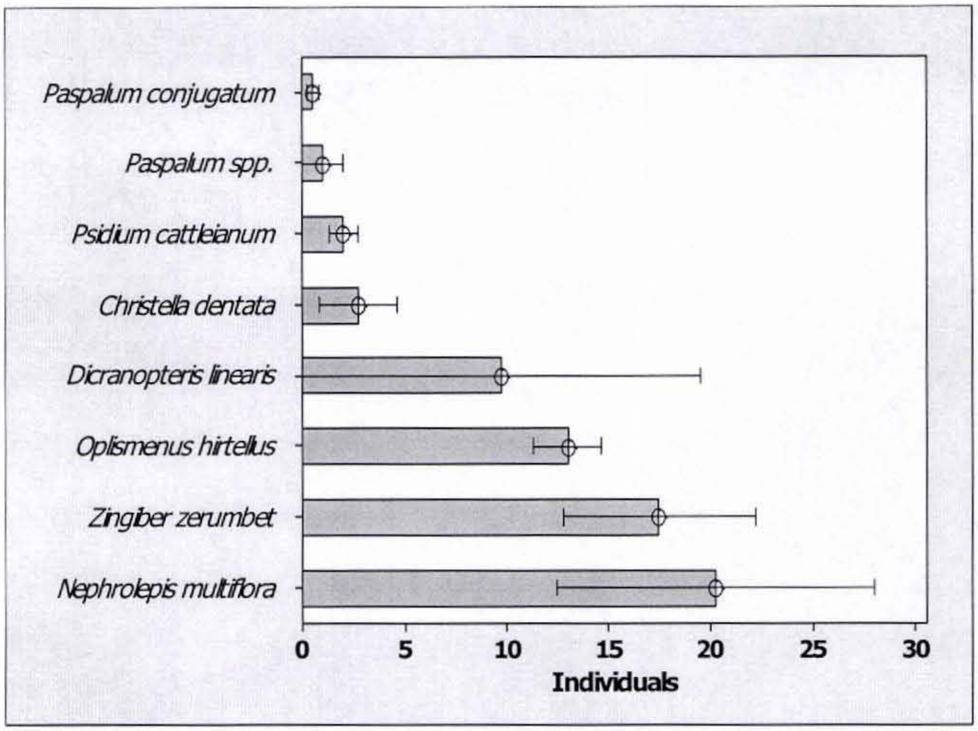


Figure 3.28: Average ground cover per plot in section MJ (summer 2004) with SEI bars

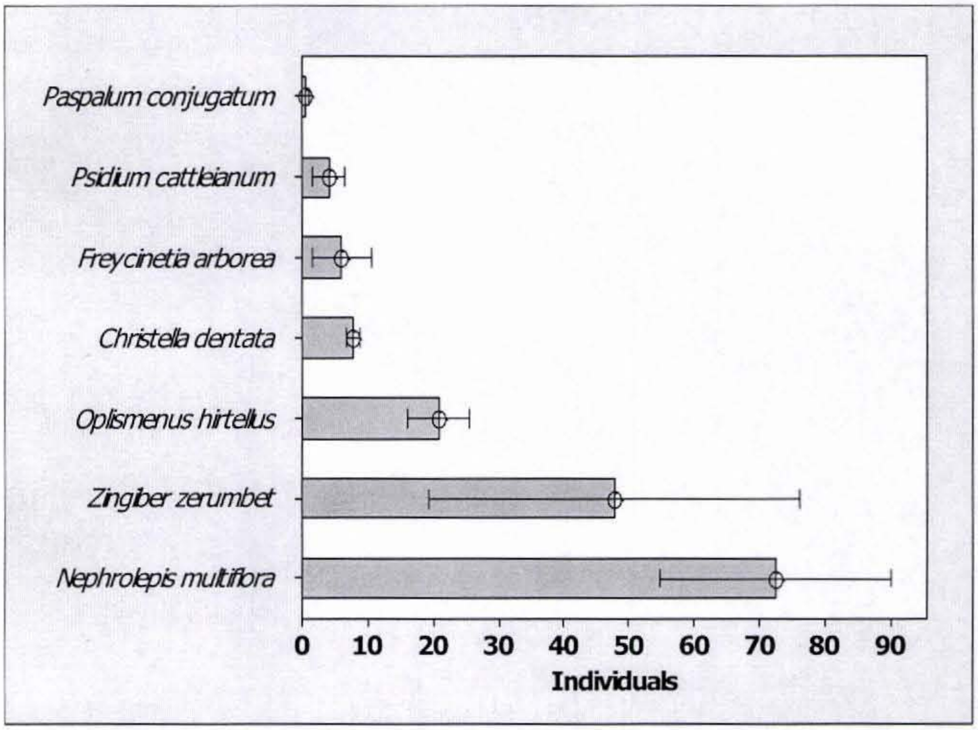


Figure 3.29: Average ground cover per plot in section GO (summer 2004) with SEI bars

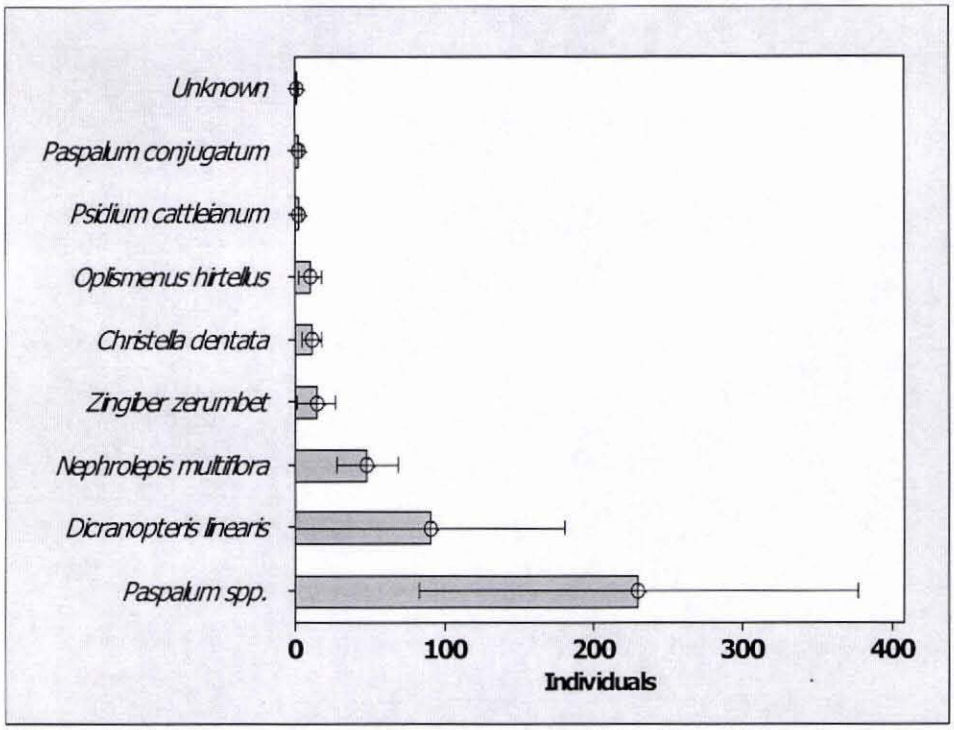


Figure 3.30: Average ground cover per plot for Kapalikea tributary (summer 2004) with SEI bars

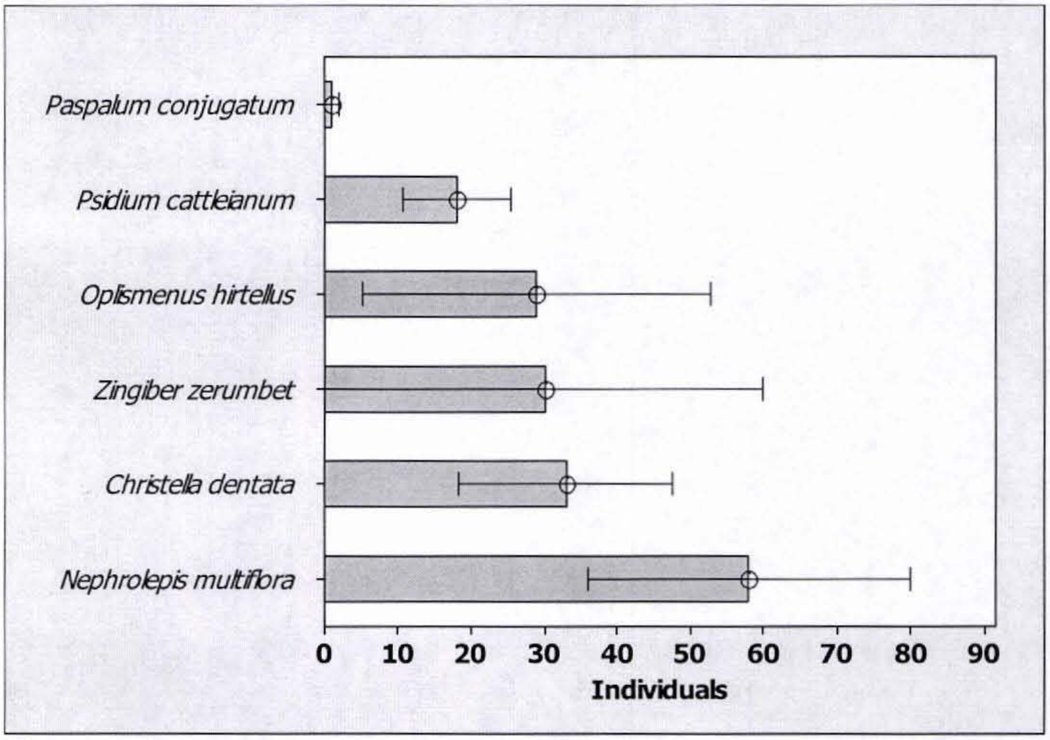


Figure 3.31: Average ground cover per plot in Kolopua tributary (summer 2004) with SEI bars

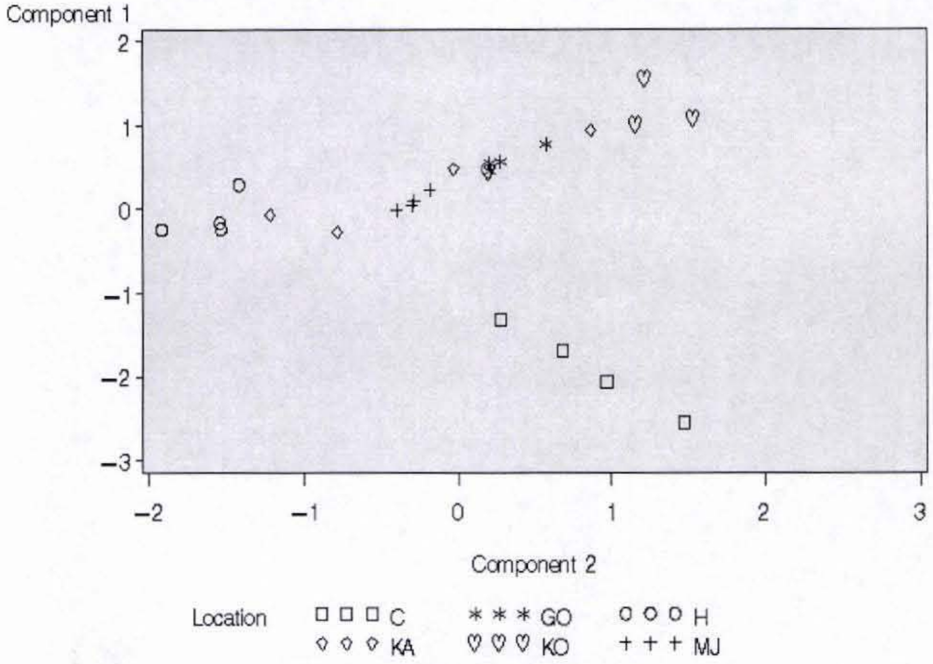


Figure 3.32: Scatterplot of PC1 vs. PC2 for vegetated ground cover (summer 2004)

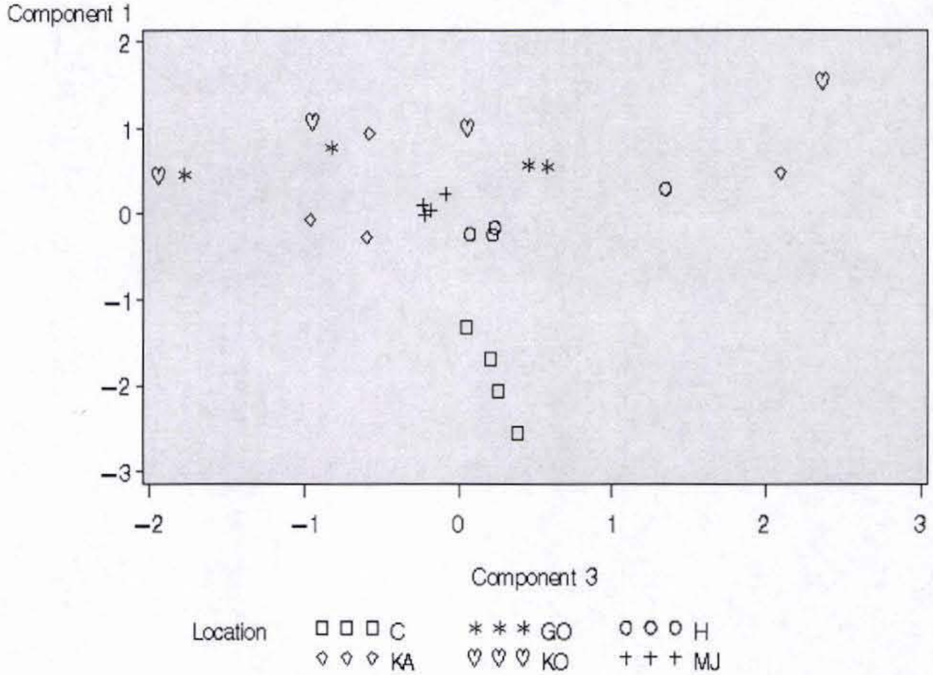


Figure 3.33: Scatterplot of PC1 vs. PC3 for vegetated ground cover (summer 2004)

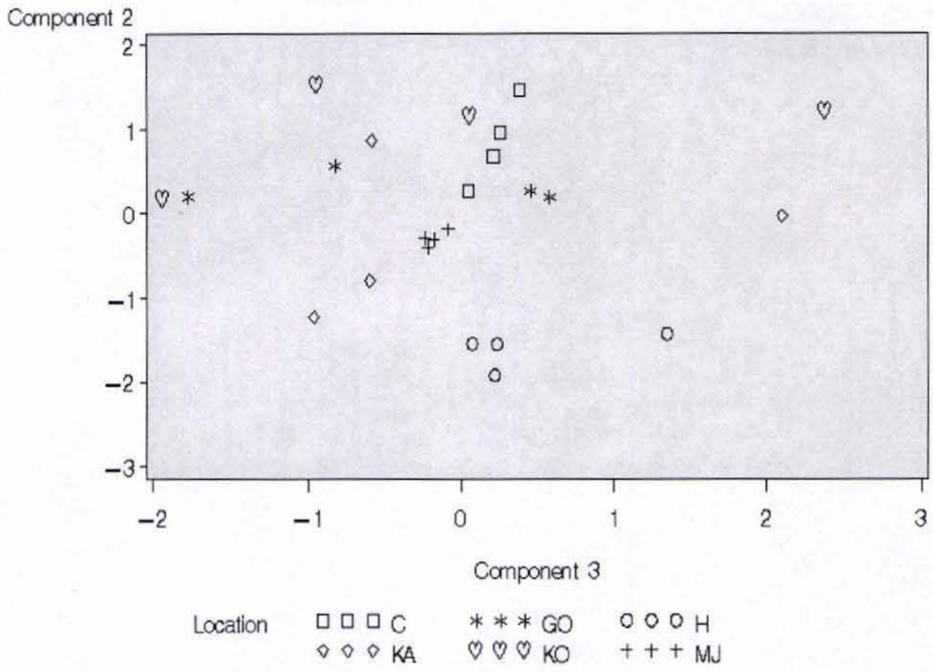


Figure 3.34: Scatterplot of PC2 vs. PC3 for vegetated ground cover (summer 2004)

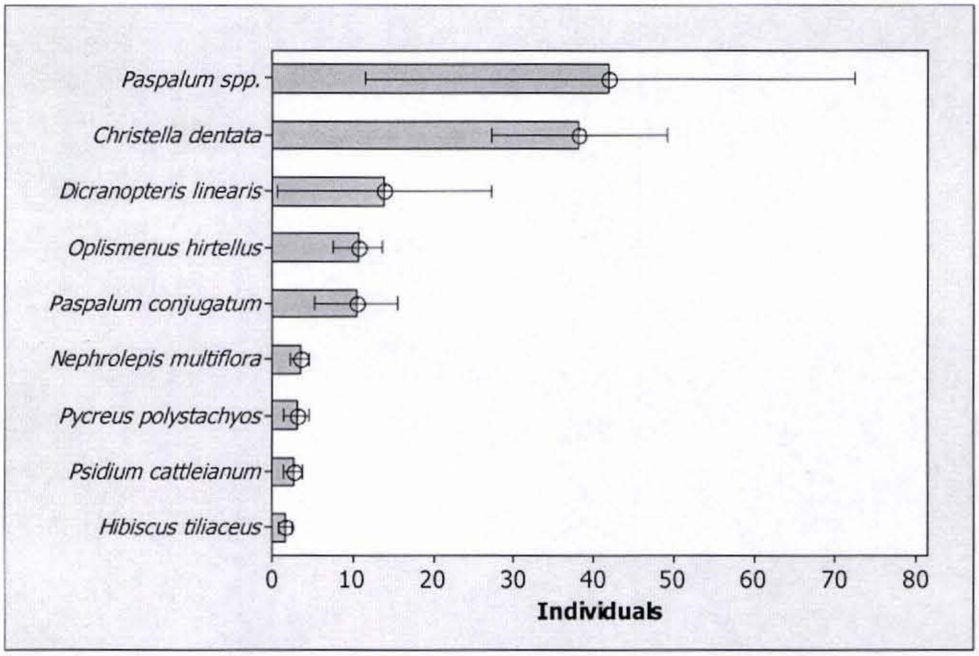


Figure 3.35: Average ground cover per plot (winter 2005) with SEI bars

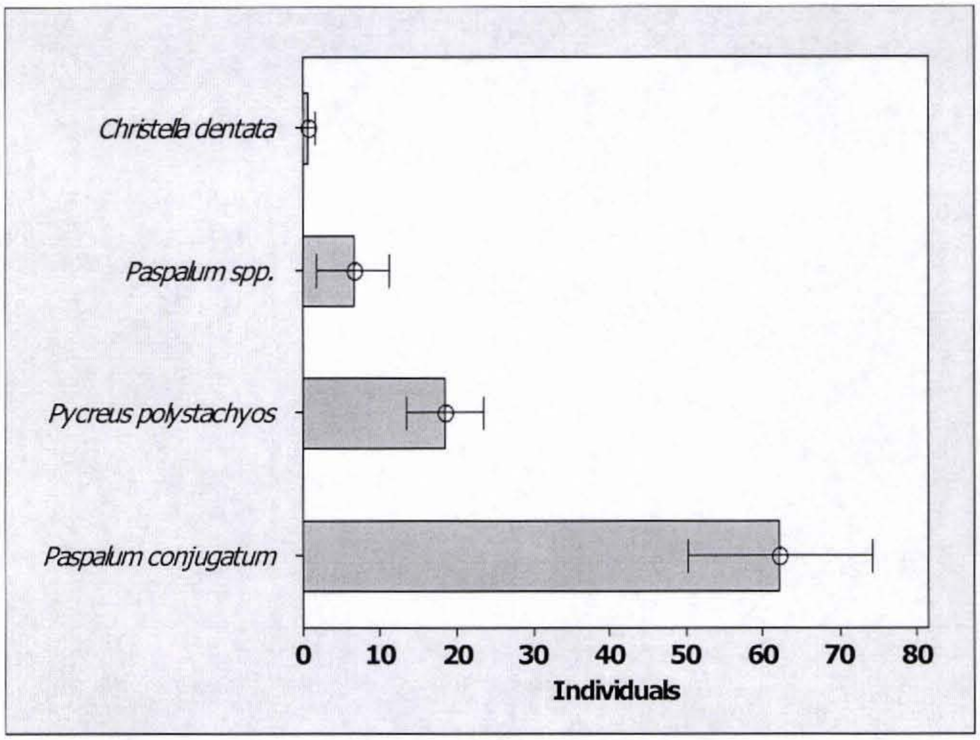


Figure 3.36: Average ground cover per plot in section C (winter 2005) with SEI bars

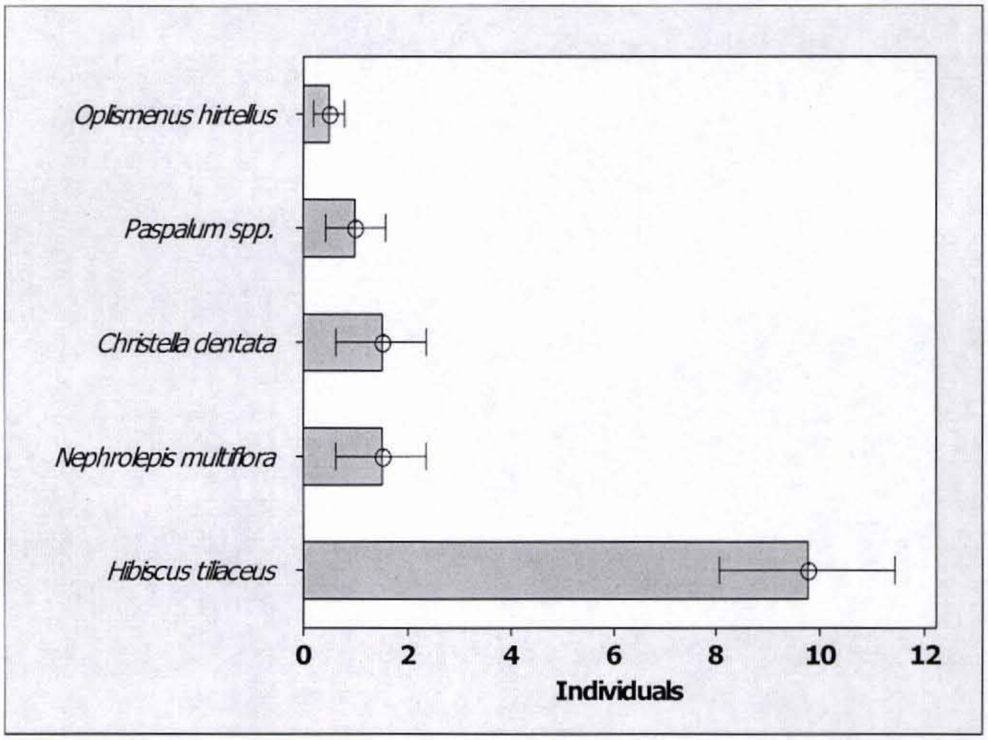


Figure 3.37: Average ground cover per plot for section H (winter 2005) with SEI bars

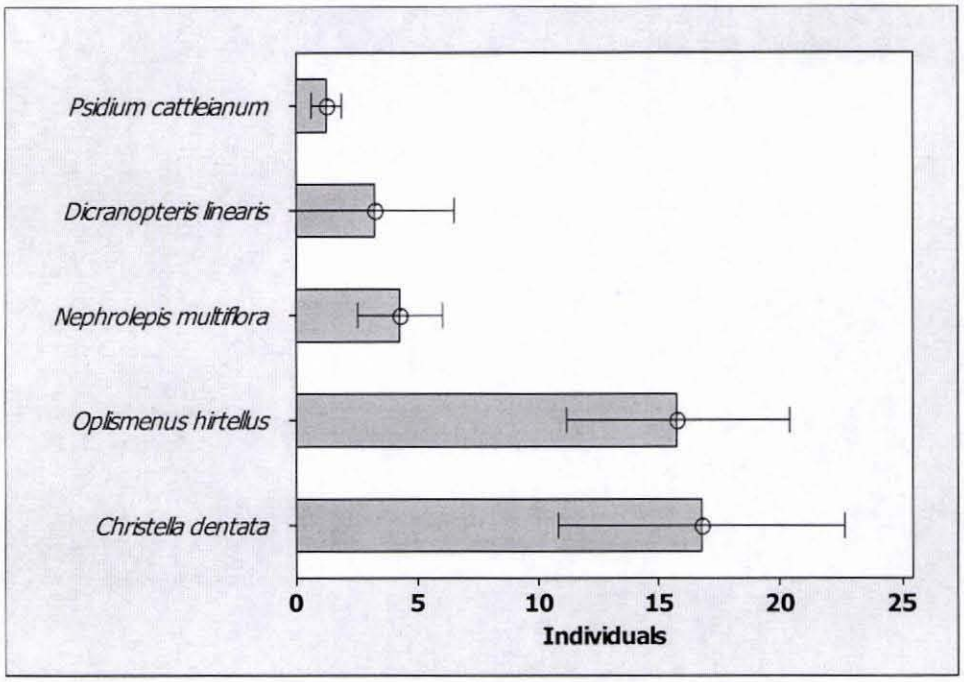


Figure 3.38: Average ground cover per plot for section MJ (winter 2005) with SEI bars

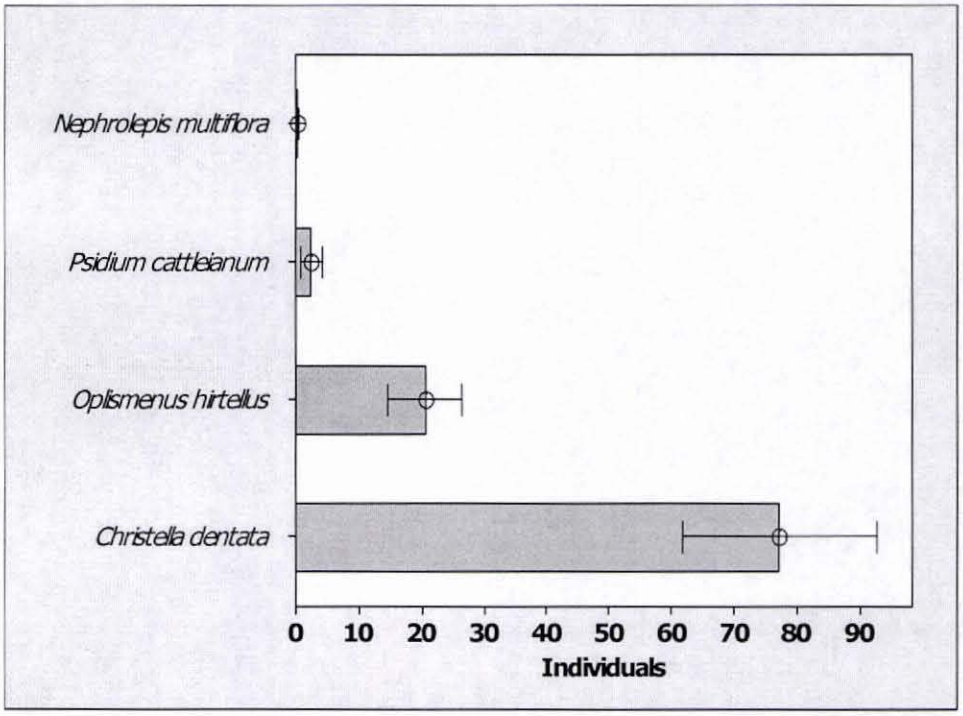


Figure 3.39: Average ground cover per plot for section GO (winter 2005) with SEI bars

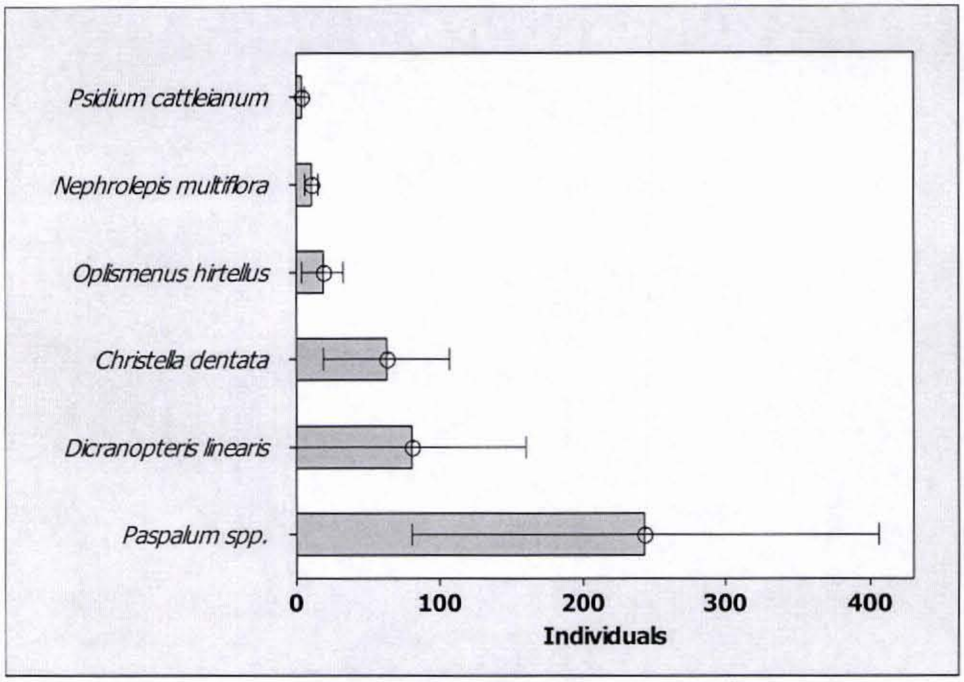


Figure 3.40: Average ground cover per plot for Kapalikea tributary (winter 2005) with SEI bars

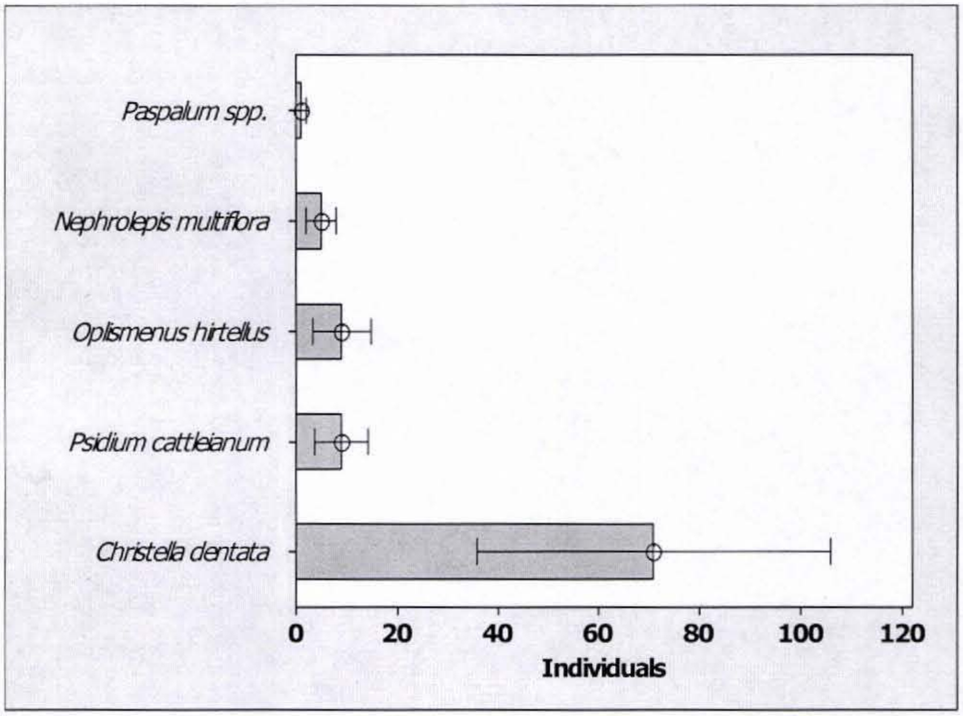


Figure 3.41: Average ground cover per plot for Kolopua tributary (winter 2005) with SEI bars

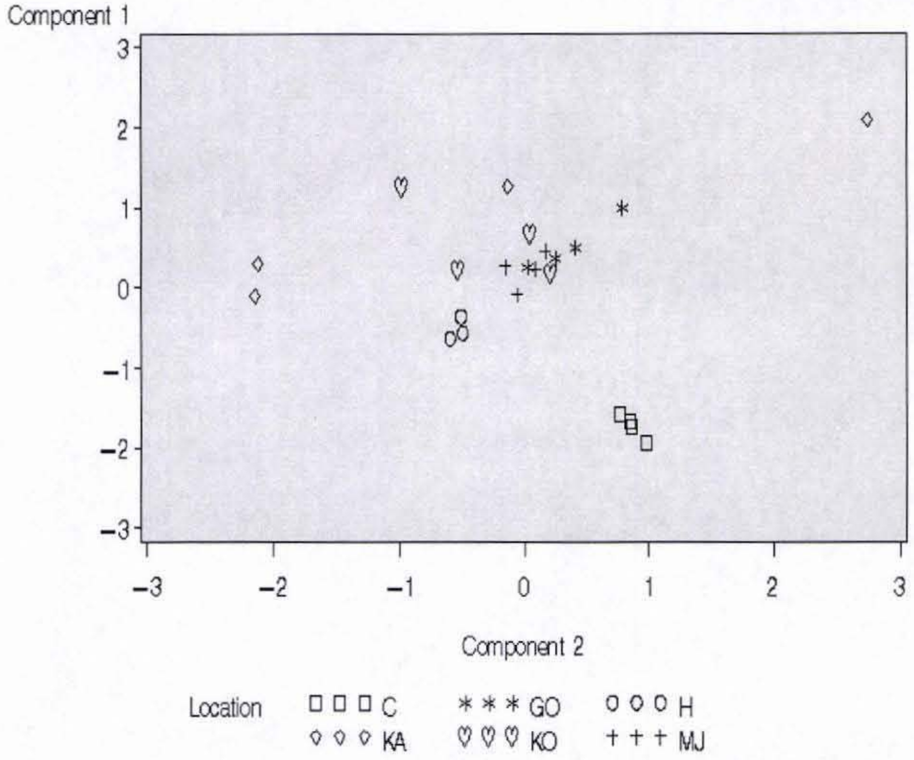


Figure 3.42: Scatterplot of PC1 vs. PC2 for vegetated ground cover (winter 2005)

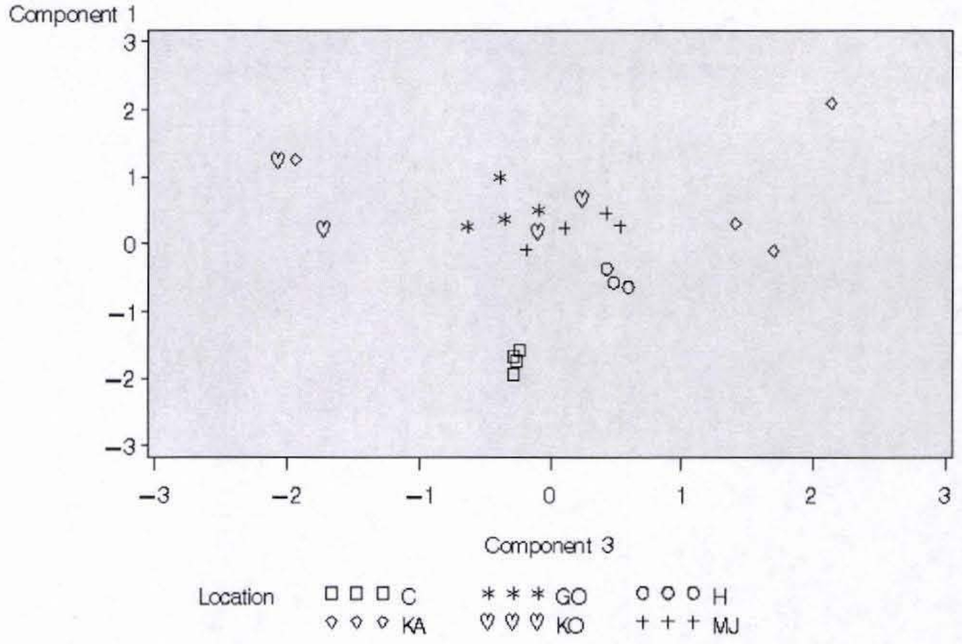


Figure 3.43: Scatterplot of PC1 vs. PC3 for vegetated ground cover (winter 2005)

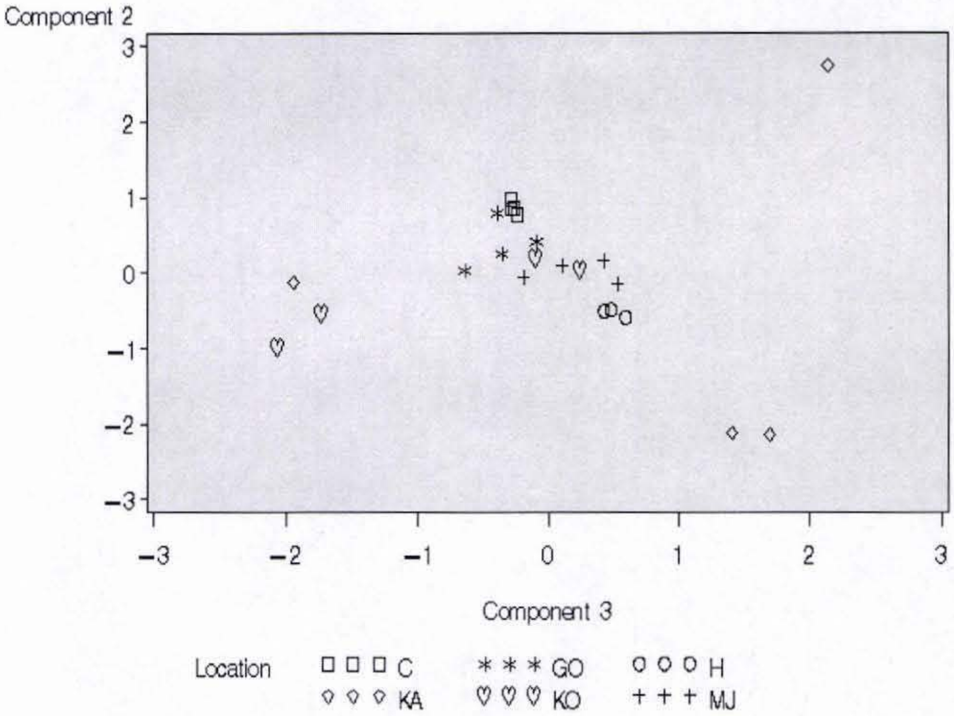


Figure 3.44: Scatterplot of PC2 vs. PC3 for vegetated ground cover (winter 2005)

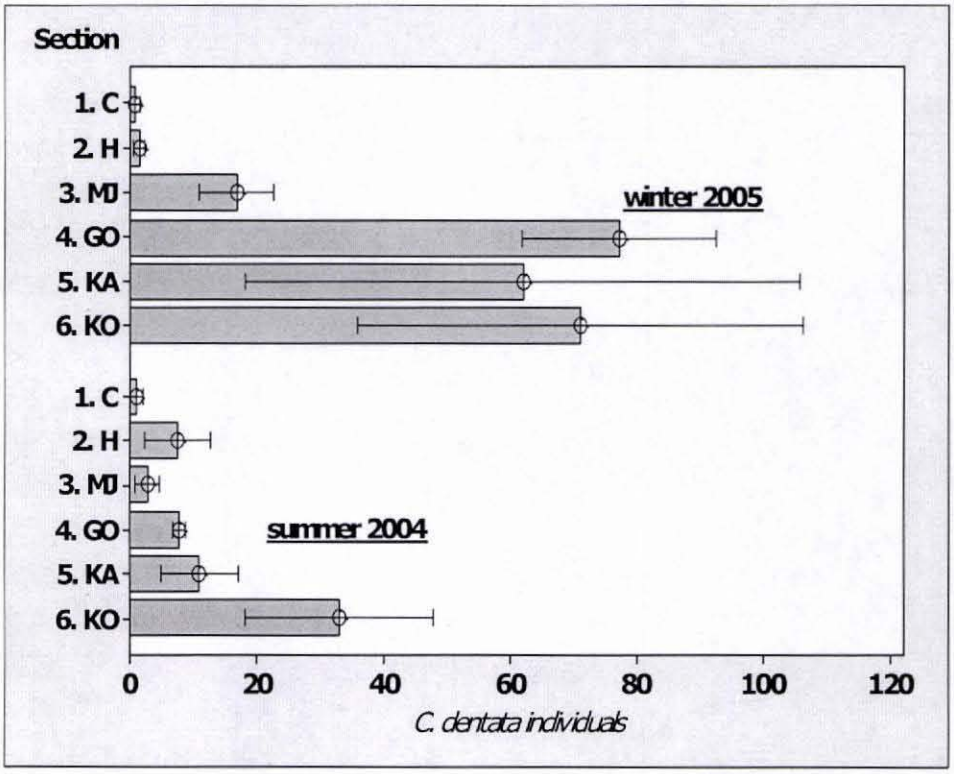


Figure 3.45: Average *C. dentata* individuals per plot between seasons

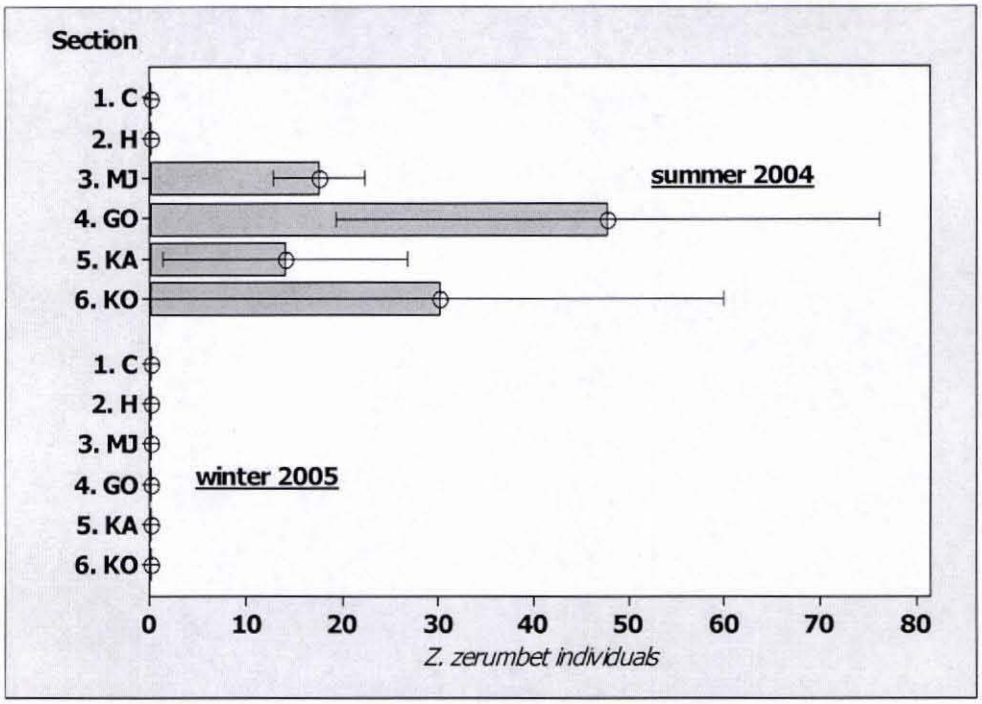


Figure 3.46: Average *Z. zerumbet* individuals per plot between seasons with SEI bars

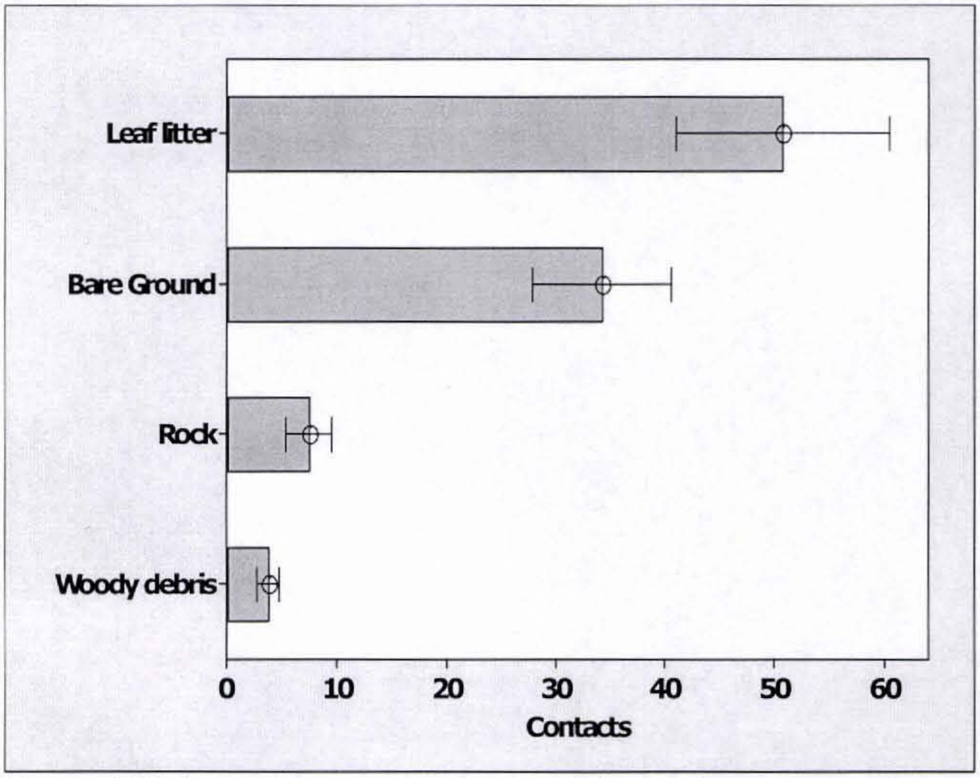


Figure 3.47: Average non-vegetative ground cover contacts per plot (summer 2004) with SEI bars

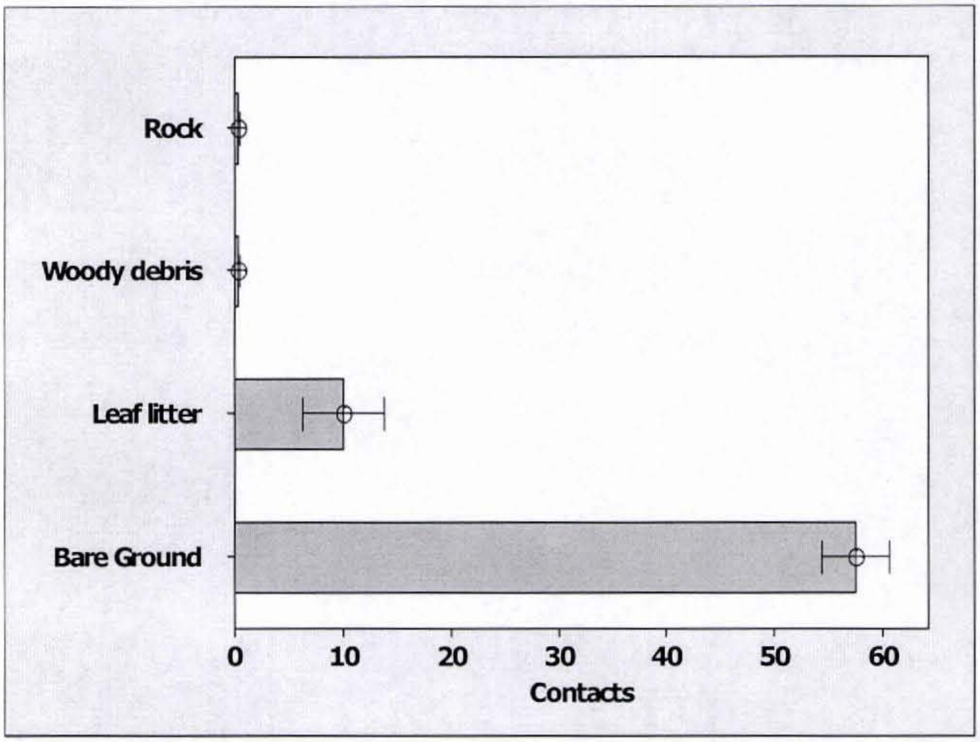


Figure 3.48: Average non-vegetative ground cover contacts per plot for section C (summer 2004) with SEI bars

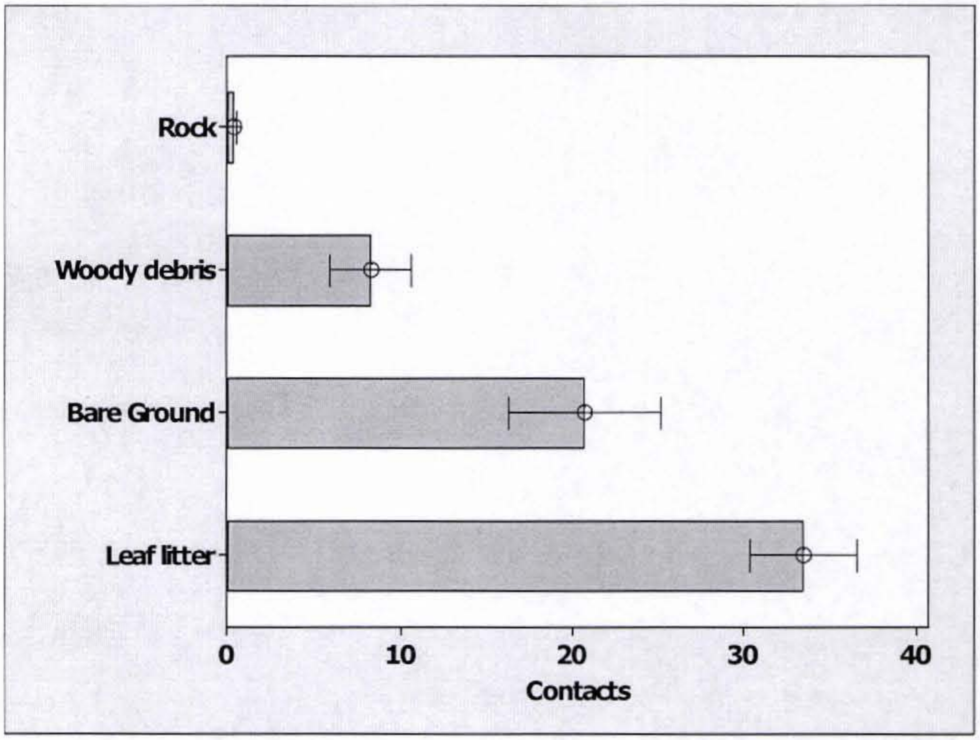


Figure 3.49: Average non-vegetative ground cover contacts per plot for section H (summer 2004) with SEI bars

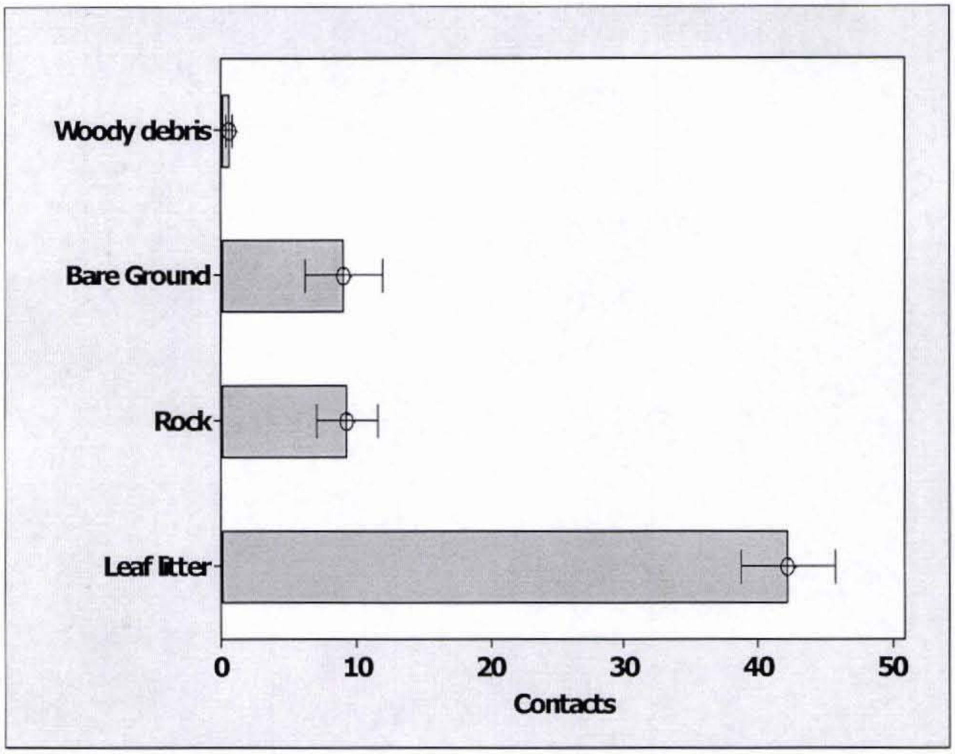


Figure 3.50: Average non-vegetative ground cover contacts per plot for section MJ (summer 2004) with SEI bars

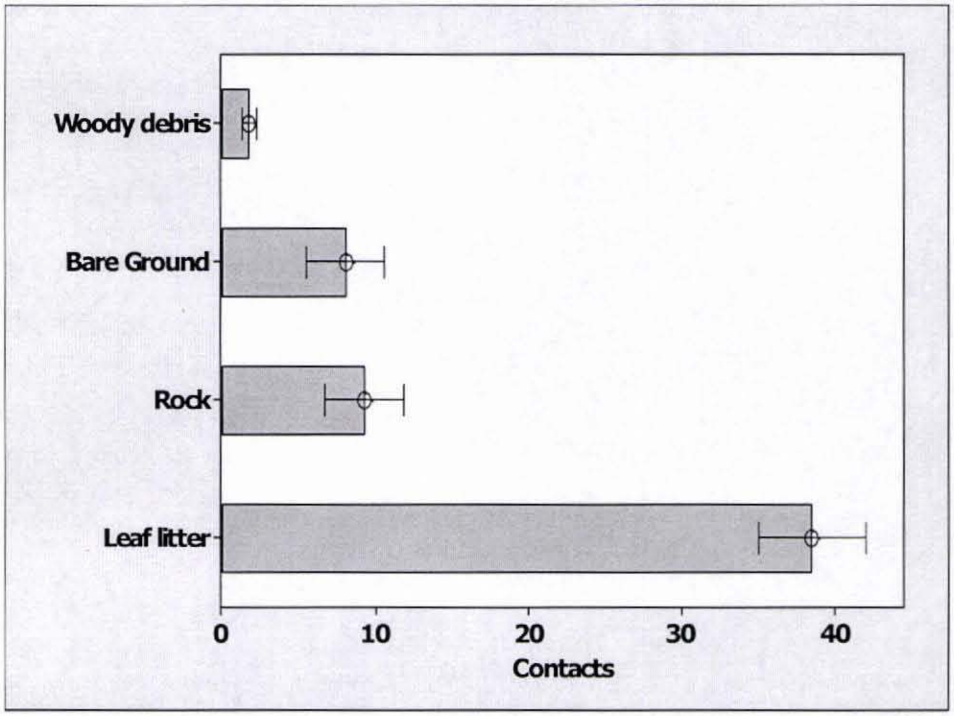
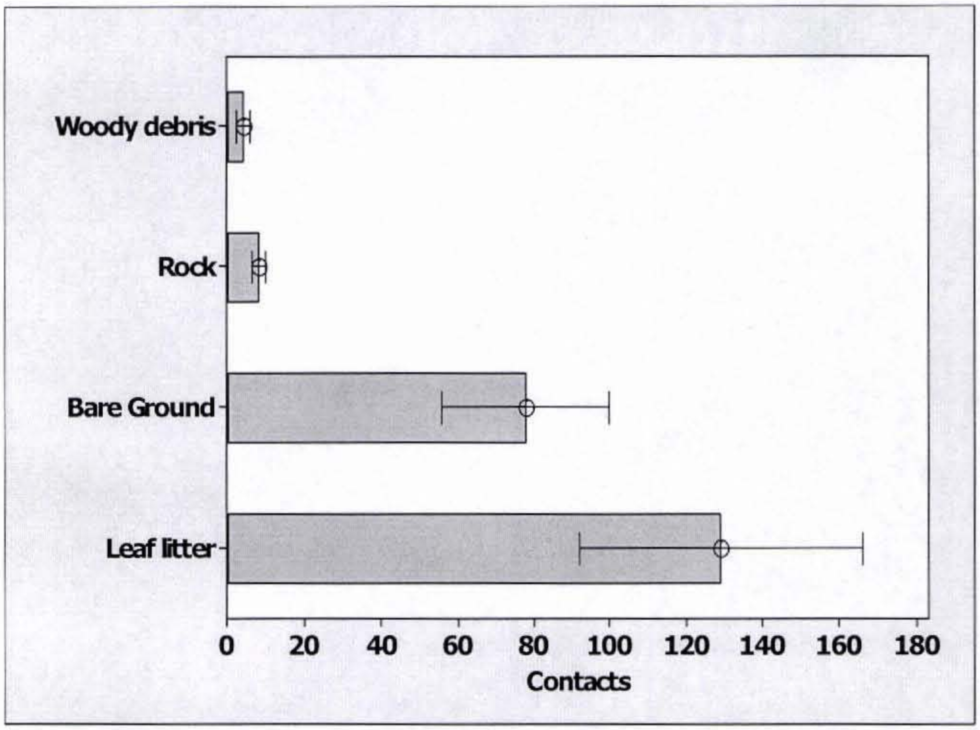
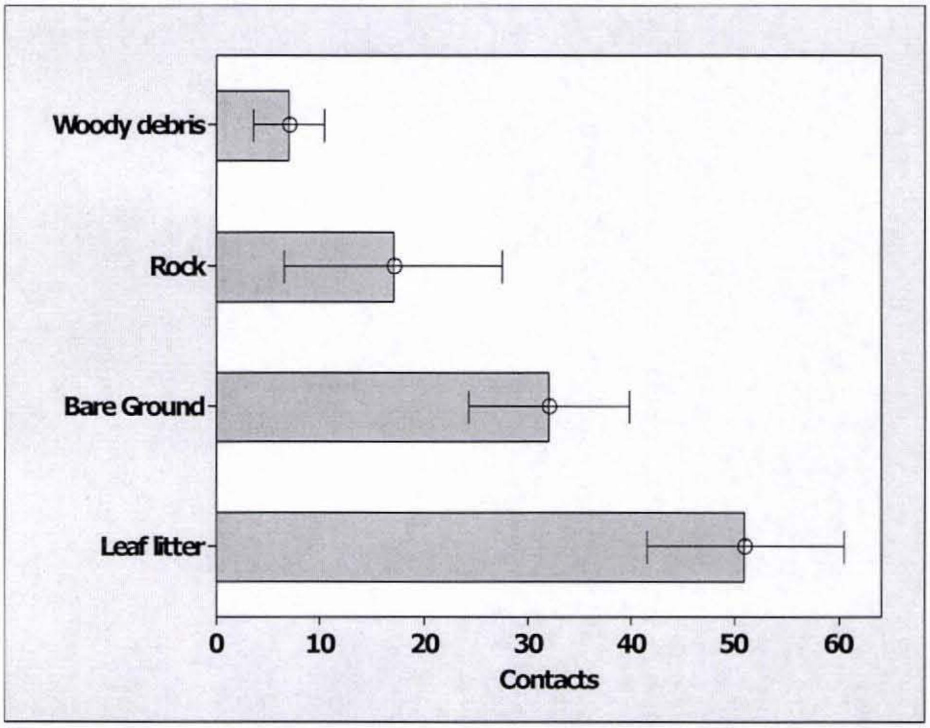


Figure 3.51: Average non-vegetative ground cover contacts per plot for section GO (summer 2004) with SEI bars



<u>**Figure 3.52: Average non-vegetative ground cover contacts per plot for Kapalikea tributary (summer 2004) with SEI bars**</u>



<u>**Figure 3.53: Average non-vegetative ground cover contacts per plot for Kolopua tributary (summer 2004) with SEI bars**</u>

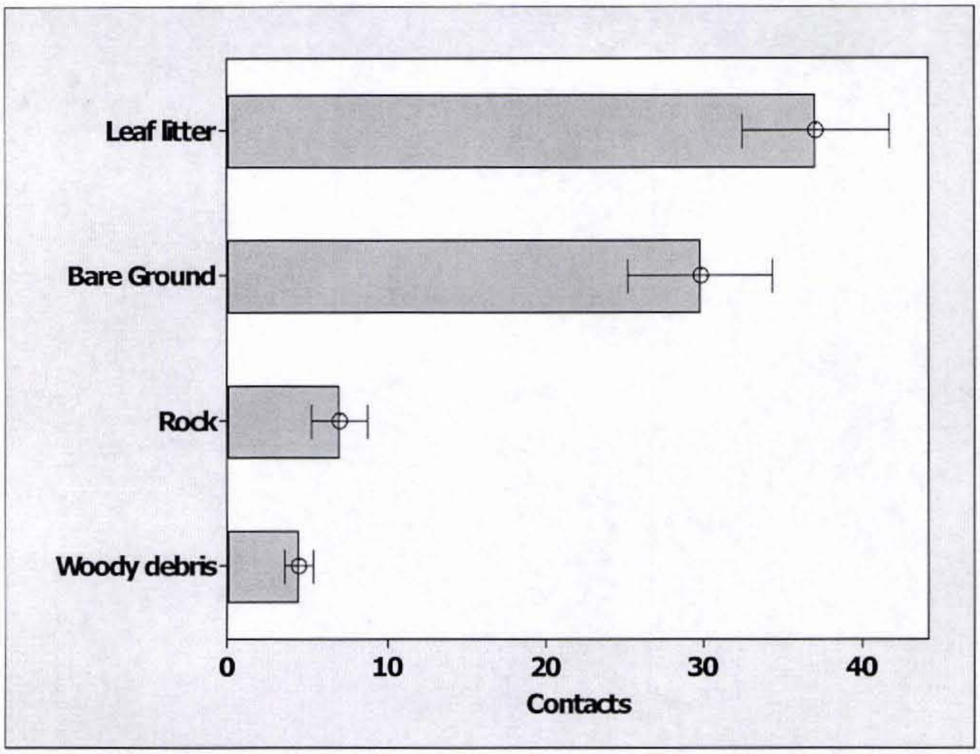


Figure 3.54: Average non-vegetative ground cover contacts per plot (winter 2005) with SEI bars

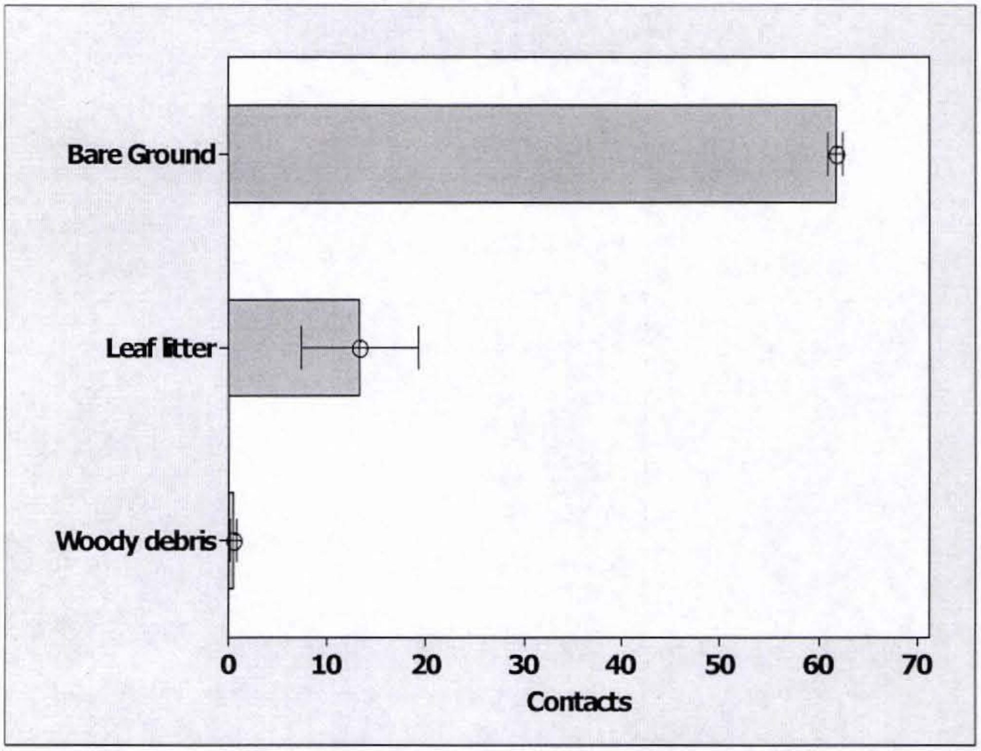


Figure 3.55: Average non-vegetative ground cover contacts per plot for section C (winter 2005) with SEI bars

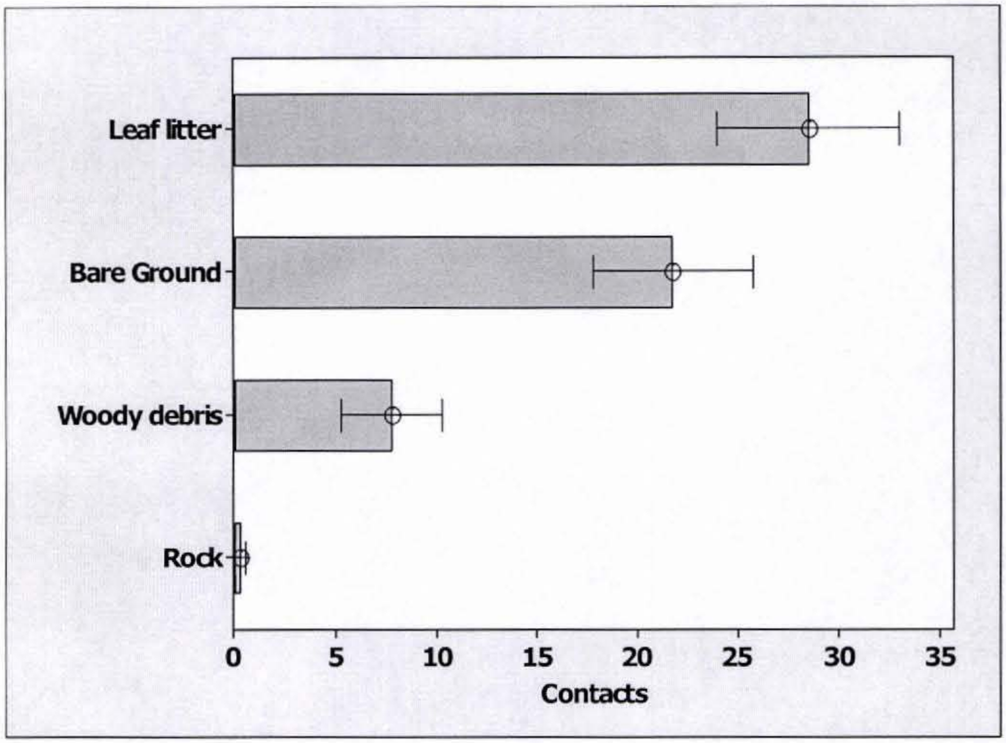


Figure 3.56: Average non-vegetative ground cover contacts per plot for section H (winter 2005) with SEI bars

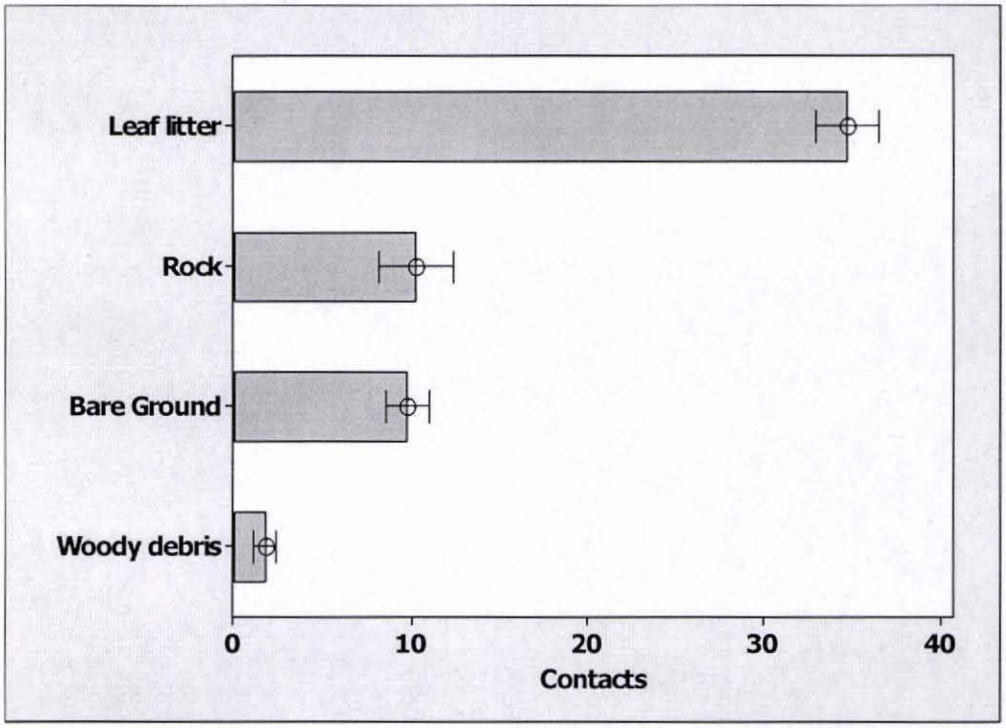


Figure 3.57: Average non-vegetative ground cover contacts per plot for section MJ (winter 2005) with SEI bars

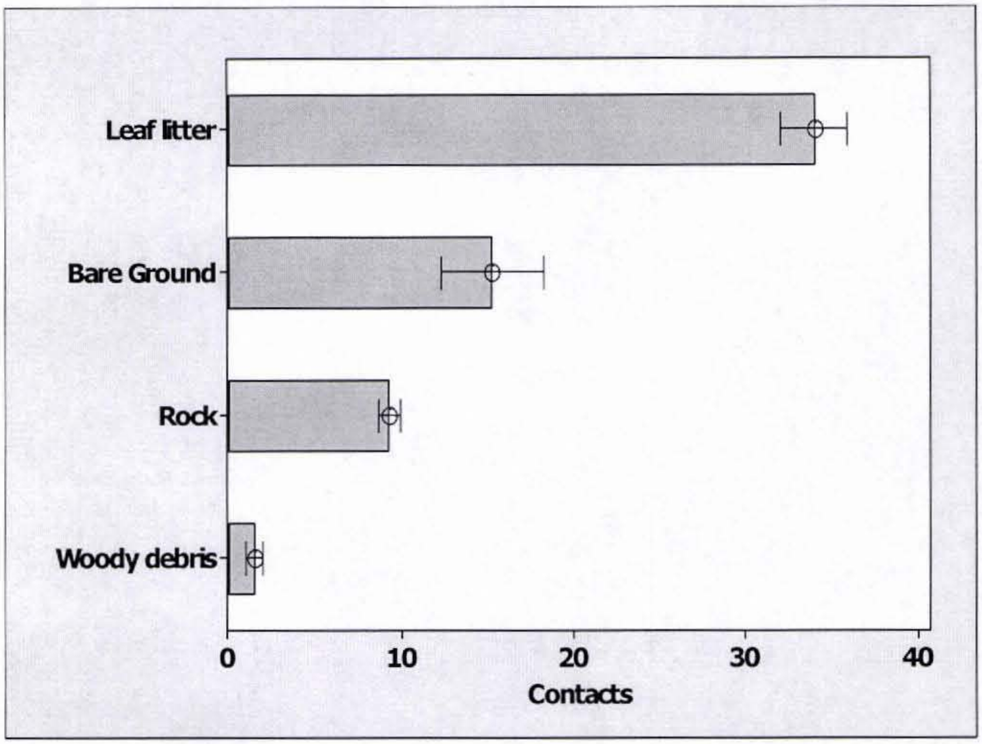


Figure 3.58: Average non-vegetative ground cover contacts per plot for section GO (winter 2005) with SEI bars

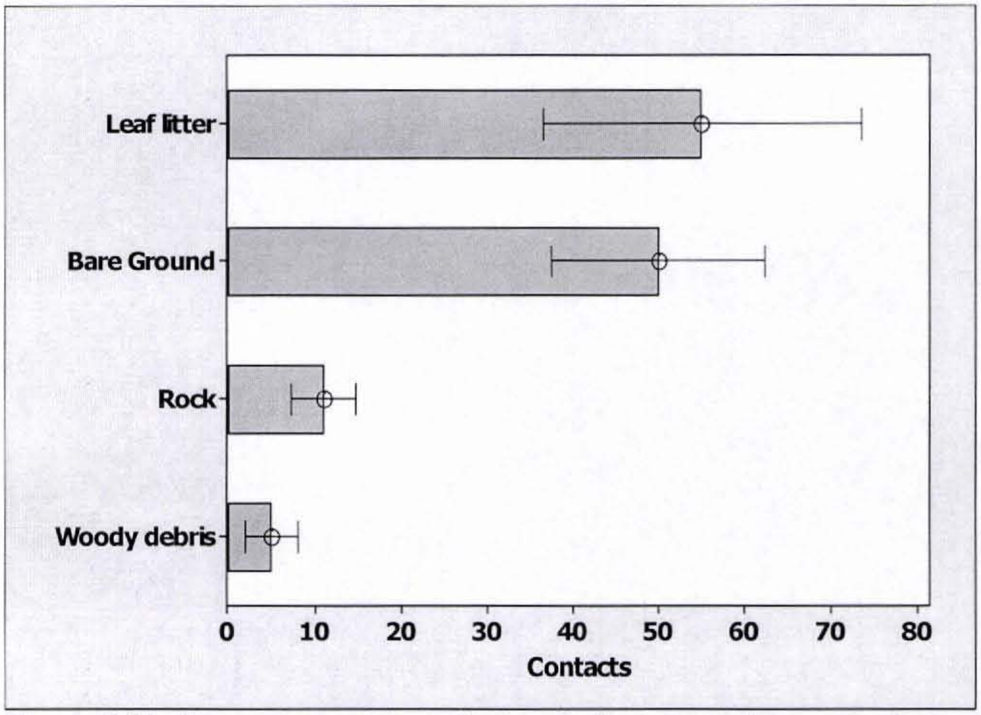
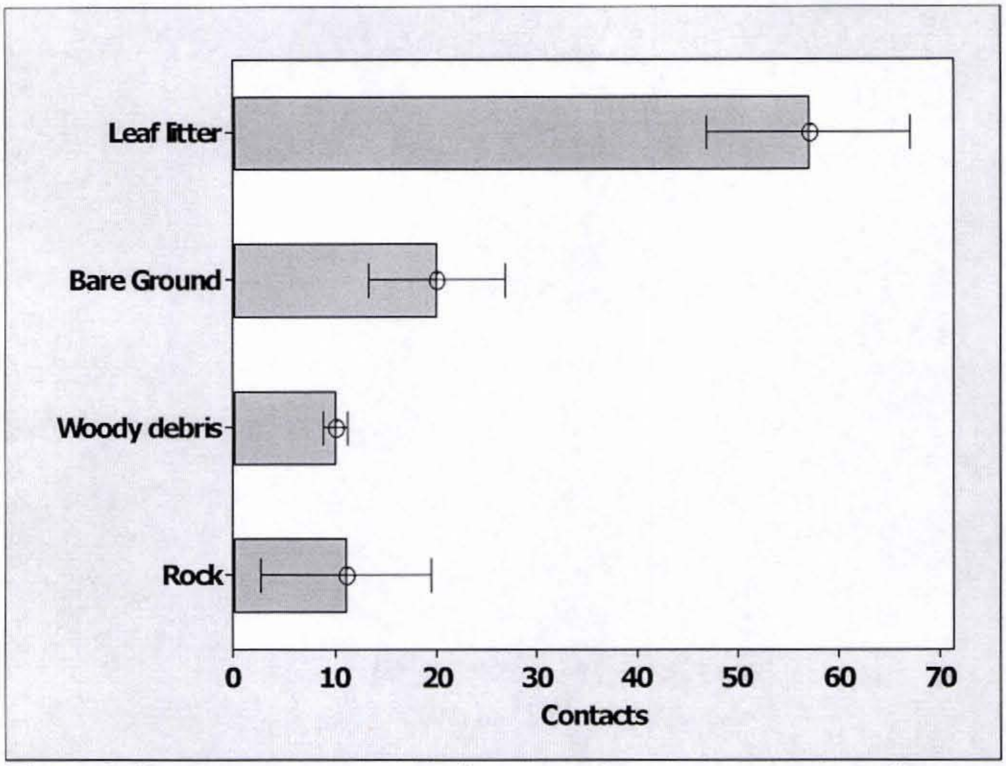


Figure 3.59: Average non-vegetative ground cover contacts per plot for Kapalikea tributary (winter 2005) with SEI bars



<u>**Figure 3.60: Average non-vegetative ground cover contacts per plot for Kolopua tributary (winter 2005) with SEI bars**</u>

Appendix 3.1: Stem-and-Leaf Display for basal area for all species along Waipā stream and tributaries:

```
Stem-and-leaf of Aleurites moluccana  N  = 16
Leaf Unit = 10


(14)  0  00000000000009
 2    1
 2    2
 2    3
 2    4  1
 1    5
 1    6
 1    7  0
```

```
Stem-and-leaf of Cordyline fruticosa  N  = 16
Leaf Unit = 10


(15)  0  000000000000002
 1    0
 1    1
 1    1
 1    2
 1    2
 1    3
 1    3
 1    4
 1    4
 1    5  4
```

```
Stem-and-leaf of Mangifera indica  N  = 16
Leaf Unit = 100


(14)  0  00000000000000
 2    1
 2    2
 2    3
 2    4
 2    5
 2    6  04
```

```
Stem-and-leaf of Melaleuca quinquenervia  N  = 16
Leaf Unit = 100


(15)  0  000000000000000
 1    0
 1    0
 1    0
 1    0
 1    1
 1    1
 1    1
 1    1  6
```

```
Stem-and-leaf of Metrosideros polymorpha  N  = 16
Leaf Unit = 100


(12)  0  000000000000
 4    0  2
 3    0
 3    0
 3    0
 3    1  0
 2    1  2
 1    1  4
```

```
Stem-and-leaf of Pandanus tectorius  N  = 16
Leaf Unit = 10


(14)  0  00000000000000
 2    0
 2    1
 2    1  9
 1    2
 1    2
 1    3
 1    3
 1    4
 1    4
 1    5  4
```

```
Stem-and-leaf of Psidium cattleianum  N  = 16
Leaf Unit = 100


 7   0  0000002
(2)  0  57
 7   1  012
 4   1  7
 3   2  2
 2   2  9
 1   3
 1   3
 1   4
 1   4
 1   5  1
```

```
Stem-and-leaf of Psidium guajava  N  = 16
Leaf Unit = 100


 7   0  0000000
(2)  0  23
 7   0  4
 6   0
 6   0
 6   1  0
 5   1  22
 3   1  5
 2   1  6
 1   1  8
```

```
Stem-and-leaf of Psychotria spp.  N  = 16
Leaf Unit = 100


(15)  0  000000000000000
 1    0
 1    1
 1    1
 1    2
 1    2
 1    3
 1    3
 1    4
 1    4  5
```

```
Stem-and-leaf of Syzigium cumini  N  = 16
Leaf Unit = 100


(14)  0  00000000000000
 2    0
 2    0
 2    0
 2    0
 2    1
 2    1  2
 1    1
 1    1
 1    1
 1    2
 1    2  2
```

```
Stem-and-leaf of Cecropia obtusifolia  N  = 16
Leaf Unit = 10


(15)  0  000000000000000
 1    0
 1    0
 1    0
 1    0
 1    1
 1    1  3
```

Appendix 3.2: Stem-and-Leaf Display for canopy cover individuals of tributaries and stream:

```
Stem-and-leaf of Hibiscus tiliaceus  N  = 20
Leaf Unit = 1.0


(16)  0  0000000000000000
 4    0
 4    1
 4    1
 4    2
 4    2
 4    3
 4    3
```

```
  4     4
  4     4
  4     5  0
  3     5
  3     6  033

Stem-and-leaf of Syzigium cumini   N  = 20
Leaf Unit = 1.0


 (14)   0  00000000000000
  6     0  2
  5     0
  5     0  77
  3     0
  3     1  0
  2     1
  2     1
  2     1  7
  1     1  8

Stem-and-leaf of Erechtites valerianifolia  N  = 20
Leaf Unit = 0.10


 (19)   0  0000000000000000000
  1     1
  1     2
  1     3
  1     4
  1     5
  1     6
  1     7
  1     8  0

Stem-and-leaf of Clidemia hirta  N  = 20
Leaf Unit = 1.0


 (12)   0  000000000233
  8     0  558
  5     1  3
  4     1  68
  2     2
  2     2  88

Stem-and-leaf of Mangifera indica  N  = 20
Leaf Unit = 1.0


 (18)   0  000000000000000000
  2     0
  2     1
  2     1
  2     2
  2     2  7
  1     3
  1     3
  1     4  4
```

```
Stem-and-leaf of Psidium cattleianum  N  = 20
Leaf Unit = 10


 10   0   0000000001
 10   0
 10   0   455
 7    0   66
 5    0   89
 3    1
 3    1
 3    1   5
 2    1   7
 1    1
 1    2
 1    2   3
```

```
Stem-and-leaf of Psidium guajava  N  = 20
Leaf Unit = 1.0


 8    0   00000004
(4)   1   3566
 8    2   014
 5    3
 5    4   488
 2    5   2
 1    6   6
```

```
Stem-and-leaf of Cecropia obtusifolia  N  = 20
Leaf Unit = 1.0


(17)   0   00000000000000004
 3     0   8
 2     1
 2     1
 2     2
 2     2
 2     3
 2     3   6
 1     4   4
```

```
Stem-and-leaf of Metrosideros polymorpha  N  = 20
Leaf Unit = 1.0


(16)   0   0000000000000000
 4     0
 4     0
 4     0   7
 3     0
 3     1   11
 1     1
 1     1
 1     1   6
```

```
Stem-and-leaf of Aleurites moluccana  N  = 20
Leaf Unit = 1.0


(16)  0  0000000000000000
 4    0
 4    1  0
 3    1  66
 1    2
 1    2  8
```

```
Stem-and-leaf of Cordyline fruticosa  N  = 20
Leaf Unit = 1.0


(17)  0  00000000000000000
 3    0  2
 2    0
 2    0
 2    0  8
 1    1
 1    1
 1    1
 1    1
 1    1
 1    2
 1    2
 1    2  4
```

```
Stem-and-leaf of Cledium jamaicense  N  = 20
Leaf Unit = 0.10


(19)  0  0000000000000000000
 1    1
 1    2
 1    3
 1    4  0
```

Appendix 3.3: Stem-and-Leaf Display for ground cover of all plots winter 2005:

```
Stem-and-leaf of Christella dentata  N  = 24
Leaf Unit = 10


(14)  0  00000000000001
 10   0  33
 8    0  55
 6    0  67
 4    0  9
 3    1  0
 2    1
 2    1
 2    1  6
 1    1  8
```

```
Stem-and-leaf of Dicranopteris linearis  N  = 24
Leaf Unit = 10
```

```
(23)  0  00000000000000000000001
 1    0
 1    1
 1    1
 1    2
 1    2
 1    3  2
```

Stem-and-leaf of *Hibiscus tiliaceus* N = 24
Leaf Unit = 1.0

```
(20)  0  00000000000000000000
 4    0
 4    0
 4    0  77
 2    0
 2    1  1
 1    1
 1    1  4
```

Stem-and-leaf of *Nephrolepis multiflora* N = 24
Leaf Unit = 1.0

```
(13)  0  0000000000001
 11   0  333
 8    0  44
 6    0  6
 5    0  888
 2    1
 2    1  2
 1    1
 1    1
 1    1
 1    2
 1    2
 1    2  4
```

Stem-and-leaf of *Oplismenus hirtellus* N = 24
Leaf Unit = 1.0

```
 12  0  000000000011
 12  0  5
 11  1  12223
 6   1  8
 5   2  24
 3   2  7
 2   3
 2   3  7
 1   4
 1   4
 1   5
 1   5
 1   6  0
```

```
Stem-and-leaf of Paspalum conjugatum  N  = 24
Leaf Unit = 1.0


(20)  0  00000000000000000000
 4    1
 4    2
 4    3  9
 3    4
 3    5  0
 2    6  6
 1    7
 1    8
 1    9  4
```

```
Stem-and-leaf of Paspalum spp.  N  = 24
Leaf Unit = 10


(22)  0  0000000000000000000002
 2    0
 2    1
 2    1
 2    2
 2    2  7
 1    3
 1    3
 1    4
 1    4
 1    5
 1    5
 1    6
 1    6  9
```

```
Stem-and-leaf of Psidium cattleianum  N  = 24
Leaf Unit = 1.0


(18)  0  000000000000000011
 6    0  33
 4    0
 4    0  7
 3    0
 3    1
 3    1  2
 2    1
 2    1  6
 1    1
 1    2  0
```

```
Stem-and-leaf of Pycreus polystachyos  N  = 24
Leaf Unit = 1.0


(20)  0  00000000000000000000
 4    0  7
 3    1  3
 2    1
 2    2
 2    2  68
```

Appendix 3.4: Stem-and-Leaf Display for ground cover of all plots summer 2004:

```
Stem-and-leaf of Christella dentata  N  = 24
Leaf Unit = 1.0


 12  0  000000000344
 12  0  67788
 7   1  12
 5   1
 5   2  02
 3   2  8
 2   3
 2   3
 2   4  4
 1   4
 1   5
 1   5
 1   6
 1   6  8
```

```
Stem-and-leaf of Dicranopteris linearis  N  = 24
Leaf Unit = 10


(23)   0  00000000000000000000003
 1     0
 1     1
 1     1
 1     2
 1     2
 1     3
 1     3  6
```

```
Stem-and-leaf of Hibiscus tiliaceus  N  = 24
Leaf Unit = 0.10


(20)   0   00000000000000000000
 4     1
 4     2
 4     3
 4     4
 4     5
 4     6
 4     7   0
 3     8   0
 2     9
 2     10  00
```

```
Stem-and-leaf of Nephrolepis multiflora  N  = 24
Leaf Unit = 1.0


 11  0   00000000499
 12  1   2
 12  2   001
 9   3
```

```
 9    4    02
 7    5    6
 6    6
 6    7
 6    8    6
 5    9    0246
 1    10   2
```

```
Stem-and-leaf of Oplismenus hirtellus  N  = 24
Leaf Unit = 1.0


(14)   0    00000000014889
 10    1    2247
 6     2    13
 4     3    12
 2     4    1
 1     5
 1     6
 1     7
 1     8
 1     9
 1     10   0
```

```
Stem-and-leaf of Paspalum conjugatum  N  = 24
Leaf Unit = 1.0


(20)   0    00000000000000112248
 4     1
 4     2
 4     3
 4     4    5
 3     5
 3     6
 3     7
 3     8
 3     9    8
 2     10   7
 1     11
 1     12   6
```

```
Stem-and-leaf of Paspalum spp.  N  = 24
Leaf Unit = 10


(22)   0  0000000000000000000000
 2     0
 2     1
 2     1
 2     2
 2     2
 2     3  0
 1     3
 1     4
 1     4
 1     5
 1     5
 1     6  1
```

```
Stem-and-leaf of Psidium cattleianum  N  = 24
Leaf Unit = 1.0


(18)  0   000000000000002334
 6    0   688
 3    1   0
 2    1
 2    2   4
 1    2
 1    3
 1    3   6
```

```
Stem-and-leaf of Pycreus polystachyos  N  = 24
Leaf Unit = 1.0


(20)  0   00000000000000000000
 4    0
 4    1   0
 3    1   8
 2    2   2
 1    2   8
```

```
Stem-and-leaf of Unknown  N  = 24
Leaf Unit = 1.0


(22)  0   0000000000000000000224
 2    0
 2    1   3
 1    1
 1    2
 1    2
 1    3   1
```

```
Stem-and-leaf of Zingiber zerumbet  N  = 24
Leaf Unit = 1.0


(17)  0    00000000000000049
 7    1    0
 6    2    38
 4    3
 4    4
 4    5    2
 3    6
 3    7    8
 2    8
 2    9
 2    10
 2    11   3
 1    12   0
```

Appendix 3.5: Descriptive Statistics for basal area of all species in stream and tributaries:

```
Variable            N  N*  Mean  SE Mean  StDev      Minimum          Q1
A. moluccana       16   0  76.3     49.5  198.1  0.000000000  0.000000000
C. fruticosa       16   0  35.9     34.2  136.6  0.000000000  0.000000000
M. indica           16   0   782      535   2139  0.000000000  0.000000000
M. quinquenervia   16   0   101      101    405  0.000000000  0.000000000
M. polymorpha      16   0   253      128    511  0.000000000  0.000000000
P. tectorius       16   0  45.9     35.2  140.9  0.000000000  0.000000000
Psidium cattleia   16   0  1071      352   1410  0.000000000  0.000000000
Psidium guajava    16   0   607      176    705  0.000000000  0.000000000
Psychotria spp.    16   0   282      282   1128  0.000000000  0.000000000
Syzigium cumini    16   0   216      154    616  0.000000000  0.000000000
Cecropia obtusif   16   0  8.55     8.55  34.21  0.000000000  0.000000000

Variable                Median           Q3  Maximum    Range          IQR
Aleurites molluc   0.000000000  0.000000000    706.7    706.7  0.000000000
Cordyline frutic   0.000000000  0.000000000    547.6    547.6  0.000000000
Mangifera indica   0.000000000  0.000000000     6477     6477  0.000000000
Melaleuca quinqu   0.000000000  0.000000000     1619     1619  0.000000000
Metrosideros pol   0.000000000          193     1492     1492          193
Pandanus tectori   0.000000000  0.000000000    543.3    543.3  0.000000000
Psidium cattleia           665         1633     5144     5144         1633
Psidium guajava            295         1257     1859     1859         1257
Psychotria spp.    0.000000000  0.000000000     4514     4514  0.000000000
Syzigium cumini    0.000000000  0.000000000     2215     2215  0.000000000
Cecropia obtusif   0.000000000  0.000000000   136.84   136.84  0.000000000

Variable           Skewness  Kurtosis
Aleurites molluc       2.78      7.39
Cordyline frutic       3.98     15.90
Mangifera indica       2.52      4.96
Melaleuca quinqu       4.00     16.00
Metrosideros pol       1.82      1.83
Pandanus tectori       3.39     11.87
Psidium cattleia       1.86      3.81
Psidium guajava        0.66     -1.32
Psychotria spp.        4.00     16.00
Syzigium cumini        2.91      8.13
Cecropia obtusif       4.00     16.00
```

Appendix 3.6: Descriptive Statistics for canopy cover individuals of tributaries and stream:

```
Variable            N  N*   Mean  SE Mean  StDev      Minimum           Q1
Hibiscus tiliace   20   0  11.80     5.44  24.34  0.000000000  0.000000000
Syzigium cumini    20   0   3.05     1.29   5.75  0.000000000  0.000000000
Erechtites valer   20   0  0.400    0.400  1.789  0.000000000  0.000000000
Clidemia hirta     20   0   6.45     2.07   9.24  0.000000000  0.000000000
Mangifera indica   20   0   3.55     2.52  11.27  0.000000000  0.000000000
Psidium cattleia   20   0   52.4     15.1   67.4  0.000000000  0.000000000
Psidium guajava    20   0  19.35     4.72  21.09  0.000000000  0.000000000
Cecropia obtusif   20   0   4.60     2.76  12.33  0.000000000  0.000000000
Metrosideros pol   20   0   2.25     1.08   4.84  0.000000000  0.000000000
Aleurites molucc   20   0   3.50     1.74   7.78  0.000000000  0.000000000
Cordyline frutic   20   0   1.70     1.24   5.55  0.000000000  0.000000000
Cledium jamaicen   20   0  0.200    0.200  0.894  0.000000000  0.000000000

Variable                Median           Q3  Maximum          IQR  Skewness
Hibiscus tiliace   0.000000000  0.000000000    63.00  0.000000000      1.66
```

```
Syzigium cumini   0.000000000         5.75   18.00         5.75      1.88
Erechtites valer  0.000000000  0.000000000   8.000  0.000000000      4.47
Clidemia hirta           2.50        11.75   28.00        11.75      1.49
Mangifera indica  0.000000000  0.000000000   44.00  0.000000000      3.20
Psidium cattleia         31.0         83.3   232.0         83.3      1.44
Psidium guajava         15.50        39.00   66.00        39.00      0.90
Cecropia obtusif  0.000000000  0.000000000   44.00  0.000000000      2.83
Metrosideros pol  0.000000000  0.000000000   16.00  0.000000000      1.99
Aleurites molucc  0.000000000  0.000000000   28.00  0.000000000      2.26
Cordyline frutic  0.000000000  0.000000000   24.00  0.000000000      3.84
Cledium jamaicen  0.000000000  0.000000000   4.000  0.000000000      4.47

Variable          Kurtosis
Hibiscus tiliace      0.91
Syzigium cumini       2.52
Erechtites valer     20.00
Clidemia hirta        1.18
Mangifera indica      9.82
Psidium cattleia      1.52
Psidium guajava      -0.39
Cecropia obtusif      7.05
Metrosideros pol      2.81
Aleurites molucc      4.60
Cordyline frutic     15.36
Cledium jamaicen     20.00
```

Appendix 3.7: Descriptive Statistics for ground cover for all plots for summer 2004:

```
Variable           N  N*   Mean  SE Mean   StDev      Minimum           Q1
Christella denta  24   0  10.50     3.34   16.35  0.000000000  0.000000000
Dicranopteris li  24   0   16.6     15.0    73.6  0.000000000  0.000000000
Hibiscus tiliace  24   0  1.458    0.689   3.375  0.000000000  0.000000000
Nephrolepis mult  24   0  33.04     7.88   38.60  0.000000000  0.000000000
Oplismenus hirte  24   0  13.88     4.47   21.88  0.000000000  0.000000000
Paspalum conjuga  24   0  16.42     7.68   37.63  0.000000000  0.000000000
Paspalum spp.     24   0   38.5     28.1   137.7  0.000000000  0.000000000
Psidium cattleia  24   0   4.33     1.77    8.66  0.000000000  0.000000000
Pycreus polystac  24   0   3.25     1.61    7.91  0.000000000  0.000000000
Unknown           24   0   2.17     1.37    6.73  0.000000000  0.000000000
Zingiber zerumbe  24   0  18.21     7.31   35.82  0.000000000  0.000000000

Variable               Median           Q3  Maximum          IQR  Skewness
Christella denta         5.00        11.75    68.00        11.75      2.43
Dicranopteris li  0.000000000  0.000000000    360.0  0.000000000      4.81
Hibiscus tiliace  0.000000000  0.000000000   10.000  0.000000000      2.02
Nephrolepis mult        16.00        78.50   102.00        78.50      0.82
Oplismenus hirte         8.00        20.00   100.00        20.00      2.91
Paspalum conjuga  0.000000000         3.50   126.00         3.50      2.27
Paspalum spp.     0.000000000  0.000000000    616.0  0.000000000      3.81
Psidium cattleia  0.000000000         5.50    36.00         5.50      2.81
Pycreus polystac  0.000000000  0.000000000    28.00  0.000000000      2.36
Unknown           0.000000000  0.000000000    31.00  0.000000000      3.90
Zingiber zerumbe  0.000000000        19.75   120.00        19.75      2.13

Variable          Kurtosis
Christella denta      6.38
Dicranopteris li     23.36
Hibiscus tiliace      2.45
Nephrolepis mult     -1.04
Oplismenus hirte     10.39
Paspalum conjuga      3.82
Paspalum spp.        14.80
```

```
Psidium cattleia     8.25
Pycreus polystac     4.51
Unknown             15.99
Zingiber zerumbe     3.56
```

Appendix 3.8: Descriptive Statistics for ground cover for all plots winter 2005:

```
Variable           N  N*   Mean  SE Mean  StDev      Minimum           Q1
Christella denta  24   0   38.2     11.0   53.9  0.000000000  0.000000000
Dicranopteris li  24   0   13.9     13.3   65.3  0.000000000  0.000000000
Hibiscus tiliace  24   0  1.625    0.798  3.910  0.000000000  0.000000000
Nephrolepis mult  24   0   3.50     1.14   5.57  0.000000000  0.000000000
Oplismenus hirte  24   0  10.63     3.05  14.92  0.000000000  0.000000000
Paspalum conjuga  24   0  10.38     5.15  25.22  0.000000000  0.000000000
Paspalum spp.     24   0   41.9     30.5  149.4  0.000000000  0.000000000
Psidium cattleia  24   0   2.63     1.13   5.53  0.000000000  0.000000000
Pycreus polystac  24   0   3.08     1.62   7.94  0.000000000  0.000000000

Variable               Median           Q3  Maximum          IQR  Skewness
Christella denta         8.00         62.0    188.0         62.0      1.66
Dicranopteris li  0.000000000  0.000000000    320.0  0.000000000      4.89
Hibiscus tiliace  0.000000000  0.000000000   14.000  0.000000000      2.34
Nephrolepis mult        0.500         5.50    24.00         5.50      2.46
Oplismenus hirte         3.00        16.75    60.00        16.75      1.90
Paspalum conjuga  0.000000000  0.000000000    94.00  0.000000000      2.43
Paspalum spp.     0.000000000         3.50    692.0         3.50      4.07
Psidium cattleia  0.000000000         2.50    20.00         2.50      2.31
Pycreus polystac  0.000000000  0.000000000    28.00  0.000000000      2.65

Variable          Kurtosis
Christella denta      2.21
Dicranopteris li     23.91
Hibiscus tiliace      4.53
Nephrolepis mult      7.40
Oplismenus hirte      4.19
Paspalum conjuga      5.20
Paspalum spp.        17.16
Psidium cattleia      4.53
Pycreus polystac      6.13
```

Appendix 3.9: Descriptive Statistics for ground cover without vegetation winter 2005:

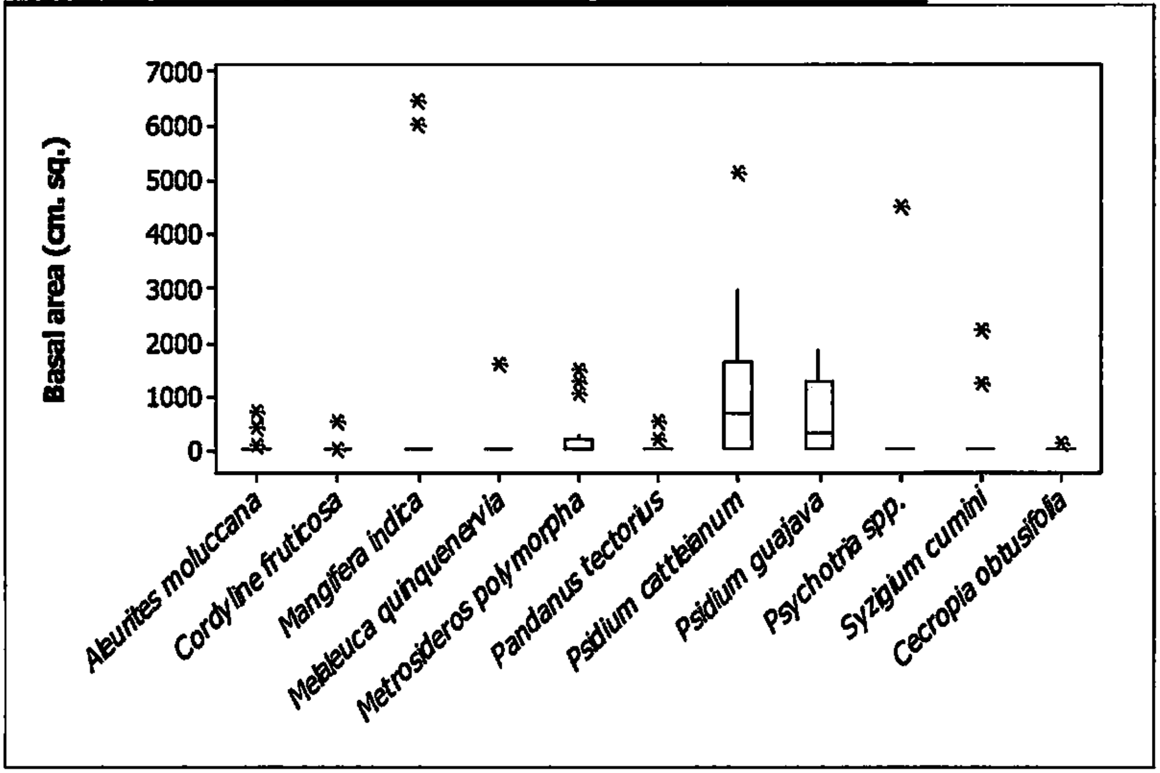
```
Variable        N  N*   Mean  SE Mean  StDev      Minimum           Q1
Bare Ground    72   0  11.39     1.35  11.44  0.000000000         3.00
Rock           72   0  2.444    0.579  4.910  0.000000000  0.000000000
Woody debris   72   0  1.208    0.256  2.169  0.000000000  0.000000000
Leaf litter    72   0  16.90     2.08  17.69  0.000000000         5.25
Surface water  72   0  0.181    0.124  1.053  0.000000000  0.000000000

Variable            Median           Q3  Maximum          IQR  Skewness
Bare Ground           7.50        19.75    44.00        16.75      1.26
Rock           0.000000000        4.000   32.000        4.000      3.68
Woody debris   0.000000000        1.000    8.000        1.000      2.03
Leaf litter          13.50        20.00    96.00        14.75      2.49
Surface water  0.000000000  0.000000000    8.000  0.000000000      6.63

Variable       Kurtosis
Bare Ground        1.11
Rock              18.39
Woody debris       3.39
Leaf litter        7.55
```

```
Surface water    46.23
```

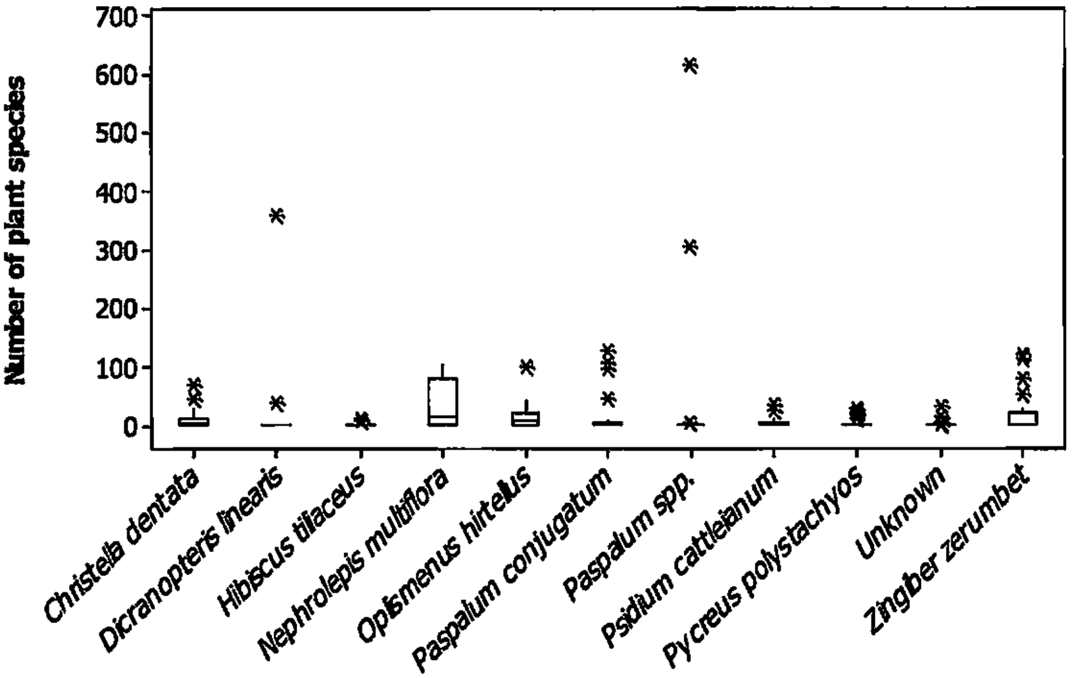
Appendix 3.10: Descriptive Statistics: Ground cover without vegetation for all plots winter 2005:

```
Variable        N   N*   Mean  SE Mean  StDev      Minimum          Q1
Bare Ground    72   0   9.92     1.08   9.15  0.000000000        4.00
Rock           72   0  2.319    0.569  4.826  0.000000000  0.000000000
Woody debris   72   0  1.472    0.291  2.467  0.000000000  0.000000000
Leaf litter    72   0  12.36     1.16   9.87  0.000000000        5.25
Surface water  72   0  0.625    0.246  2.086  0.000000000  0.000000000

Variable           Median           Q3  Maximum          IQR  Skewness
Bare Ground          7.50        17.50    44.00        13.50      1.43
Rock          0.000000000        3.000   28.000        3.000      3.09
Woody debris  0.000000000        1.750    8.000        1.750      1.77
Leaf litter         11.00        16.00    48.00        10.75      1.48
Surface water 0.000000000  0.000000000    8.000  0.000000000      3.24

Variable       Kurtosis
Bare Ground        2.44
Rock              11.73
Woody debris       1.94
Leaf litter        2.60
Surface water      8.96
```

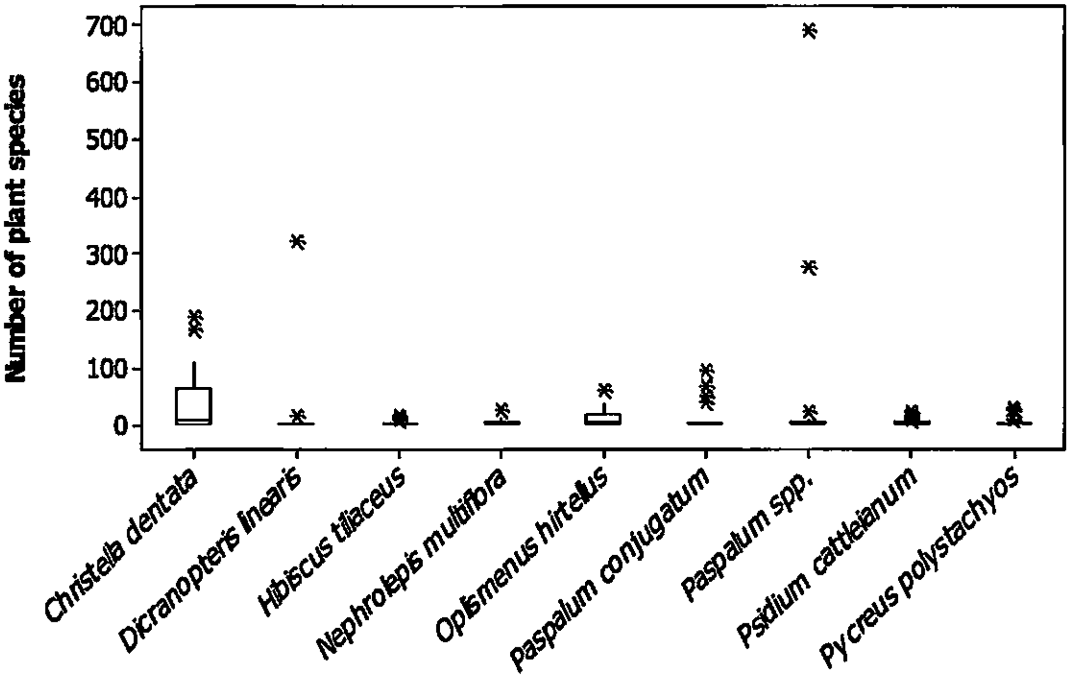
Appendix 3.11: Boxplot of basal area along stream and tributaries:



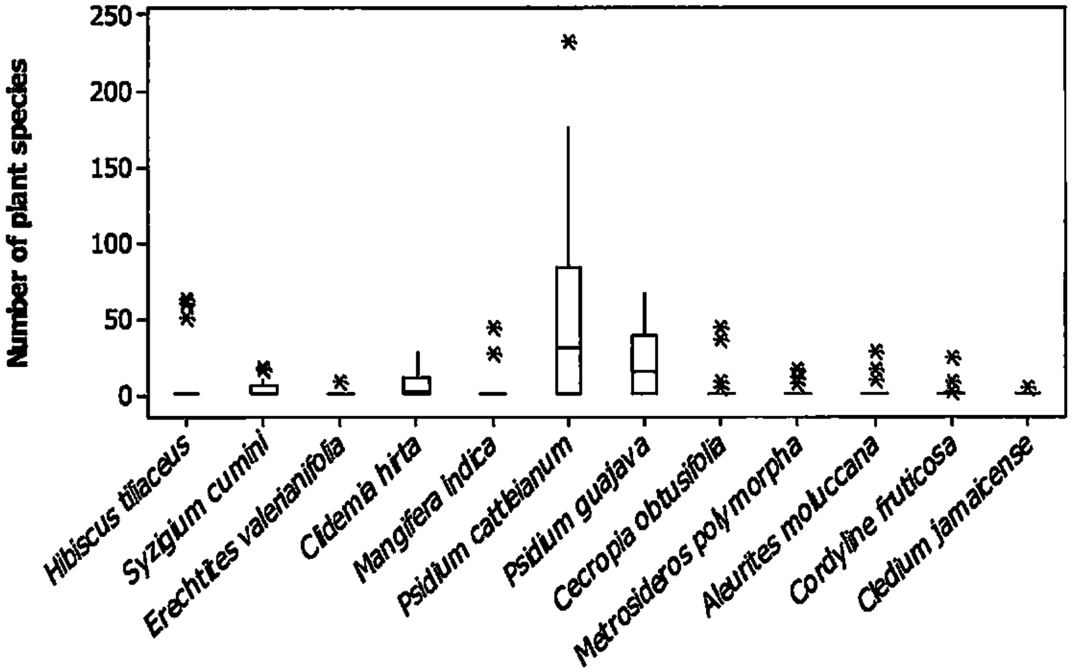
Appendix 3.12: Boxplot of ground cover for all plots during summer 2004:



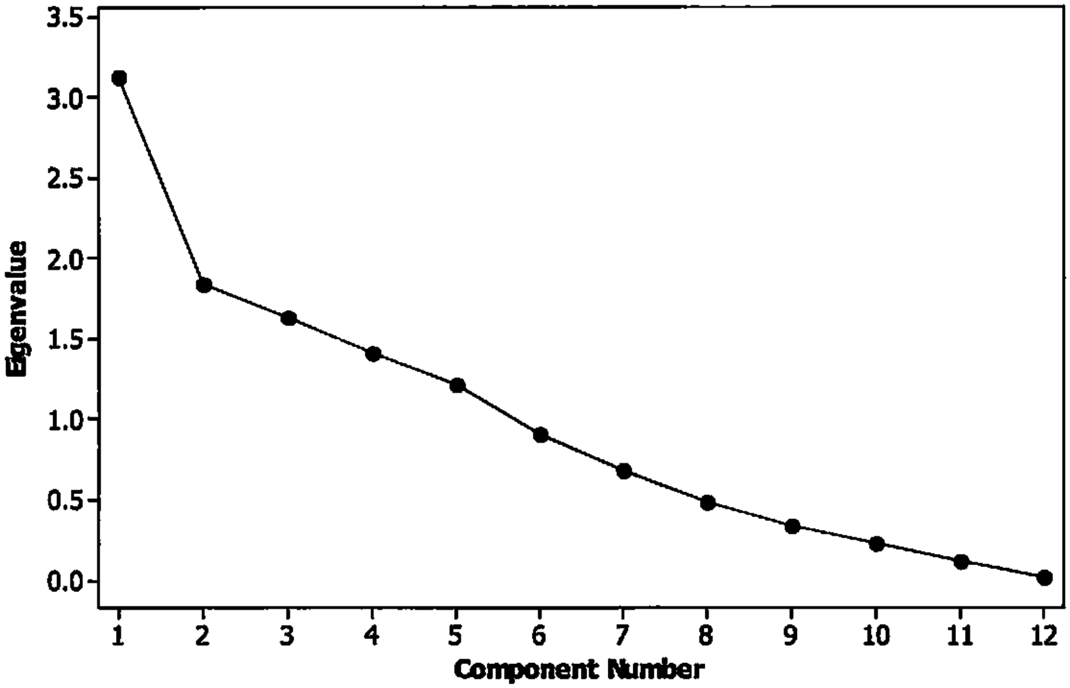
Appendix 3.13: Boxplot of all plots for ground cover of winter 2005:



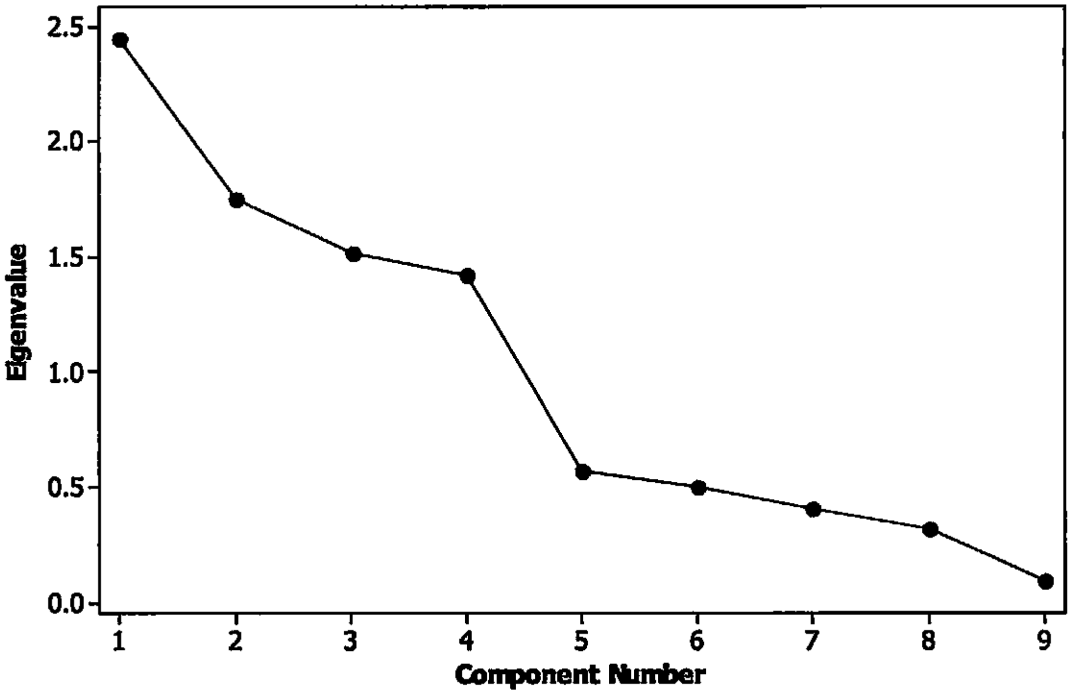
Appendix 3.14: Boxplot for canopy cover individuals of tributaries and stream:



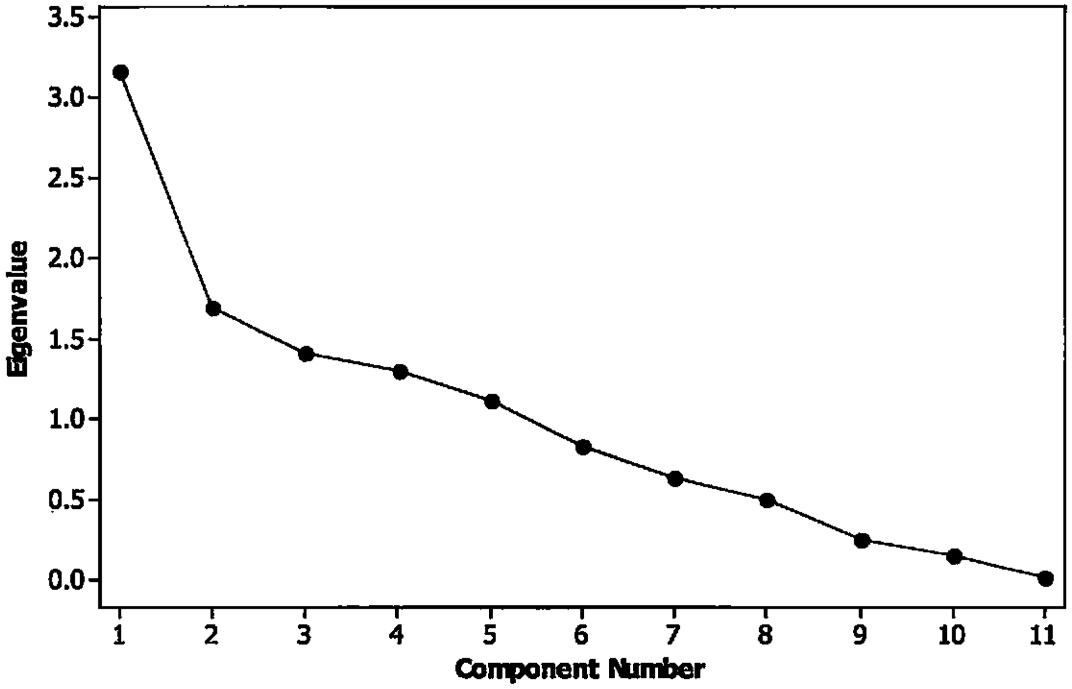
Appendix 3.15: Scree plot for canopy cover of stream and tributaries:



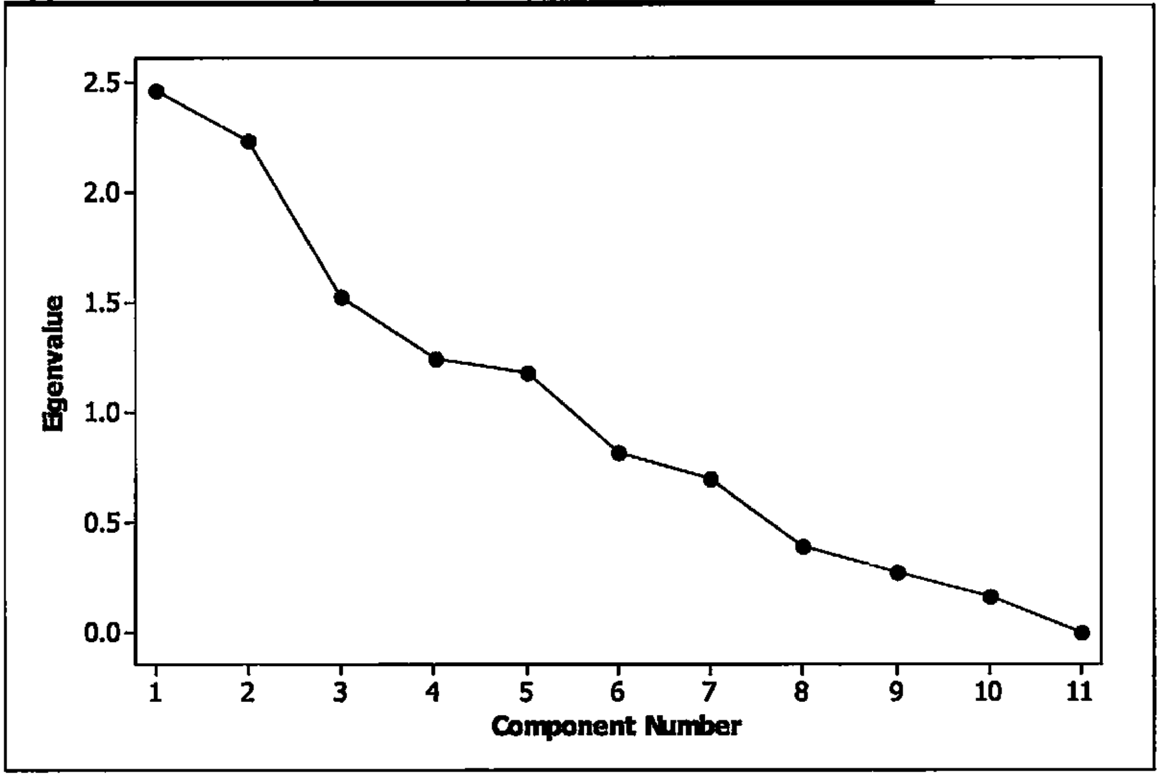
Appendix 3.16: Scree plot for ground cover of all plots winter 2005:



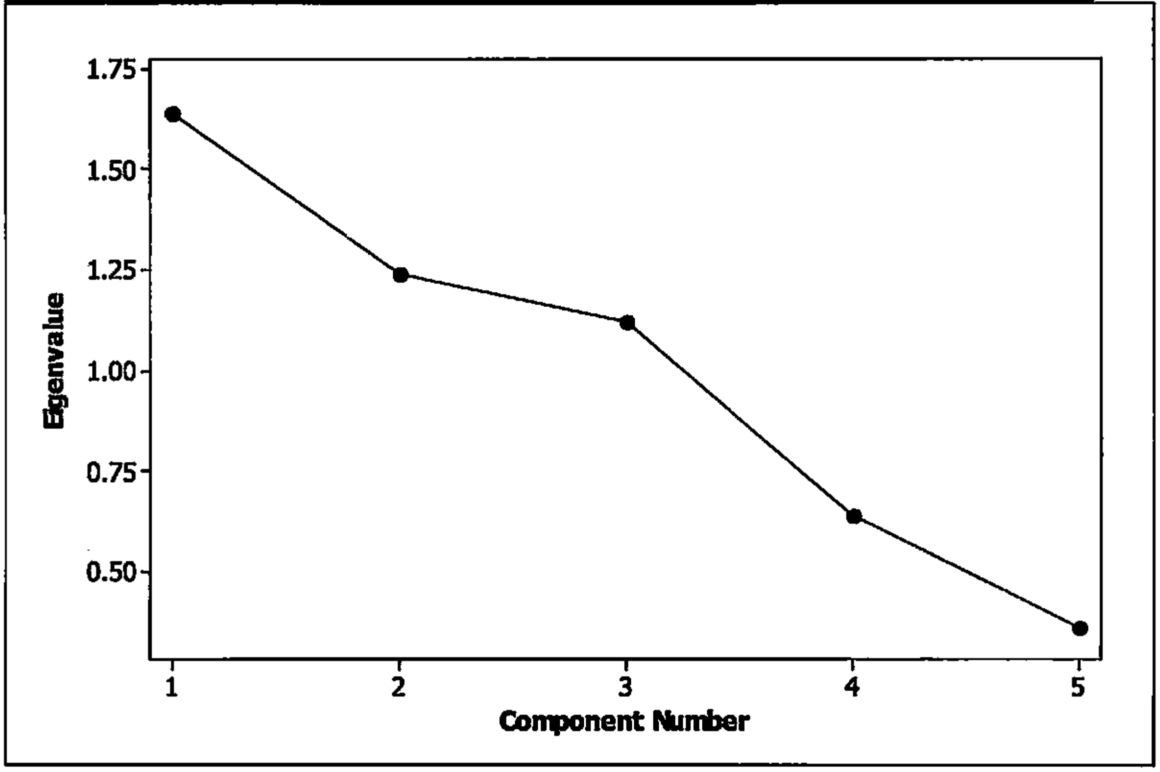
Appendix 3.17: Scree plot for ground cover of all plots summer 2004:



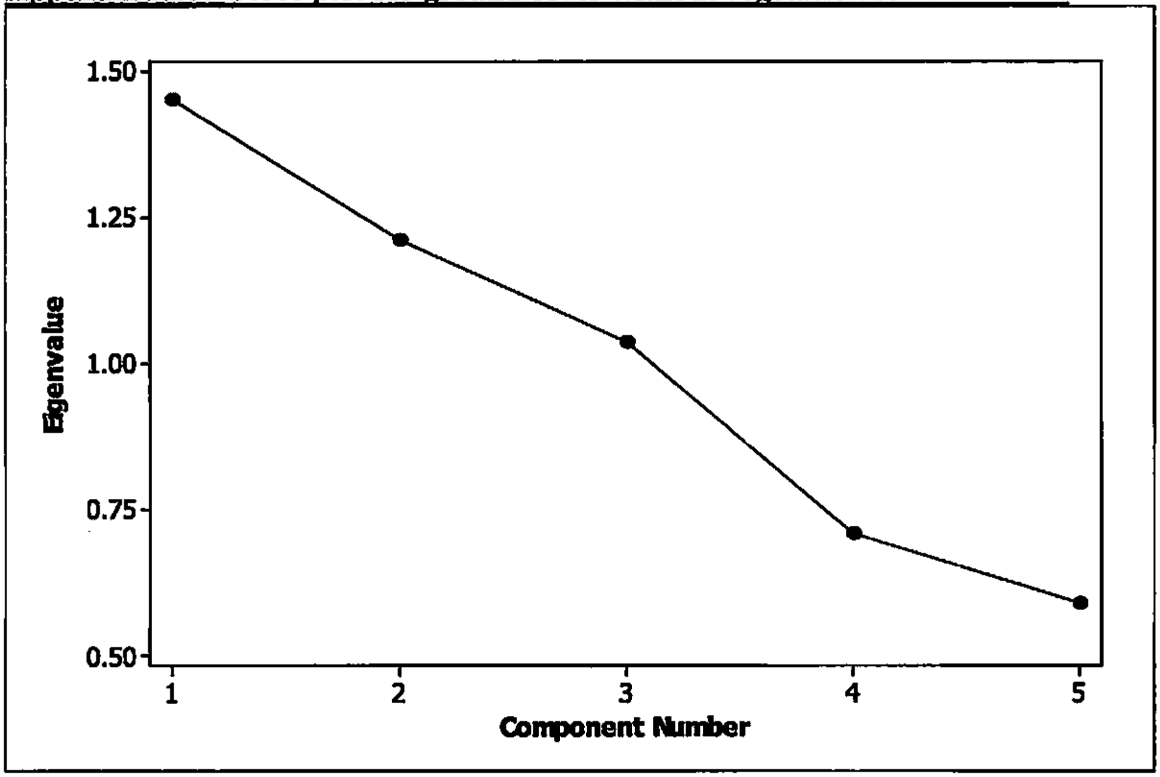
Appendix 3.18: Scree plot for basal area of streams and tributaries:



Appendix 3.19: Scree plot for ground cover without vegetation for winter 2005:



Appendix 3.20: Scree plot for ground cover without vegetation summer 2004:



Appendix 3.21: Principal Component Analysis for ground cover of all plots winter 2005:

```
Eigenanalysis of the Correlation Matrix

Eigenvalue  2.4436  1.7498  1.5175  1.4157  0.5687  0.4992  0.4029  0.3127
Proportion   0.272   0.194   0.169   0.157   0.063   0.055   0.045   0.035
Cumulative   0.272   0.466   0.635   0.792   0.855   0.911   0.955   0.990

Eigenvalue  0.0898
Proportion   0.010
Cumulative   1.000


Variable                   PC1     PC2     PC3     PC4     PC5     PC6     PC7
Paspalum spp.            0.005   0.449  -0.369   0.387   0.170  -0.530  -0.412
Christella dentata      -0.420  -0.069   0.433   0.112  -0.286   0.135  -0.703
Dicranopteris linearis  -0.286  -0.443  -0.371   0.068   0.609   0.104  -0.144
Oplismenus hirtellus    -0.434  -0.462  -0.249   0.044  -0.182  -0.082   0.078
Paspalum conjugatum      0.470  -0.278   0.093   0.300   0.073   0.157  -0.105
Nephrolepis multiflora  -0.219   0.423  -0.224   0.391   0.007   0.735   0.130
Pycreus polystachyos     0.462  -0.273   0.087   0.308   0.112   0.176  -0.268
Psidium cattleianum     -0.225   0.150   0.615   0.061   0.642  -0.083   0.169
Hibiscus tiliaceus       0.143   0.175  -0.179  -0.700   0.237   0.282  -0.425

Variable                   PC8
Paspalum spp.            0.040
Christella dentata       0.085
Dicranopteris linearis   0.064
Oplismenus hirtellus    -0.058
```

```
Paspalum conjugatum      0.713
Nephrolepis multiflora  -0.006
Pycreus polystachyos    -0.688
Psidium cattleianum     -0.023

Hibiscus tiliaceus       0.035
```

Appendix 3.22: Principal Component Analysis for ground cover of all plots summer 2004:

```
Eigenanalysis of the Correlation Matrix

Eigenvalue  3.1940  1.7082  1.5033  1.3363  1.1135  1.0652  0.7368  0.6195
Proportion   0.266   0.142   0.125   0.111   0.093   0.089   0.061   0.052
Cumulative   0.266   0.409   0.534   0.645   0.738   0.827   0.888   0.940

Eigenvalue  0.3386  0.2364  0.1380  0.0101
Proportion   0.028   0.020   0.012   0.001
Cumulative   0.968   0.988   0.999   1.000


Variable                    PC1     PC2     PC3     PC4     PC5     PC6     PC7
Paspalum spp.            -0.026   0.249  -0.093  -0.147  -0.808   0.247  -0.171
Nephrolepis multiflora    0.378  -0.383   0.148  -0.223  -0.023  -0.057   0.015
Zingiber zerumbet         0.143  -0.054  -0.400  -0.521   0.342  -0.079  -0.394
Dicranopteris linearis    0.059  -0.020   0.343  -0.146   0.227   0.747   0.322
Paspalum conjugatum      -0.424  -0.258   0.030   0.066   0.058   0.026   0.165
Oplismenus hirtellus      0.297  -0.191   0.435   0.239   0.080   0.086  -0.551
Christella dentata        0.297  -0.242  -0.139   0.575  -0.159   0.068  -0.113
Psidium cattleianum       0.241  -0.300  -0.513   0.225  -0.000   0.019   0.415
Pycreus polystachyos     -0.489  -0.339   0.032   0.091   0.022  -0.022  -0.094
Unknown                  -0.404  -0.293   0.027   0.065  -0.047  -0.019  -0.265
Hibiscus tiliaceus       -0.023   0.557   0.103   0.373   0.298  -0.227   0.020
Freycinetia arborea       0.123  -0.156   0.454  -0.205  -0.225  -0.553   0.340

Variable                    PC8     PC9    PC10    PC11
Paspalum spp.             0.002  -0.040   0.358  -0.183
Nephrolepis multiflora    0.104  -0.653   0.320   0.308
Zingiber zerumbet        -0.038   0.343   0.380  -0.053
Dicranopteris linearis    0.190   0.241   0.220  -0.011
Paspalum conjugatum      -0.634  -0.082   0.338  -0.084
Oplismenus hirtellus     -0.160  -0.022  -0.049  -0.531
Christella dentata       -0.067   0.412   0.224   0.485
Psidium cattleianum       0.188  -0.071   0.073  -0.565
Pycreus polystachyos      0.065  -0.005   0.232  -0.031
Unknown                   0.656   0.026  -0.001  -0.001
Hibiscus tiliaceus        0.207  -0.162   0.568  -0.082
Freycinetia arborea       0.086   0.433   0.167  -0.131
```

Appendix 3.23: Principal Component Analysis for canopy cover of stream and tributaries:

```
Eigenanalysis of the Correlation Matrix

Eigenvalue  3.1317  1.8491  1.6379  1.4157  1.2161  0.9011  0.6847  0.4787
Proportion   0.261   0.154   0.136   0.118   0.101   0.075   0.057   0.040
Cumulative   0.261   0.415   0.552   0.670   0.771   0.846   0.903   0.943

Eigenvalue  0.3359  0.2260  0.1075  0.0155
Proportion   0.028   0.019   0.009   0.001
```

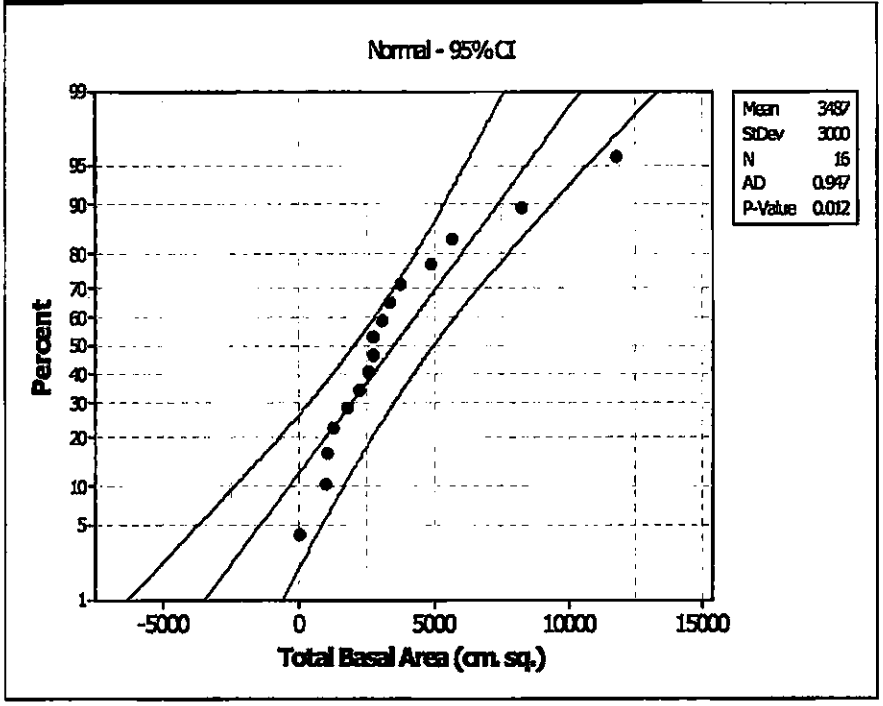
```
Cumulative   0.971   0.990   0.999   1.000

Variable                      PC1      PC2      PC3      PC4      PC5      PC6
Psidium cattleianum        -0.162    0.243    0.413   -0.055    0.556   -0.216
Psidium guajava            -0.404   -0.024    0.280   -0.168   -0.227   -0.369
Hibiscus tiliaceus          0.307    0.077   -0.437   -0.359    0.026    0.054
Clidemia hirta             -0.463   -0.047   -0.264    0.123   -0.174   -0.301
Cecropia obtusifolia       -0.092   -0.661   -0.059    0.144   -0.067   -0.266
Mangifera indica            0.196    0.159    0.146    0.615   -0.217   -0.050
Aleurites moluccana        -0.445    0.178   -0.306    0.154   -0.042    0.133
Syzigium cumini             0.311    0.186    0.001    0.397   -0.305   -0.193
Cordyline fruticosa        -0.306    0.193   -0.421    0.290    0.247    0.257
Metrosideros polymorpha    -0.179    0.022    0.197   -0.279   -0.590    0.457
Erechtites valerianifolia   0.177    0.075   -0.392   -0.240   -0.110   -0.507
Cledium jamaicense          0.060   -0.601   -0.043    0.155    0.204    0.252

Variable                      PC7      PC8      PC9     PC10     PC11
Psidium cattleianum        -0.241    0.006    0.014    0.520    0.238
Psidium guajava             0.138    0.155   -0.419   -0.378    0.414
Hibiscus tiliaceus          0.407   -0.043   -0.298    0.373    0.419
Clidemia hirta              0.147   -0.144    0.165    0.351   -0.229
Cecropia obtusifolia        0.134    0.019    0.288    0.224    0.255
Mangifera indica            0.020   -0.613   -0.209    0.053    0.252
Aleurites moluccana        -0.094    0.083   -0.504    0.210   -0.262
Syzigium cumini            -0.092    0.715   -0.010    0.219    0.068
Cordyline fruticosa        -0.111    0.114    0.314   -0.276    0.525
Metrosideros polymorpha    -0.333   -0.057    0.176    0.298    0.246
Erechtites valerianifolia  -0.653   -0.191    0.007   -0.110    0.045
Cledium jamaicense         -0.389    0.075   -0.445    0.052    0.063
```

Appendix 3.24: Principal Component Analysis for basal area of stream and tributaries:

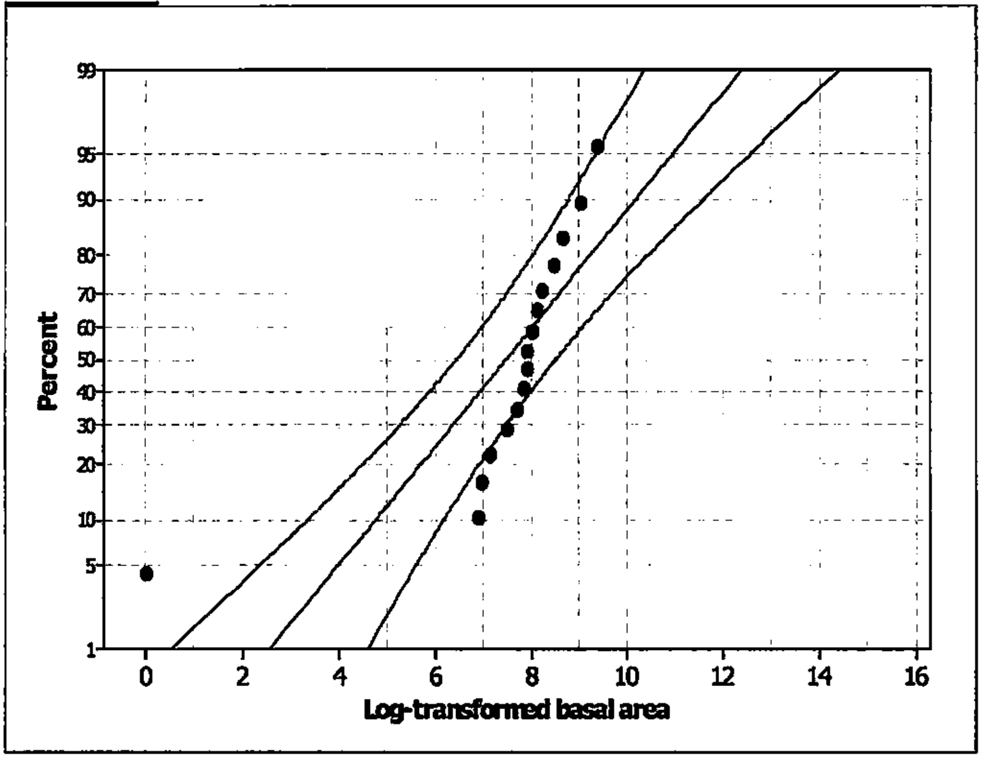
```
Eigenanalysis of the Correlation Matrix

Eigenvalue   2.4633  2.2377  1.5291  1.2446  1.1772  0.8216  0.7028  0.3920
Proportion    0.224   0.203   0.139   0.113   0.107   0.075   0.064   0.036
Cumulative    0.224   0.427   0.566   0.680   0.787   0.861   0.925   0.961

Eigenvalue   0.2685  0.1631  0.0000
Proportion    0.024   0.015   0.000
Cumulative    0.985   1.000   1.000


Variable                    PC1      PC2      PC3      PC4      PC5      PC6      PC7
Aleurites moluccana      -0.442    0.051    0.401    0.123   -0.208    0.291   -0.250
Cordyline fruticosa      -0.189   -0.026    0.568   -0.340   -0.377   -0.195    0.010
Mangifera indica          0.424    0.198    0.272    0.314   -0.008    0.233   -0.263
Melaleuca quinquenervia   0.089   -0.638   -0.040    0.166   -0.082    0.101   -0.102
Metrosideros polymorpha  -0.446    0.101   -0.023    0.424    0.103    0.436   -0.095
Pandanus tectorius        0.154    0.153   -0.307    0.018   -0.594   -0.176   -0.624
Psidium cattleianum       0.364    0.259   -0.127    0.036   -0.316    0.501    0.345
Psidium guajava          -0.357    0.171   -0.426    0.228    0.078   -0.272   -0.119
Psychotria spp.           0.022   -0.005   -0.116   -0.617    0.398    0.405   -0.492
Syzigium cumini           0.302    0.118    0.365    0.319    0.417   -0.302   -0.272
Cecropia obtusifolia      0.089   -0.638   -0.040    0.166   -0.082    0.101   -0.102

Variable                    PC8      PC9     PC10
Aleurites moluccana       0.099    0.313   -0.573
Cordyline fruticosa       0.283   -0.073    0.510
Mangifera indica          0.310   -0.616   -0.098
```

```
Melaleuca quinquenervia   0.141   0.066   0.067
Metrosideros polymorpha  -0.303  -0.103   0.546
Pandanus tectorius       -0.267   0.089   0.084
Psidium cattleianum       0.278   0.453   0.175
Psidium guajava           0.714   0.033   0.067
Psychotria spp.           0.156   0.067   0.109
Syzigium cumini          -0.010   0.528   0.203
Cecropia obtusifolia      0.141   0.066   0.067
```

Appendix 3.25: Probability plot of total basal area:



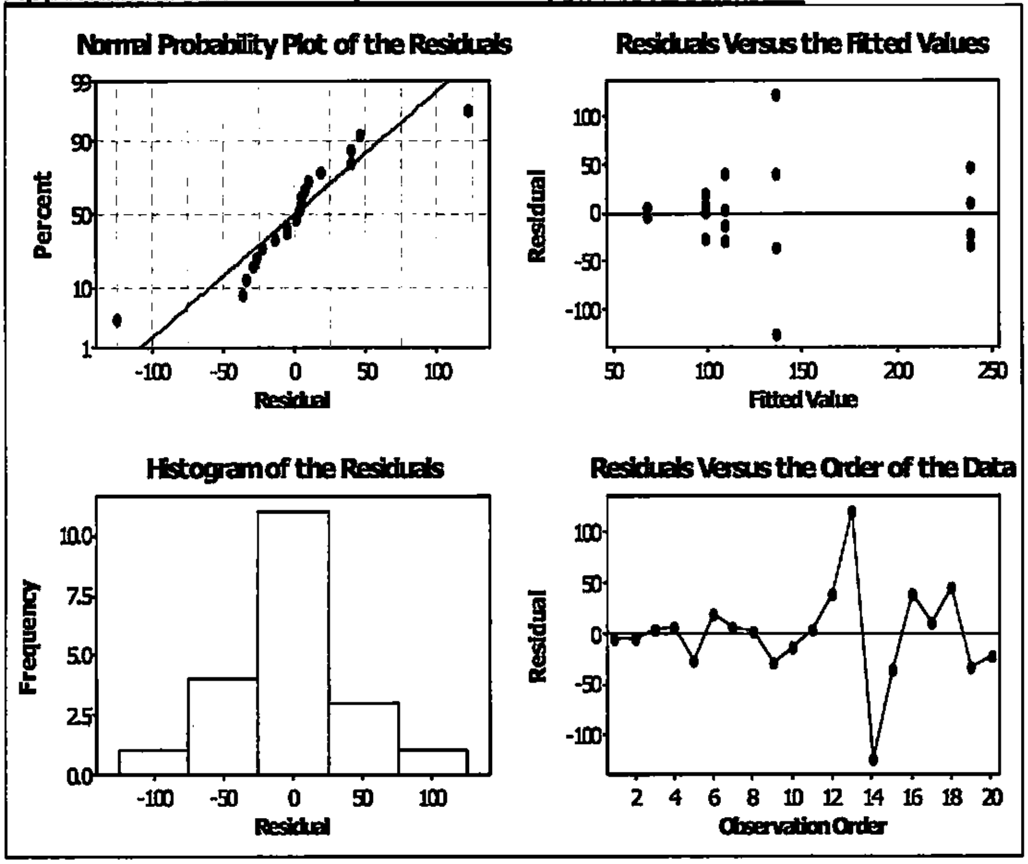
Appendix 3.26: Probability plot of log-transformed data for basal area:



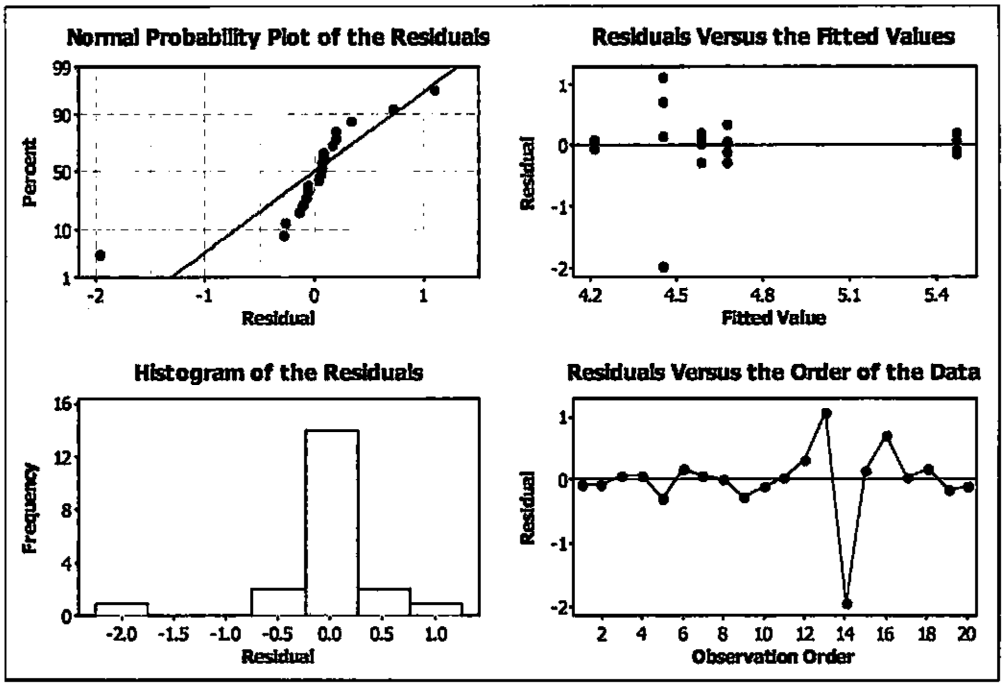
Appendix 3.27: Kruskal-Wallis Test: log transformation for basal area versus Section:

```
Kruskal-Wallis Test on Log transformation

Section    N  Median  Ave Rank      Z
1. MJ      4   8.751      13.0   2.18
2. GO      4   7.962       9.5   0.49
3. KA      4   7.306       5.3  -1.58
4. KO      4   7.327       6.3  -1.09
Overall   16               8.5

H = 6.51  DF = 3  P = 0.089
```

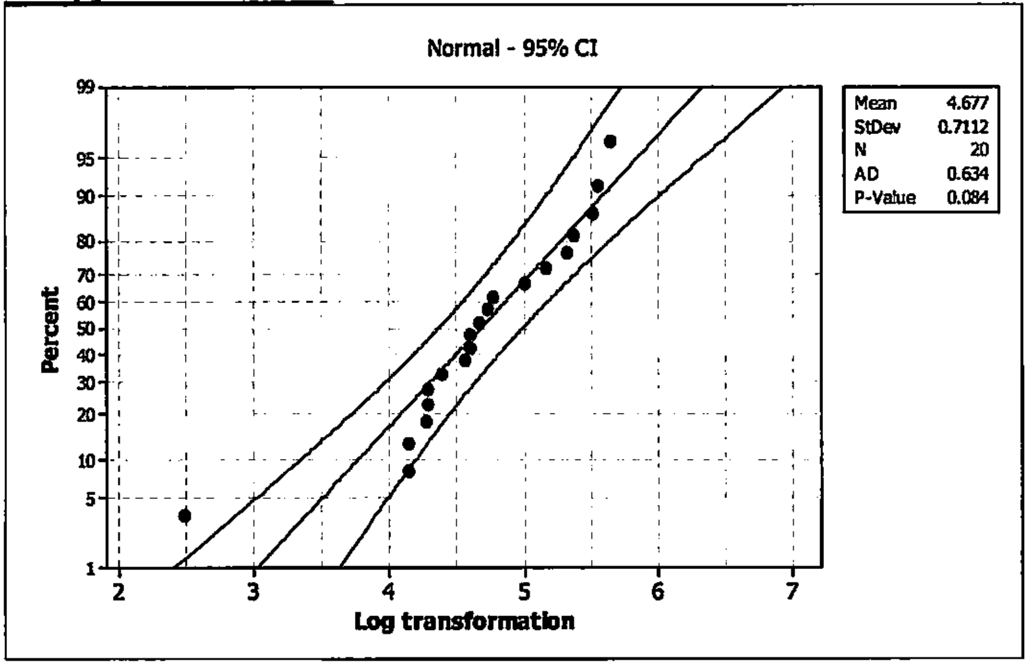
Appendix 3.28: Residual plots for canopy cover contacts:



Appendix 3.29: Residual plots for log transformation of canopy cover contacts:



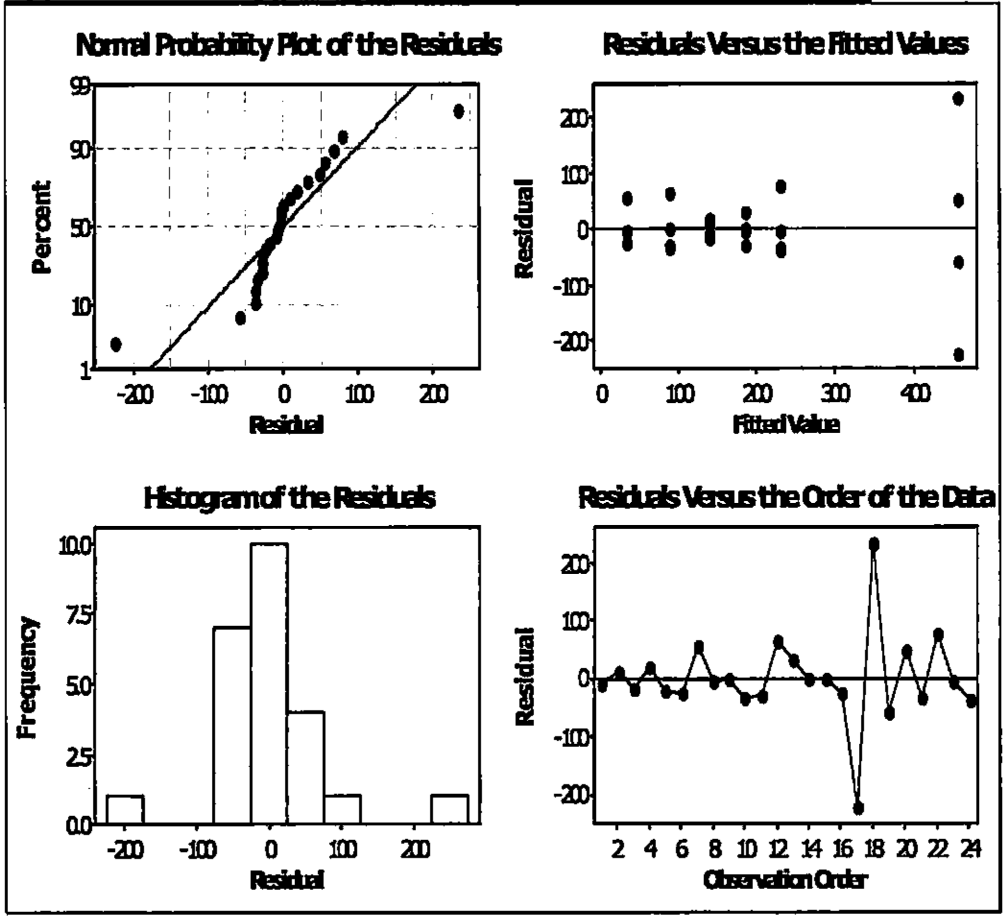
Appendix 3.30: Probability plot of log transformation of canopy cover contacts:



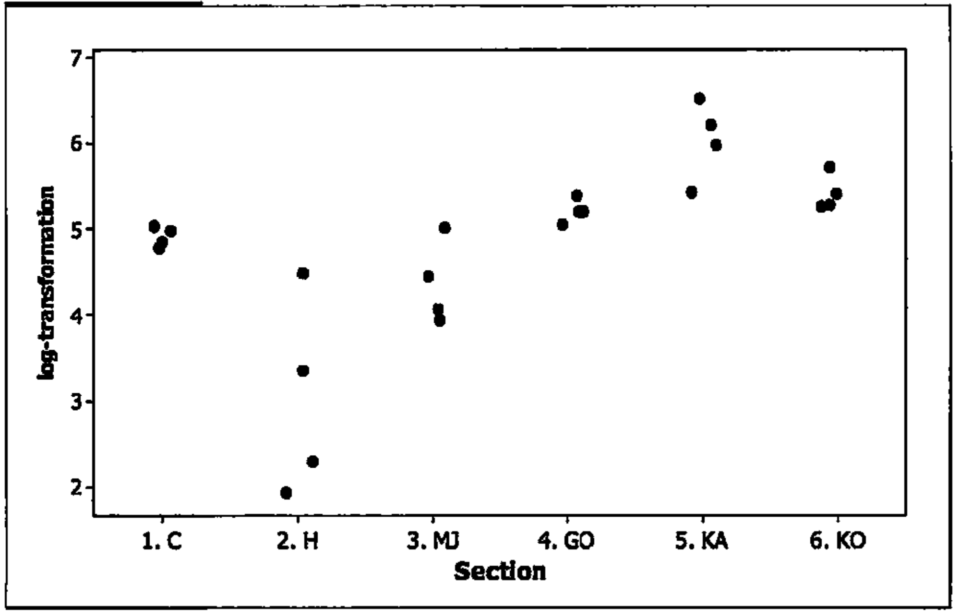
Appendix 3.31: Kruskal-Wallis Test: Log transformation of canopy cover contacts versus section:

```
Kruskal-Wallis Test on Log transformation

Section    N  Median  Ave Rank      Z
1. H       4   4.210       3.6  -2.60
2. MJ      4   4.634       9.8  -0.28
3. GO      4   4.646      10.3  -0.09
4. KA      4   4.888      11.1   0.24
5. KO      4   5.444      17.8   2.74
Overall   20              10.5

H = 11.53  DF = 4  P = 0.021
H = 11.55  DF = 4  P = 0.021  (adjusted for ties)
```

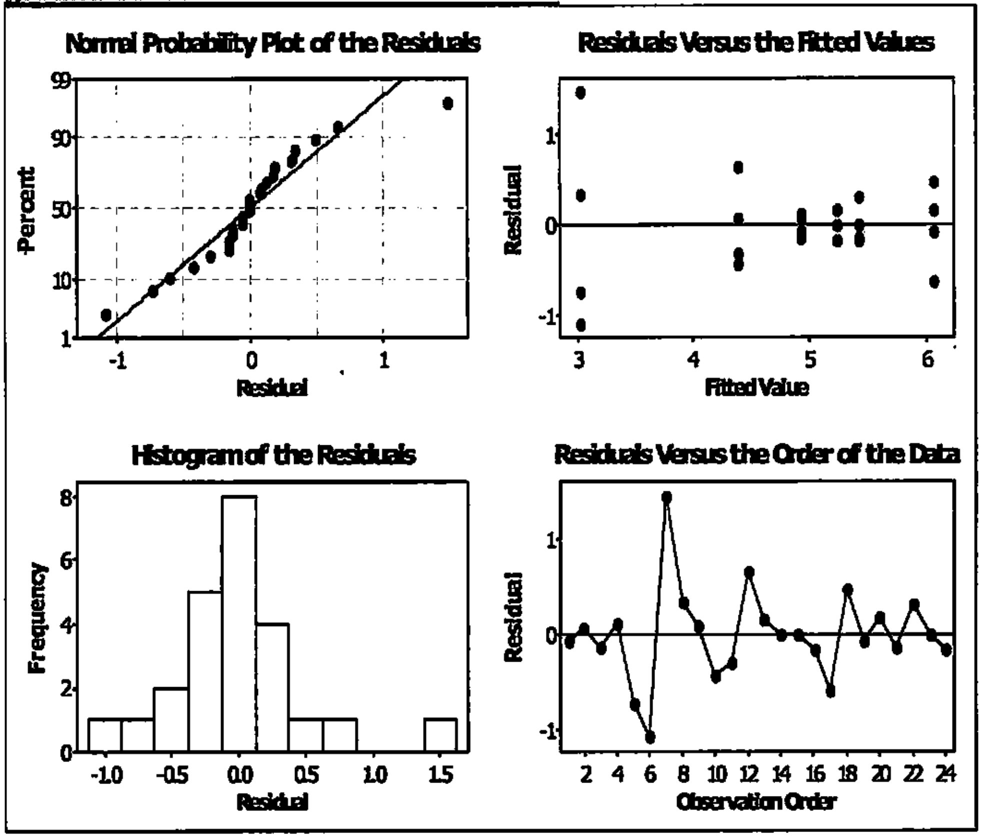
Appendix 3.32: Residual plots for ground cover summer 2004:



Appendix 3.33: Log-transformed data for ground cover individuals summer 2004:



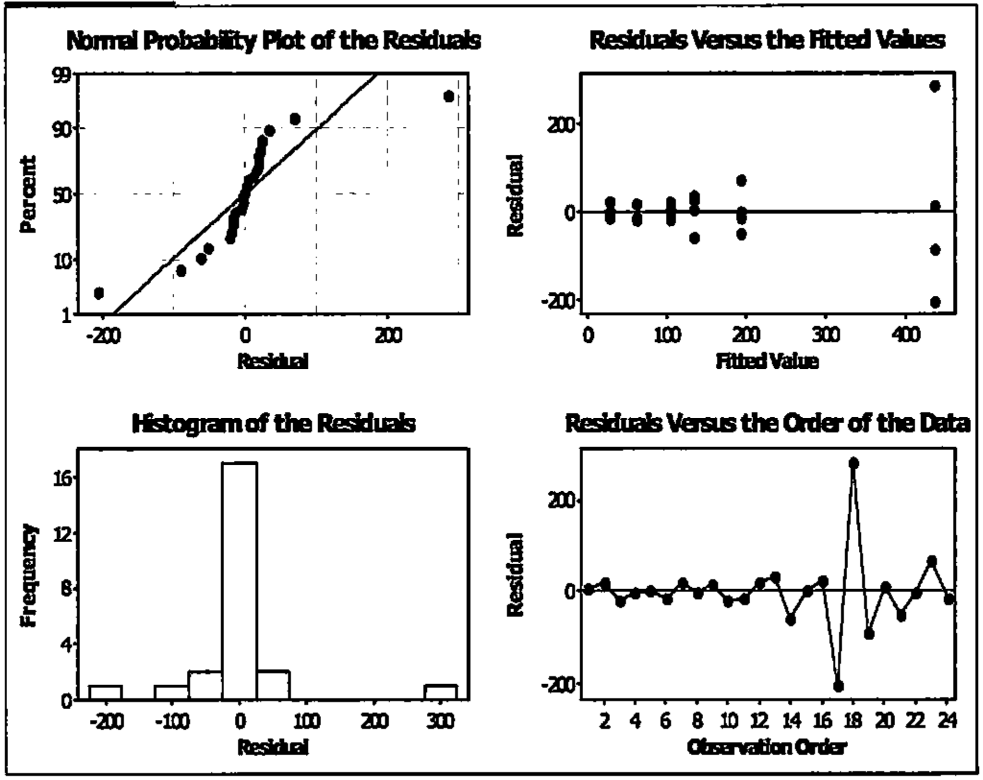
Appendix 3.34: Residual plots for log-transformed data of ground cover individuals summer 2004:



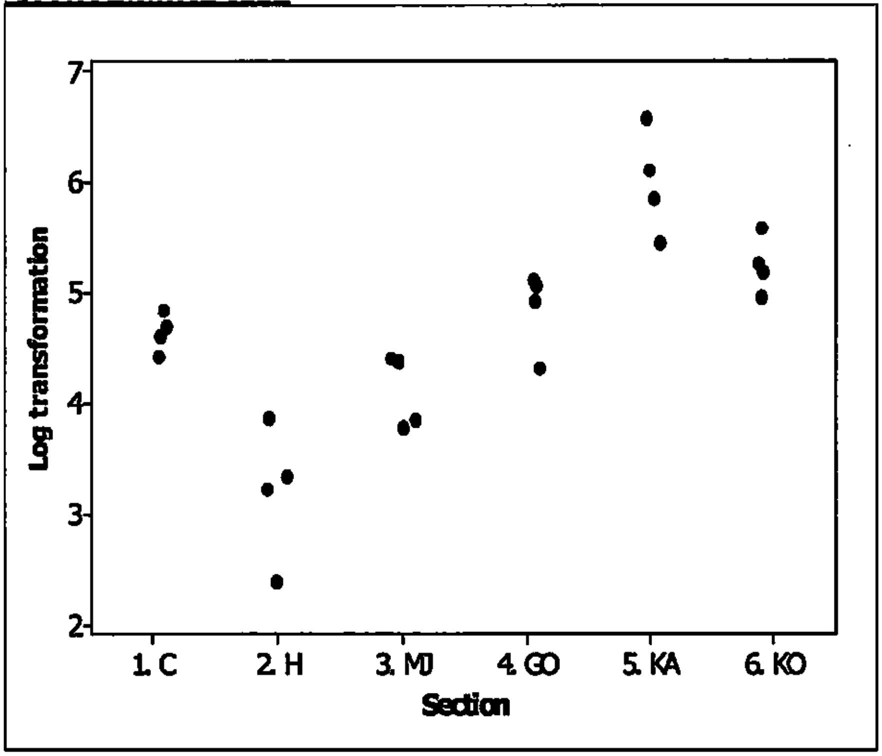
Appendix 3.35: Kruskal-Wallis test on log-transformed data of ground cover individuals summer 2004:

```
Location   N  Median  Ave Rank      Z
1. C       4   4.932       9.8  -0.85
2. H       4   2.835       3.3  -2.87
3. MJ      4   4.272       6.5  -1.86
4. GO      4   5.218      15.0   0.77
5. KA      4   6.102      22.3   3.02
6. KO      4   5.345      18.3   1.78
Overall   24              12.5

H = 21.08  DF = 5  P = 0.001
```

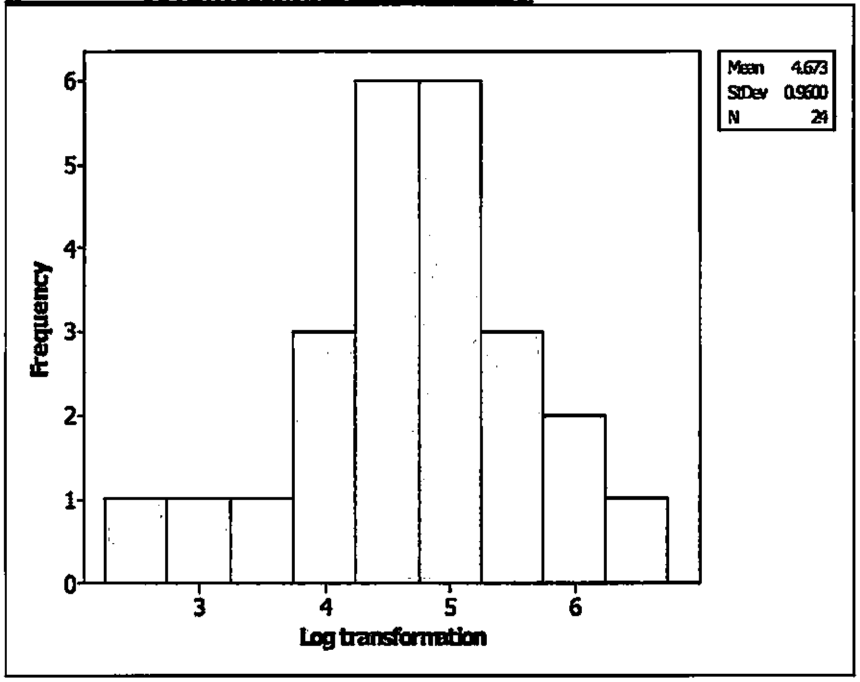
Appendix 3.36: Residual plots for ground cover individuals winter 2005:



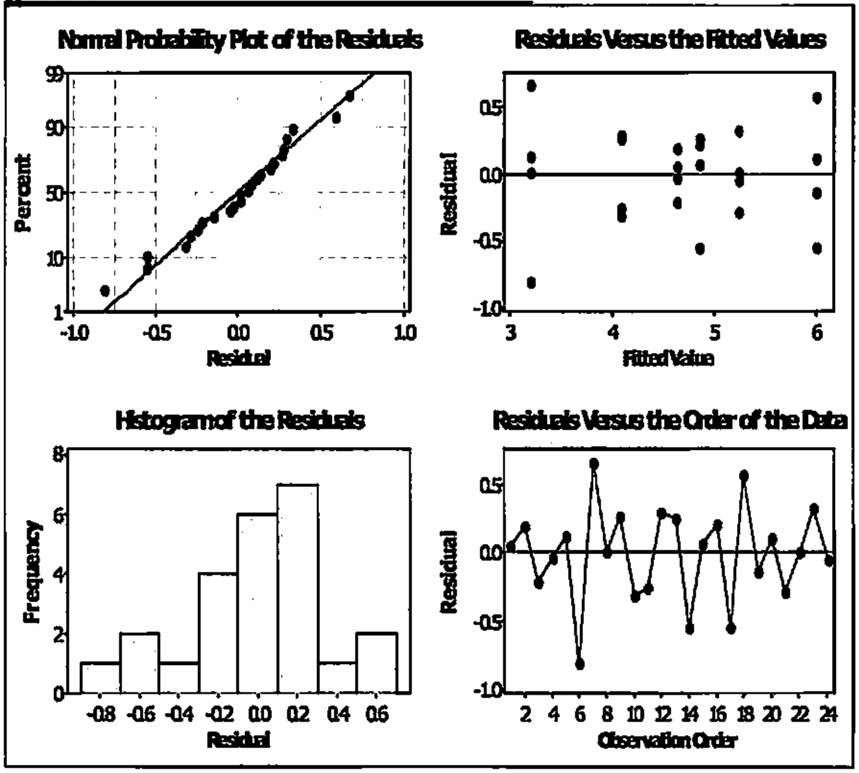
Appendix 3.37: Log transformation of ground cover individual species winter 2005:



Appendix 3.38: Histogram of log transformation of ground cover individuals winter 2005:



Appendix 3.39: Residual plots for log transformation of ground cover individuals winter 2005:



Appendix 3.40: One-way ANOVA: Log transformation ground cover individuals winter 2005 versus location:

```
Source    DF      SS     MS      F      P
Location   5  18.382  3.676  23.51  0.0001
Error     18   2.815  0.156
Total     23  21.197

S = 0.3955   R-Sq = 86.72%   R-Sq(adj) = 83.03%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --+---------+---------+---------+-------
1. C   4  4.6359  0.1714                (---*----)
2. H   4  3.2050  0.6087  (---*---)
3. MJ  4  4.0996  0.3273           (---*---)
4. GO  4  4.8546  0.3758                  (----*---)
5. KA  4  5.9957  0.4741                              (---*---)
6. KO  4  5.2456  0.2556                      (---*----)
                          --+---------+---------+---------+-------
                          3.0       4.0       5.0       6.0

Pooled StDev = 0.3955


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Location

Individual confidence level = 99.48%


Location = 1. C subtracted from:

Location    Lower   Center    Upper  --------+---------+---------+---------+-
2. H      -2.3187  -1.4309  -0.5430        (----*---)
3. MJ     -1.4242  -0.5364   0.3515             (---*----)
4. GO     -0.6692   0.2186   1.1065                 (---*----)
5. KA      0.4720   1.3598   2.2477                      (----*---)
6. KO     -0.2782   0.6096   1.4975                   (---*---)
                                     --------+---------+---------+---------+-
                                          -2.0       0.0       2.0       4.0


Location = 2. H subtracted from:

Location   Lower  Center   Upper  --------+---------+---------+---------+-
3. MJ     0.0067  0.8945  1.7824                    (---*----)
4. GO     0.7617  1.6495  2.5374                        (---*----)
5. KA     1.9028  2.7907  3.6786                              (---*---)
6. KO     1.1527  2.0405  2.9284                          (---*----)
                                  --------+---------+---------+---------+-
                                       -2.0       0.0       2.0       4.0


Location = 3. MJ subtracted from:

Location    Lower  Center    Upper  --------+---------+---------+---------+-
4. GO     -0.1329  0.7550  1.6429                   (----*---)
5. KA      1.0083  1.8962  2.7840                         (---*----)
6. KO      0.2581  1.1460  2.0339                     (----*---)
                                   --------+---------+---------+---------+-
                                        -2.0       0.0       2.0       4.0
```

```
Location = 4. GO subtracted from:

Location    Lower  Center   Upper  --------+---------+---------+---------+-
5. KA       0.2533  1.1412  2.0290                    (----*---)
6. KO      -0.4969  0.3910  1.2789                 (---*---)
                                   --------+---------+---------+---------+-
                                        -2.0       0.0       2.0       4.0


Location = 5. KA subtracted from:

Location    Lower   Center   Upper  --------+---------+---------+---------+-
6. KO     -1.6380  -0.7502  0.1377          (---*----)
                                    --------+---------+---------+---------+-
                                         -2.0       0.0       2.0       4.0
```

Appendix 3.41: Paired T-Test and CI: *Christella dentata* ground coverage comparisons between winter 2005 and summer 2004:

```
Paired T for summer 2004 - winter 2005

               N       Mean     StDev  SE Mean
summer 2004   24    10.5000   16.3521   3.3379
winter 2005   24    38.2083   53.8855  10.9993
Difference    24   -27.7083   49.1621  10.0352


95% CI for mean difference: (-48.4677, -6.9490)
T-Test of mean difference = 0 (vs not = 0): T-Value = -2.76  P-Value = 0.011
```

Appendix 3.42: Paired T-Test and CI: *Zingiber zerumbet* ground coverage comparisons between summer 2004 versus winter 2005:

```
Paired T for Z. zerumbet Summer 2004 - Winter 2005

               N     Mean    StDev  SE Mean
Summer 2004   24  18.2083  35.8196   7.3116
Winter 2005   24   0.0000   0.0000   0.0000
Difference    24  18.2083  35.8196   7.3116


95% CI for mean difference: (3.0831, 33.3336)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.49  P-Value = 0.020
```

Appendix 3.43: Nested ANOVA comparing vegetated ground cover among plots within sections, and transects within plots (summer 2004):

Source	df	SS	MS	F	P
Section	5	166056	33211	10.2	0
Plot	18	58488	3249	1.7	0.076
Transect	48	92425	1925		
Total	71	316969	4464.352		

Appendix 3.44: Nested ANOVA comparing vegetated ground cover among plots within sections, and transects within plots (winter 2005):

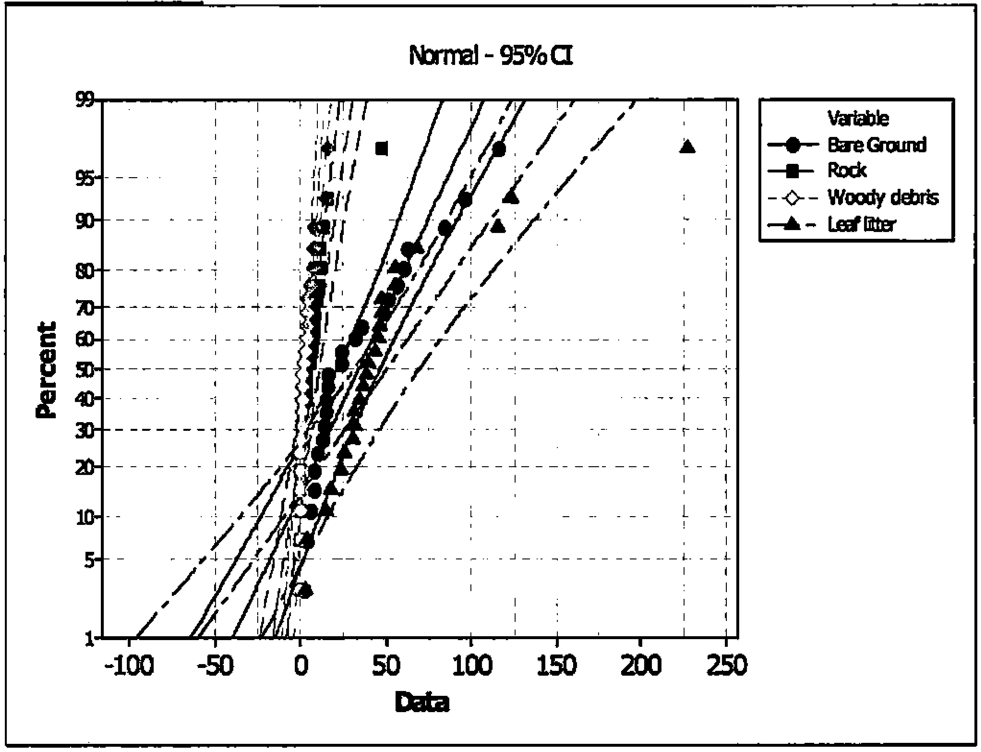
Source	df	SS	MS	F	P
Section	5	148057	29611	10.2	0

Plot	18	52285	2905	1.5	0.13
Transect	48	92663	1931		
Total	71	293004			

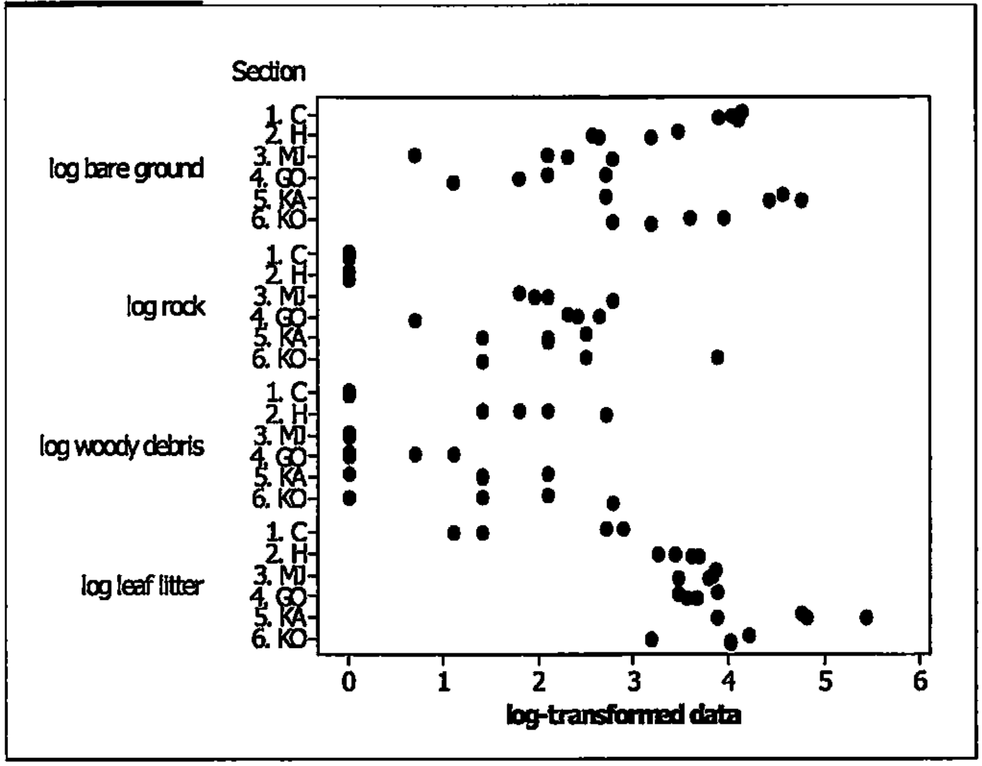
Appendix 3.45: Nested ANOVA comparing canopy cover among plots within sections, and transects within plots:

Source	df	SS	MS	F	P
Section	4	12203	3051	2.8	0.065
Plot	15	16452	1097	1.8	0.067
Transect	40	24197	605		
Total	59	52852			

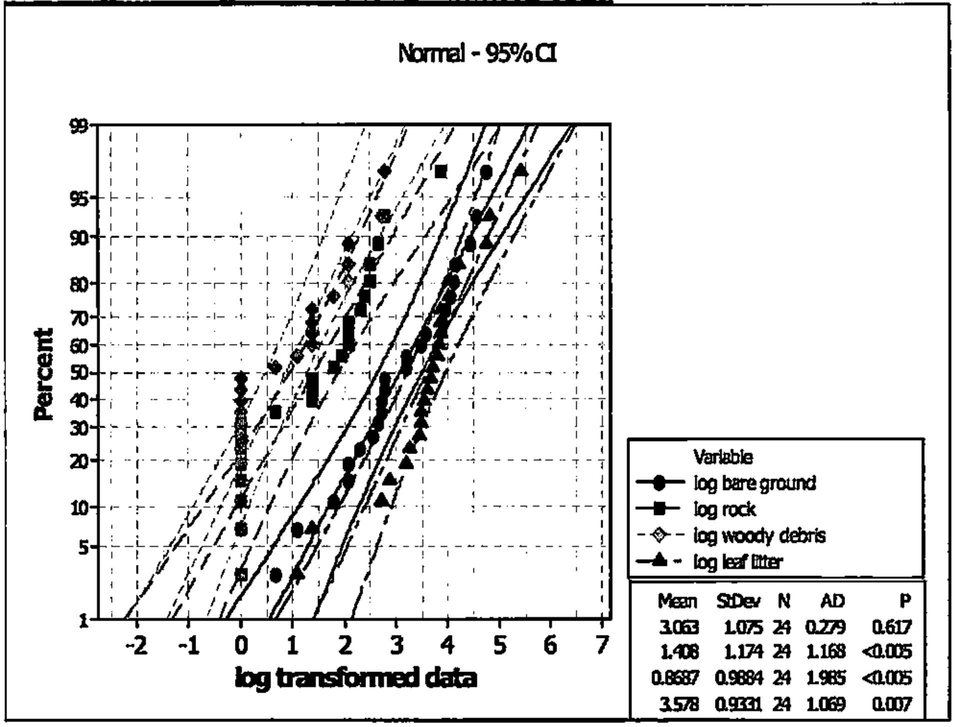
Appendix 3.46: Probability plot of non-vegetative ground cover for summer 2004:



Appendix 3.47: Log-transformed data for non-vegetative ground cover summer 2004:



Appendix 3.48: Probability plot of log-transformed data for non-vegetative ground cover summer 2004:



Mean	StDev	N	AD	P
3.063	1.075	24	0.279	0.617
1.408	1.174	24	1.168	<0.005
0.8687	0.9884	24	1.985	<0.005
3.578	0.9331	24	1.069	0.007

Appendix 3.49: Kruskal-Wallis Test: log transformation of bare ground values for summer 2004 versus section:

```
Kruskal-Wallis Test on log bare ground

Section    N  Median  Ave Rank      Z
1. C       4   4.077      19.3   2.09
2. H       4   2.909      10.9  -0.50
3. MJ      4   2.191       5.8  -2.09
4. GO      4   1.936       4.8  -2.40
5. KA      4   4.498      19.6   2.21
6. KO      4   3.381      14.8   0.70
Overall   24              12.5

H = 16.77  DF = 5  P = 0.005
H = 16.80  DF = 5  P = 0.005  (adjusted for ties)
```

Appendix 3.50: Kruskal-Wallis Test: log transformation of rock values for summer 2004 versus Section:

```
Kruskal-Wallis Test on log rock

Section    N       Median  Ave Rank      Z
1. C       4  0.000000000       4.5  -2.48
2. H       4  0.000000000       4.5  -2.48
3. MJ      4  2.012675846      16.5   1.24
4. GO      4  2.350240183      17.0   1.39
5. KA      4  2.079441542      15.9   1.05
6. KO      4  1.935600506      16.6   1.28
Overall   24                   12.5

H = 15.41  DF = 5  P = 0.009
H = 16.06  DF = 5  P = 0.007  (adjusted for ties)
```

Appendix 3.51: Kruskal-Wallis Test: log transformation of woody debris values for summer 2004 versus section:

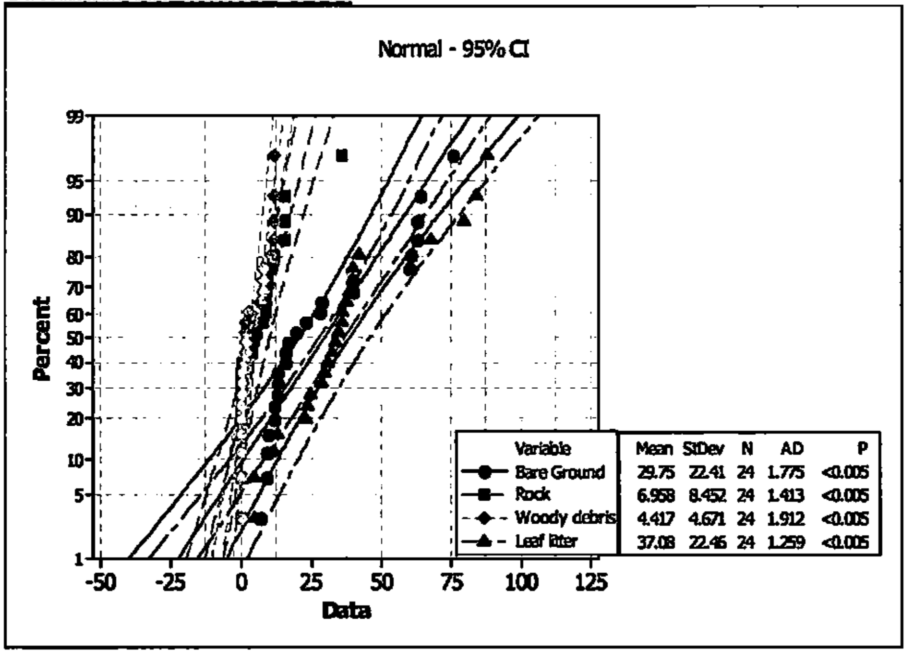
```
Kruskal-Wallis Test on log woody debris

Section    N       Median  Ave Rank      Z
1. C       4  0.000000000       6.5  -1.86
2. H       4  1.935600506      19.9   2.29
3. MJ      4  0.000000000       6.5  -1.86
4. GO      4  0.346573591      10.0  -0.77
5. KA      4  1.386294361      15.1   0.81
6. KO      4  1.732867952      17.0   1.39
Overall   24                   12.5

H = 12.78  DF = 5  P = 0.026
H = 14.70  DF = 5  P = 0.012  (adjusted for ties)
```

Appendix 3.52: Kruskal-Wallis Test: log transformation of leaf litter values for summer 2004 versus section:

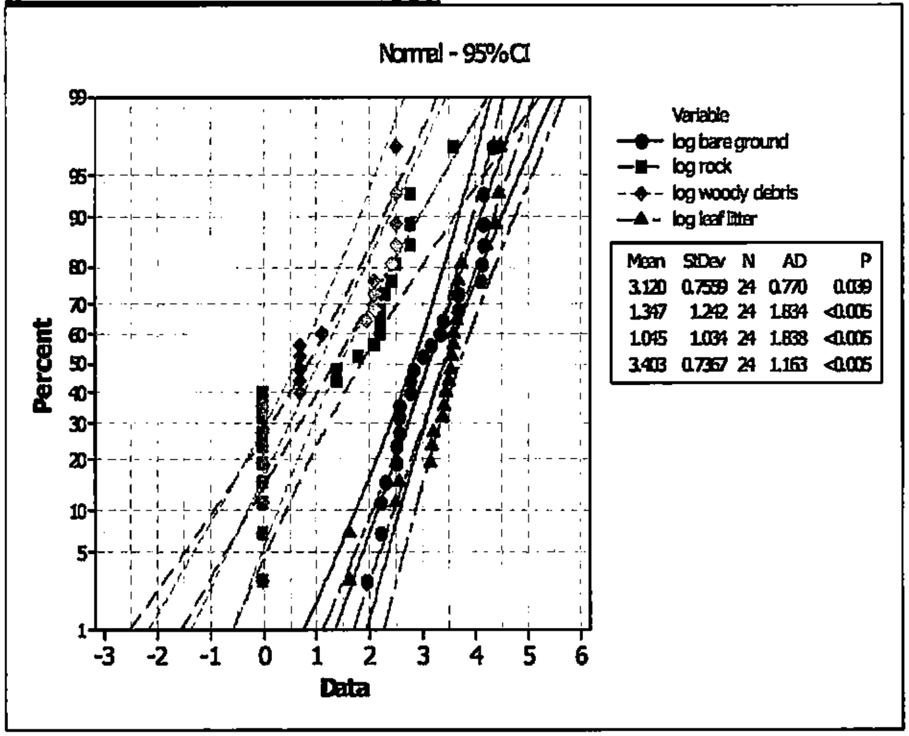
```
Kruskal-Wallis Test on log leaf litter

Section    N  Median  Ave Rank      Z
1. C       4   2.047       2.5  -3.10
2. H       4   3.522       9.3  -1.01
3. MJ      4   3.806      13.4   0.27
4. GO      4   3.609      12.0  -0.15
```

```
5. KA       4    4.787       21.6   2.83
6. KO       4    4.025       16.3   1.16
Overall    24                12.5

H = 16.71  DF = 5  P = 0.005
H = 16.73  DF = 5  P = 0.005  (adjusted for ties)
```

Appendix 3.53: Probability plot of non-vegetative ground cover contacts for winter 2005:



Appendix 3.54: Probability plot of log-transformed non-vegetative ground cover data winter 2005:



Appendix 3.55: Kruskal-Wallis Test: log-transformed bare ground contacts data for winter 2005 versus section:

```
Kruskal-Wallis Test on log bare ground

Section    N  Median  Ave Rank      Z
1. C       4   4.127      20.5   2.48
2. H       4   3.083      12.8   0.08
3. MJ      4   2.250       3.9  -2.67
4. GO      4   2.669       8.8  -1.16
5. KA      4   3.924      19.4   2.13
6. KO      4   2.629       9.8  -0.85
Overall   24              12.5

H = 16.59  DF = 5  P = 0.005
H = 16.65  DF = 5  P = 0.005  (adjusted for ties)
```

Appendix 3.56: Kruskal-Wallis Test: log-transformed rock contacts data for winter 2005 versus Section:

```
Kruskal-Wallis Test on log rock

Section    N       Median  Ave Rank      Z
1. C       4  0.000000000       5.5  -2.17
2. H       4  0.000000000       5.5  -2.17
3. MJ      4  2.249904835      17.3   1.47
4. GO      4  2.197224577      16.3   1.16
5. KA      4  2.628747686      17.4   1.51
```

```
6. KO     4  1.386294361      13.1   0.19
Overall  24                   12.5

H = 12.70  DF = 5  P = 0.026
H = 13.74  DF = 5  P = 0.017  (adjusted for ties)
```

Appendix 3.57: Kruskal-Wallis Test: log-transformed woody debris contacts data for winter 2005 versus Section:

```
Kruskal-Wallis Test on log woody debris

Section   N       Median  Ave Rank      Z
1. C      4  0.000000000       5.0  -2.32
2. H      4  2.171902711      15.9   1.05
3. MJ     4  0.693147181      11.0  -0.46
4. GO     4  0.693147181      10.3  -0.70
5. KA     4  1.039720771      12.6   0.04
6. KO     4  2.282174096      20.3   2.40
Overall  24                   12.5

H = 10.80  DF = 5  P = 0.055
H = 11.58  DF = 5  P = 0.041  (adjusted for ties)
```

Appendix 3.58: Kruskal-Wallis Test: log-transformed leaf litter contacts data for winter 2005 versus Section:

```
Kruskal-Wallis Test on log leaf litter

Section   N  Median  Ave Rank      Z
1. C      4   2.087       4.0  -2.63
2. H      4   3.198       9.5  -0.93
3. MJ     4   3.540      13.1   0.19
4. GO     4   3.541      12.3  -0.08
5. KA     4   4.007      16.1   1.12
6. KO     4   3.954      20.0   2.32
Overall  24              12.5

H = 12.09  DF = 5  P = 0.034
H = 12.10  DF = 5  P = 0.033  (adjusted for ties)
```

Appendix 3.59: Nested ANOVA for leaf litter values among plots within sections and among transects within plots (summer 2004):

```
Analysis of Variance for Leaf litter

Source    DF          SS         MS      F      P
Section    5  11071.4028  2214.2806  6.568  0.001
Plot      18   6068.2500   337.1250  3.189  0.001
Transect  48   5074.6667   105.7222
Total     71  22214.3194


Variance Components

                       % of
Source    Var Comp.   Total   StDev
Section     156.430   46.11  12.507
Plot         77.134   22.73   8.783
Transect    105.722   31.16  10.282
Total       339.286          18.420
```

```
Expected Mean Squares

1  Section     1.00(3) +  3.00(2) + 12.00(1)
2  Plot        1.00(3) +  3.00(2)
3  Transect    1.00(3)
```

Appendix 3.60: Nested ANOVA for bare ground comparisons among plots within sections and among transects within plots (summer 2004):

```
Analysis of Variance for Bare Ground

Source    DF         SS         MS      F      P
Section    5  5262.2778  1052.4556  8.068  0.000
Plot      18  2348.1667   130.4537  3.726  0.000
Transect  48  1680.6667    35.0139
Total     71  9291.1111


Variance Components

                      % of
Source    Var Comp.  Total    StDev
Section      76.833  53.48    8.765
Plot         31.813  22.14    5.640
Transect     35.014  24.37    5.917
Total       143.661          11.986


Expected Mean Squares

1  Section     1.00(3) +  3.00(2) + 12.00(1)
2  Plot        1.00(3) +  3.00(2)
3  Transect    1.00(3)
```

Appendix 3.61: Nested ANOVA for rock comparisons among plots within sections and among transects within plots (summer 2004):

```
Analysis of Variance for Rock

Source    DF         SS       MS      F      P
Section    5   268.7778  53.7556  1.936  0.138
Plot      18   499.6667  27.7593  1.412  0.169
Transect  48   943.3333  19.6528
Total     71  1711.7778


Variance Components

                      % of
Source    Var Comp.  Total  StDev
Section       2.166   8.83  1.472
Plot          2.702  11.02  1.644
Transect     19.653  80.15  4.433
Total        24.521         4.952


Expected Mean Squares
```

```
1  Section     1.00(3) +  3.00(2) + 12.00(1)
2  Plot        1.00(3) +  3.00(2)
3  Transect    1.00(3)
```

Appendix 3.62: Nested ANOVA for woody debris comparisons among plots within sections and among transects within plots (summer 2004):

```
Analysis of Variance for Woody debris

Source    DF        SS        MS       F      P
Section    5   76.7917   15.3583   3.382  0.025
Plot      18   81.7500    4.5417   1.243  0.267
Transect  48  175.3333    3.6528
Total     71  333.8750

Variance Components

                       % of
Source    Var Comp.   Total  StDev
Section       0.901   18.58  0.949
Plot          0.296    6.11  0.544
Transect      3.653   75.31  1.911
Total         4.850          2.202

Expected Mean Squares

1  Section     1.00(3) +  3.00(2) + 12.00(1)
2  Plot        1.00(3) +  3.00(2)
3  Transect    1.00(3)
```

Appendix 3.63: Nested ANOVA for bare ground comparisons among plots within sections and among transects within plots (winter 2005):

```
Analysis of Variance for Bare Ground

Source    DF         SS         MS        F      P
Section    5  2937.8333   587.5667   11.592  0.000
Plot      18   912.3333    50.6852    1.162  0.328
Transect  48  2093.3333    43.6111
Total     71  5943.5000

Variance Components

                       % of
Source    Var Comp.   Total  StDev
Section      44.740   49.32  6.689
Plot          2.358    2.60  1.536
Transect     43.611   48.08  6.604
Total        90.709          9.524

Expected Mean Squares

1  Section     1.00(3) +  3.00(2) + 12.00(1)
2  Plot        1.00(3) +  3.00(2)
3  Transect    1.00(3)
```

Appendix 3.64: Nested ANOVA for rock comparisons among plots within sections and among transects within plots (winter 2005):

```
Analysis of Variance for Rock

Source     DF         SS        MS      F      P
Section     5   189.5694   37.9139  1.906  0.143
Plot       18   358.0833   19.8935  0.863  0.621
Transect   48  1106.0000   23.0417
Total      71  1653.6528


Variance Components

                       % of
Source     Var Comp.   Total  StDev
Section        1.502    6.12  1.225
Plot          -1.049*   0.00  0.000
Transect      23.042   93.88  4.800
Total         24.543          4.954

* Value is negative, and is estimated by zero.


Expected Mean Squares

1  Section      1.00(3) +  3.00(2) + 12.00(1)
2  Plot         1.00(3) +  3.00(2)
3  Transect     1.00(3)
```

Appendix 3.65: Nested ANOVA for woody debris comparisons among plots within sections and among transects within plots (winter 2005):

```
Analysis of Variance for Woody debris

Source     DF        SS        MS      F      P
Section     5   98.1111   19.6222  5.107  0.004
Plot       18   69.1667    3.8426  0.697  0.797
Transect   48  264.6667    5.5139
Total      71  431.9444


Variance Components

                       % of
Source     Var Comp.   Total  StDev
Section        1.315   19.26  1.147
Plot          -0.557*   0.00  0.000
Transect       5.514   80.74  2.348
Total          6.829          2.613

* Value is negative, and is estimated by zero.


Expected Mean Squares

1  Section      1.00(3) +  3.00(2) + 12.00(1)
2  Plot         1.00(3) +  3.00(2)
3  Transect     1.00(3)
```

Appendix 3.66: Nested ANOVA for leaf litter comparisons among plots within sections and among transects within plots (winter 2005):

```
Analysis of Variance for Leaf litter

Source     DF         SS         MS       F       P
Section     5  1832.4444   366.4889   3.240   0.029
Plot       18  2036.1667   113.1204   1.780   0.057
Transect   48  3050.0000    63.5417
Total      71  6918.6111


Variance Components

                       % of
Source     Var Comp.   Total   StDev
Section       21.114   20.87   4.595
Plot          16.526   16.33   4.065
Transect      63.542   62.80   7.971
Total        101.182          10.059


Expected Mean Squares

1  Section      1.00(3) +  3.00(2) + 12.00(1)
2  Plot         1.00(3) +  3.00(2)
3  Transect     1.00(3)
```

Chapter 4:

"Microbial and chemical surface soil and water analysis of Waipā riparian zone and tributaries of Kaua‘i of the Hawaiian islands"

4.1 ABSTRACT:

Very minimal research exists on background levels of fecal indicator bacteria (*E. coli*, enterococci, total coliform) for riparian zone surface soils and ambient water in rural tropical island watersheds. This study assesses background levels of *E. coli*, enterococci, total coliform, pH, percent N, percent OC, Ca, Mg, K, and P within randomly located plots from composite surface soil samples of Waipā riparian zone, tributaries, and cattle pasture drainage ditch. The soil samples were analyzed using a defined substrate medium and enumeration system for fecal indicator bacteria, and for chemical components. We also tested water samples for *Enterococcus* at 7 different locations in Waipā watershed using standard techniques and protocol. Seventy-five percent of our composite surface soil samples contained a detectable limit of < 3.3 MPN/g of soil for enterococci. A range of < 3.3 MPN to > 80,654 MPN/g soil was found for *E. coli* between plots, and very high levels of total coliform were found in the majority of our composite soil samples in all plots. Principal component analysis (PCA) for microbial (0-10 cm) and chemical (0-5 cm) surface soil composite samples along Waipā stream and cattle pasture drainage ditch for PC1 showed an inverse relationship between pH and Mg on the one hand, and K and percent OC on the other hand. PC2 reflects a gradient that when surface soil values of *E. coli* are low, enterococci values are also low. PC3 reflects a gradient that when P values are low, *E. coli* values are also low in surface soil.

4.2 Introduction:

While much is known about nutrient and solids transport from land to our waterways, far less is understood about the survival and transport of the major pathogen groups (viruses, bacteria, and protozoa) (CRC, 2004). When considering water-quality parameters such as nutrients, and sediments, it is important to examine both concentration and load (concentration times flow volume) (Tate et al., 2005). Over the past decade, an increased understanding of the ecology of fecal indicator bacteria has seen many countries around the world shift away from total and fecal coliforms as the preferred fecal indicator bacteria for freshwater to *Escherichia coli* now being favored (Niemela et al., 2003). It has long been recognized that total coliform proliferate in nature (Mark, 1986).

Bacteria are also considered to be more likely to survive a longer period in soils with high water-holding capacity (Gerba and Bitton, 1984). Other studies have suggested that *E. coli* may be able to survive and regrow for extended periods in tropical habitats (Bonde, 1977). A study done in Puerto Rico stated that *E. coli* would seem to be invalid as an indicator of recent fecal contamination in tropical environments (Carillo et al., 1985). Rosen (2001) found the following survival times of *E. coli* for: slurry=300+ days, fecal pats=200+ days, soil=200+ days, and water=35 days.

Antibiotic resistant strains of *E. coli* and *Streptococcus faecalis* were found to persist in high numbers over a period of at least 32 days in saturated soil conditions (Hagedorn et al., 1978). In warm conditions, fecal coliform regrowth increases fecal coliform/fecal streptococci ratios to levels indicative of human contamination even where none clearly exists (Howell et al., 1996). Fecal coliform and fecal streptococci organisms survived significantly longer in sediment laden waters than with those without sediment and further the survival was longer in the sediment-laden waters than in a supernatant from that same sediment suspended in water (Sherer et al., 1992).

Enterococci were found to survive/multiply within specific non-fecal environments in New Zealand suggesting that multiple sources, environmental persistence, and environmental expansion of enterococci within selected niches add considerable complexity to the interpretation of water quality data (Anderson et al., 1997). Soil samples obtained near the stream bank, 10 m from the stream bank, and from a grassy area on the University of Hawai'i at Mānoa campus, were determined to be sources of both *E. coli* and enterococci (Hardina and Fujioka, 1991). Mānoa streambank is in Honolulu, O'ahu, which is the most heavily urbanized sector of the Hawaiian island chain, suggesting that perhaps the source of enterococci in soils of Mānoa stream and campus comes from non-point transport of microbial contaminants (e.g., mongoose, *Rattus* spp., birds, human sewage during flash floods, urban runoff, etc.). Another study by Fujioka and colleagues (1999) found enterococci in soil samples taken from the Pago River streambank of the tropical island of Guam. The Ordot landfill, which has been a dumping ground since the 1940's, serves as Guam's primary landfill for industrial and municipal waste and runoff from this site exits into the Lonfit river, which merges with the Sigua river to form the Pago river (U.S. EPA Region IX, 2002). Perhaps soil samples from Pago river streambank contain artificially elevated values of enterococci due to non-point source microbial contamination transported via surface and subsurface flow from the Ordot landfill.

The U.S. EPA recommends testing for *E. coli* and enterococci indicators for ambient waters in place of total and fecal coliform indicators, since "*E. coli* and enterococci show a direct correlation with gastrointestinal illness rates associated with swimming, while fecal coliforms do not (U.S. EPA, 2003)." But, studies on correlations between *E. coli* and enterococci with swimming associated gastrointestinal illness rates in ambient waters are lacking in Hawai'i and other tropical island watershed communities. The potential for microbial survival and regrowth in tropical areas has resulted in doubts concerning the interpretation of elevated indicator microbe concentrations in tropical environments, especially given that the studies used to establish the U.S. EPA guidelines were conducted in Boston Harbor, MA, New York City, NY, and New Orleans, LA, which are not representative of tropical regions (Shibata et al., 2004).

Perhaps *E. coli* and enterococci enter riparian surface soils of places such as Hawaiʻi, Guam, Puerto Rico and other tropical islands from point and non-point fecal sources, and survive and/or multiply over varying degrees of space and time. Survival times for fecal indicator bacteria upon entering into tropical island riparian zones are not known. Nor is it known if fecal indicator bacteria multiply upon introduction to tropical island riparian zones. If these fecal indicator bacteria *are* surviving and multiplying in tropical island riparian zones, do MPN values still correlate to gastrointestinal illness rates or other illnesses associated with use of ambient waters?

Potential point and non-point sources of microbial contamination and their ability to move through Hawaiian or other tropical island riparian zones have not been extensively studied. This study assesses background levels of fecal indicator bacteria (enterococci, *E. coli*, total coliform) and chemical components (percent N, percent OC, K, Mg, Ca, P, and pH) in surface soils of Waipā riparian zone, tributaries, and along a cattle pasture drainage ditch. Most of Waipā's 650 hectare watershed is uninhabited by people and covered in ferns, grasses, shrubs, and trees. But, the lower floodplain area is more altered by humans. Land use activities around lower Waipā watershed include taro and organic vegetable farming, residential buildings, a two-lane highway, grass parking area, beach campgrounds, cattle grazing and rodeo, frequent community meetings and educational seminars. It is well documented that land degradation caused by humans and animals changes the levels of fecal indicator bacteria and nutrients in associated soil and water systems. The transport of organic matter and sediment in pasture runoff can increase in-stream turbidity levels; however, well-vegetated pastures can also serve as sinks, or filters, for suspended solids (Tate et al., 2005).

Upper relatively uninhabited elevations of heavily vegetated Waipā riparian zone and tributaries receive the majority of their channel water via subsurface flow (Author's observation). Rock values significantly increase upstream at $P < .05$. Greater than 250 m high waterfalls appear during heavy rains along the south back wall of Mamalahoa peak (about 1141 m above mean sea level) which runs bowl style east to Kapalikea peak and west to Kolopua peak. Kapalikea and Kolopua ridges run downslope towards Waipā stream into the coastal zone of Hanalei Bay.

The potential regrowth of fecal indicator bacteria released into coastal environments in recreational water bodies has been of concern, especially in tropical and subtropical areas where the number of these bacteria can be artificially elevated beyond that from fecal impacts alone (Desmarais et al., 2002) primarily due to the persistence and regrowth of indicator microbes within the environment (Shibata et al., 2004). A study in Puerto Rico showed that water samples from bromeliads (*G. berteroniana*) contained elevated levels of *E. coli* (Rivera et al., 1988), and debate ensued as to the potential source of *E. coli* being from regrowth, survival over time, birds, rats, or naturally present in the environment. Thus, a dilemma exists with respect to which indicator is suitable for regulating recreational water bodies within the tropics, in particular for water bodies that lack a known sewage source of contamination (Shibata et al., 2004). Fujioka et al (1997) concluded that *C. perfringens* is the most reliable indicator of fecal contamination of environmental waters in Hawai'i and Guam, and recommended that *C. perfringens* be used to establish recreational water quality standards for both fresh (50 CFU/100 ml) and marine waters (5 CFU/100 ml) in Hawai'i (Fujioka, 2001).

Until now, as far as the authors know, no one has scientifically and methodically assessed a full length rural tropical island stream for background levels of fecal indicator bacteria in riparian surface soils. Studies on the tropical islands of O'ahu, Guam, and Puerto Rico assessed levels of fecal indicator bacteria in riparian surface soils and ambient waters, but all of these islands under U.S. jurisdiction are heavily urbanized and densely populated tropical island ecosystems. This study, conducted on the island of Kaua'i, is significantly less populated and urbanized than the islands of O'ahu, Guam, or Puerto Rico. Furthermore, virtually nobody frequents the majority of heavily vegetated Waipā watershed excluding a few researchers on a weekly basis. A wildlife survey of native and non-native animal migration patterns could increase knowledge of microbial transport throughout Waipā. And as development encroaches upon places such as Hanalei, the potential for increasing numbers of point and non-point source microbial contaminants to ambient waters will most likely increase.

4.3 Objectives:

This study evaluates temporal and spatial variation of fecal indicator bacteria in surface soil and water, and chemical components of surface soil across the tropical island rural watershed of Waipā, Kaua'i (Figure 4.1 and 4.2). Conflict exists as to which bacterial test is appropriate to determine the safety of tropical island ambient waters with regards to public health. Data from this study can be used to assess the applicability of U.S. EPA requirements for testing ambient waters of Hawai'i and other tropical island ecosystems for fecal indicator bacteria. Eventually, we want to examine correlations of fecal indicator bacteria levels in ambient waters and soils of Hawai'i to illness rates of concern by tracking the movement of bacteria such as enterococci through Waipā and other rural watersheds. Ideally, concurrent studies will occur by epidemiologists in order to assess illness rates associated with waterborne contaminants in Hawaiian communities of concern.

4.4 Methods and Materials:

4.4.1 Field techniques for collection of surface soil samples to test for fecal indicator bacteria:

Soil samples were collected 0-10 cm depth to test for fecal indicator bacteria (*E. coli*, enterococci, total coliform) in each of 24 randomly selected plots along Waipā stream, Kapalikea and Kolopua tributaries, and along a drainage ditch in the cattle pasture (Figure 4.2) in June through August 2005. Plot sizes along Waipā stream and the cattle pasture drainage ditch were 10 x 10 m, and 5 x 5 m in the tributaries. Four randomly located soil samples were collected within each plot based on size of the plot. For example, a 10 x 10 m plot has a 1000 cm length parallel to the stream, and a length of 1000 cm upslope and perpendicular to channel flow. A random number was selected for the parallel and perpendicular length of each plot and 4 soil samples were collected at 4 locations in each plot where these two numbers intersect, and these samples were composited. Samples were collected in a sterile manner using a spatula, immediately placed in a Whirlpak bag, sealed, placed on ice, and transported directly to the lab for analysis within approximately 6 hours for all soil samples.

4.4.2 Laboratory techniques for analyzing soil samples for E. coli, total coliform, and enterococci:

Processing steps were performed, which generally followed but slightly modified as in the protocol of Shibata et al (2004) for soil analysis for enterococci, *E. coli*, and total coliform using a chromogenic substrate technique (IDEXX, Westbrook, MN). In order to extract the microbes from the soil particles to a liquid, approximately 3 g of undried composite soil was removed from Whirlpak bags and placed into 100 ml IDEXX containers and mixed with 100 ml of solution (.85 g table salt, 100 ml distilled water).

The samples were shaken vigorously for 90-120 seconds to promote the transfer of microbes into the liquid phase, and homogenization of solution. The samples were allowed to settle for approximately 5 minutes. The only modification to the Shibata et al (2004) method included extracting 10 ml from the upper 50-70 percent of the eluate of the soil solution and mixing it with 90 ml of distilled water prior to filtering the sample. The dilution was necessary due to clogging of the 30 μm pore size nylon net filters (Type NY30, Millipore, Bedford, MA) by soil particles. After filtering, the diluted solution was transferred into individual IDEXX containers labeled Colilert and Enterolert. 100 ml of the liquid extract was then used for subsequent bacterial enumeration with the use of a chromogenic substrate (IDEXX, Westbrook, MN).

In the Shibata et al (2004) study, only beach sand was analyzed using the chromogenic substrate method, and this study examines riparian soils of heavy clay, silt and organic matter content. Enumeration of the microbe population is based upon the use of a tray [(Quanti-Tray/2000), IDEXX, Westbrook, MN] which separates the sample into 49 large and 48 small wells. The number of test wells that show the characteristic color or fluorescence under ultraviolet (UV) light indicate the concentration of indicator bacteria according to a standardized table that provides the concentration in terms of the most probable number (MPN). IDEXX's Colilert and Enterolert reagents were used for the simultaneous detection of total coliform, *E. coli* and enterococci.

Colilert and enterolert reagent were added into individual IDEXX sample bottles containing the filtrate and mixed until the reagent dissolved. The samples were poured into trays, sealed, and incubated at 35°C for total coliform and *E. coli* and 41°C for enterococci for 24 h. Test wells showing a yellow color were positive for total coliform and wells that fluoresced under UV light were positive for *E. coli* and enterococci.

Calculations to account for dilutions were: 3 g soil + 100 ml solution→ extraction of 10 ml soil solution + 90 ml distilled water→ Result x 100→ MPN/g soil. The detectable limits using our methods were < 3.3 MPN/g of soil, and >80,653.3 MPN/g of soil. Values of < 3.3 MPN/g soil for all fecal indicator bacteria were given values of zero for graphical and statistical analysis. Values that were > 80,653.3 MPN g/soil for *E. coli* and total coliform were changed to 80654 MPN/g of soil for graphical and statistical analysis.

Water content of the soil sample was calculated as: $WC = (m_{wetsoil} - m_{drysoil})/m_{wetsoil}*100$. The computation for mass of dry sediment (m_{dry}) is: $m_{dry} = (1 - WC)*(m_{wetsoil})$. Water content measurements were performed by measuring the weight of the soil before and after oven drying (110°C for 24 h) approximately 12 g of composite sample (Table 4.1).

All gear was sterilized prior to sample collection and analysis to prevent contamination. Blank Indian Arrowhead Distilled water samples were tested for total coliform, enterococci, and *E. coli* in order to confirm that there was no cross contamination prior to diluting the composite soil samples.

The method used for testing soils for fecal indicator bacteria in this study (ie, IDEXX) is not an approved standard method. But, the commercially available enumeration system (IDEXX) was significantly more precise for measuring *E. coli* numbers in feces and soil than the miniaturized standard MPN method ($P < .001$) (Muirhead et al., 2004). The test used in this study (IDEXX) is also much easier to use in adverse field conditions, and hard to reach rural areas in comparison to approved standard methods to test soils for fecal bacteria.

4.4.3 Techniques for control for microbial soil tests

3 g of 100 percent fresh cattle manure was tested using IDEXX as done for quantifying fecal indicator bacteria of soil samples in this study. Also, 1.5 g of manure was mixed with 1.5 g of composite soil from each plot in the tributaries, and the two highest elevation plots along Waipā stream and tested using IDEXX. For example, after a 3 g composite soil sample was analyzed from each plot in the tributaries, another 1.5 grams was extracted from the undried composite soil sample

and mixed with 1.5 grams of fresh cattle manure collected on the same day that soil samples were collected and analyzed for that particular plot.

4.4.4 Chemical surface soil analysis:

Soil samples were randomly collected in 16 plots along Waipā stream and cattle pasture drainage ditch from 0-5 cm, and 5-15 cm below the surface at random locations within each plot in November 2004 and mixed as a composite sample for each plot and depth. Samples were analyzed by the Agricultural Diagnostic Services Center at the University of Hawai‘i at Mānoa for pH, percent OC, percent N, K, Ca, Mg, and P.

4.4.5 Water quality analysis:

Different teams of people from the Waipā Foundation, UH Mānoa, Hanalei Watershed Hui, and Kaua‘i Youth Conservation Corps walked to 7 different monitoring locations up and down Waipā stream, and at the confluence of two upper elevation tributaries (Table 2.2) (Figure 4.2) on July 9, 2004, July 23, 2004, February 9, 2005, March 9, 2005, March 23, 2005, April 1, 2005, and June 1, 2005. Each person collected three 100 ml water samples in IDEXX containers from their monitoring location at approximately 8:30 a.m. Hawai‘i time according to the standard microbiological sampling protocol of the American Public Health Association (Franson, 1992). Samples were immediately brought to the lab on ice and analyzed for enterococci using a chromogenic substrate technique (IDEXX, Westbrook, MN), as approved by the U.S. EPA (2003). 10:90 dilutions of water sample:distilled water were used for all water samples collected on sampling dates in February and March of 2005. No dilutions were used on all other sampling dates for all monitoring sites. Blank distilled water samples were tested as a control to confirm no cross contamination. Perhaps in the future all water samples collected at or near Waipā stream mouth should be diluted at least 10:90 to avoid potential skewed results due to increased salinity in water samples, and the potential for very high levels of fecal bacteria at Waipā stream mouth. Water sampling collection results from April 1, 2005 were void due to improper use of the Menehune brand distilled water to dilute samples 10:90 (Personal communication with Dr. Carl Berg of Hanalei Watershed Hui). Menehune brand distilled water is ozonated and might contain an anti-microbial agent that kills enterococci (Personal communication with Dr. Carl Berg, Hanalei Watershed Hui).

At the same 7 locations where water samples were collected for enterococci analysis, 3 water samples were collected and tested per location twice in July 2004, 3 times in March 2005, and twice in April 2005 for turbidity (nephelometric turbidity units [ntu]) using an OakTon Turbidimeter T-100. Salinity (ppt), dissolved oxygen (mg/L), electrical (deciSiemens per meter [dS/m]) and specific conductivity (dS/m) were measured 3 times per monitoring day at each location twice during July 2004, on February 21, 2005, 3 times in March 2005, and once in April 2005 using a YSI MPS (Multiprobe sensor) 556 model.

Electrical conductivity measures the ability of water to conduct electricity (dS/m), and can serve as an inexpensive surrogate for laboratory-based chemical analysis. The electrical conductivity of water generally increases as levels of dissolved pollutants (such as nitrate, ammonium, phosphate, sulfate and potassium) and salinity increases. Turbidity measures the cloudiness or opaqueness of a water sample, and it increases with the level of suspended solids (such as particulate organic matter and sediments ≥ 0.45 micrometer [µm] in size) and dissolved solids (such as dissolved organic carbon < 0.45 µm in size) (Tate et al., 2005).

Due to the availability of relatively inexpensive and accurate field meters, five water-quality variables (electrical and specific conductivity, turbidity, salinity, and dissolved oxygen) can serve as "indicators," which can be monitored frequently in the field with appropriate training and quality-control procedures (Tate et al., 2005). In contrast, laboratory-based water-quality analysis (such as of nitrate and phosphate) is relatively expensive and time-sensitive, while sample analysis for other water-quality constituents (such as ammonium or bacteria) must be done within 24 hours of collection (Tate et al., 2005).

4.5 Results:

4.5.1 Microbial surface soil analysis:

Results for enterococci are highly skewed to the right, reflecting the high frequency of < 3.3 MPN/g of soil of enterococci in seventy-five percent of the composite soil samples tested at Waipā (Figure 4.3) (Appendix 4.2 and 4.5). The results for *E. coli* are also skewed to the right, reflecting the high occurrence of < 3.3 MPN/g of soil of *E. coli* in approximately 36 percent of the composite soil samples tested at Waipā (Appendix 4.2 and 4.5). The stem and leaf plot for total coliform is bimodal, reflecting some low and many very high values of MPN/g soil for total coliform (Appendix 4.2 and 4.5).

The MPN/g of soil per plot for all fecal indicator bacteria collected and tested using IDEXX shows the high frequency of < 3.3 MPN/g of soil for enterococci and highly variable results for *E. coli* and total coliform (Appendix 4.3). The mean per plot for fecal indicator bacteria of composite soil samples shows major differences between enterococci, *E. coli*, and total coliform values per gram of soil (Appendix 4.3) within each section. A normal probability plot for the fecal indicator bacteria data shows an abnormal distribution (Appendix 4.4). The log-transformed data is also not normally distributed (Appendix 4.6). So, using a non-parametric test (Kruskal-Wallis) shows that no significant differences exist at $P < .05$ between sections for fecal indicator bacteria values of surface soil (Appendix 4.7 through 4.9).

PCA for microbial soil analysis (Appendix 4.10 and 4.11) showed that the eigenvalue associated with PC1 is equal to 1.6. The first component reflects a gradient where if *E. coli* values are low, enterococci and total coliform values are low. The second component shows an inverse relationship where if enterococci values are high, total coliform values are low. Perhaps a competitive interaction effect occurs when high levels of enterococci coincide with low levels of total coliform.

4.5.2 Control for microbial soil tests:

Control tests using 50-50 soil-manure mixture, and 100 percent manure show increases in MPN/g of enterococci with increasing amounts of manure added to the soil (Table 4.2 and 4.3). Analysis of domestic and feral animal feces in New Zealand found enterococci in the range of 10^1-10^6 cfu/g with considerable variation between species (Anderson et al., 1997). Cattle manure tested at Waipā ranged from 179 to > 80,653 enterococci MPN/g feces (Table 4.3), within the range of results found in New Zealand by Anderson et al (1997).

4.5.3 Water quality data:

Enterococcus levels in water quality samples along Waipā stream showed major differences between monitoring locations over time and space. Water samples at Waipā bridge monitoring site had a higher geometric mean of enterococci values (MPN/100 ml) compared to all other sites on 5 out of 6 monitoring dates (Table 4.4). The geometric mean of enterococci for water samples at Waipā bridge ranged from 1 to 3 orders of magnitude higher than all other monitoring sites. Over all monitoring dates the geometric mean of enterococci decreases with increasing elevation up Waipā stream (Figure 4.4), to almost 0 MPN/100 ml on two dates at the highest elevation monitoring site [Site 5.) End GO] (Table 4.4). Comparing the geometric mean of water samples between Kapalikea and Kolopua tributaries shows similar results in enterococci MPN values between tributaries excluding samples taken during July 2004 (Figure 4.5).

A logarithmic transformation of all water samples tested for enterococci shows distinct differences of MPN levels between sites over time (Figure 4.6). Because of the wide range in data, and in order to preserve normality (but not make the data normal), we did the log-transformation to summarize with a measure of central tendency (Personal communication with Dr. Mark Walker, 2006). Comparing the log-transformed data between monitoring sites at Waipā Bridge and End GO gives a > 2 MPN/100 ml log-value for enterococci for the majority of water samples at Waipā bridge versus End GO (Figure 4.7).

Major differences in the logarithmically transformed enterococci water values for Kapalikea and Kolopua tributaries are seen during July 2004 (Figure 4.8), which coincides with the time that *P. cattleianum* trees bear fruit which feral pigs love to eat. Kapalikea tributary has a much higher geometric mean of enterococci water sample values during July 2004 compared to Kolopua tributary. Perhaps the huge pig den that exists atop the peak of fire-stricken Kapalikea during the growth of strawberry guava fruits correlates to high geometric mean values of enterococci in the water column. More research on feral pig migration patterns, and fruiting phenology of *P. cattleianum* in the watershed could provide valuable information on transport of fecal indicator bacteria thru Waipā.

Very high geometric means for enterococci (>1500 MPN/100 ml) for water samples (10 ml sample:90 ml distilled water) taken on 02/04/2005 at 2:30 p.m. at Waipā bridge appear to correlate to a heavy rain system from January 31st 2004 to February 4th 2005 where > 20" of rain fell in the upper watershed (Figure 4.9 and 4.10) (Table 4.5). Another heavy rain system of about 3" in the upper watershed from March 25th to 26th 2005 also appears to correlate to very high geometric means for enterococci (>1000 MPN/100 ml) water samples taken on 3/26/2005 at 8:30 a.m. at Waipā bridge (10 ml sample: 90 ml distilled water) (Figure 4.9 and 4.10) (Table 4.5).

A Pearson product moment-correlation analysis was used to evaluate relationships between dissolved oxygen, turbidity, electrical conductivity, specific conductivity, and salinity collected over different dates at all monitoring locations (Table 4.6). A highly strong positive relationship exists between electrical and specific conductivity, and salinity. The influx of ocean water at Waipā bridge mixing with freshwater at the stream mouth creates strongly positive correlated conductivity and salinity levels. Perhaps particles in the water column from surrounding land use also contribute to the high conductivity levels at Waipā bridge. Stream-flow diversions can increase conductivity by concentrating the existing dissolved pollutants within the stream and transporting new pollutants from pastures in runoff (Tate et al., 2005). Most monitoring collection dates were not directly after heavy rains.

Table 4.6 also shows a strong negative relationship between turbidity and dissolved oxygen. Perhaps when Waipā bridge monitoring site mixes with ocean water as the stream mouth flows into Hanalei Bay the streambed sediment stirs up in the water column causing turbidity and fecal indicator values to increase.

Statistics for field water quality variables show that the highest average over all monitoring dates was: turbidity at End C at 7.52 ntu, salinity at 1.383 ppt at Waipā bridge, EC at 2783 dS/m and SC at 2383 dS/m at Waipā bridge, and DO at End MJ at 9.09 mg/L (Table 4.7). Perhaps correlations exist between highest streamflow averages at End MJ and highest average dissolved oxygen levels at End MJ over time versus all other monitoring sites. The range of average DO between End H and all other upstream monitoring sites is 8.23 to 9.08 mg/L. The average DO at End C is 3.83 mg/L, and 5.08 mg/L at Waipā bridge.

4.5.4 Chemical soil analysis 0-5 cm below the surface:

A normal probability plot showed that the data is not normally distributed (Appendix 4.16). Log-transformation of the data shows an abnormal distribution (Appendix 4.17). A non-parametric Kruskal-Wallis test was used for all chemical soil variables, and showed that section C has a significantly higher pH than section H at P .02 (Table 4.8) (Appendix 4.18). Section C has a significantly lower percent N than section H at P .05 (Table 4.8) (Appendix 4.19). Section C has significantly lower values of percent OC than section H and GO at P .04 (Table 4.8) (Appendix 4.20). Section C has significantly lower values of K than section GO at P .02 (Table 4.8) (Appendix 4.21). No significant differences exist for values of P, Ca, and Mg between sections (Table 4.8) (Appendix 4.21, 4.23, and 4.24).

PCA for chemical soil components at 0-5 cm below the surface showed that the eigenvalue associated with PC1 is 2.91 (Appendix 4.25 and 4.26). The first component reflects a gradient that when pH values are low, percent N and percent OC values are high. The second component reflects a gradient that when P levels are high, Mg and Ca levels are also high. The third component reflects a gradient that when pH is high, K and Ca values are also high.

4.5.5 Chemical soil components 5-15 cm below the surface:

A normal probability plot of chemical soil components shows an abnormal distribution (Appendix 4.34). Log-transformation of the data is also abnormally distributed (Appendix 4.35). A non-parametric Kruskal-Wallis test for all chemical soil variables showed that pH was significantly higher in section C versus section H at P .02 (Table 4.9) (Appendix 4.36). Percent N and OC were significantly lower at P < .05 in section C versus section H (Table 4.9) (Appendix 4.37 and 4.38). K values were significantly lower in section C versus section GO at P .02 (Table 4.9) (Appendix 4.40). No significant differences were found for P, Ca, or Mg values between sections (Table 4.9) (Appendix 4.39, 4.41, and 4.42).

The eigenvalue associated with PC1 equals 3.32 (Appendix 4.43 and 4.44). The first component shows an inverse relationship in one hand with low pH and Mg values, and in the other hand with high K and percent OC values. PC2 reflects a gradient that when Ca is low, percent OC and percent N are also low. PC3 reflects a gradient that when pH and Ca values are high, P values are low.

4.5.6 PCA for microbial (0-10 cm) and chemical (0-5 cm) surface soil analysis of Waipā stream and cattle pasture drainage ditch:

The first component reflects a gradient that when pH and Mg values are low, K values are high. The second component reflects a gradient that when *E. coli* values are low, enterococci values are also low. The third component reflects a gradient that when P values are low, *E. coli* values are also low. Perhaps P values, which tend to be high in fecal material, correlate to low fecal indicator bacteria levels in the surface soil (Appendix 4.45 and 4.46).

4.6 Discussion:

While research technology for testing microorganisms in waters and soils improves, we often learn new techniques through trial and error. U.S. EPA recently approved Enterolert and Quanti-tray for testing ambient waters of the USA (U.S. EPA, 2003) for enterococci. In a sampling study on waters in Australia for a suite of indicators, enterococci (rather than *E. coli*), was the preferred indicator for timely warning of fecal contamination (CRC, 2004).

The number of *E. coli* recovered from feces and soil samples using the defined substrate medium and enumeration system (IDEXX) and a miniaturized MPN method (using traditional media) was compared by analyzing the difference between the two methods in relation to the mean (Muirhead et al., 2004). Placing 10 ml of a 1:10

dilution in the IDEXX Colilert-Quanti-Tray resulted in a detection limit of 1 CFU g^{-1} of soil, which should be sufficient for most environmental studies (Muirhead et al., 2004). The commercially available enumeration system (IDEXX) was significantly more precise than the miniaturized MPN method ($P < 0.001$) and found to be a suitable method for the measurement of *E. coli* numbers in feces and soil samples and should provide a reduction in laboratory analysis time (Muirhead et al., 2004).

The enumeration of bacteria in sediments and soils was achieved in a study by Desmarais et al (2002) using a modified version of a procedure by Van elsas et al (1997) by adding sediment to sterile distilled water, mixing vigorously, and then filtering through a 30-µm-pore-size nylon filter and testing the filtrate for enterococci, *E. coli*, and total coliform using IDEXX. In addition the Colilert method has recently been shown to be an appropriate means of enumerating *E. coli* in sewage sludge (Eccles et al., 2004), and because of the use of defined substrates Colilert was expected to be suitable for the recovery of stressed *E. coli* cells (Palmer et al., 1993; Eckner, 1998).

The importance of IDEXX to rural communities such as Waipā for testing soils for fecal indicator bacteria should not be underestimated. Standard methods require much more lab time, expertise, and equipment. If continued research on using IDEXX to test soils, sediment, and feces for fecal indicator bacteria prove that results are comparable to standard MPN methods, rural communities lacking adequate lab facilities will have the power to track microbial contaminants and establish Total Maximum Daily Loads (TMDL) in their watersheds at a significantly more efficient and affordable rate than is currently available with the standard methods. The U.S.

EPA and Hawai'i State Department of Health should continue evaluating IDEXX and its ability to provide significantly comparable results to the standard methods for testing soils for all fecal indicator bacteria similar to the Muirhead et al (2004) study. Many tropical island rural communities are so isolated and poor, that attaining the expertise and equipment required for the current standard methods to test soils and feces for fecal indicator bacteria is not plausible. IDEXX is a potentially powerful tool for people of developing rural tropical islands suffering from poor microbial soil and water quality to establish high quality Total Maximum Daily Load programs.

The concentration of human and animal feces applied to soil is an important parameter determining the potential for transportation of microbial contamination of water resources. The type and number of micro-organisms in manure can vary with the animal species, age of animals, the type of bedding used, the method of storage (liquid or solid), and the storage period (Lachica, 1990; Nodar et al., 1992). As the concentration of *E. coli* and/or enterococci increase(s), the illness rates also increase (U.S. EPA, 2003). But, neither the U.S. EPA nor Hawai`i State Department of Health has scientifically and methodically researched the correlation of illness rates of residents and visitors to fecal indicator concentrations in ambient waters and soils of rural Hawaiian watersheds.

But, much research exists from neighboring countries and land masses which can be used as models or idea generators for future research in the Hawaiian island chain. For example, cattle of live weight 450 kg produces 12 pats per day on average, and each pat contains 1.3×10^9 *E. coli* (Wilcock et al., 1999). In feces (cowpats) samples, the *E. coli* concentration, averaged over methods, was relatively constant between days 0 and 6, averaging 5•8 log g^{-1} ww, but increased to 7•0 (SED 0•10; $P <$ 0•001) log g^{-1} ww by day 29 (Muirhead et al., 2004). Ruprich (1994) found that liquid cattle manure samples contained: 4.5×10^2 to 1.5×10^6 (*E. coli*) and 4.5×10^2 to 9.5×10^5 for fecal streptococci (streptococci-D). CFU g^{-1} *E. coli* concentrations in cow feces can vary by over three orders of magnitude (Gregory et al., 2000).

Competitive interaction with native soil bacteria in the soil-manure mixtures is an important aspect governing survival of introduced organisms (Unc and Goss, 2003). After infiltrating the soil, the retention of bacteria depends on the physical configuration of soil, the soil chemistry, and the properties of microbial cells (Unc and Goss, 2003). There is little information on how the variable expression of bacterial cell surface properties affects retention within soil and manured soil (Unc and Goss, 2003).

Temperature, moisture content, sunlight, pH and the availability of organic matter have been shown to influence the survival of microorganisms in soil (Tyrrel and Quinton, 2003). Indicator bacteria, whether suspended in water or retained on membranes, are susceptible to inactivation by sunlight (Fujioka and Narikawa, 1981). An alkaline pH can result in immobilization of certain surface associated cations, thereby increasing the chances for bacteria to be removed from the adsorption sites and released into the soil solution (Stotzky, 1985). Average pH per plot in Waipā cattle pasture was 6.9 from 0-5 cm below the surface, and 7.4 for 5-15 cm. Perhaps we found values of < 3.3 MPN/g of enterococci in soil in the cattle pasture section because the enterococci were released into the soil solution. At 5-15 cm below the soil surface in the cattle pasture section, Ca values had the highest mean per plot of any section at 2959 µg/g, reflecting the sandy content of the soil and it's proximity to the ocean. Most likely, the current location of the cattle pasture used to be a sandy beach, and it is hypothesized that subsurface infiltration in this area is very high and water can move relatively easily through this type of substratum.

Catchment characteristics such as soil type and hydrology need to be accounted for in pathogen transport models (CRC, 2004). The path followed by water, infiltration or surface runoff determines the direction of transport of bacteria from manure (Unc and Goss, 2003). Streamflow diversions can increase conductivity by concentrating the existing dissolved pollutants within the stream and transporting new pollutants from pastures in runoff (Tate et al., 2005). Size of waterborne bacteria ranges from .1 to 10 µm (Gerba, 1996). By limiting pore occlusion at the soil surface, there is a greater likelihood that colloidal particles and bacteria will move below the soil surface (Unc and Goss, 2003). There is evidence that bacterial transport in the vadose zone may occur very rapidly in any field that receives water at a sufficient rate to fill the soil pores (McMurry et al., 1998; Unc and Goss, 2003). Preferential flow paths may give contaminants a more direct and rapid path to groundwater (Goss et al., 2002; Unc and Goss, 2003), and perhaps into the water column of tributaries and streams. Rain events mobilize significant concentrations of *E. coli* (particularly from fresh fecal material) over distances of many meters (CRC, 2004), making places such as riparian water columns and streambed sediments focal points for bacteria transport from non-point sources of fecal contamination. As water flows toward a stream channel via surface and subsurface flow, streamflow varies spatially and temporally and deposition of microorganisms on the streambed sediment will fluctuate.

Benthic sediments have been found to harbor significantly higher concentrations of enteric bacteria than the overlying water (Sherer et al., 1992). Different bacteria may thrive at different depths in streambed sediment and most human fecal bacteria are common only in the uppermost few millimeters (Moriarty and Pullin, 1987). Extended survival of fecal bacteria in sediment can obscure the source and extent of fecal contamination in agricultural settings (Howell et al., 1996). When the streambed sediment is next disturbed, whether by flood, aquatic animals or human activity, these bacteria are lifted into the water column again (Buckley et al., 1998).

In riparian transition zones, the quality of exfiltrating water is heavily influenced by microbial activities within the bed sediments (Pusch et al., 1998). The total stock of bacteria in any watercourse includes those in shallow streambed sediments as well as those in the water column, and though the volume of sediment may be many times smaller than the volume of water, its bacterial concentrations may be many times higher (Van Donsel and Geldreich, 1971; Stephenson and Rychert, 1982). Bacterial concentrations in sediments are independent of short-term streamflow and disturbance: these factors affect short-term partitioning of bacteria-laden sediment between streambed and water column, but not short-term concentrations of bacteria in sediment remaining on the streambed (Buckley et al., 1998). Sometimes, Waipā stream mouth clogs up behind a sandberm creating a stagnant pond environment until appropriate tidal conditions and rainfall force water out to Hanalei Bay, potentially carrying fecal indicator bacteria from the streambed sediments into the coastal zone.

Studies in South Florida found that indicator microbes are capable of multiplying in soil, in particular within soils subjected to tidal action (Desmarais et al., 2002) (Solo-Gabriel et al., 2002). In another study on beaches in Miami, Florida, concentrations of enterococci were elevated at the shore line during high tide with spikes of 306 and 270 CFU/100 ml for enterococci water samples, and sand samples ranging from 1 to 37 CFU enterococci/g (Shibata et al., 2004). The largest concentration of enterococci (37 CFU/g of dry sand) and fecal coliform (49 CFU/g of dry sand) were detected from submerged sand near the east end of the Miami beach (Shibata et al., 2004).

Appropriate recommendations for manure management to protect water resources from pathogens cannot be formulated without a detailed understanding of the factors affecting the survival and transport of micro-organisms from manure between source locations and surface or groundwater bodies (Unc and Goss, 2003). Continued research on movement, reproduction, and survival of *fecal indicator bacteria*, specifically enterococci through tropical island watersheds and their correlation to illnesses of concern could improve knowledge and application of buffer zones for decreasing microbial contaminants to ambient water. Waipā stream links Hanalei Bay, and future studies of pathogen movement through Waipā watershed should include riparian and coastal zone water and substrate analysis.

Future research is required to evaluate the effect of manure composition on soil properties controlling water transport, the flow regime within the soil, and the potential impact of manure components on the water partitioning at the soil surface (Unc and Goss, 2003). Encouraging animals not to defecate in the riparian zones by placing shade trees, watering and feed points as far away from watercourses as possible and by fencing where acceptable (CRC, 2004) could greatly improve ambient water quality at Waipā and ultimately Hanalei Bay.

Perhaps data from this study indicates that enterococci are not an indigenous source in riparian zones of Hawai'i, or other rural tropical islands. We can only speculate at this point as to the efficacy of using enterococci to provide relevant data for determining the safety of ambient waters in tropical waters. But this study does show important differences in water quality and surface soil values for enterococci over different areas of land use along Waipā stream, tributaries, and cattle diversion ditch. If soil and water are not indigenous sources of enterococci in Hawai'i, then the use of enterococci as a bacterial test in ambient waters could provide rural and urban tropical island communities with a powerful easy to use tool, IDEXX, a Federally recognized standard test for ambient waters. Also, if we correlate enterococci values in ambient waters to illness rates of concern and know the source, movement, and reproductive capacity of enterococci in tropical island watersheds, we can create healthier communities by implementing best management practices such as riparian buffer zones.

4.7 References:

Anderson, S.A., Turner, S.J., Lewis, G.D. 1997. Enterococci in the New Zealand environment: implications for water quality monitoring. Water Science and Technology 35(11-12): 325–331.

Anon. (1986) Ambient Water Quality Criteria for Bacteria. U.S. Environmental Protection Agency, Washington, DC.

Berg, Carl. 2006. Personal Communication. Hanalei Watershed Hui.

Bonde, G.J. 1977. Bacterial indicators of water pollution. Adv. Aquatic Microbiology. 1: 273-364.

Buckley R, Clough E, Warnken W, Wild C (1998) Coliform Bacteria in Streambed Sediments in a Subtropical Rainforest Conservation Reserve. Water Resources 32:1852-1856.

Carillo, M., Estrada, E., Hazen, T.C. 1985. Survival and enumeration of the fecal indicators *Bifidobacterium adolescentis* and *Escherichia coli* in a tropical rain forest watershed. Appl Environ Microbiol. 1985 August; 50(2): 468–476.

Cooperative Research Center (CRC) for Water Quality and Treatment. 2004. Pathogen movement and survival in catchments, groundwaters, and raw water storages: management implications from the CRC Water Quality and Treatment Catchments and Storages Research Program. 22 pp. Salisbury, South Australia.

Desmarais TR, Solo-Gabriele HM, Palmer CJ. 2002. Influence of soil on fecal indicator organisms in a tidally influenced subtropical environment. Appl. Environ. Microbiol. 1165–1172.

Eccles JP, Searle R, Holt D, Dennis PJ (2004) A comparison on methods used to enumerate *Escherichia coli* in conventionally treated sewage sludge. Journal of Applied Microbiology 96:375–383.

Eckner KF (1998) Comparison of membrane filtration and multiple tube fermentation by the Colilert and Enterolert methods for detection of waterborne coliform bacteria, *Escherichia coli*, and enterococci used in drinking and bathing water quality monitoring in Southern Sweden. Applied and Environmental Microbiology 64:3079-3083.

Franson, M.A.H. 1992. Standard Methods for the Examination of Water and Wastewater, 18th ed. American Public Health Association, Washington D.C.

Fujioka, R., Narikawa, O. 1981. Effect of Sunlight on Enumeration of Indicator Bacteria Under Field Conditions. Applied and Environmental Microbiology 44(2): 395-401.

Fujioka, R. B. Roll, and M. Byappanahalli. 1997. Appropriate recreational water quality standards for Hawaii and other tropical regions based on concentrations of *Clostridium perfringens*, p. 405-411. In Proceedings of WEF-TEC 97, 70th Annual Conference and Exposition, vol. 4. Surface Water and Ecology. Water Environment Federation, Alexandria, VA.

Fujioka, R., C. Sian-Denton, M. Borja, J. Castro, and K. Morphew. 1999. Soil: the environmental source of *Escherichia coli* and Enterococci in Guam's streams. The Journal of Applied Microbiology Symposium Supplement. 85: 83S-89S.

Fujioka, R.S. 2001. Monitoring coastal marine waters for spore-forming bacteria of faecal and soil origin to determine point from non-point source pollution. Water Science and Technology. 44:181-188.

Gerba CP, Bitton G (1984) Microbial pollutants: their survival and transport pattern to groundwater. In: Gerba CP, Bitton G (Eds.), Groundwater Pollution Microbiology. Wiley, New York, pp. 66-88.

Gerba, CP (1996) Pathogens in the Environment. Pollution Science. pp. 279-296.

Goss, M.J., Rollins, K.S., McEwan, K., Shaw, J.R., Lammershelps, H., 2002. The management of manure in Ontario with respect to water quality (Commissioned Paper No. 6). In: The Walkerton Inquiry. Queen's Printer for Ontario. Ontario Ministry of the Attorney General, Toronto, Ont.

Gregory, NG, Jacobson LH, Nagle TA, Muirhead RW, Le Roux GL (2000) Effect of preslaughter feeding systems on weight loss, gut bacteria, and the physico-chemical properties of digesta in cattle. New Zealand Journal of Agricultural Research 43:351–361.

Hagedorn C, Hansen TD, Simonson GH (1978). Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. Journal of Environmental Quality 7:55-59.

Hardina, C.M., R.S. Fujioka. 1991. Soil: the Environmental Source of *Escherichia coli* and Enterococci in Hawaii's Streams. Environmental Toxicology and Water Quality: An International Journal. 6: 185-195.

Howell JM, Coyne MS, Cornelius, PL (1996) Effect of sediment particle size and temperature on fecal bacteria mortality rates and the fecal coliform/fecal streptococci ratio. Journal of Environmental Quality 25: 1216-1220.

Lachica RV (1990) Significance of hydrophobicity in the adhesiveness of pathogenic Gram-negative bacteria. In: Doyle RJ, Rosenberg M (Eds.), Microbial Cell Surface Hydrophobicity. American Society for Microbiology, Washington, DC, pp. 297-314.

Mark, W.N. 1986. Total Coliform Bacteria. The American Society for Testing and Materials, 1977; 59-64.

McMurry SW, Coyne MS, Perfect E (1998) Fecal coliform transport through intact soil blocks amended with poultry manure. Journal of Environmental Quality 27:86-92.

Moriarty, D.J.W. and Pullin R.S.V. (eds.). 1987. *Detritus and Microbial Ecology in Aquaculture*. International Centre for Living Aquatic Resources Management (ICLARM). Manilla.

Muirhead, R.W., Littlejohn, R.P., Bremer, P.J. 2004. Evaluation of the effectiveness of a commercially available defined substrate medium and enumeration system for measuring *Escherichia coli* numbers in faeces and soil samples. Letters in Applied Microbiology, 39: 383-387.

Niemela, S.I., Lee, J.V. and Fricker, C.R. (2003). A comparison of the international standards organisation reference method for the detection of coliforms and *Escherichia coli* in water with a defined substrate procedure. Journal of Applied Microbiology 95: 1285–1292.

Nodar R, Acea MJ, Carballas T (1992) Poultry slurry microbial population: composition and evolution during storage. Bioresources Technology 40:29-34.

Palmer CJ, Tsai YL, Lang AL, Sangermano LR (1993). Evaluation of Colilert-marine water for detection of total coliforms and *Escherichia coli* in the marine environment. Applied and Environmental Microbiology 59: 786–79.

Pusch M, Fiebig D, Brettar I, Eisenmann H, Ellis BK, Kaplan LA, Lock MA, Naegeli MW, Traunspurger W (1998) The role of micro-organisms in the ecological connectivity of running waters. Freshwater Biology 40: 453-495.

Rivera, S., Hazen, T., Toranzos, G. 1988. Isolation of Fecal Coliforms from Pristine Sites in a Tropical Rain Forest. Applied and Environmental Microbiology. 54(2): 513-517.

Rosen BH, Croft R, Atwill ER, Wade S, Stehman S (2000) Waterborne pathogens in agricultural watersheds. Technical note 2, p.1-64. Watershed Science Institute, University of Vermont, Burlington, VT.

Rüprich, A., 1994. Felduntersuchungen zum Infiltrationvermogen und zur Lebensfahigkeit von Fakalkeimen in Boden nach Gulledungung. Ph.D. Thesis. University of Hohenheim, Germany.

Sherer, B.M., Miner, R., Moore, J., Buckhouse, J.C. 1992. Indicator Bacterial Survival in Stream Sediments. J. of Environ. Qual. 21: 591-595.

Shibata, T., Solo-Gabriele, H., Fleming, L., Elmir, S. 2004. Monitoring marine recreational water quality using multiple microbial indicators. Water Research 38: 3119-3131.

Solo-Gabriele HM, Wolfert MA, Desmarais TR, Palmer CJ. 2000. Sources of *Escherichia coli* in a coastal subtropical environment. Appl Environ Microbiol. 66(1): 230–7.

Stephenson G.R., Rychert R.C. 1982. Bottom sediment: A reservoir of *Escherichia coli* in rangeland streams. *J. Range Manag.* 35: 119-123.

Stotzky, G. 1985. Mechanisms of adhesion to clays, with reference to soil systems. In: Savage, D.C., Fletcher, M. (Eds.), Bacterial Adhesion: Mechanisms and Physiological Significance. Plenum Press, New York, pp. 195-254.

Tate, K., Lancaster, D., Morrison, J., Lile D., Sado, Y., Huang, B. 2005. Monitoring helps reduce water-quality impacts in flood-irrigated pasture. California Agriculture, Volume 59, Number 3. pp 168-175.

Tyrell SF, Quinton JN (2003) Overland flow transport of pathogens from agricultural land receiving faecal wastes. Journal of Applied Microbiology. 94s1:87-94.

Unc A, Goss M (2003) Transport of bacteria from manure and protection of water resources. Applied Soil Ecology 25:1-18.

U.S. Environmental Protection Agency (2003). Guidelines Establishing Test Procedures for the Analysis of Pollutants; Analytical Methods for Biological Pollutants in Ambient Water; Final Rule. U.S. Federal Register- 40 CFR Part 136 Vol. 68, No. 139.

U.S. Environmental Protection Agency Region IX. "Ordot Landfill, Guam, EPA

ID #GUD980637649". 2002. http://www.yosemite.epa.gov/r9/sfund/overview.nsf/0/63cce65b1eb302cc8825660b007ee666?OpenDocument#descr (17 Oct. 2005).

Van Donsel DJ, Geldreich EE (1971) Relationships of salmonellae to faecal coliforms in bottom sediments. Water Resources 5:1079-1087.

Van Elsas, J. D., and K. Smalla. 1997. Methods for sampling soil microbes, p. 383-390. *In* C. J. Hurst, G. R. Knudsen, M. J. McInernery, L. D. Stetzenbach, and M. V. Walter (ed.), Manual of environmental microbiology. ASM Press, Washington, D.C.

Walker, Mark. 2006. Personal Communication.

Wilcock RJ, Nagels JW, Rodda HJE, O'Connor MB, Thorold BS, Barnett JW (1999) Water quality of a lowland stream in a New Zealand dairy farming catchment. New Zealand Journal of Marine Freshwater Resources 33:683-696.

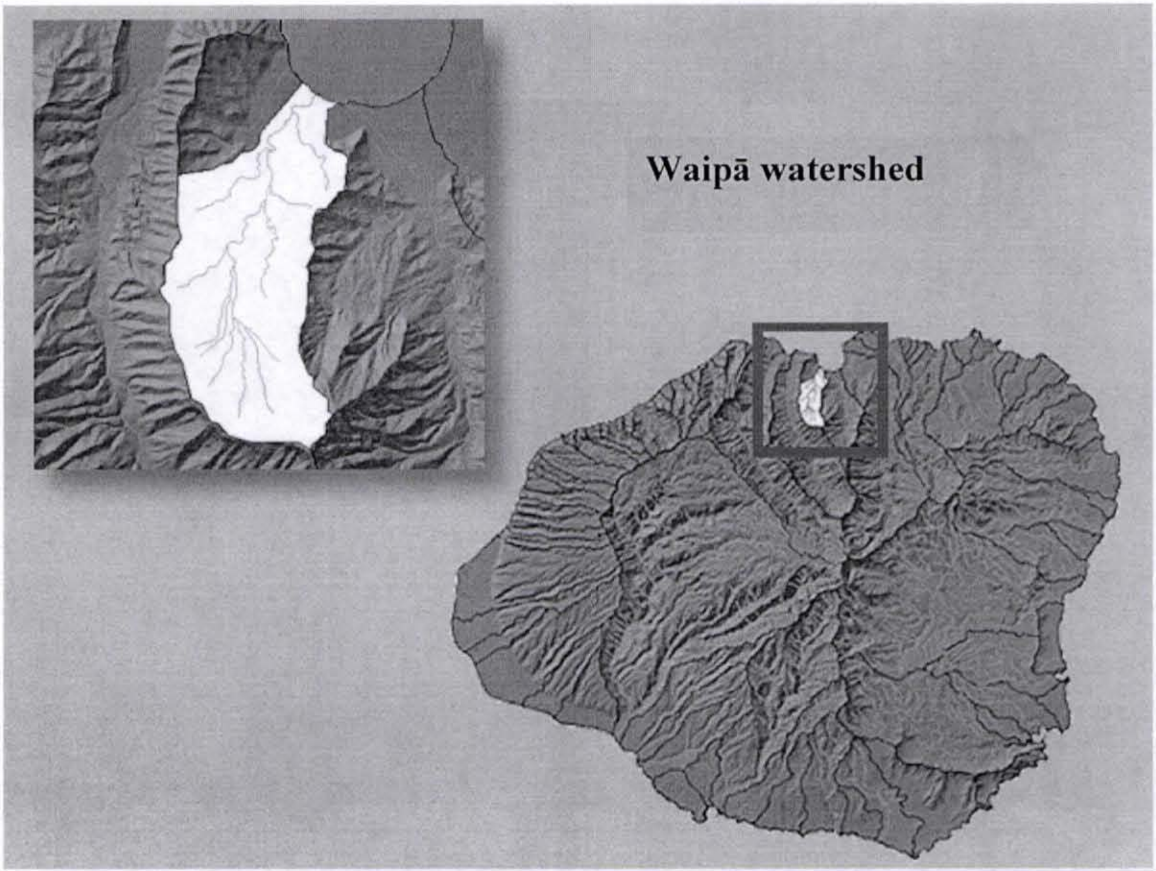


Figure 4.1: Waipā watershed and Island of Kaua`i

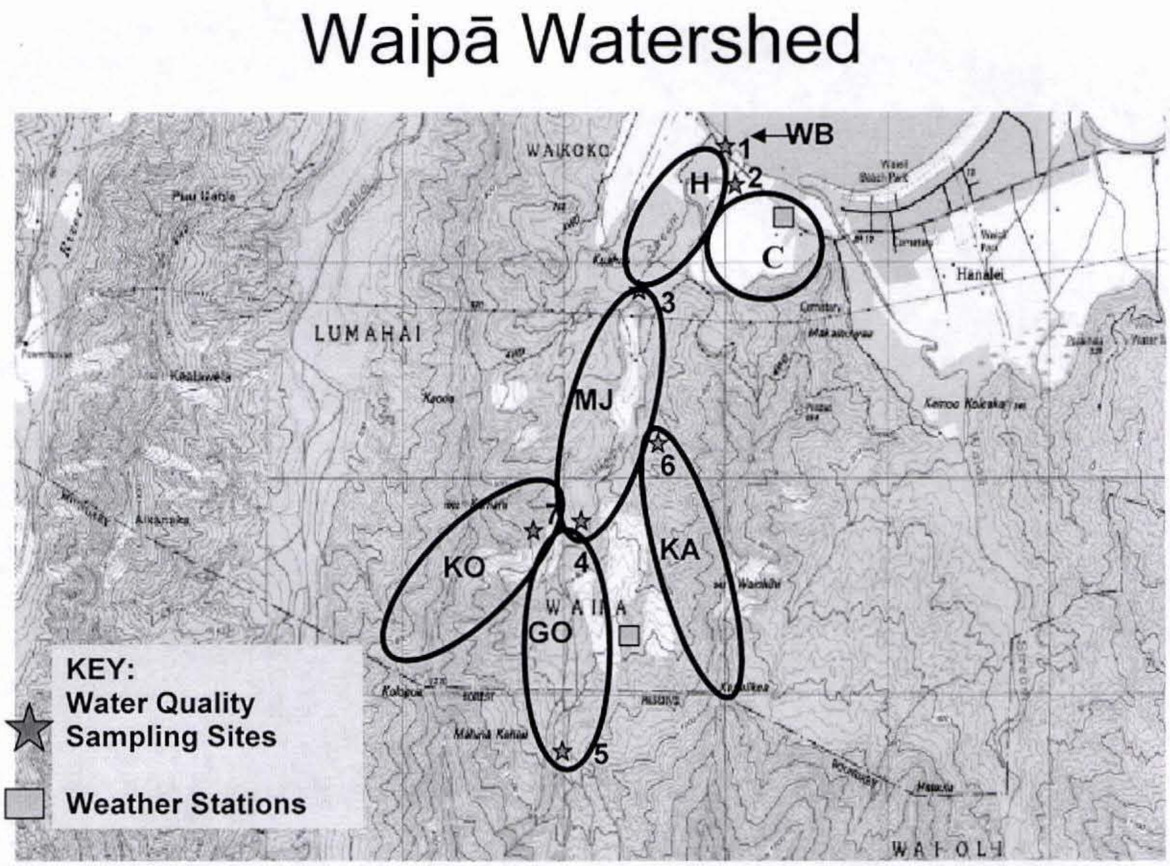


Figure 4.2: Waipā Topography Map labeled with major areas of study: stratified dominant riparian canopy communities, two major tributaries, and cattle pasture. Stream temperature and water quality monitoring sites were placed at the beginning and end of each riparian vegetation community, at the confluence of two tributaries, and at the end of a cattle pasture drainage ditch.

Site 1.) WB=Waipā bridge at stream mouth
Site 2.) C= Cattle pasture drainage ditch (300 meters long)
Site 3.) H=*H. tiliaceus* section (1000 meters long)
Site 4.) MJ= *M. indica* and *S. cumini* section (2000 meters long)
Site 5.) GO = *P. guajava*, *P. cattleianum*, and *M. polymorpha* section (1100 meters long)
Site 6.) KA= Kapalikea tributary (2000 meters long)
Site 7.) KO= Kolopua tributary (1000 meters long)

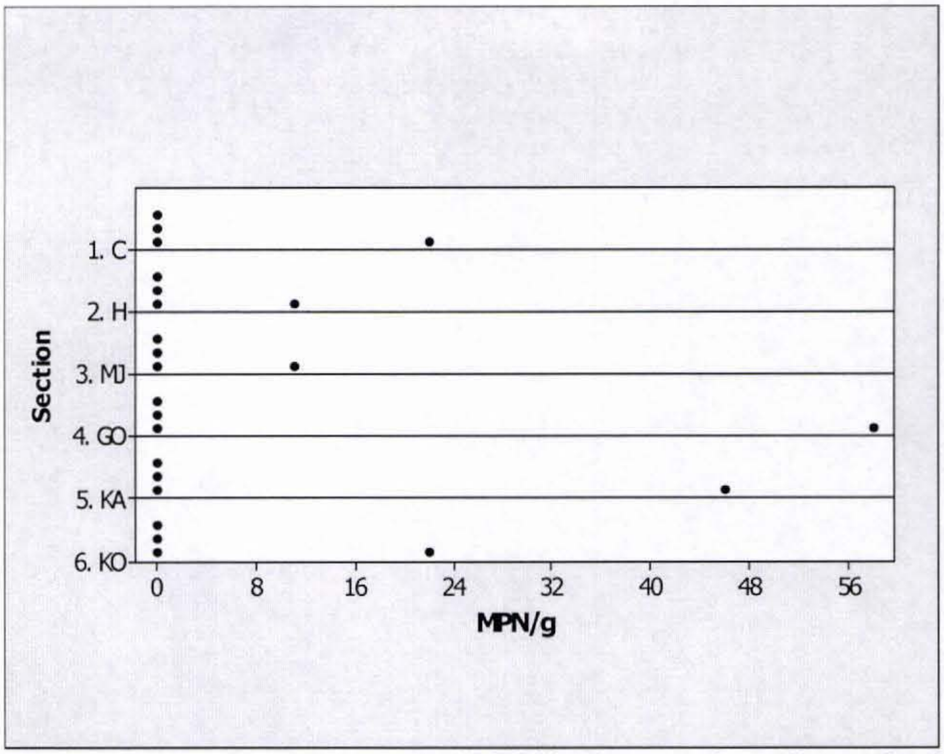


Figure 4.3: Dotplot of enterococci MPN/g of composite soil samples for all plots

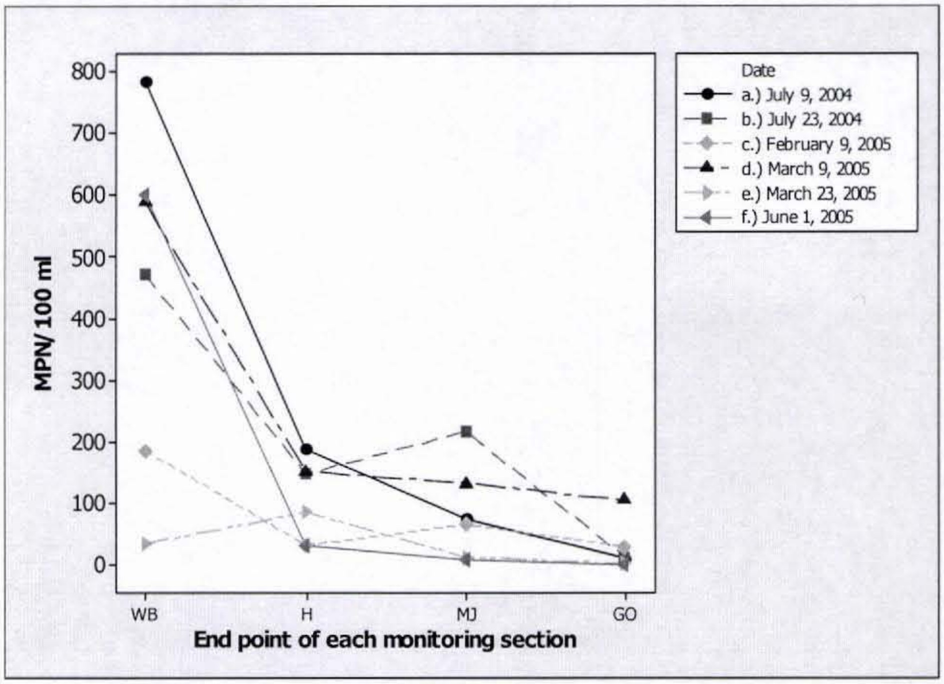


Figure 4.4: Geometric mean of water samples tested for enterococci along Waipā stream

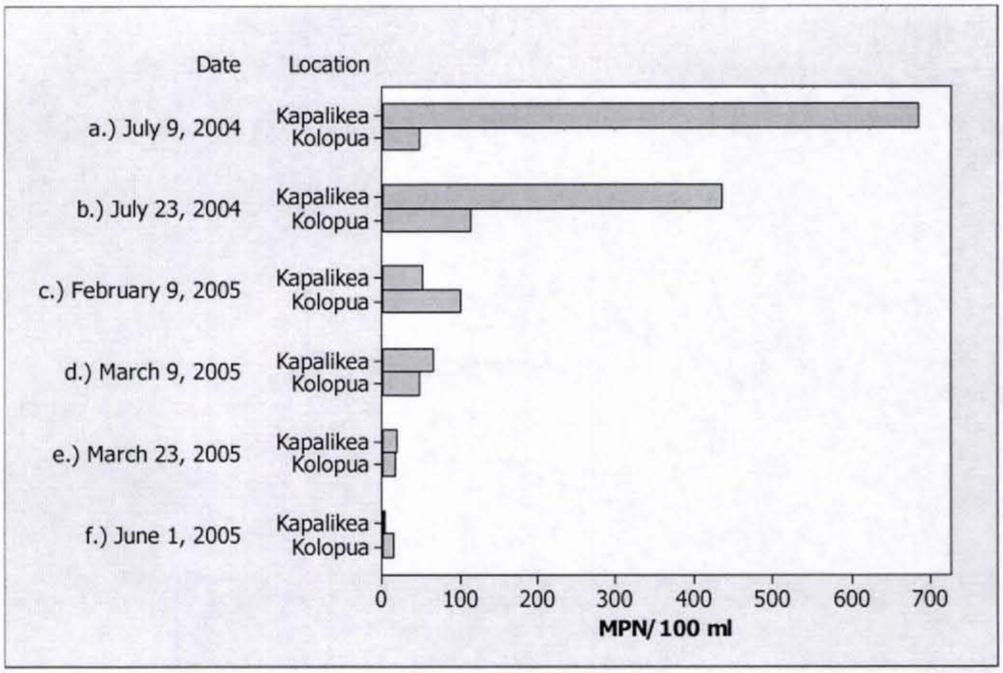


Figure 4.5: Geometric mean of water samples tested for enterococci in Waipā tributaries

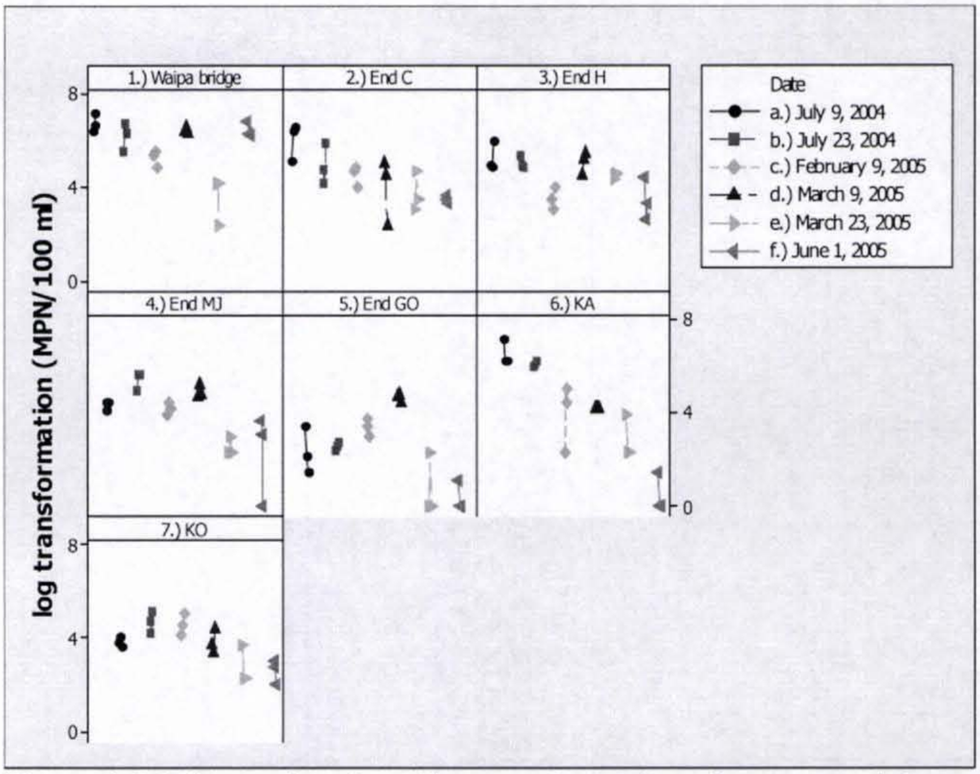


Figure 4.6: Time series plot of log transformation of enterococci data (MPN/100ml) for all monitoring sites for water samples

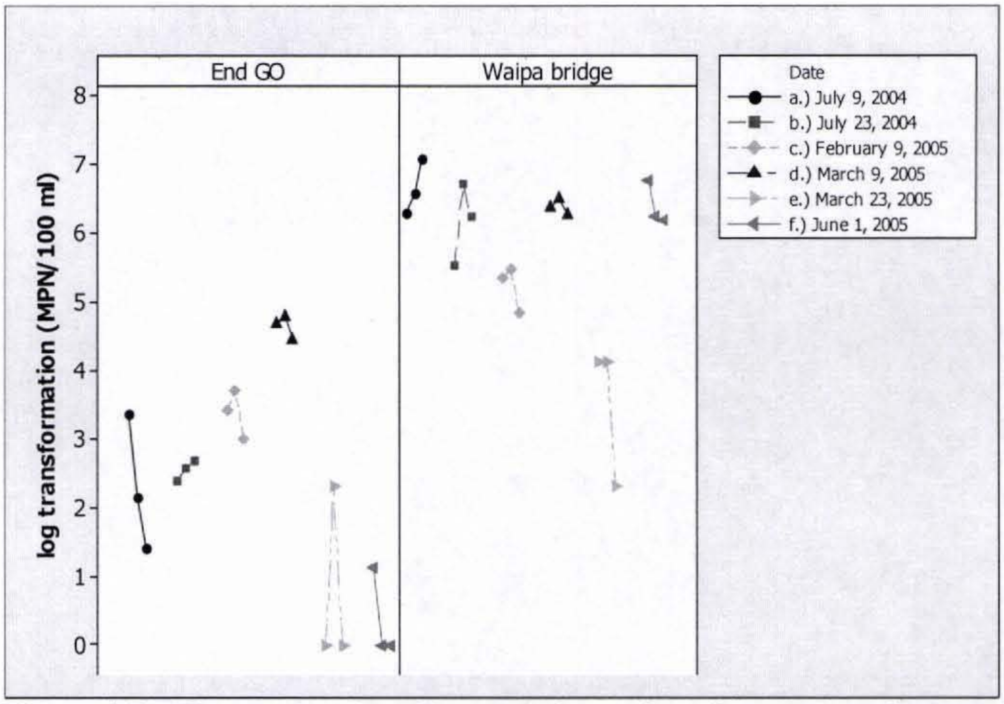


Figure 4.7: Time series plot of log transformation of water samples tested for enterococci (MPN/100 ml) at highest (Site 5: End GO) versus lowest (Site 1: WB) elevation monitoring sites along Waipā stream

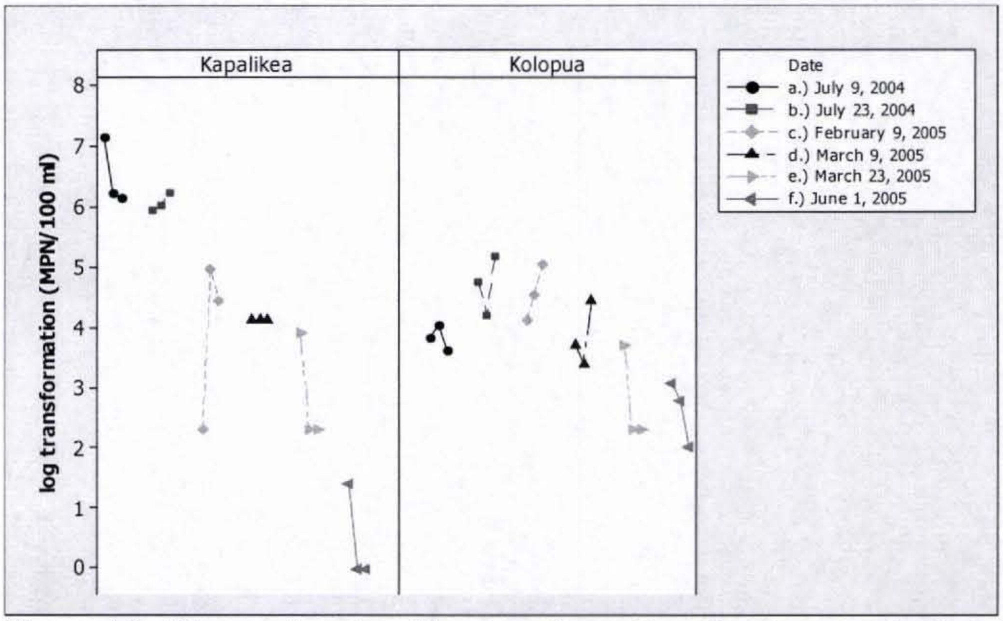


Figure 4.8: Time series plot of log transformation of water samples tested for enterococci (MPN/100 ml) at Waipā tributaries

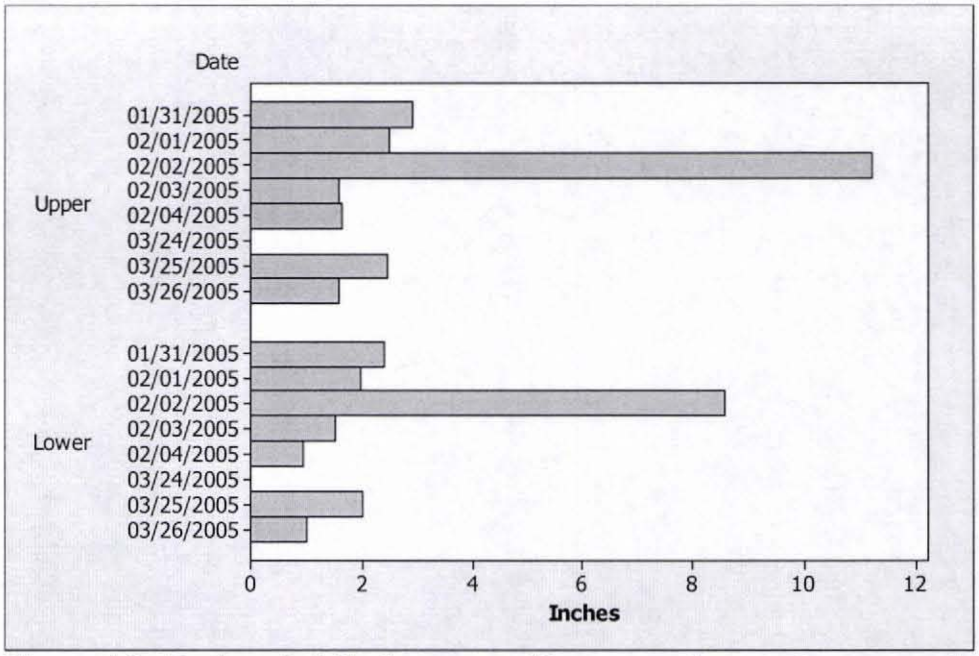


Figure 4.9: Daily rainfall of upper and lower weather stations around the time of intense storms

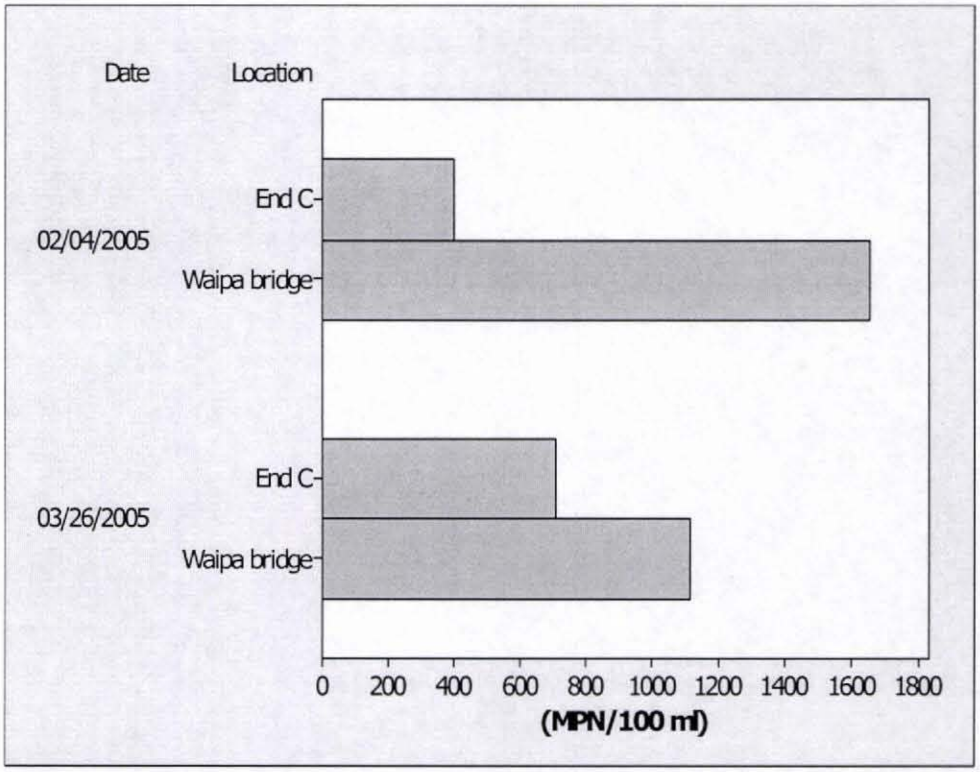


Figure 4.10: Geometric mean of enterococci in water samples after heavy rainstorms

Table 4.1: Average water content per plot of composite soil samples 0-10 cm below surface tested for fecal indicator bacteria:

Section	Water Content (%)	Standard Deviation
1.) C	39.46	2.37
2.) H	39.27	13.73
3.) MJ	27.63	12.98
4.) GO	45.69	7.65
5.) KA	49.44	3.84
6.) KO	42.33	3.05

Table 4.2: MPN g^{-1} of fecal indicator bacteria of 50-50 cattle manure-composite soil samples used as a control for microbial soil lab techniques:

Location	Section	MPN/g (*E. coli*)	MPN/g (total coliform)	MPN/g (enterococci)
GO3	GO	>80653	>80653	1515.7
GO4	GO	>80653	>80653	>80653
KA1	KA	6813.3	>80653	398.9
KA2	KA	>80653	>80653	276.7
KA3	KA	10230.0	>80653	11.1
KA4	KA	>80653	>80653	236.7
KO1	KO	>80653	>80653	436.7
KO2	KO	>80653	>80653	448.9
KO3	KO	10893.3	>80653	4835.6
KO4	KO	13370.0	>80653	1036.7

Table 4.3: MPN g^{-1} of fecal indicator bacteria of 100 percent fresh cattle manure samples used as a control for microbial soil lab techniques:

Plot	Section	MPN/g (*E. coli*)	MPN/g (total coliform)	MPN/g (enterococci)
GO3	GO	>80653	>80653	>80653
G04	GO	>80653	>80653	>80653
KA1	KA	>80653	>80653	730
KA2	KA	>80653	>80653	310
KA3	KA	>80653	>80653	178.9
KA4	KA	>80653	>80653	291.1
KO1	KO	>80653	>80653	8077.8
KO2	KO	>80653	>80653	3616.7
KO3	KO	22070	>80653	6812.2
KO4	KO	>80653	>80653	6083.3

Table 4.4: Geometric mean of water samples tested for enterococci at monitoring locations:

Day	1.) WB	2.) END C	3.) END H	4.) END MJ	5.) END GO	6.) KA	7.) KO
July 9, 2004	825.9	463.1	216.2	76.2	13.8	765.2	47.2
July 23, 2004	527.5	171.4	151.2	227.7	13	438.4	121
Feb. 9, 2005	193	91.7	34	67	30.7	80.3	105.7
March 9, 2005	593.7	80.3	164	135.3	105.3	63	52.3
March 23, 2005	45.3	51.7	85.7	13.3	9.3	23.7	20.3
June 1, 2005	624	31.8	40.8	20	1.7	1.7	15.1

Table 4.5: Enterococci values in water samples after heavy storms:

Location	Date	MPN/100 ml
1.) Waipā bridge	02/04/2005	2046
1.) Waipā bridge	02/04/2005	2046
1.) Waipā bridge	02/04/2005	1086
2.) End C	02/04/2005	602
2.) End C	02/04/2005	529
2.) End C	02/04/2005	199
1.) Waipā bridge	03/26/2005	1106
1.) Waipā bridge	03/26/2005	1071
1.) Waipā bridge	03/26/2005	1172
2.) End C	03/26/2005	624
2.) End C	03/26/2005	798
2.) End C	03/26/2005	712

Table 4.6: Pearson product moment correlations: Dissolved Oxygen (mg/L), Electrical Conductivity, Specific Conductivity, Salinity (ppt), and Turbidity (ntu):

	DO(mg/L)	EC	SC	Salinity(ppt)
EC	-0.244			
	0.193			
SC	-0.247	1.000		
	0.188	0.000		
Salinity (ppt)	-0.218	0.996	0.996	
	0.247	0.000	0.000	
Turbidity(ntu)	-0.560	-0.059	-0.060	-0.060
	0.001	0.755	0.754	0.753

Table 4.7: Statistics for field-water quality variables at monitoring locations as an average over 6 dates from June 2004 to April 2005:

Variable	SITE	Mean	Maximum
DO (mg/L)	1. Waipā bridge	5.60	7.60
	2. End C	3.83	5.20
	3. End H	8.23	9.30
	4. End MJ	9.08	9.70
	5. End GO	8.92	9.60
	6. KA	8.62	9.20
	7. KO	8.68	9.20
EC (dS/m)	1. Waipā bridge	2719	11077
	2. End C	182.65	211.00
	3. End H	94.03	102.00
	4. End MJ	85.52	92.00
	5. End GO	69.73	80.00
	6. KA	103.55	110.40
	7. KO	116.52	123.70
SC	1. Waipā bridge	2583	10507
	2. End C	174.67	200.30
	3. End H	88.65	99.50
	4. End MJ	81.33	92.10
	5. End GO	65.38	76.00
	6. KA	97.88	111.50
	7. KO	111.42	119.00
Salinity (ppt)	1. Waipā bridge	1.383	6.200
	2. End C	0.100	0.100
	3. End H	0.067	0.100
	4. End MJ	0.000	0.000
	5. End GO	0.000	0.000
	6. KA	0.100	0.100
	7. KO	0.100	0.100
Turbidity (NTU)	1. Waipā bridge	3.13	4.20
	2. End C	7.52	16.00
	3. End H	2.35	5.30
	4. End MJ	1.73	3.20
	5. End GO	1.57	3.30
	6. KA	2.53	4.20
	7. KO	3.42	6.60

Table 4.8: Table of means and significant differences for chemical soil analysis 0-5 cm below surface:

Section	pH	% OC	%N	P µg/g	K µg/g	Ca µg/g	Mg µg/g
C	6.9_{a}	4_{a}	0.29_{a}	31.5_{ns}	108_{a}	2737_{ns}	2615_{ns}
H	6_{b}	11.2_{b}	0.79_{b}	23.2_{ns}	466_{ab}	3201_{ns}	2120_{ns}
MJ	6.1_{ab}	7.8_{ab}	0.45_{ab}	12.8_{ns}	526_{ab}	2310_{ns}	1840_{ns}
GO	6.3_{ab}	9.1_{b}	0.53_{ab}	16_{ns}	858_{b}	3072_{ns}	1825_{ns}

Table 4.9: Table of means and significant differences for chemical soil analysis 5-15 cm below surface:

Section	pH	% OC	%N	P µg/g	K µg/g	Ca µg/g	Mg µg/g
C	7.4_{a}	3.5_{a}	0.26_{a}	27.8_{ns}	27_{a}	2959_{ns}	2609_{ns}
H	5.8_{b}	6.6_{b}	0.52_{b}	19.3_{ns}	255.8_{ab}	2246_{ns}	1809_{ns}
MJ	6_{ab}	5.4_{ab}	0.35_{ab}	12.3_{ns}	312.3_{ab}	1737_{ns}	1572_{ns}
GO	6.1_{ab}	6.2_{ab}	0.41_{ab}	13.7_{ns}	592_{b}	2115_{ns}	1505_{ns}

Appendix 4.1: Water content per plot for surface soil samples (0-10 cm) tested for fecal bacteria:

Sample location	Wet weight (g)	Mass of dry sample (g)	Water content of sample (%)
C1	12	7.63	36.4
C2	12	7.21	39.9
C3	12	7.28	39.3
C4	12	6.94	42.2
H1	12	6.41	46.6
H2	12	5.98	50.2
H3	12	7.10	40.8
H4	12	9.66	19.5
MJ1	12	10.92	9.0
MJ2	12	8.21	31.6
MJ3	12	8.31	30.8
MJ4	12	7.30	39.2
GO1	12	5.33	55.6
GO2	12	6.74	43.8
GO3	12	6.45	46.3
GO4	12	7.55	37.1
KA1	12	6.08	49.3
KA2	12	6.51	45.8
KA3	12	5.43	54.8
KA4	12	6.25	47.9
KO1	12	6.74	43.8
KO2	12	7.43	38.1
KO3	12	6.92	42.3
KO4	12	6.59	45.1

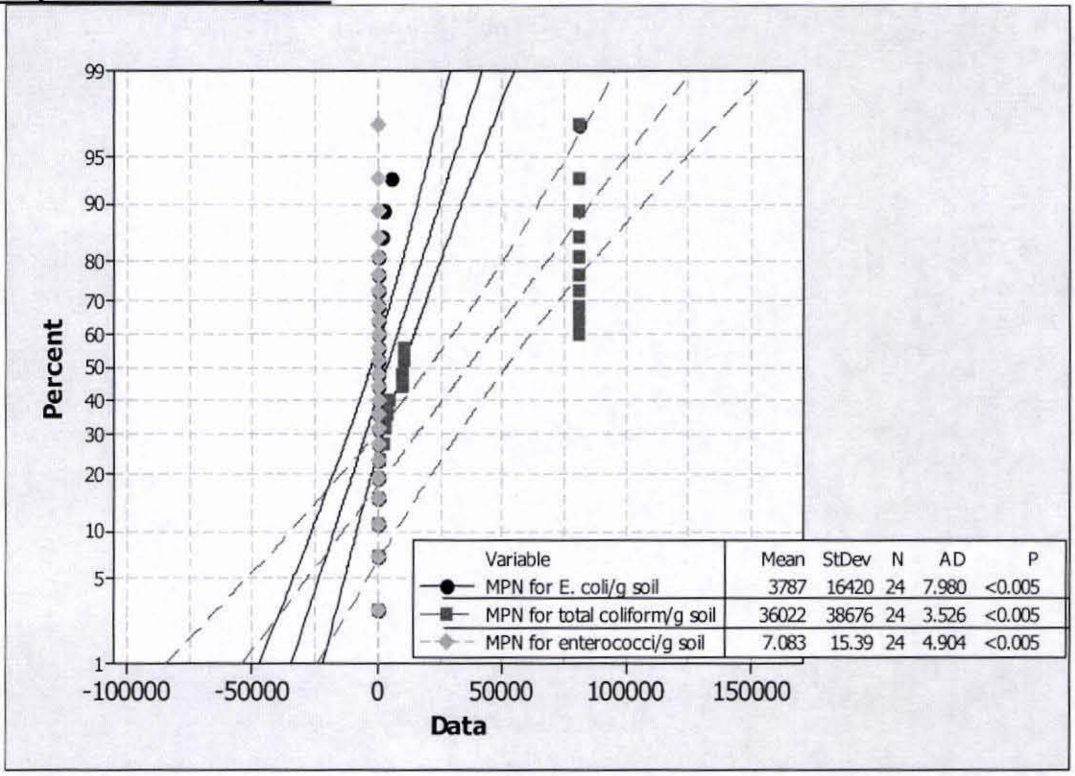
Appendix 4.2: MPN g^{-1} of fecal indicator bacteria of composite soil samples for all plots:

Plot	MPN for *E. coli*/g soil	MPN for total coliform/g soil	MPN for *Enterococcus*/g soil
C1	< 3.3	< 3.3	< 3.3
C2	11.1	> 80653	22.2
C3	< 3.3	< 3.3	< 3.3
C4	251.1	> 80653	< 3.3
H1	1556.7	4835.6	< 3.3
H2	< 3.3	106.7	< 3.3
H3	< 3.3	< 3.3	11.1
H4	2237.8	> 80653	< 3.3
MJ1	11.1	> 80653	< 3.3
MJ2	207.8	> 80653	11.1
MJ3	< 3.3	722.2	< 3.3
MJ4	< 3.3	> 80653	< 3.3
GO1	10.0	4303.3	< 3.3
GO2	107.8	> 80653	< 3.3
GO3	11.1	10893.3	< 3.3
GO4	5746.7	> 80653	57.8
KA1	< 3.3	551.1	< 3.3
KA2	11.1	10893.3	< 3.3
KA3	22.2	2496.7	< 3.3
KA4	< 3.3	3318.9	45.6
KO1	34.4	> 80653	< 3.3
KO2	< 3.3	9626.7	< 3.3
KO3	11.1	10231.1	< 3.3
KO4	>80653	> 80653	22.2

Appendix 4.3: Fecal indicator bacteria average MPN g^{-1} of composite soil samples per plot:

Variable	Section	Mean	StDev
MPN *E. coli/g*	1. C	65.6	123.8
	2. H	949	1130
	3. MJ	54.7	102.2
	4. GO	1469	2852
	5. KA	8.33	10.63
	6. KO	20175	40319
MPN coliform/g	1. C	40327	46566
	2. H	21399	39568
	3. MJ	60671	39966
	4. GO	44126	42264
	5. KA	4315	4536
	6. KO	45291	40834
MPN enterococci/g	1. C	5.55	11.10
	2. H	2.78	5.55
	3. MJ	2.78	5.55
	4. GO	14.5	28.9
	5. KA	11.4	22.8
	6. KO	5.55	11.10

Appendix 4.4: Normal probability plot of fecal indicator bacteria values per gram of composite soil in all plots:

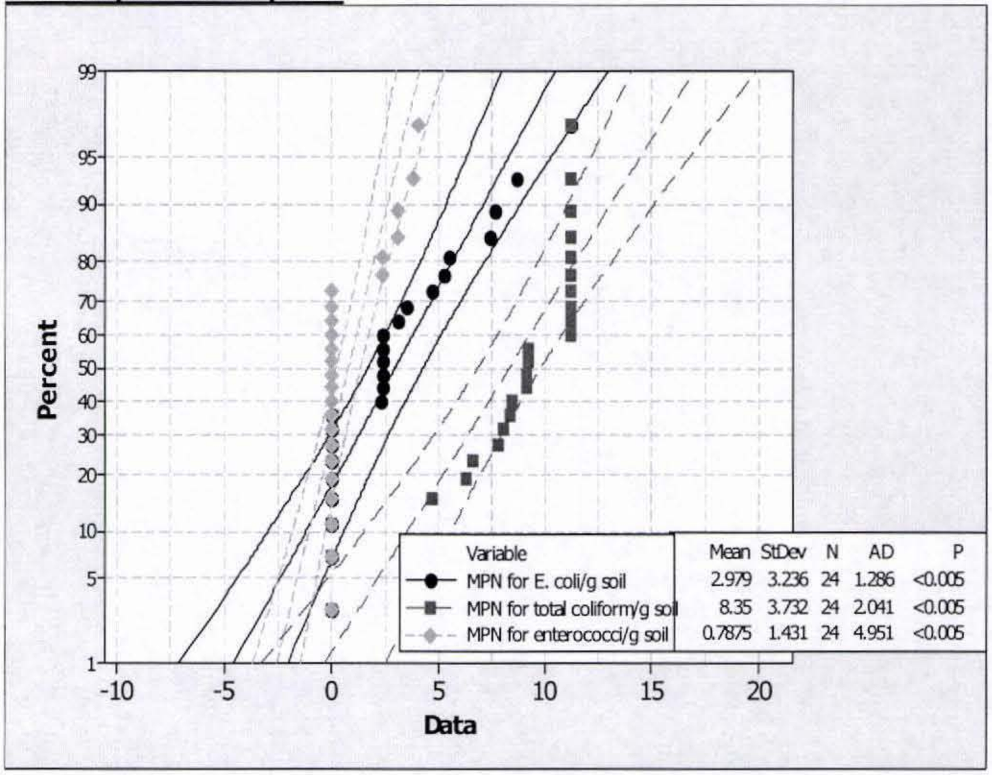


Appendix 4.5: Stem-and-Leaf Display: MPN for microbial soil analysis for all plots:

```
Stem-and-leaf of MPN for E. coli/g soil  N  = 24
Leaf Unit = 1000

(23)  0  00000000000000000000125
 1    1
 1    2
 1    3
 1    4
 1    5
 1    6
 1    7
 1    8  0


Stem-and-leaf of MPN for total coliform/g soil  N  = 24
Leaf Unit = 1000

 11  0  00000023449
(3)  1  000
 10  2
 10  3
 10  4
 10  5
 10  6
 10  7
 10  8  0000000000
```

```
Stem-and-leaf of MPN for enterococci/g soil  N  = 24
Leaf Unit = 1.0

(18)  0  000000000000000000
 6    0
 6    1  11
 4    1
 4    2  22
 2    2
 2    3
 2    3
 2    4
 2    4  5
 1    5
 1    5  7
```

Appendix 4.6: Log-transformed fecal indicator bacteria values for composite soil samples for all plots:



Appendix 4.7: Kruskal-Wallis Test: MPN for *E. coli*/g soil versus section:

```
Section    N  Median  Ave Rank       Z
1. C       4   1.200      10.8   -0.54
2. H       4   3.700      13.3    0.23
3. MJ      4   1.200      10.5   -0.62
4. GO      4   3.550      16.0    1.08
5. KA      4   1.200       9.8   -0.85
6. KO      4   2.950      14.8    0.70
Overall   24              12.5

H = 2.60  DF = 5  P = 0.761
H = 2.77  DF = 5  P = 0.736  (adjusted for ties)
```

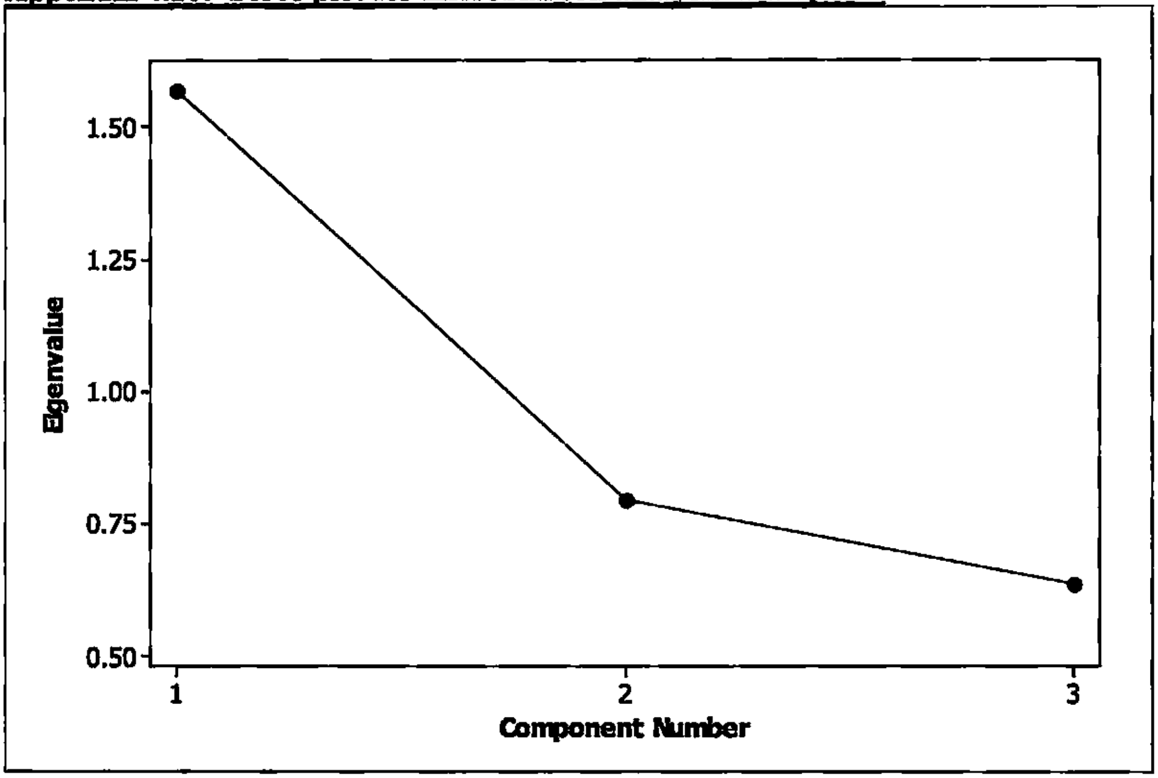
Appendix 4.8: Kruskal-Wallis Test: MPN for enterococci/g soil versus section:

```
Section    N       Median  Ave Rank       Z
1. C       4  0.000000000      12.5    0.00
2. H       4  0.000000000      12.0   -0.15
3. MJ      4  0.000000000      12.0   -0.15
4. GO      4  0.000000000      13.1    0.19
5. KA      4  0.000000000      12.9    0.12
6. KO      4  0.000000000      12.5    0.00
Overall   24                   12.5

H = 0.08  DF = 5  P = 1.000
H = 0.14  DF = 5  P = 1.000  (adjusted for ties)
```

Appendix 4.9: Kruskal-Wallis Test: MPN for total coliform/g soil versus section:

```
Section    N  Median  Ave Rank       Z
1. C       4   5.650      10.8   -0.54
2. H       4   6.600       8.9   -1.12
3. MJ      4  11.300      16.1    1.12
4. GO      4  10.300      15.4    0.89
5. KA      4   7.950       8.4   -1.28
6. KO      4  10.250      15.5    0.93
Overall   24              12.5

H = 5.09  DF = 5  P = 0.405
H = 5.50  DF = 5  P = 0.358  (adjusted for ties)
```

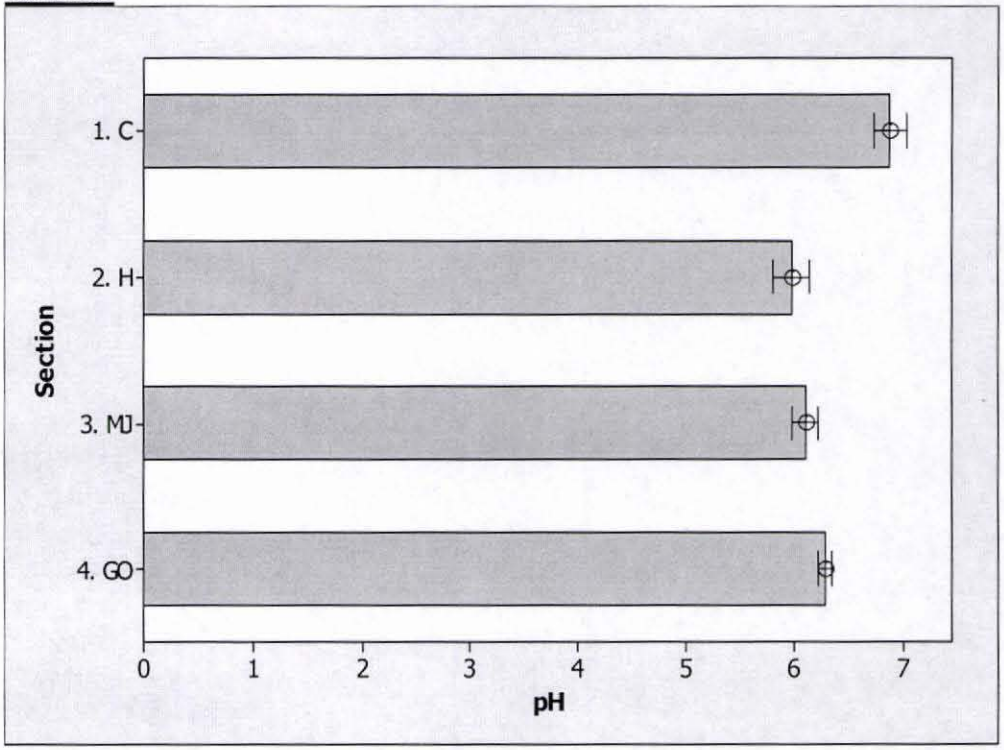
Appendix 4.10: Scree plot for microbial soil analysis of all plots:



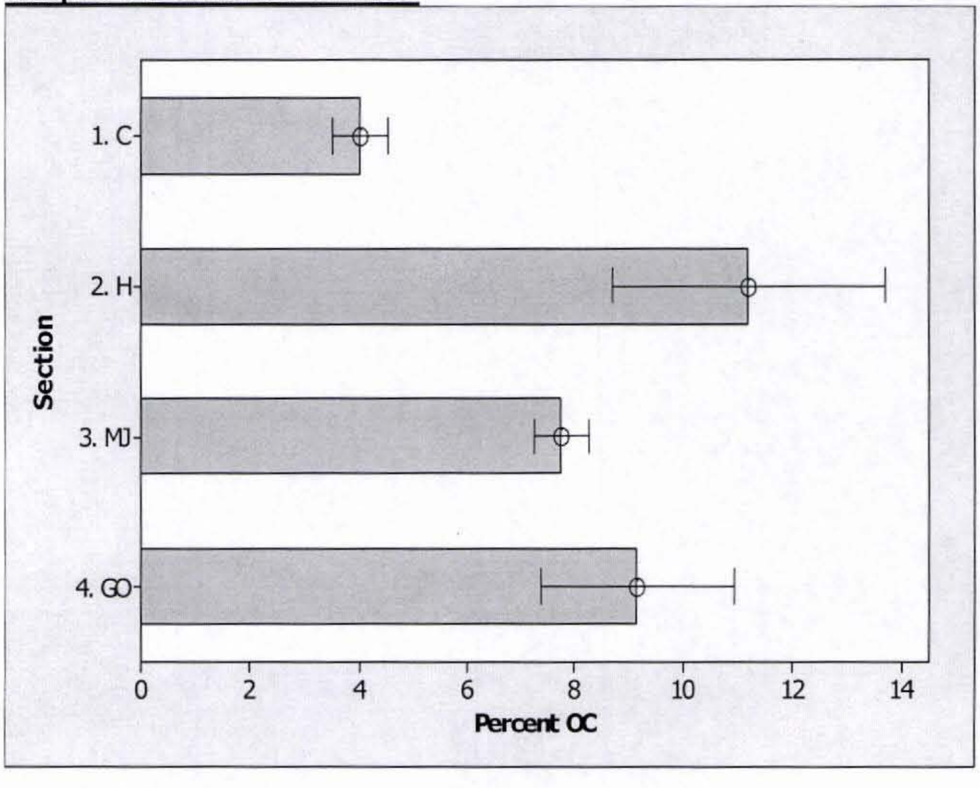
Appendix 4.11: Principal Component Analysis: microbial surface soil analysis of all plots:

```
Eigenanalysis of the Correlation Matrix

Eigenvalue  1.5709  0.7936  0.6355
Proportion   0.524   0.265   0.212
Cumulative   0.524   0.788   1.000


Variable                           PC1     PC2
MPN for E. coli/g soil          -0.623   0.099
MPN for total coliform/g soil   -0.537  -0.776
MPN for enterococci/g soil      -0.569   0.623
```

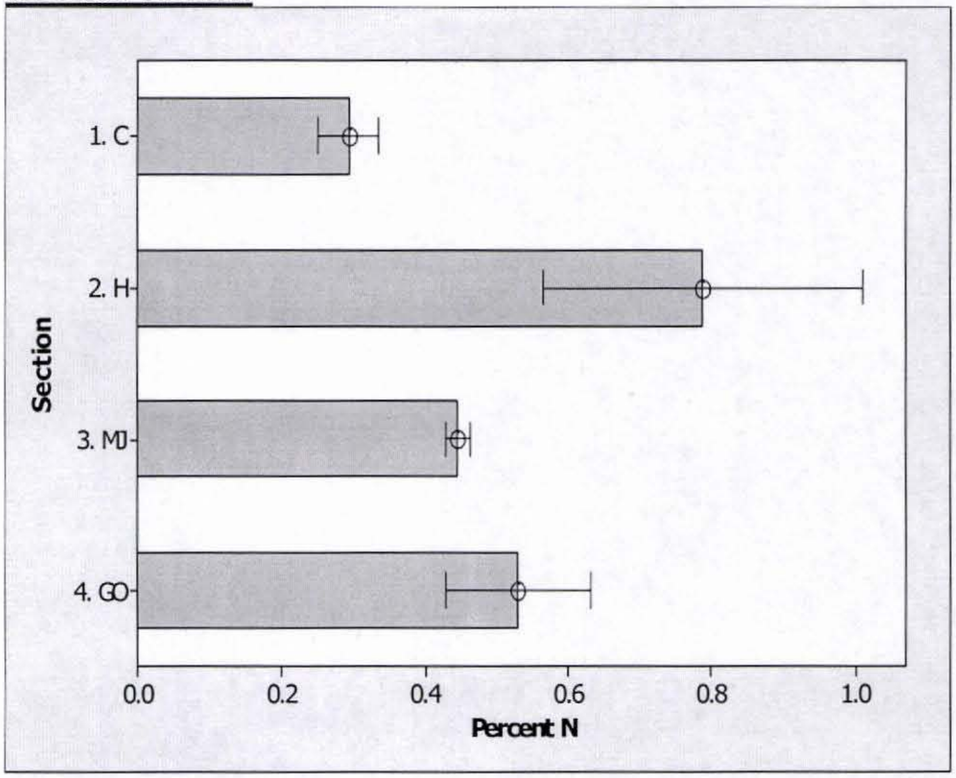
Appendix 4.12: Average pH per plot in composite soil samples 0-5 cm below surface:



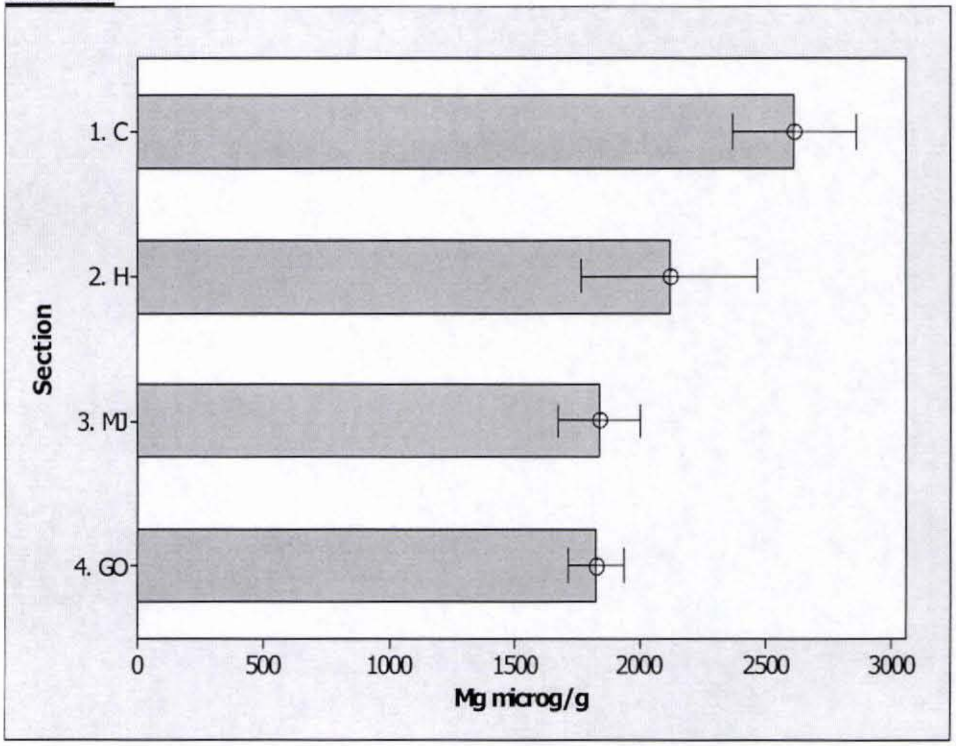
Appendix 4.10: Average percent organic carbon per plot in composite soil samples 0-5 cm below surface:



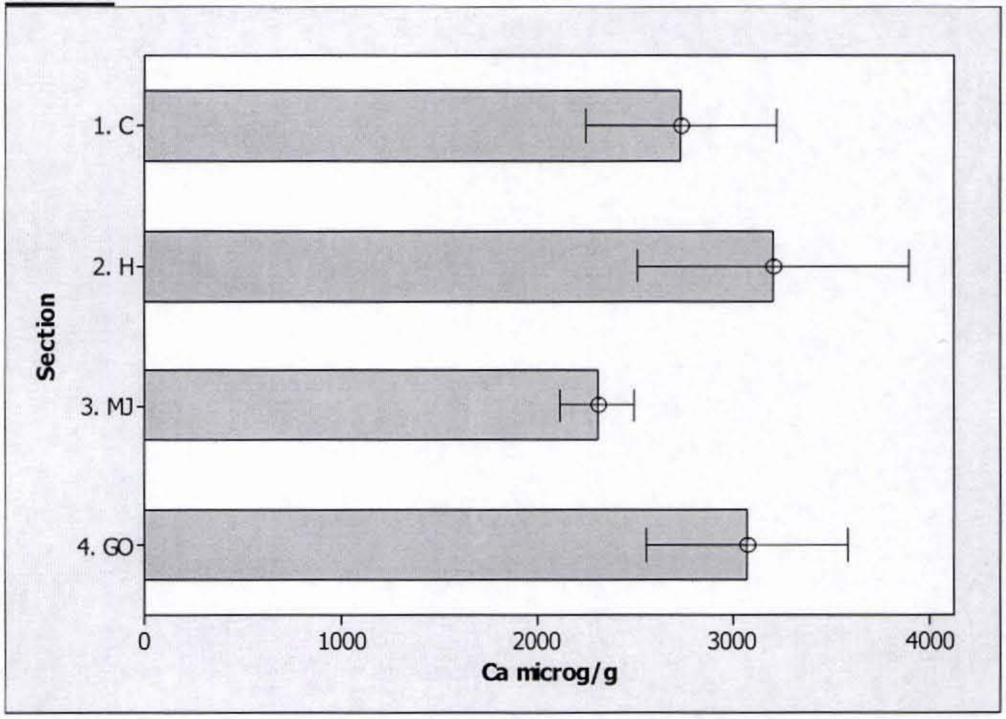
Appendix 4.13: Average percent nitrogen per plot in composite soil samples 0-5 cm below surface:



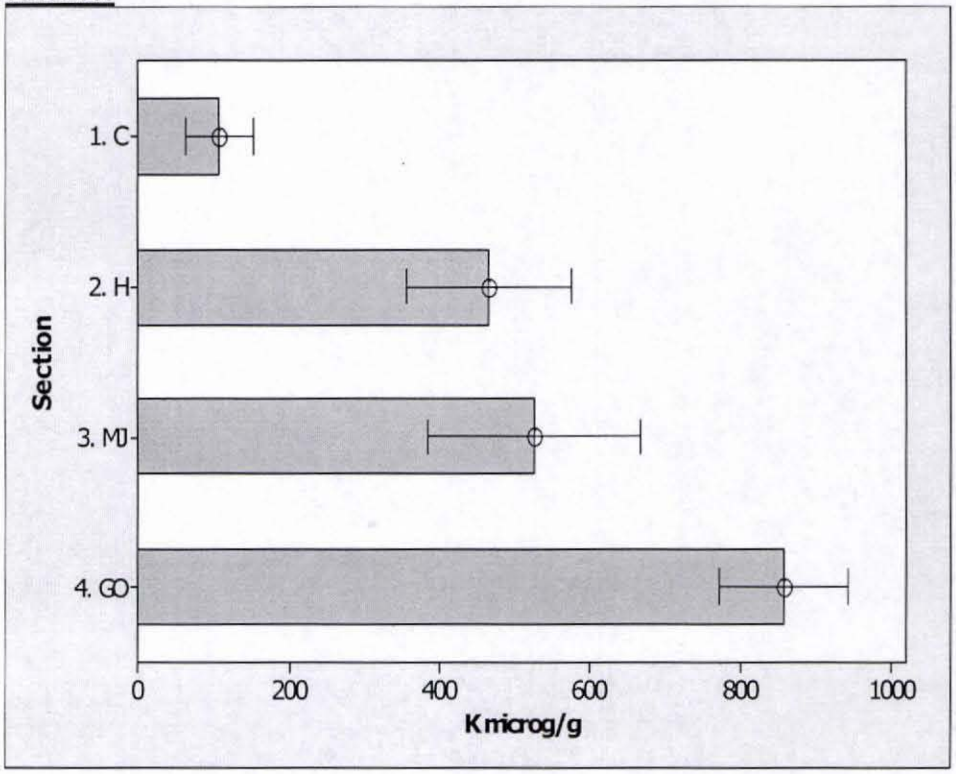
Appendix 4.12: Average Mg per plot in composite soil samples 0-5 cm below surface:



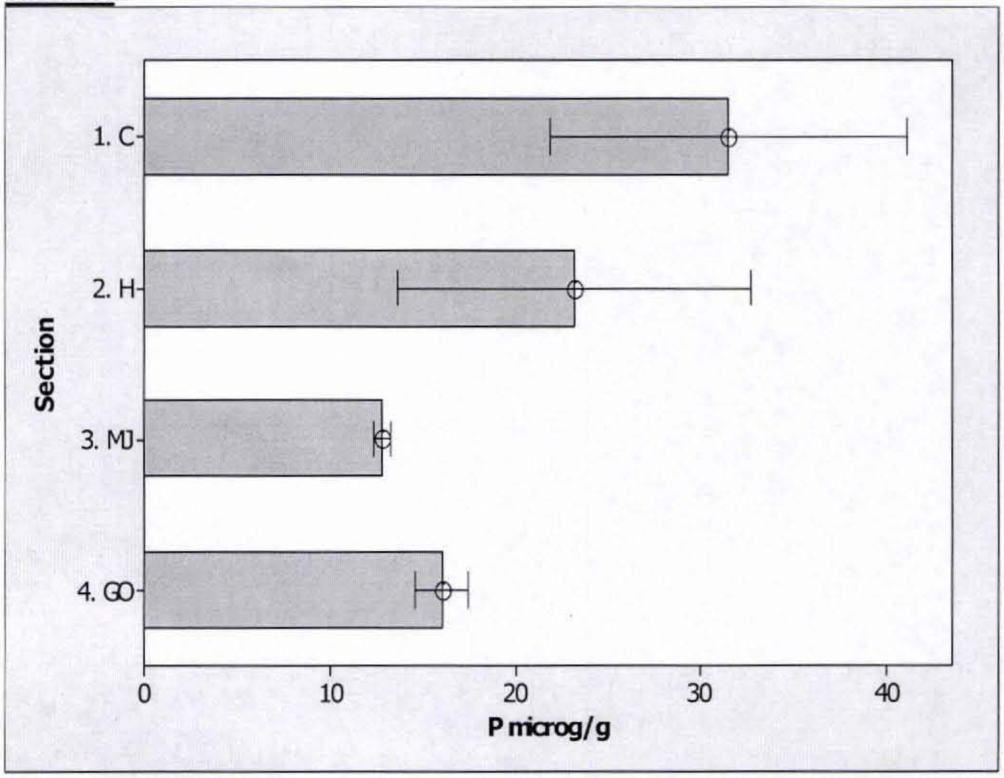
Appendix 4.13: Average Ca per plot in composite soil samples at 0-5 cm below surface:



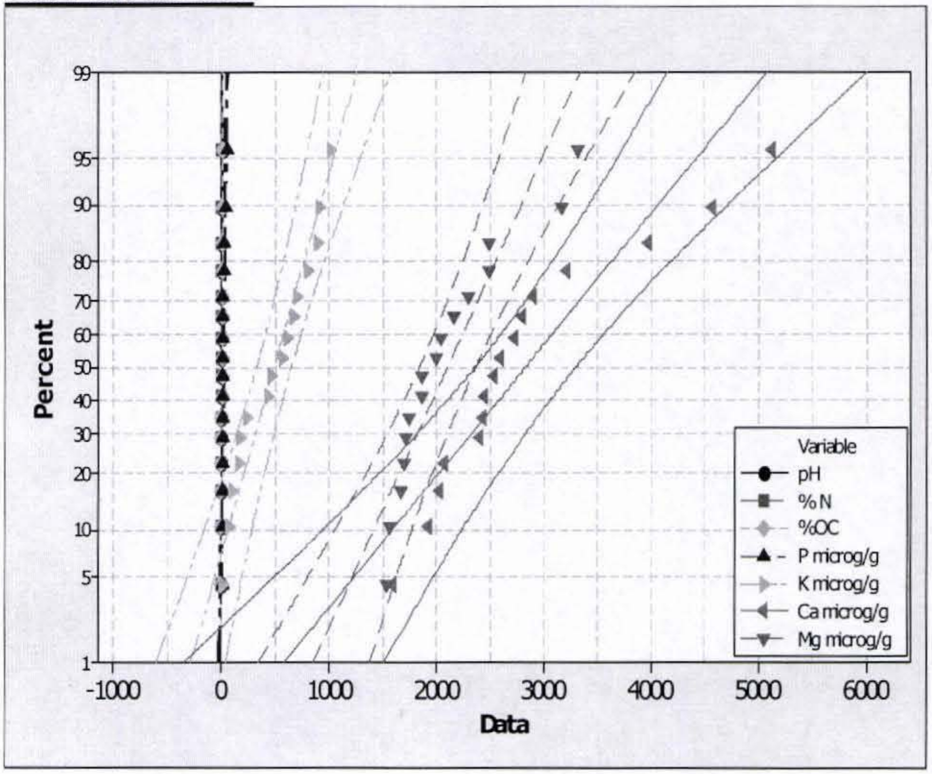
Appendix 4.14: Average K per plot in composite soil samples at 0-5 cm below surface:



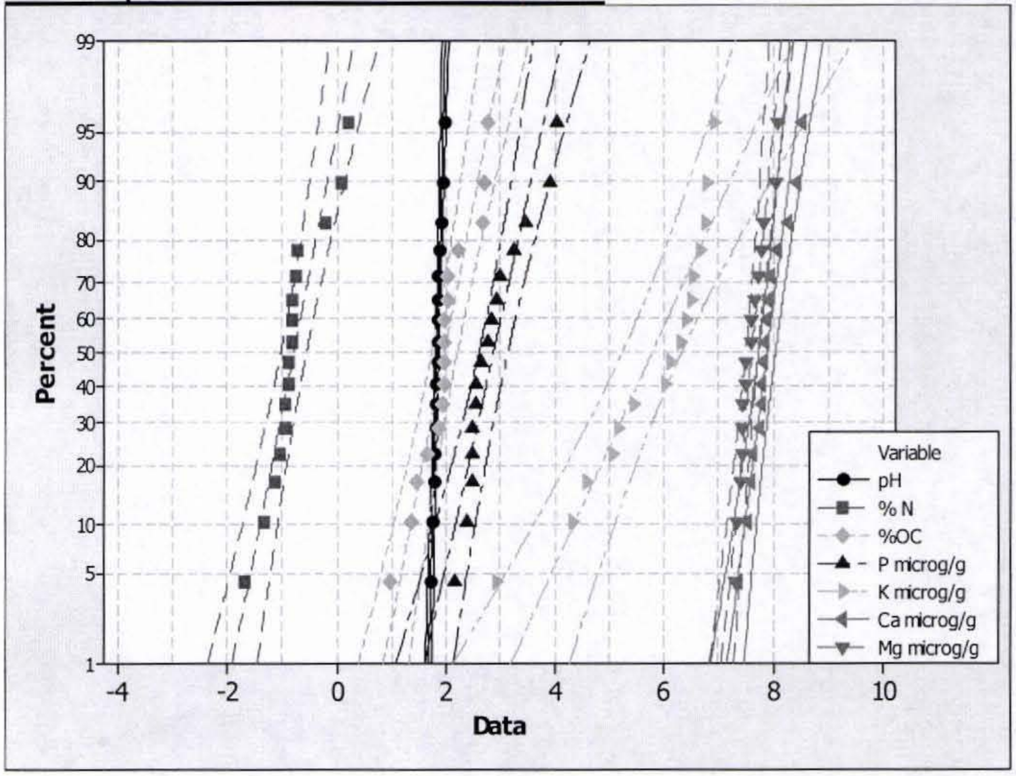
Appendix 4.15: Average P per plot in composite soil samples at 0-5 cm below surface:



Appendix 4.16: Normal probability plot for chemical soil components 0-5 cm below the surface:



Appendix 4.17: Normal probability plot of log-transformed data for chemical soil components 0-5 cm below the surface:



Appendix 4.18: Kruskal-Wallis Test: log-transformed pH values versus section for composite soil samples 0-5 cm below the surface:

```
Section     N  Median  Ave Rank      Z
1. C        4   1.931      14.5   2.91
2. H        4   1.808       4.4  -2.00
3. MJ       4   1.816       6.1  -1.15
4. GO       4   1.841       9.0   0.24
Overall    16               8.5

H = 10.40  DF = 3  P = 0.015
H = 10.58  DF = 3  P = 0.014  (adjusted for ties)
```

Appendix 4.19: Kruskal-Wallis Test: log-transformed values of percent N versus section for composite soil samples 0-5 cm below the surface:

```
Section     N    Median  Ave Rank      Z
1. C        4   -1.2174       3.0  -2.67
2. H        4   -0.3312      11.8   1.58
3. MJ       4   -0.8309       9.8   0.61
4. GO       4   -0.8028       9.5   0.49
Overall    16                 8.5

H = 7.65  DF = 3  P = 0.054
```

Appendix 4.20: Kruskal-Wallis Test: log-transformed values of percent OC versus section for composite soil samples 0-5 cm below the surface:

```
Section    N  Median  Ave Rank      Z
1. C       4   1.415       2.5  -2.91
2. H       4   2.329      11.0   1.21
3. MJ      4   2.008       9.8   0.61
4. GO      4   2.014      10.8   1.09
Overall   16               8.5

H = 8.63  DF = 3  P = 0.035
```

Appendix 4.21: Kruskal-Wallis Test: log-transformed values of P microg/g versus section for composite soil samples 0-5 cm below the surface:

```
Section    N  Median  Ave Rank      Z
1. C       4   3.362      11.3   1.33
2. H       4   2.780       8.6   0.06
3. MJ      4   2.525       5.6  -1.39
4. GO      4   2.803       8.5   0.00
Overall   16               8.5

H = 2.80  DF = 3  P = 0.424
H = 2.82  DF = 3  P = 0.421  (adjusted for ties)
```

Appendix 4.22: Kruskal-Wallis Test: log-transformed values of K microg/g versus section for composite soil samples 0-5 cm below the surface:

```
Section    N  Median  Ave Rank      Z
1. C       4   4.488       3.0  -2.67
2. H       4   6.234       8.0  -0.24
3. MJ      4   6.296       9.3   0.36
4. GO      4   6.803      13.8   2.55
Overall   16               8.5

H = 10.35  DF = 3  P = 0.016
```

Appendix 4.23: Kruskal-Wallis Test: log-transformed values of Ca microg/g versus section for composite soil samples 0-5 cm below the surface:

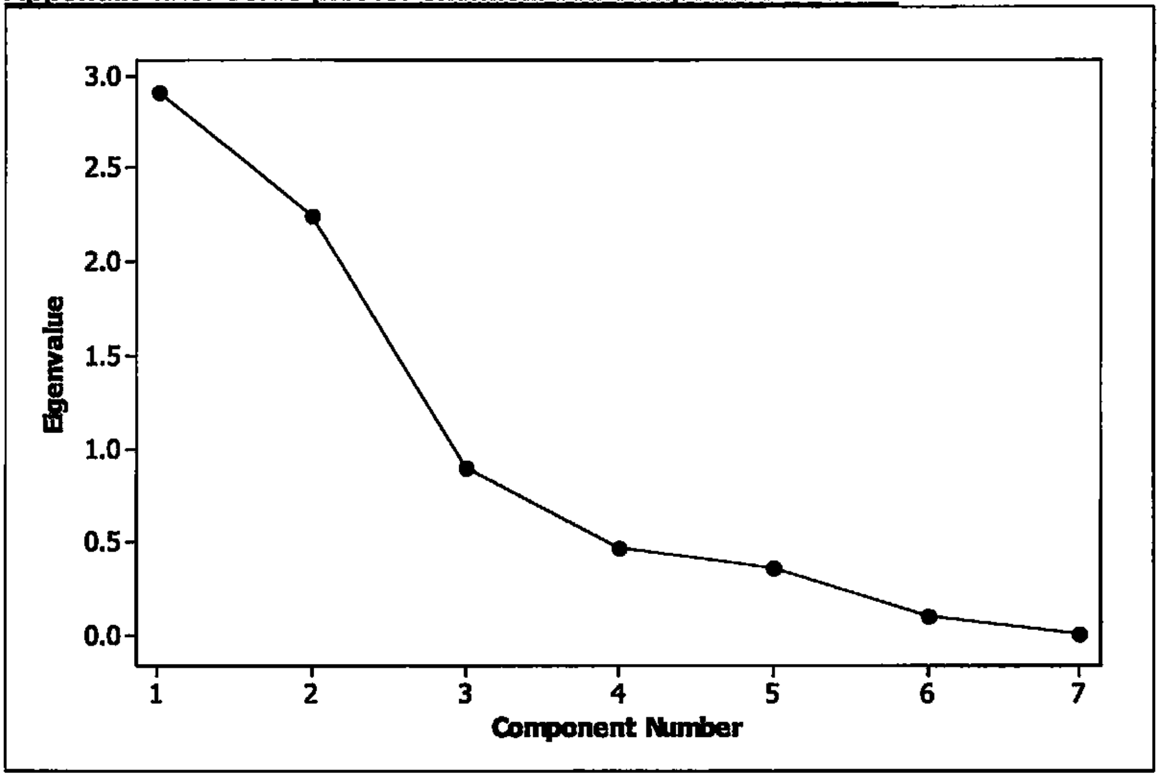
```
Section    N  Median  Rank      Z
1. C       4   7.896   8.8   0.12
2. H       4   7.938   9.8   0.61
3. MJ      4   7.735   6.0  -1.21
4. GO      4   7.883   9.5   0.49
Overall   16           8.5

H = 1.57  DF = 3  P = 0.667
```

Appendix 4.24: Kruskal-Wallis Test: log-transformed values of Mg microg/g versus section for composite soil samples 0-5 cm below the surface:

```
Section    N  Median  Ave Rank      Z
1. C       4   7.819      13.5   2.43
2. H       4   7.494       8.5   0.00
3. MJ      4   7.473       5.8  -1.33
```

```
4. GO      4   7.518       6.3  -1.09
Overall  16                8.5

H = 6.64  DF = 3  P = 0.084
```

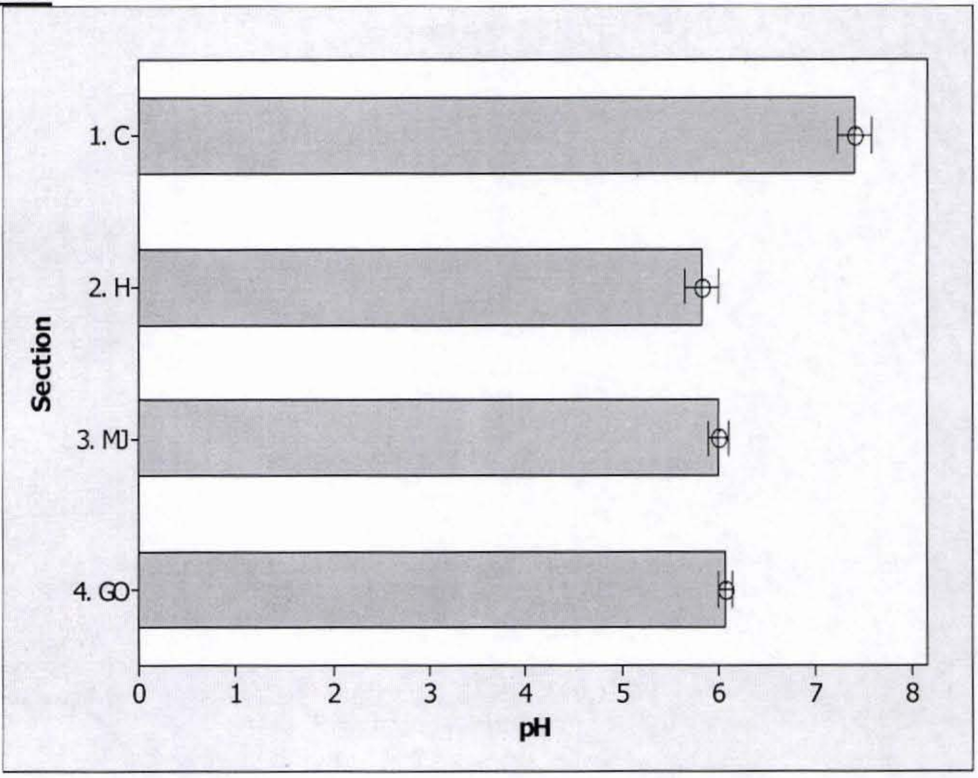
Appendix 4.25: Scree plot for chemical soil components 0-5 cm:



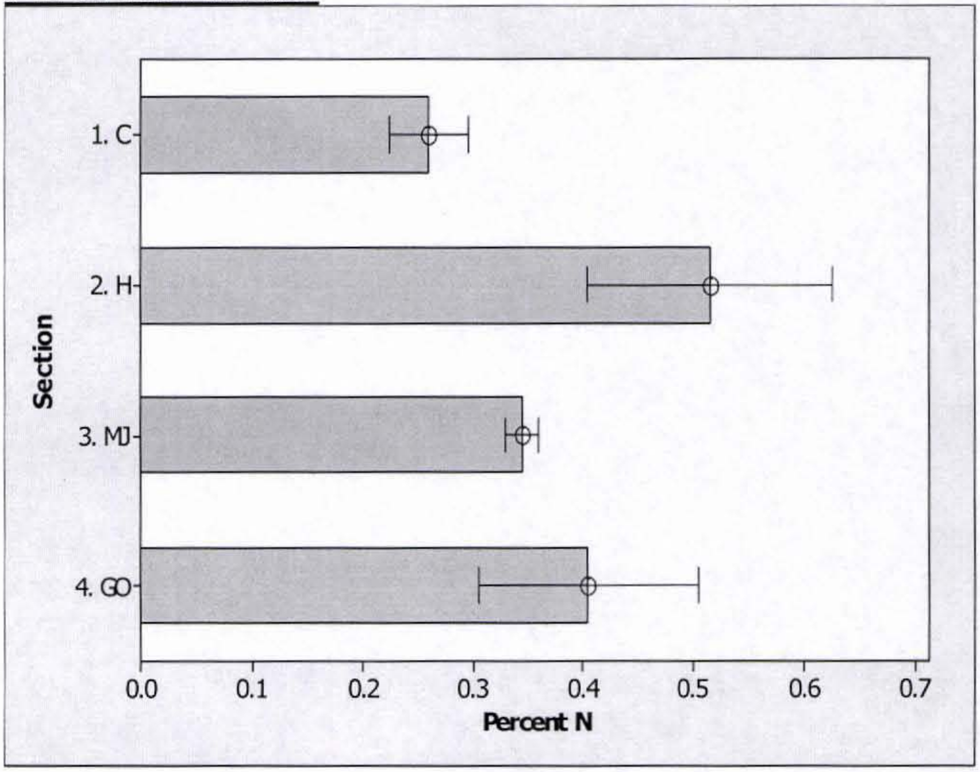
Appendix 4.26: Principal Component Analysis: chemical soil components 0-5 cm:

```
        Eigenanalysis of the Correlation Matrix

Eigenvalue  2.9093  2.2496  0.9015  0.4649  0.3611  0.1042  0.0094
Proportion   0.416   0.321   0.129   0.066   0.052   0.015   0.001
Cumulative   0.416   0.737   0.866   0.932   0.984   0.999   1.000


Variable         PC1      PC2      PC3      PC4      PC5      PC6
pH            -0.418    0.259    0.553    0.173   -0.160   -0.627
% N            0.532    0.209   -0.195    0.210   -0.038   -0.433
%OC            0.570    0.099   -0.054    0.156   -0.130   -0.240
P microg/g    -0.035    0.558   -0.172   -0.641    0.452   -0.182
K microg/g     0.364   -0.254    0.514   -0.638   -0.338    0.004
Ca microg/g    0.269    0.421    0.567    0.285    0.330    0.484
Mg microg/g   -0.106    0.571   -0.191   -0.049   -0.727    0.308
```

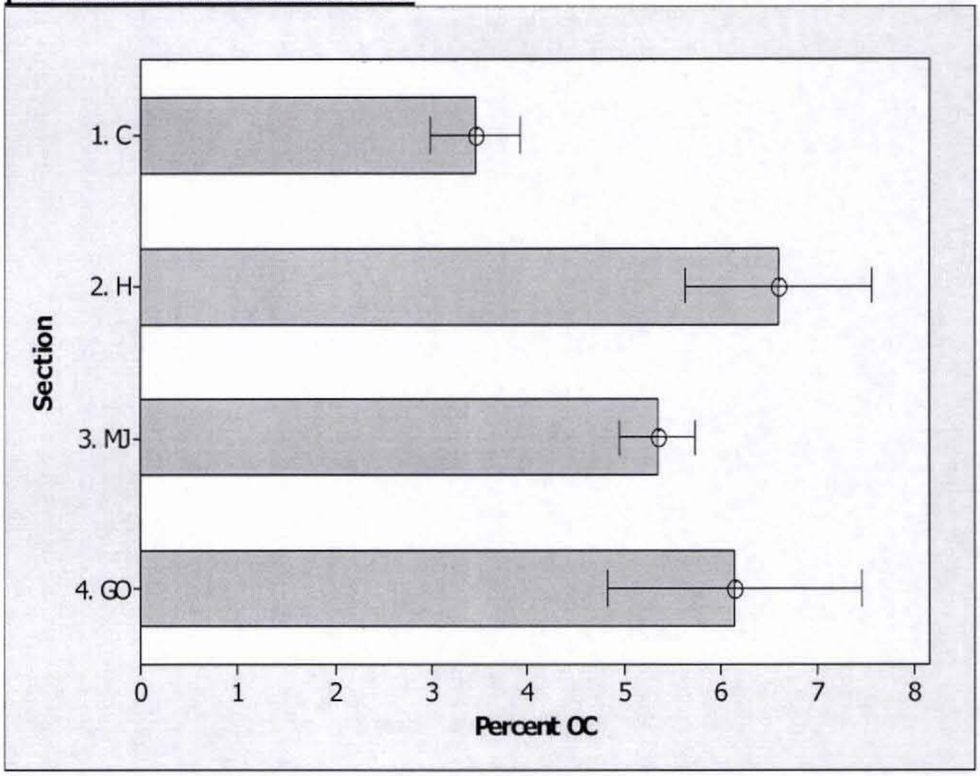
Appendix 4.27: Average pH for composite soil samples per plot at 5-15 cm below surface:



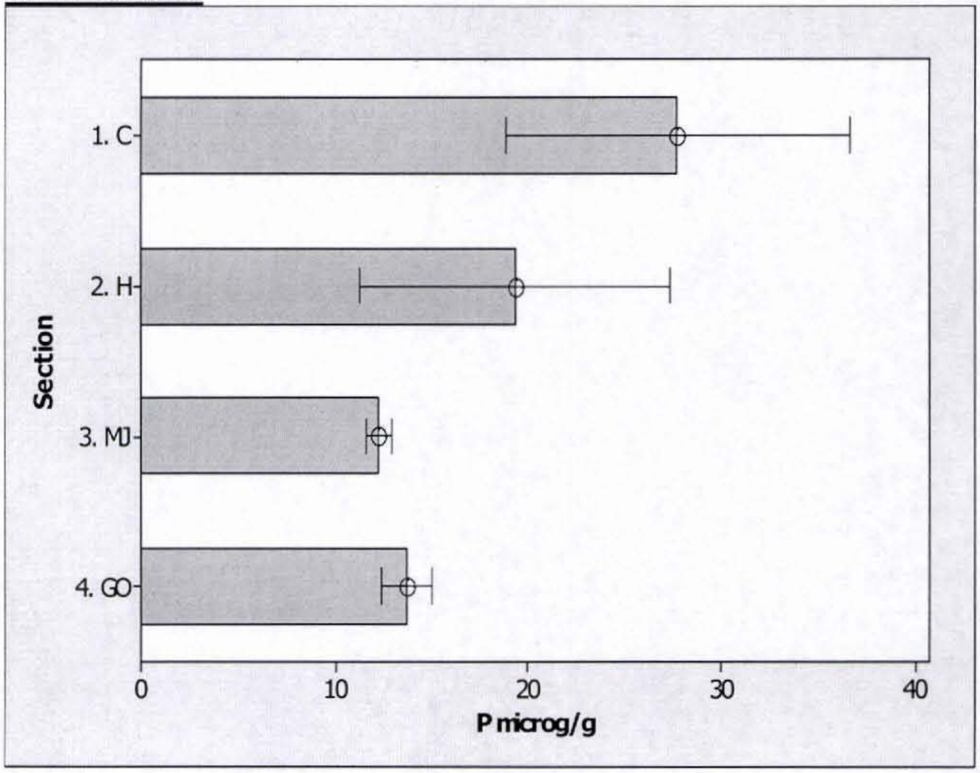
Appendix 4.28: Average percent nitrogen for composite soil samples per plot at 5-15 cm below surface:



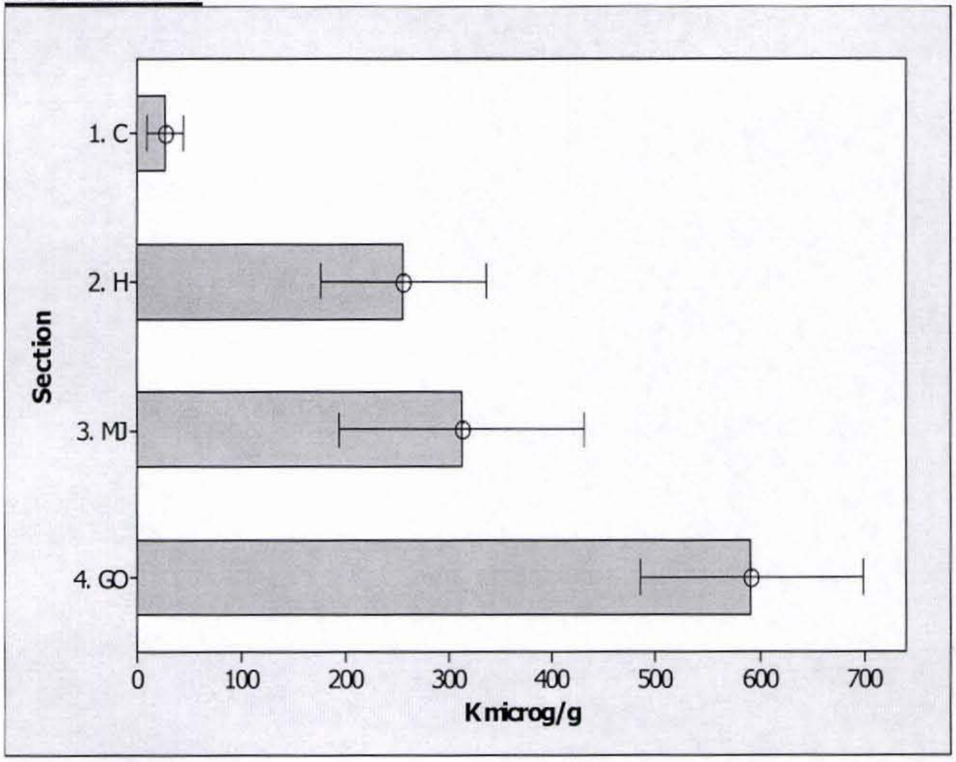
Appendix 4.29: Average percent organic carbon for composite soil samples per plot at 5-15 cm below surface:



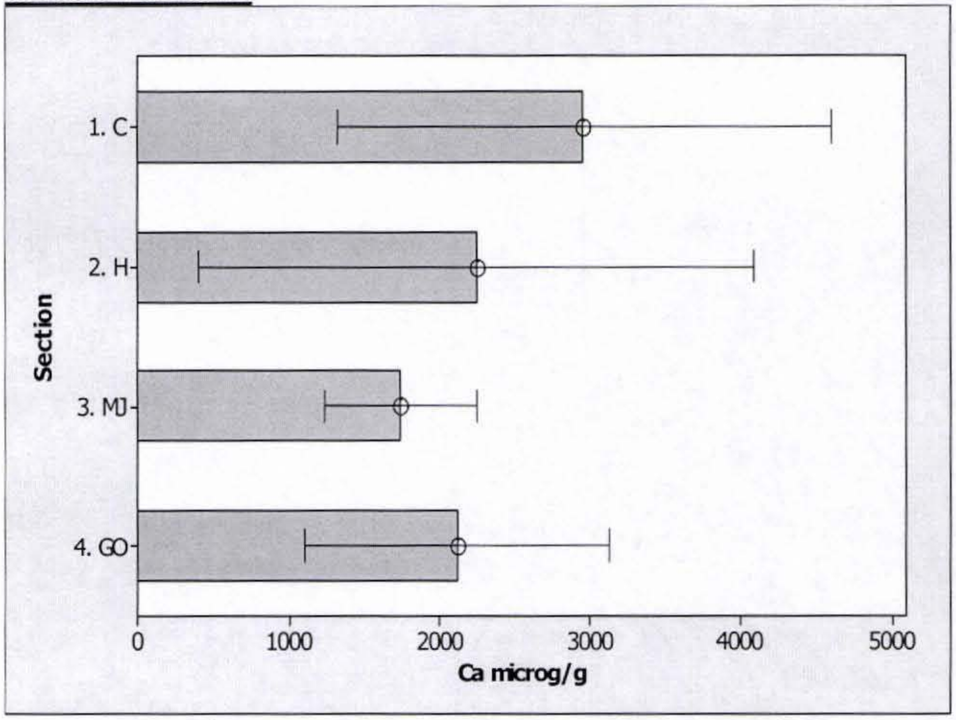
Appendix 4.30: Average P values for composite soil samples per plot at 5-15 cm below surface:



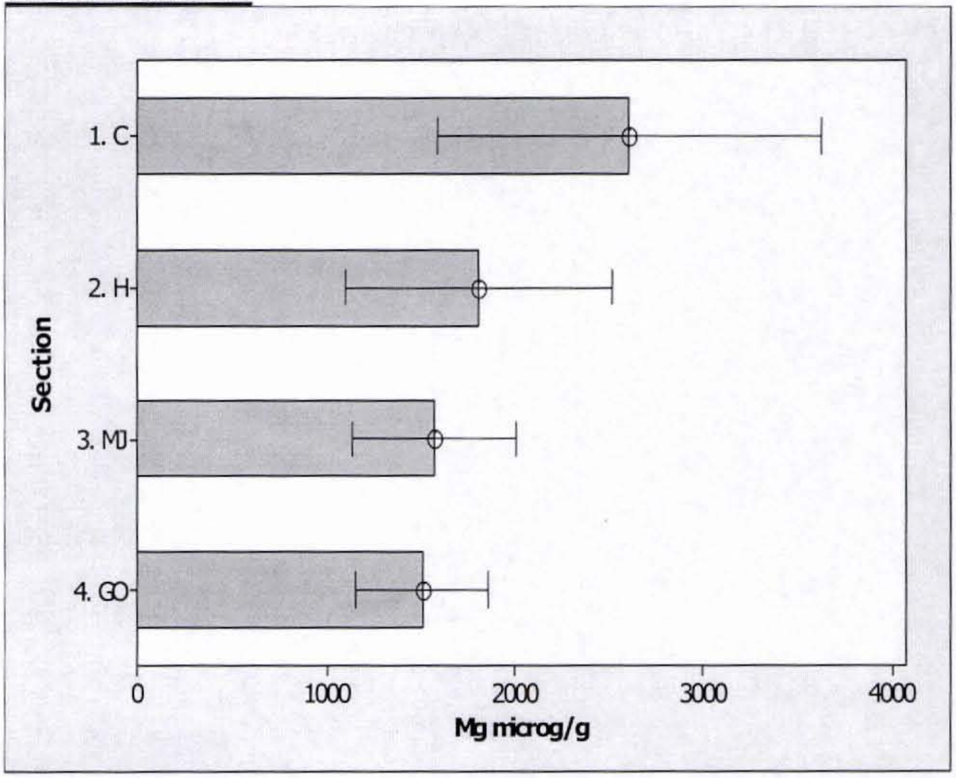
Appendix 4.31: Average K values for composite soil samples per plot at 5-15 cm below surface:



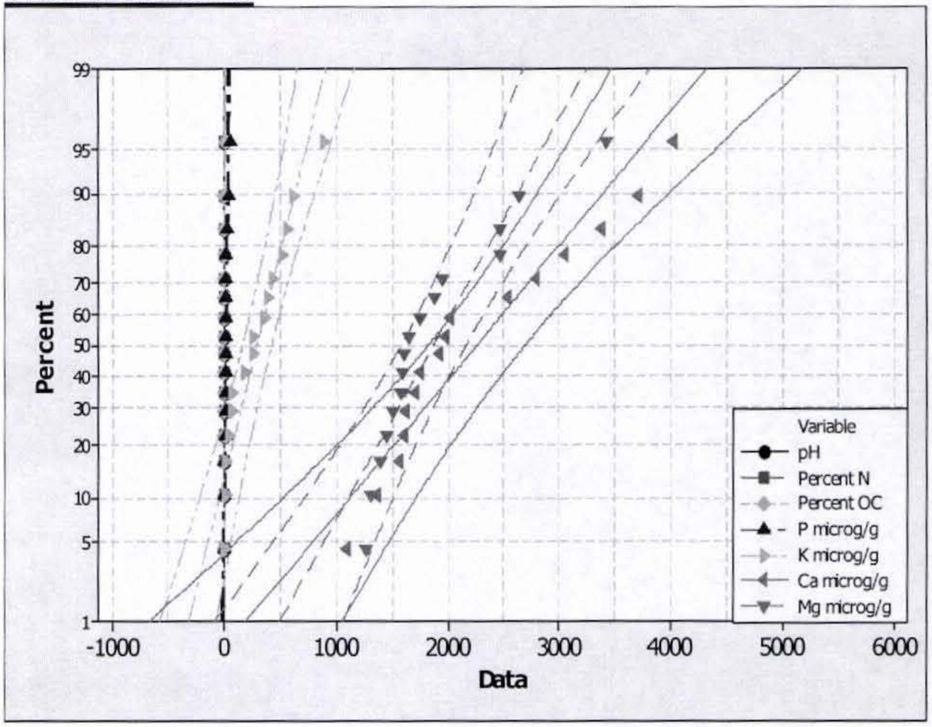
Appendix 4.32: Average Ca values for composite soil samples per plot at 5-15 cm below surface:



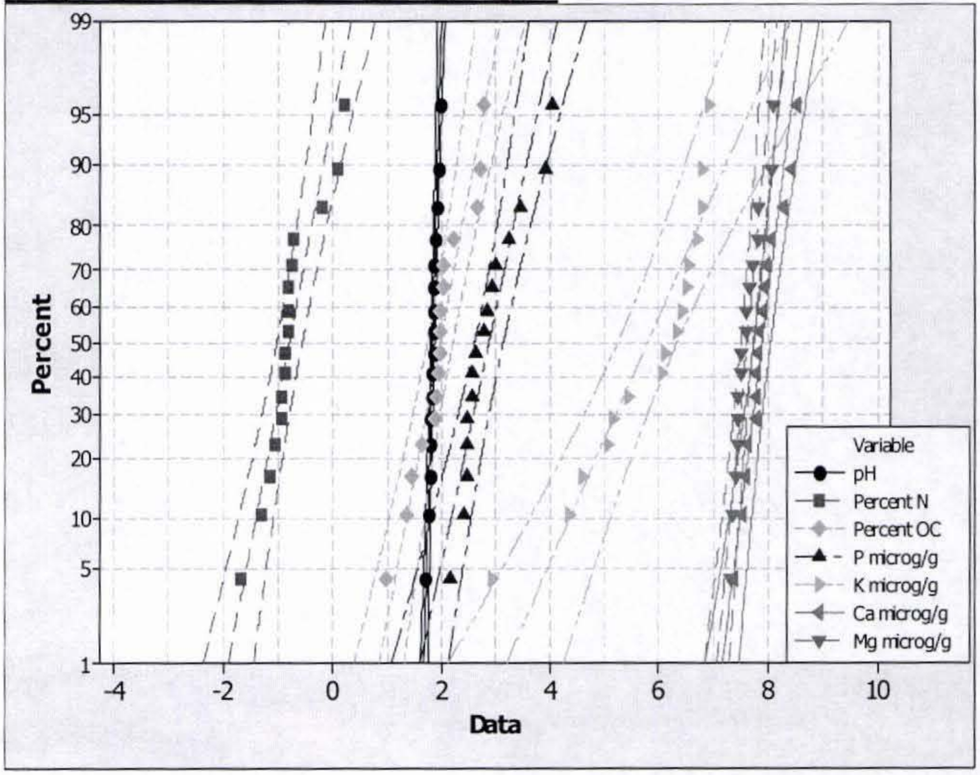
Appendix 4.33: Average Mg values for composite soil samples per plot at 5-15 cm below surface:



Appendix 4.34: Normal probability plot for chemical soil components 5-15 cm below the surface:



Appendix 4.35: Normal probability plot for log-transformed chemical soil components data 5-15 cm below surface:



Appendix 4.36: Kruskal-Wallis Test: log-transformed average pH versus section for composite soil samples 5-15 cm below the surface:

```
Kruskal-Wallis Test on pH

Section   N  Median  Ave Rank      Z
C         4   1.931      14.5   2.91
GO        4   1.841       9.0   0.24
H         4   1.808       4.4  -2.00
MJ        4   1.816       6.1  -1.15
Overall  16               8.5

H = 10.40  DF = 3  P = 0.015
H = 10.58  DF = 3  P = 0.014  (adjusted for ties)
```

Appendix 4.37: Kruskal-Wallis Test: log-transformed average percent N versus section for composite soil samples 5-15 cm below the surface:

```
Kruskal-Wallis Test on Percent N

Section   N   Median  Ave Rank      Z
C         4  -1.2244       2.9  -2.73
GO        4  -0.7985       9.9   0.67
H         4  -0.3344      11.8   1.58
MJ        4  -0.8330       9.5   0.49
Overall  16                8.5

H = 7.96  DF = 3  P = 0.047
H = 8.03  DF = 3  P = 0.045  (adjusted for ties)
```

Appendix 4.38: Kruskal-Wallis Test: log-transformed average percent OC versus section for composite soil samples 5-15 cm below the surface:

```
Kruskal-Wallis Test on Percent OC

Section    N  Median  Ave Rank      Z
C          4   1.410       2.5  -2.91
GO         4   2.015      10.6   1.03
H          4   2.341      11.1   1.27
MJ         4   2.008       9.8   0.61
Overall   16               8.5

H = 8.64  DF = 3  P = 0.034
H = 8.67  DF = 3  P = 0.034  (adjusted for ties)
```

Appendix 4.39: Kruskal-Wallis Test: log-transformed average P microg/g versus section for composite soil samples 5-15 cm below the surface:

```
Kruskal-Wallis Test on P microg/g

Section    N  Median  Ave Rank      Z
C          4   3.362      11.3   1.33
GO         4   2.803       8.5   0.00
H          4   2.780       8.6   0.06
MJ         4   2.525       5.6  -1.39
Overall   16               8.5

H = 2.80  DF = 3  P = 0.424
H = 2.82  DF = 3  P = 0.421  (adjusted for ties)
```

Appendix 4.40: Kruskal-Wallis Test: log-transformed average K microg/g versus section for composite soil samples 5-15 cm below the surface:

```
Kruskal-Wallis Test on K microg/g

Section    N  Median  Ave Rank      Z
C          4   4.486       3.0  -2.67
GO         4   6.803      13.8   2.55
H          4   6.235       8.0  -0.24
MJ         4   6.296       9.3   0.36
Overall   16               8.5

H = 10.35  DF = 3  P = 0.016
```

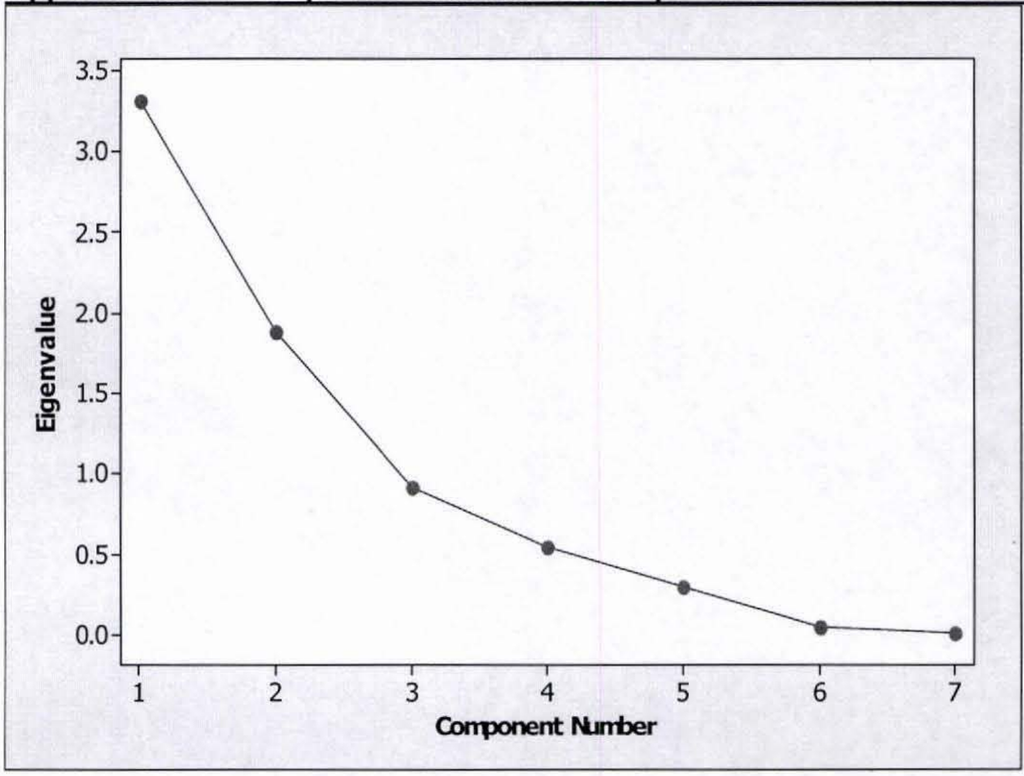
Appendix 4.41: Kruskal-Wallis Test: log-transformed average Ca microg/g versus section for composite soil samples 5-15 cm below the surface:

```
Kruskal-Wallis Test on Ca microg/g

                        Ave
Section    N  Median   Rank      Z
C          4   7.896    8.8   0.12
GO         4   7.883    9.5   0.49
H          4   7.938    9.8   0.61
MJ         4   7.735    6.0  -1.21
Overall   16            8.5

H = 1.57  DF = 3  P = 0.667
```

Appendix 4.42: Kruskal-Wallis Test: log-transformed average Mg microg/g versus section for composite soil samples 5-15 cm below the surface:

```
Kruskal-Wallis Test on Mg microg/g

Section   N  Median  Ave Rank      Z
C         4   7.819      13.5   2.43
GO        4   7.518       6.3  -1.09
H         4   7.494       8.5   0.00
MJ        4   7.473       5.8  -1.33
Overall  16                 8.5

H = 6.64  DF = 3  P = 0.084
```

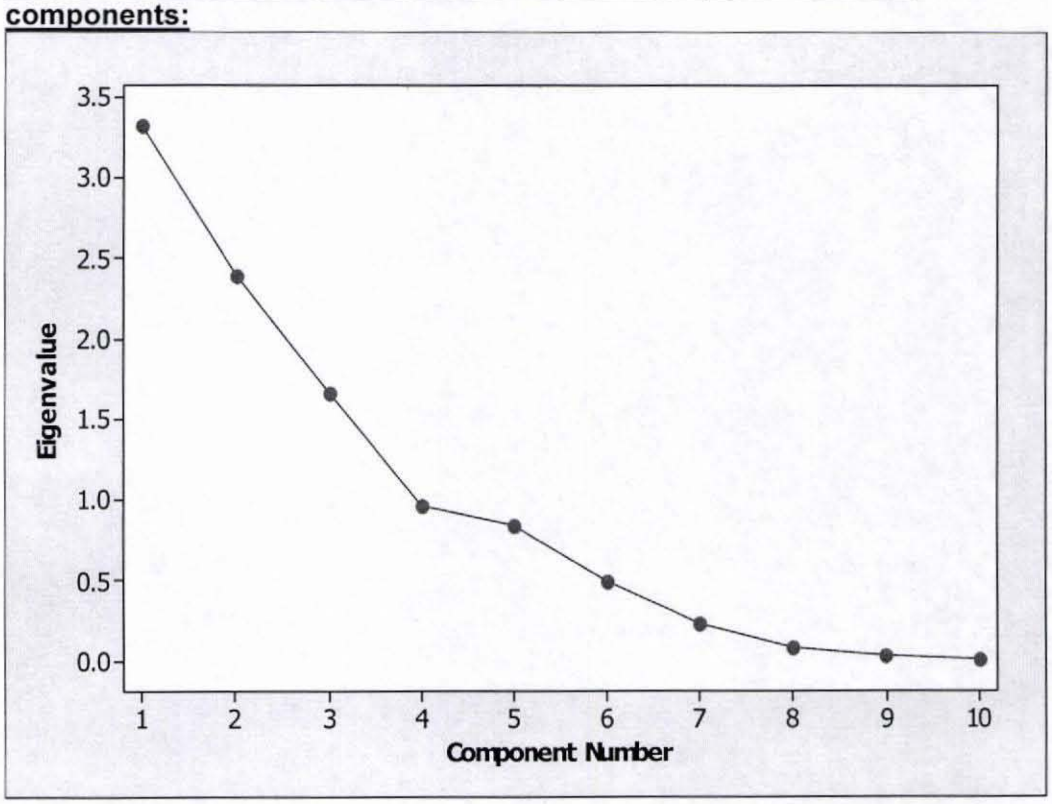
Appendix 4.43: Scree plot for chemical soil components 5-15 cm below surface:



Appendix 4.44: Principal Component Analysis: chemical soil components 5-15 cm below surface:

```
Eigenanalysis of the Correlation Matrix

Eigenvalue  3.3153  1.8841  0.9210  0.5383  0.2956  0.0396  0.0062
Proportion   0.474   0.269   0.132   0.077   0.042   0.006   0.001
Cumulative   0.474   0.743   0.874   0.951   0.993   0.999   1.000


Variable        PC1     PC2     PC3     PC4     PC5     PC6
pH           -0.465  -0.174   0.429  -0.070  -0.349   0.634
% N           0.351  -0.500  -0.160   0.394  -0.138   0.367
%OC           0.426  -0.451  -0.036   0.113  -0.112  -0.078
P microg/g   -0.319  -0.359  -0.547  -0.326   0.534   0.265
K microg/g    0.401  -0.158   0.173  -0.843  -0.172   0.011
Ca microg/g  -0.201  -0.512   0.584   0.071   0.404  -0.405
Mg microg/g  -0.419  -0.316  -0.345  -0.070  -0.607  -0.472
```

Appendix 4.45: Scree plot for chemical (0-5cm) and microbial soil components:



Appendix 4.46: Principal Component Analysis: chemical soil (0-5 cm) and microbial soil (0-10 cm) variables:

```
Eigenanalysis of the Correlation Matrix

Eigenvalue  3.3299  2.4009  1.6522  0.9490  0.8118  0.5010  0.2419  0.0797
Proportion   0.333   0.240   0.165   0.095   0.081   0.050   0.024   0.008
Cumulative   0.333   0.573   0.738   0.833   0.914   0.964   0.989   0.997

Eigenvalue  0.0306  0.0031
Proportion   0.003   0.000
Cumulative   1.000   1.000


Variable                          PC1     PC2     PC3     PC4     PC5     PC6
pH                             -0.463   0.192  -0.041  -0.343  -0.167   0.135
Percent N                       0.352   0.336  -0.338   0.237  -0.025  -0.340
Percent OC                      0.426   0.292  -0.320   0.071   0.007  -0.090
P microg/g                     -0.315   0.052  -0.483   0.348   0.295   0.180
K microg/g                      0.403   0.053  -0.172  -0.228  -0.010   0.841
Ca microg/g                    -0.194   0.338  -0.375  -0.553  -0.226  -0.201
Mg microg/g                    -0.419   0.200  -0.234   0.390   0.011   0.229
MPN for E. coli/g soil          0.060  -0.448  -0.420  -0.108  -0.444  -0.068
MPN for total coliform/g soil   0.005  -0.321  -0.277  -0.380   0.755  -0.146
MPN for enterococci/g soil     -0.036  -0.549  -0.264   0.184  -0.258  -0.010
```

Chapter 5:

Conclusions:

It is believed that ancient Waipā residents extensively lived and worked in a vertically integrated system from mountain to sea. Now, a lack of management exists along the majority of Waipā stream, as evidenced by the significantly dominant canopy cover of hau (*H. tiliaceus*) along lower Waipā stream, and vivi (*P. cattleianum*) along all of Waipā stream and tributaries, and the higher fecal indicator bacteria levels at Waipā bridge over almost all monitoring dates compared to all other upstream uninhabited monitoring sites along Waipā stream. It is believed that in the old *ahupua`a* system, Hawaiians sustainably harvested plants along all of Waipā stream and tributaries for daily uses such as art, sustenance, and warfare. Perhaps pigs and cattle were managed differently, maintaining their balance with nature by avoiding land degradation and associated water quality decline.

Today the cattle drink and navigate out of the same delivery ditches in which they defecate and urinate, and feed on what might have previously been a Palustrine, Marine, and/or Estuarine wetland(s) as categorized by the US Fish and Wildlife Service wetland classification system. Or perhaps Waipā stream meandered through the now overgrazed cattle pasture. Hunters are rarely seen or permitted in the watershed, complicating the issue of whether or not pig populations are increasing or decreasing, and whether or not hunters can help evaluate and manage the spreading of invasive plant species by feral pigs and birds. Of specific concern is the presence of feral pigs and cattle near drainage systems where waterborne diseases can potentially be transported to downstream users.

Fencing off riparian zones, major tributaries, and delivery ditches and planting native species at appropriate locations could improve microbial water quality within Waipā watershed and ultimately Hanalei bay. Because of the excessive growth rate of many invasive weeds, shrubs, and trees; native plant restoration along Waipā stream and tributaries will probably require a number of full-time land managers dependent upon the extent and desired success of proposed restoration and successive eradication of invasive plants.

Building troughs for cattle in the lower floodplain pasture could keep the cattle away from delivery ditches and improve water quality. Perhaps rejuvenating rotational cattle grazing in upland areas of Waipā such as the open grasslands around Kapalikea tributary could decrease bulk density of the lower floodplain pasture and allow land managers to determine appropriate areas for riparian buffer zone creation while keeping the rodeo tradition alive. The lack of a full-time cattle manager contributes to the low quality cattle foraging area in lower Waipā watershed. A full-time cattle manager could greatly improve water quality and land restoration by practicing techniques such as rotational grazing and riparian buffer zones. Allowing flow from the lower eastern mountain road and Chinese irrigation ditch to enter the lower floodplain area could increase infiltration and allow a diversified agroforestry rotational grazing system to thrive at Waipā while increasing water supply for irrigation purposes. Potential exists to rejuvenate an old abandoned rice mill in the upper pasture below a delivery ditch built by the Chinese after their arrival to Kaua'i. Basically, an improvement of water quality and reinvigoration of native plant systems could be accomplished with a coexisting sustainable movement of people and resources from the mountain to the sea, *mauka to makai*. Current land managers at Waipā focus the majority of their work on the lower coastal floodplain area.

Continued water quality monitoring throughout the watershed at specific locations along Waipā stream, tributaries, pastures, delivery ditches, and coastal zone could improve knowledge of the effects that irrigation and stream diversion have on native fish populations, stream temperature fluctuations, and fecal bacteria levels. Water, soil, and sediment quality monitoring for fecal indicator bacteria in frequently submerged areas such as delivery ditches, taro patches, streambed and tributary sediments, and intertidal zones could improve knowledge about how *E. coli* and enterococci survive and multiply in heavily saturated areas versus other ecosystems of concern. Bacteria are considered to be more likely to survive a longer period in soils with high water-holding capacity (Gerba and Bitton, 1984). Perhaps there is a connection with fecal indicator bacteria levels in soils and water and occurrence of leptospirosis infection rates, staph infections, gastrointestinal illness, urinary tract infections, premature birth rates, and other illnesses of concern. An epidemiological study on correlating water quality variables with illnesses of concern could help public health officials find preventive measures to curb waterborne diseases in tropical island ecosystems.

Maybe the frequently clogged Waipā stream mouth and subsequent stagnant water system creates an ideal environment for fecal indicator bacteria to thrive and multiply in streambed sediment and surface and subsurface waters. Concurrent monitoring of nutrients and pathogens of concern in the water columns and subsurface of Waipā riparian zones and delivery ditches above, below, and within designated sections could provide valuable information on movement, survival, and reproduction of microorganisms through a rural tropical island watershed and how to use plants to filter out contaminants.

Unknown relationships could exist between plant species such as shampoo ginger (*Z. zerumbet*) and *C. dentata*. Results from this study showed that ground cover values for *Z. zerumbet* levels were significantly higher during summer 2004 versus winter 2005 in upper elevation areas studied. *C. dentata* ground cover values were significantly lower during summer 2004 versus winter 2005 in upper elevation areas.

The Hawaiians had many uses for plants now labeled invasive species such as *Z. zerumbet*, *M. indica, P. guajava,* and *H. tiliaceus*. Investigating the use of invasive species at Waipā and their economic value for sustainable harvest purposes as riparian buffer zones for medicine, timber, and food could provide useful income for the Waipā Foundation while decreasing the amount of invasive species within the watershed and improving water quality. Hawaiians may have purposely brought hau (*H. tiliaceus*) wood to Hawai'i (Pratt, 1998). Harvesting hau for firewood, to make canoes, fences, and other important cultural uses at Waipā could subsequently increase streamflow in the lower watershed. The young leaves of kuawa *(P. guajava)* can be chewed or ground and taken internally to stop diarrhea (Kaiahua and Noyes, 1997). According to Jamaican Maroon healers Lee Henry and Ivelyn Harris, *P. guajava*, *M. indica, W. trilobata*, and *D. incanum* (all invasive species at Waipā) leaves can be used as teas for a variety of medicinal purposes (Austin and Thomas, 2003). *A. moluccana* (*kuku'i*) has many uses in Hawaiian tradition such as dye, oil for lamps, adornment, and medicine (Kaiahua and Noyes, 1997). The state tree of Hawai'i, kuku'i was brought to the islands by the first Polynesians who used the oil-rich nuts for lighting and for the most prestigious of leis (Pratt, 1998). What is the market for harvesting, selling, and using invasive plant species at Waipā for medicinal and cultural purposes and integrating the most appropriate species in riparian buffer zone systems?

Pigs and introduced birds love vivi (*P. cattleianum*), and therein lies much of the problem as it grows in very tight thickets and produces soil chemicals that inhibit the growth of other plants (Pratt, 1998). Perhaps an in-depth study on *P. cattleianum* growth rates, water use, and rhizome interactions with specified nutrients and microorganisms would provide more information on controlling the menacing spread of strawberry guava and other invasives in Waipā and reinvigorate sustainable riparian ecosystems of Hawai'i.

References:

Austin, S. and Thomas, M.B. eds.; Harris, I., Harris, L., Henry, L.G.; Pennycooke I. illustrations. 2003. Common Medicinal Plants of Portland, Jamaica. MAPCO Business Printers Ltd., 71 Montgomery Avenue, Kingston 10, Jamaica, West Indies.

Gerba, C.P., Bitton, G. 1984. Microbial pollutants: their survival and transport pattern to groundwater. In: Gerba, C.P., Bitton, G. (Eds.), Groundwater Pollution Microbiology. Wiley, New York, pp. 66-88.

Kaiahua, K., Noyes, M. 1997. Hawaiian Healing Herbs: a book of recipes. Ka`imi Pono Press, P.O. Box 751, Honolulu, Hawai`i, 96808.

Pratt, H.D. 1998. A Pocket Guide to Hawai`i`s Trees and Shrubs. Mutual Publishing, 1215 Center Street, Suite 210, Honolulu, Hawai`i, 96816.