GEOG 401
CLIMATE CHANGE

Climate Change – Ecosystem Change – Hydrological Change
Tropical Terrestrial Environments

GLOBAL CHANGE

NATIVE FOREST

PRESENT CLIMATE

FOREST REGROWTH

GLOBAL WARMING

REFORESTATION

RESTORATION

SPECIES INVASION

INVAGED FOREST

FUTURE CLIMATE

ABANDONMENT

CLEARING

DEFORESTATION

AG LAND

URBANIZATION

PERI-URBAN & URBAN LAND
Climate Change – Ecosystem Change Interactions

Vegetation Change Effects on Climate
• Carbon cycle
  – Land clearing $\rightarrow$ biomass decrease $\rightarrow$ CO$_2$ emissions
• Energy balance
  – Deforestation $\rightarrow$ increased albedo $\rightarrow$ decreased $R_{net}$ $\rightarrow$ cooler
  – Deforestation $\rightarrow$ decreased ET $\rightarrow$ increased surface temperature $\rightarrow$ hotter

Atmospheric Change Effects on Terrestrial Ecosystems
• Increasing CO$_2$ concentration $\rightarrow$ enhanced photosynthesis
• Increasing temperature:
  • Longer growing season
  • Shifting vegetation zones
  • Effects on photosynthesis and respiration
  • Higher ET
  • More disease and pests
• Changing precipitation:
  • Plant water stress
  • Fire frequency
• Increasing storm frequency
• Habitat loss
• Species invasion

Climate & Ecosystem Change Impacts on Hydrological Cycle

Climate Change Effects
• Higher ET and/or Lower Precipitation
  – Reduced stream/river flows
  – Aquatic habitat change
  – Reduced groundwater recharge
  – Irrigation requirement increase
  – Greater evaporative loss from reservoirs
  – Water supply decrease
  – Loss of hydroelectric power capacity
• Higher extreme precipitation
  – Higher flood frequency
  – More severe floods
  – Agricultural impacts
• Climate-change-related vegetation change
  – Effects on ET
Climate & Ecosystem Change Impacts on Hydrological Cycle

Ecosystem Change Effects

- Deforestation
  - Reduced ET
  - Higher flood frequency?
  - Reduced low flows?
  - Erosion & reduced water quality
  - Changes in precipitation?

- Afforestation
  - Increased ET
  - Reduced water supply

- Species Invasion
  - Increased ET?
  - Decreased streamflow & groundwater recharge?
  - Increased surface runoff & erosion?
Let’s Look at Tropical Land Cover Change

Tropical Land-Cover Change: A Partial List of Transitions

DEFORESTATION
- Forest → Pasture
- Forest → Shifting Agriculture
- Forest → Permanent Cropping
- Forest → Tree Plantations

AGRICULTURAL LAND TRANSITIONS
- Pasture → Secondary Vegetation
- Shifting Agriculture → Secondary Vegetation
- Shifting Agriculture → Permanent Cropping
- Shifting Agriculture → Tree Plantations
- Agriculture → Peri-urban & Urban Land

SECONDARY VEGETATION TRANSITIONS
- Secondary Vegetation → Permanent Cropping
- Secondary Vegetation → Tree Plantations
- Secondary Vegetation → Forest

SPECIES INVASION
- Native Forest → Invaded Forest
Changing land cover dynamics in SE Asia

• Once-dominant shifting cultivation has largely given way to permanent agriculture
• Area covered by rubber, oil palm and other tree plantations is expanding rapidly in the region

What effects will this land cover change have on ecosystem services?

• Evapotranspiration
• Carbon exchange
• Carbon sequestration
Traditional and non-traditional rubber-growing regions

Local hydrologic effects of introducing non-native vegetation in a tropical catchment.
Ecohydrology 1: 13–22, DOI: 10.1002/eco.3.
Research Questions
Hydrology of *Hevea brasiliensis* Plantations

- What are the hydrological **consequences of conversion** of land to rubber plantations in non-traditional rubber growing areas?

- What are the **rates of ET in rubber** stands, and how do they compare with those of other land-cover types in the region?

- What are the **environmental controls** that affect spatial differences in rubber ET?
Som Sanuk
NE Thailand
Trees planted: 1992
Tower installed: Feb. 2009

CRRI
Kampong Cham, Cambodia
Trees planted: 2004
Tower installed: Sep. 2009
Seasonal Climate Contrasts (CRRI)

- Wind Direction
- Rainfall
- VPD

- Soil Moisture
- Leaf Wetness

Summer Monsoon
Winter Monsoon

Leaf Area

- Rubber is deciduous
- Leaf fall in late December or early January
- Leaf out beginning in late January
Controls on ET (Som Sanuk)

LAI

Controls on ET (CRRI)

LAI
Controls on ET (Som Sanuk)

Soil Moisture

Controls on ET (CRRI)

Soil Moisture
Controls on ET

Leaf Wetness

Vapor Pressure Deficit

Strength of Controls on Evapotranspiration by Season

<table>
<thead>
<tr>
<th>Forcing Variable</th>
<th>vs.</th>
<th>Dry Season</th>
<th>Wet Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Energy</td>
<td>LE</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Leaf Area</td>
<td>LE/A</td>
<td>Dominant</td>
<td>Weak</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>LE/A</td>
<td>Weak</td>
<td>Moderate</td>
</tr>
<tr>
<td>VPD</td>
<td>LE/A</td>
<td>Weak</td>
<td>Weak</td>
</tr>
<tr>
<td>Leaf Wetness</td>
<td>LE/A</td>
<td>Weak</td>
<td>Null</td>
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</table>
### CRRI Mean ET and Mean Transpiration (mm day\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ET</td>
<td>3.92</td>
<td>4.08</td>
<td></td>
</tr>
<tr>
<td>(T_{\text{sap flow}})</td>
<td>1.28</td>
<td>1.80</td>
<td></td>
</tr>
<tr>
<td>(T_{\text{leaf level}})</td>
<td></td>
<td></td>
<td>2.02</td>
</tr>
<tr>
<td>T/ET</td>
<td>0.33</td>
<td>0.44</td>
<td></td>
</tr>
</tbody>
</table>

### Mean Annual Evapotranspiration

<table>
<thead>
<tr>
<th>Year</th>
<th>SS</th>
<th>ET (mm)</th>
<th>RF (mm)</th>
<th>CRRI</th>
<th>ET (mm)</th>
<th>RF (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009-10</td>
<td>1237</td>
<td>1430</td>
<td>1332</td>
<td>2010</td>
<td>1488</td>
<td>1544</td>
</tr>
<tr>
<td>2010-11</td>
<td>1185</td>
<td>2069</td>
<td>2221</td>
<td>2011</td>
<td>1459</td>
<td>1439</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1211</strong></td>
<td><strong>1459</strong></td>
<td><strong>2145</strong></td>
<td><strong>1439</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Comparison with Natural Ecosystems

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Prec</th>
<th>( R_{\text{net}} )</th>
<th>ET</th>
<th>LE</th>
<th>( \frac{\text{LE}}{R_{\text{net}}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mm)</td>
<td>(W m(^{-2}))</td>
<td>(mm)</td>
<td>(W m(^{-2}))</td>
<td></td>
</tr>
<tr>
<td>Tropical Rainforest (6)</td>
<td>2277</td>
<td>141</td>
<td>1311</td>
<td>102</td>
<td>0.729</td>
</tr>
<tr>
<td>Tropical Seasonal Forest</td>
<td>1590</td>
<td>133</td>
<td>1013</td>
<td>79</td>
<td>0.593</td>
</tr>
<tr>
<td>Savanna (7)</td>
<td>1257</td>
<td>135</td>
<td>803</td>
<td>62</td>
<td>0.548</td>
</tr>
<tr>
<td>Rubber Plan (3)</td>
<td>1696</td>
<td>135</td>
<td>1265</td>
<td>98</td>
<td>0.725</td>
</tr>
</tbody>
</table>
Giambelluca et al. (in review) Evapotranspiration of rubber in two plantations in SE Asia.


**Rubber Study Summary**

- **Controls on ET differ strongly between seasons**
  - Available energy dominant in wet season
  - Leaf Area and Soil moisture play a role in dry season
- **Rubber ET may be significantly higher than forest ET**
  - Implications for water and food security as area under rubber and other tree plantations expands in region
- **Remaining questions include:**
  - How will rubber ecosystem respond under wetter or drier conditions?
  - What is the carbon balance of the rubber plantation?
  - How do management practices affect fluxes and sequestration?

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**Species Invasion in Hawaiian Forests**

- State of Hawaiʻi lists 106 highly invasive plant species in the Islands
- Many tree species have been found to be invasive


Our Field Studies of Invasive Tree Impacts

- Strawberry Guava:
  - Evapotranspiration and Carbon Exchange
  - Sapflow of Different Species
  - Leaf-level Observations
  - Fog interception
  - Rainfall and Fog Water Partitioning
- Miconia
  - Light extinction
  - Throughfall
- Kiawe
  - Sapflow
  - Leaf-level Observations

Strawberry Guava (*Psidium cattleianum*)

- Grows fast
- Invades quickly
- Already widespread in Hawai’i
- Difficult to eradicate
- High stem density
- Smooth bark
Strawberry Guava Field Sites

- **Invaded Forest Site**
  - 'ohia forest invaded by *Psidium cattleianum* (strawberry guava)

- **Native Forest Site**
  - *Metrosideros polymorpha* ('ohia)
  - *Cibotium spp.* (hapū 'u; tree fern)

Epiphyte water storage: Ryan Mudd
### Epiphyte Study

**Master’s Student, Ryan Mudd**

<table>
<thead>
<tr>
<th></th>
<th>Thurston</th>
<th>Ola’a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass (t ha⁻¹)</td>
<td>2.57</td>
<td>0.89</td>
</tr>
<tr>
<td>Surface Area per Ground Area (%)</td>
<td>26.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Water Storage Capacity (mm)</td>
<td>1.48</td>
<td>0.59</td>
</tr>
</tbody>
</table>

### Stand-level Comparison

Eddy Covariance Measurements

Energy Use for ET: Native vs Invaded Forest

**LE<sub>invaded</sub> 27% higher**

- **INVASED FOREST**
  - \( y = 0.4233x + 25.94 \)
  - \( r^2 = 0.8648 \)

- **NATIVE FOREST**
  - \( y = 0.3253x + 21.93 \)
  - \( r^2 = 0.6754 \)

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Difference is here. LE<sub>invaded</sub> has lower minimum.
Dry Periods

During dry canopy periods, when physiological control over gas exchange is important, ET is much higher in the invaded stand.

Why?

We looked to our sapflow measurements for answers.

Photo credit: Forest & Kim Starr
Sapflow Study
PhD Student, John DeLay

Are sapflow velocities higher in guava?

Sample period mean sapflow velocities:

Native ‘Ōhi‘a **3.3** cm/hr
Native *Ilex* **3.6** cm/hr
Native *Olapa* **3.3** cm/hr
Invasive Guava **2.7** cm/hr

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**Stand Basal Area**

Legend:
- Cibotium
- Metrosideros
- *Ilex*
- Coprosma
- *Cheirodendron*
- Podocarpus
- Native Tree
- Invasive Tree

Native Forest Site

Invaded Forest Site
**Basal Area-Xylem Area**

<table>
<thead>
<tr>
<th></th>
<th>Large 'Ōhi’a</th>
<th>Small 'Ōhi’a</th>
<th>Guava</th>
</tr>
</thead>
<tbody>
<tr>
<td>16% Xylem</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% Xylem</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% Xylem</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on 400-m² survey areas

<table>
<thead>
<tr>
<th>Based on 400-m² survey areas</th>
<th>Basal Area (cm²)</th>
<th>Xylem Area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Native</td>
<td>Invaded</td>
</tr>
<tr>
<td>'Ōhi’a</td>
<td>19195</td>
<td>4795</td>
</tr>
<tr>
<td>Ilex</td>
<td>1760</td>
<td>0</td>
</tr>
<tr>
<td>Guava</td>
<td>0</td>
<td>5392</td>
</tr>
<tr>
<td>Cheirodendron</td>
<td>0</td>
<td>859</td>
</tr>
<tr>
<td>Total</td>
<td>20955</td>
<td>11046</td>
</tr>
<tr>
<td>Sapwood/Basal</td>
<td>0.18</td>
<td>0.79</td>
</tr>
</tbody>
</table>

How about the effects of canopy wetting?

Photo: Trade Wind Fruits
Canopy Water Balance Study
Master’s Students Ryan Mudd and Mami Takahashi

Throughfall Measurements

Stemflow Measurements

Single-Layer Canopy Water Balance Model

RF

CWI

IE

FF

TF

SF

Canopy

FF
Canopy Water Balance: Native vs. Invaded

<table>
<thead>
<tr>
<th></th>
<th>IE</th>
<th>EC ET</th>
<th>Total ET</th>
<th>Transpiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native</td>
<td>500</td>
<td>1249</td>
<td>961</td>
<td>461</td>
</tr>
<tr>
<td>Invaded</td>
<td>396</td>
<td>1392</td>
<td>1102</td>
<td>706</td>
</tr>
<tr>
<td>Diff</td>
<td>-21%</td>
<td>+11%</td>
<td>+15%</td>
<td>+53%</td>
</tr>
</tbody>
</table>

Mean Diurnal Cycle June 2007-May 2008
Strawberry Guava: Implications For Water Resources

- Guava-invaded forest may use more water than native forest.
- Higher ET has significant negative impacts on streamflow and ground-water recharge.
Miconia Characteristics

- Grows fast
- Invades quickly
- Difficult to eradicate
- Dark, opaque leaves
- Large leaves
- Superficial roots
- Prefers steep slopes

Miconia Pilot Study

- Under-canopy light levels
- Soil characteristics
- Throughfall drop size and velocity
- Root exposure as evidence of erosion
Light Abundance Comparison

NATIVE

INVADED

% of light reaching forest floor

Thurston

Ol'a's

Home depot

Guava/melastoma

Mixed invasive

Miconia

Faya

Light Abundance

Light under canopy

Light in parking lot

Light fraction

light fraction

0 1 2 3 4 5 6 7 8 9 10 11 12

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

0 200 400 600 800 1000 1200 1400 1600 1800 2000
Ground Cover

<table>
<thead>
<tr>
<th>Light under canopy</th>
<th>Light in parking lot</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Light Graph" /></td>
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</table>

Light fraction

<table>
<thead>
<tr>
<th>Light fraction</th>
<th>0</th>
<th>0.01</th>
<th>0.02</th>
<th>0.03</th>
<th>0.04</th>
<th>0.05</th>
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<td><img src="image" alt="Light Graph" /></td>
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</tr>
</tbody>
</table>

DROP SIZE MEASUREMENTS

Kazuki Nanko
Univ. Tsukuba

Onomea

Laser disdrometer
Results of Drop Size Survey

Median drop size:
- **Miconia**: 3.8 mm
- **Miconia**: 5.5 mm
- **'Ohi'a**: 3.7 mm

Very high compared with previous observations.

*Miconia* median drop size = 3.8 mm
Miconia’s potential impact on rainfall distribution and energetics

Miconia Covered Area vs. an Open Area:

• Decreased number of raindrops impacting the soil surface
• Decreased terminal velocity ($V_t$) of raindrops,
  - 2 mm drops falling from 3 m, $V_t = 83\%$ of open
  - 2 mm drops falling from 5 m, $V_t = 92\%$ of open
• Significant increases in drop size (mass), and therefore significant increases in kinetic energy (KE) and momentum
• Result is a more erosive rainfall that has a greater effective KE to erode and transport sediment, organics and nutrients
• Combining a more energetic input with a surface more susceptible to erosion produces an enhanced degradation scenario

Measuring Root Exposure Using LiDAR

• Root exposure is an obvious sign of soil erosion.
• Ground-based LiDAR imaging may allow precise measurements of soil loss
The Alien Tree *Prosopis pallida* (kiawe): How Does it Affect Flows of Freshwater and Nitrogen into Coastal Waters
Kiawe Commonly Thrives Along Dry Leeward Coastlines in Hawai‘i

Kiawe Can Send Roots Down to Tap Groundwater

Under dry conditions, no water available to shallow roots

Increased Water Loss to Air

Groundwater Flow to Ocean

Reduced Groundwater Flow
Kiawe Leaves and Twigs Have High Nitrogen Content

Measuring Sapflow by the Heat Dissipation Probe Method
Dr. Miyazawa installing sapflow probe in kiawe at Kiholo Bay

Sample Sapflow Results

Sapflow at Kiholo Bay Lower Station
May 30 - June 29, 2010

Mean Diurnal Cycle of Sapflow at Kiholo Bay Lower Station
May 30 - June 29, 2010
Preliminary Findings

- Because of access to groundwater, transpiration of coastal kiawe not responsive to rainfall
- Despite this, transpiration is reduced to very low levels by mid-morning
- Water use by kiawe may not have a significant effect on groundwater flows
- Effects of kiawe on nitrogen inputs is still under investigation
Summary of Invasive Tree Impacts

- Strawberry Guava:
  - ET appears to be high
  - Cloud water interception low
  - Negative impacts on water supply
- Miconia
  - Reduces ground cover
  - Increases throughfall drop size
  - Potentially increases runoff and erosion
  - Other impacts?
- Kiawe
  - Taps groundwater in coastal areas
  - Water use is low
  - Nitrogen input?