What’s Next?

- **Midterm II** - April 27 (Wed): Does Not Include Today’s Lecture

- **Final** - May 2 (Mon) 8:00 - 9:45 Symposium
  - **Group Oral Presentation** (5 groups) 15%
    - 15 minute presentation
    - 5 minutes questions / answers
  - **Group Extended Abstract** 10%

- **Individual Take-Home Final** - May 6 (Fri) - by email) 10%
  - Self-evaluation & Project questions
Returning Equipment

- **April 27 (Wednesday):**

<table>
<thead>
<tr>
<th>TEAM</th>
<th>Tape</th>
<th>Sieves</th>
<th>Binos</th>
<th>Camera</th>
<th>Altimeter</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird People</td>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three Amigos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sebastian</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Jonathan</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PART III

Hawaiian nature and its fate
Polynesian Exploration

Polynesia: Subregion of Oceania, made up of over 1,000 islands scattered over the central and the southern Pacific Ocean. Between ~ 3000 - 1000 BCE, speakers of Austronesian languages spread through South-East Asia, starting from Taiwan.
Polynesian Settlement

Lapita Peoples appeared in the Bismarck Archipelago (1000 BCE).

Polynesian expansion, reaching Marquesas (200 BCE), Hawai‘i (400 CE), and Rapa Nui (400 CE).

Introductions: polynesian rats, pigs, chickens, canoe plants
Western Contact

On January 18, 1778, explorer Captain Cook becomes the first European to reach Hawai‘i, when he sails past O‘ahu.

Two days later, he landed at Waimea (Kauai) and named the Sandwich Islands, in honor of his patron, the earl of Sandwich.

Introductions: diseases, mosquitos, western pigs
Western Settlement

Human population declined drastically due to diseases, then increased with western settlement.
Today

Population of **Honolulu** city and county: 953,207 in 2010
(1.4 Million people state-wide, according to the census)

Linked to global trade via shipping
Avoiding Environmental Collapse: Pre-European Cultural Response to Deforestation On Pacific Islands

Some Pacific island societies, such as those of Easter Island and Mangareva, inadvertently contributed to their own collapse by causing massive deforestation.

Others retained their forest cover and survived.

How can those fateful differences be explained?
Avoiding Environmental Collapse - Questions

The answers involve both different cultural responses of peoples and different susceptibilities of environments.

Do some environmental factors predispose towards deforestation?

Do some environmental factors predispose towards replacement of native trees with useful introduced tree species?
Avoiding Environmental Collapse - Observations

All Pacific islands suitable for agriculture occupied before European arrival by colonists originating from Asia, in a wave of Polynesian travelers (1200 BCE to 1200 CE)

These colonizers cleared land and cut trees, especially for agriculture, timber and fuel ... and in doing so, drove many species extinct.
Avoiding Environmental Collapse - Observations

Early European visitors observed that forest cover varied greatly between islands, from totally deforested with original tree species extinct (Easter, Necker and Nihoa) to extensive forests (Samoa, Taveuni, Bismarck).

These forests also varied greatly in composition, from ones still dominated by native species to others whose native species had been replaced by introduced species.
Avoiding Environmental Collapse - Approach

Coded European-contact conditions (forest type) and nine environmental variables for 81 sites on 69 Pacific islands, spanning from Yap (west) to Easter (east), and from Hawai‘i (north) to New Zealand (south).

In 12 of our 69 islands, studied 2 different Sites on the island (windward and leeward) because of different rainfall values often associated with different degrees of deforestation.
Avoiding Environmental Collapse - Approach

From accounts of early European visitors, coded every site according to five-point scales for deforestation and for forest replacement.

NOTE:

Deforestation and forest replacement significantly correlated, but measure different processes.

(Spearman rank correlation $r = 0.43$, $p = 0.001$, $n = 81$ entries - 69 islands + 12 duplicate wind / lee ward sites)
Avoiding Environmental Collapse - Approach

From accounts of early European visitors, coded every site according to a five-point scale for deforestation:

(1 represents virtually no deforestation and 5 represents complete deforestation)
Avoiding Environmental Collapse - Approach

From accounts of early European visitors, coded study sites according to five-point scale for forest replacement.

(1 represents virtually no replacement and 5 represents complete replacement)

Natives Not Replaced (1)             Natives Replaced (5)
Avoiding Environmental Collapse - Approach

Four statistical approaches:

1) correlations and regressions, among 2 outcomes (deforestation / replacement) and 9 independent variables

2) multivariate regression analyses, to take account of correlations among the independent variables

3) analysis of residuals (actual values minus model predictions) from multiple regression and tree models, to identify data points fitted poorly by models and suggest explanatory factors not incorporated into the models

4) multivariate tree models to divide the data, based on more than one independent variable, into groups each homogenous in outcome value within the group but maximally contrasting in outcome value between groups
Avoiding Environmental Collapse - Predictions

Hypothesis: deforestation should be less severe in areas where tree regrowth kept pace with logging

Low latitude and high precipitation (tropical islands) should support high plant growth – low deforestation

Three variables (island age, volcanic ash fallout, Asian dust fallout) influence soil nutrient levels

Regrowth is rapid on nutrient-rich soils (but those are also the soils preferred by farmers)

Some sites (inhospitable for introduced plants) were not deforested – Makatea
Avoiding Environmental Collapse - Predictors

What environmental variables predict forest loss / replacement?

Two variables rainfall and latitude (as a surrogate for temperature), were chosen because they are primary determinants of plant growth rates.
Avoiding Environmental Collapse - Predictors

Three variables used to quantify nutrient patterns

Island Age

[Map showing the movement of the Pacific tectonic plate with island ages marked.]
Avoiding Environmental Collapse - Predictors

Three variables used to quantify nutrient patterns

Volcanic ash fallout

Asian dust transport

Tephra = fragmental material from eruptions, regardless of composition, fragment size or emplacement mechanism.

Figure 6: Map showing estimates of the long-term (integrated glacial plus interglacial) rate of dust deposition to the Pacific Ocean (from ref. 58). The isopachs (mg m⁻² yr⁻¹) are based on models of atmospheric dust transport and are in general agreement with data collected from numerous ocean cores.
Avoiding Environmental Collapse - Predictors

Variable influencing overall likelihood of deforestation:

Makatea terrain (uplifted reef) = Raised terrace of coral limestone surrounding a South Pacific atoll

Henderson Island is currently one of the most undisturbed makatea islands in the world

In makatea zones, most species are indigenous, and have been preserved because of the rough, almost inaccessible terrain - not suitable for agriculture
Avoiding Environmental Collapse - Predictors

What other variables do we need to control for?

Some variables have multiple indirect effects:

Area:

Elevation:

Isolation:
Avoiding Environmental Collapse - Results

**Table 1: Significant predictors of deforestation**

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Bivariate regression</th>
<th>Multivariate regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>81</td>
<td>69</td>
</tr>
<tr>
<td>Rainfall (log)</td>
<td>-1.9**</td>
<td>-1.6**</td>
</tr>
<tr>
<td>Latitude</td>
<td>+0.066***</td>
<td>+0.092***</td>
</tr>
<tr>
<td>Makatea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>+0.53†</td>
<td>+0.53†</td>
</tr>
<tr>
<td>Tephra</td>
<td>-0.46***</td>
<td>-0.37***</td>
</tr>
<tr>
<td>Dust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation (log)</td>
<td>-0.42*</td>
<td>-0.25†</td>
</tr>
<tr>
<td>Area (log)</td>
<td>-0.31**</td>
<td>-0.24†</td>
</tr>
<tr>
<td>Distance (log)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance accounted for</td>
<td>0.82</td>
<td>0.75</td>
</tr>
</tbody>
</table>

**Positive:** Latitude, Age, Isolation

**Negative:** Rainfall, Tephra (Elevation, Area)

The Methods section explains the nine independent variables and the bivariate regression, multivariate regression and multivariate tree analyses. Numbers in the two bivariate columns are bivariate regression coefficients; numbers in the multivariate columns are the corresponding multivariate regression coefficients. The signs in the tree columns are the sign of the relationship between deforestation and that independent variable; numbers in the tree columns denote the sequence in which predictor variables enter the tree (earlier-entering predictors, with lower numbers, are more important). Levels of statistical significance are as follows: ***, P < 0.0001; **, P < 0.001; *, P < 0.01; †, P < 0.05. Cells left blank failed to reach significance at P < 0.05. We used as alternatives a full data set of 81 entries and a reduced data set with 69 of those entries (numbers ‘81’ and ‘69’ in the first row). Multivariate regression of the full set with all nine independent variables (81, A) was repeated after dropping area as an independent variable (81, no A); that repetition was unnecessary for the 69-entry set because area proved not to be a significant predictor of deforestation in that set.
Avoiding Environmental Collapse - Results

**Positive:** Age, Isolation

**Negative:** Latitude, Rainfall, Makatea, Tephra, Dust (Elevation, Area)

---

Table 2: Significant predictors of forest replacement

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Bivariate regression</th>
<th>Multivariate regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>81</td>
<td>69</td>
</tr>
<tr>
<td>Rainfall (log)</td>
<td>-0.45†</td>
<td></td>
</tr>
<tr>
<td>Latitude</td>
<td>+0.56***</td>
<td></td>
</tr>
<tr>
<td>Makatea</td>
<td>-0.58***</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>0.49*</td>
<td>-0.03**</td>
</tr>
<tr>
<td>Tephra</td>
<td>-0.003***</td>
<td>-0.002**</td>
</tr>
<tr>
<td>Dust</td>
<td>-0.84***</td>
<td>-0.45***</td>
</tr>
<tr>
<td>Elevation (log)</td>
<td>-0.83***</td>
<td>-0.43***</td>
</tr>
<tr>
<td>Area (log)</td>
<td>-0.63***</td>
<td></td>
</tr>
<tr>
<td>Distance (log)</td>
<td>+0.18†</td>
<td></td>
</tr>
</tbody>
</table>

|                      | 81, A                | 69, A                   |
|                      | -0.03**              | -0.03*                  |
|                      | -1.0†                | -1.08**                 |
|                      | +0.27†               | +0.27†                  |
|                      | -0.72***             | -0.48***                |
|                      | -0.002***            | -0.001†                 |
|                      | -0.82*               | -0.28†                  |
|                      | -0.28*               | -0.27*                  |
|                      | +0.15†               | +0.15†                  |

|                      | 81, no A             | 69, no A                |
|                      | -0.04***             | -0.03†                  |
|                      | -0.32†               | -0.14†                  |
|                      | -0.94***             | -0.74***                |
|                      | -0.002**             | -0.96***                |
|                      | -0.06*               | 0.12§                   |

|                      | Variance accounted for |
|                      | 0.86                  | 0.73                    |
|                      | 0.84                  | 0.73                    |

As Table 1, but for forest replacement instead of deforestation. Levels of statistical significance are as follows: ***, \( P < 0.0001 \); **, \( P < 0.001 \); *, \( P < 0.01 \); †, \( P < 0.05 \); ††, \( P = 0.06 \); ‡‡, \( P = 0.07 \). Cells left blank failed to reach significance at \( P < 0.05 \).
Avoiding Environmental Collapse - Conclusion

Age

Island or terrain age relevant because soil nutrients lost from volcanic rocks over time by chemical weathering and leaching.

Evident in controlled natural experiments within islands: on Easter Island the oldest surface, the Poike Peninsula, became deforested several centuries before the younger remainder of the island.

Deforestation increased with age, but the relation of forest replacement to age was inconsistent.
Avoiding Environmental Collapse - Conclusion

Precipitation

Inversely associated with deforestation (all analyses) and replacement (1 analysis)

On 8 of the 12 islands separately coded into two locations, one was much drier and also more deforested than the other. Offering a controlled natural experiment

Dry islands more likely to end up deforested. Why?

Rainfall most important determinant of plant growth

Low rainfall increases forest vulnerability to fire and hence to formation of deforested grassland
Avoiding Environmental Collapse - Conclusion

Latitude

Deforestation increased with latitude in all analyses, as expected from the decrease in temperature and plant growth rates with latitude.

In contrast, forest replacement decreased with latitude, because two of the most important introduced tree species (breadfruit and Tahitian chestnut) are tropical species whose cultivation decreases with latitude.

Breadfruit
(Artocarpus altilis)

Tahitian chestnut
(Inocarpus fagifer)
Avoiding Environmental Collapse - Conclusion

Makatea

This uplifted reef formation of sharp, fissured coral bears little soil and is painfully difficult to walk on.

All seven islands provide controlled natural experiments: makatea terrain retained forests, whereas non-makatea terrain became deforested.

Statistical analysis showed low forest replacement.
Avoiding Environmental Collapse - Discussion

Area - Inversely associated with deforestation and forest replacement: large islands retained more forest and more native tree species than small islands. Why?

Multiple factors probably contribute, including:

1. larger islands have greater habitat and tree species diversity (hence higher likelihood of some species being spared from logging)

2. larger islands are steeper and have tracts of inaccessible land

3. larger islands have lower perimeter/area ratios (fewer coastal resources support human population)
Avoiding Environmental Collapse - Discussion

Elevation - Inversely associated with deforestation and forest replacement: high islands supported more forest and more native trees than low islands

Why?

At least four factors probably involved:

1. orographic rain generated at high elevations, descends in streams and makes lowlands wetter

2. nutrients and soil eroded carried in streams to lowlands

3. orographic rain captures atmospheric dust

4. agriculture decreases with elevation (cool / steep)
Avoiding Environmental Collapse - Discussion

Isolation - Distance positively associated with deforestation and forest replacement, which was most severe on remote islands.

Why?

Reasons might include:

1. low tree species diversity on remote islands decreasing likelihood of any tree species being spared

2. people on islands near other islands have option of emigrating, trading or raiding instead of staying at home and having an impact on the forests
Avoiding Environmental Collapse - Conclusion

Comparative analyses of deforestation much more detailed interpretations than previously possible.

Geological and ecological determinants of ecological outcomes (deforestation / replacement of natives) and social outcomes (societal collapse / survivorship).
Easter island (Rapa Nui)

Suffered the most extreme deforestation and social and population collapse of any Pacific island, even though the Polynesians who colonized Easter colonized hundreds of other islands without wreaking such extreme impacts.

This study suggests part of the answer to be Easter’s extreme environmental fragility predisposing towards deforestation. Of 69 islands:

- lowest tephra and dust fallout
- second greatest isolation
- third highest latitude
- no makatea
- relatively low, small and dry
Easter island (Rapa Nui)

This study correctly predicts correctly that Easter Island should have third highest deforestation, exceeded only by Necker and Nihoa, which ended up completely deforested.

In conclusion:

Diamond argues the fate of societies is largely driven by exogenous factors - determinism.

Easter island’s collapse was not because its people were especially careless, but because they faced one of Pacific’s most fragile environments.

But... perhaps certain social factors can also influence the fate of societies.
Mechanisms for Sustainability

Hawaiian culture is grounded on the land and on the sense of love and responsibility towards the land.

Illustrated in Kumulipo, which emphasize connection between land and people: www.sacred-texts.com/pac/lku/

Aloha 'aina
to love and respect the land, make it yours and claim stewardship for it.

Malama 'aina
care and nurture the land so it can give back all we need to sustain life now and for future generations.
An ahupua'a is a traditional concept of resource use and management based on families living in a division of land that connects the mountains to the reefs and the sea.
Mechanisms for Sustainability

**Kapu System:** Strict code of laws and regulations.

*Kapu* is usually translated as "forbidden", though it carries meaning of "sacred", "consecrated", or "holy".

System of lifestyle, gender roles, politics, religion, and harvesting.

Constrained resource use: including sea food harvesting.
References


Degrees of Deforestation
Scale: 1 - 5

Easter Island

5: Almost completely deforested
4: Largely deforested

Forests mainly on coastal plain, valley floors, and very steep slopes
3: Densely Forested:

Primary forest at high elevations;
secondary forest at low elevations;
extensive grass/fern savannas on ridges, slopes, plateaus

Marquesas
2: Densely Forested:

Primary forest at high elevations; secondary forest at low elevations; no grass/fern savannas
1: No Deforestation
Degrees of forest replacement

1: Introduced tree species less than 10% of all trees

Marquesas

New Zealand

4: Introduced tree species 50-75% of all trees up to 600 meters; less than 10% above 600 meters
Avoiding Environmental Collapse - Results

Tree Model: Deforestation

Number of terminal nodes: 8
Residual mean deviance: 0.8702 = 56.57 / 65
Misclassification error rate: 0.1842 = 14 / 76
Avoiding Environmental Collapse - Results

Replacement

log(area) < 5.84

- tephra < 2.5
  - dust < 325
    - 4
    - 3
  - NA
    - 3

- dust < 485
  - log(area) < 9.25
    - 3
    - 2

Number of terminal nodes: 6
Residual mean deviance: 0.5818 = 39.56 / 68
Misclassification error rate: 0.1184 = 9 / 76