

The Blind Spot in the Green Revolution: Temples, Terraces, and Rice Farmers of Bali

Dr. Cynthia A. Wei, Dr. William Burnside, and Dr. Judy Che-Castaldo
National Socio-Environmental Synthesis Center



Balinese rice terraces (Wikipedia.org)



rice terrace (commons.wikimedia.org)



Balinese water temple (Wikipedia.org)

Authors' note: We are interested in improving this case and in tracking its use. We welcome any comments on the use of this case, suggestions to improve it, and basic information about how it was used. Please contact Dr. Cynthia Wei at cwei@sesync.org. Thank you in advance!

Summary

This case explores the complex interactions in a socio-environmental system, the Balinese wet rice cultivation system. Using a combination of the interrupted case and directed case methods, students are presented with an issue that arose during the implementation of Green Revolution agricultural policies in Bali: rice farmers were required to plant new high yield rice varieties continuously rather than following the coordinated cropping schedules set up by water temple priests. Students examine qualitative and quantitative data from classic anthropological research by Dr. Steven Lansing to learn about the important role that water temples play in achieving sustainable rice cultivation in Bali. Using a model that synthesizes ecological, hydrological, and ethnographic data, Lansing and his colleague, Dr. James Kremer, were able to demonstrate that temple priests determine the cropping schedules for farmers in a way that reduces pest growth and helps to manage limited water resources, maximizing rice yields. This four-part case can be used for a wide range of courses in a few class periods (total class time approximately 4.5-5 hrs.)



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Topical areas: Anthropology, Agriculture, Ecology, Environmental Science, Socio-environmental Synthesis

Education level: Undergraduate- introductory level, Undergraduate- upper level, Graduate (with modifications)

Case Type/method: Discussion case and interrupted case

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This case study addresses the following **Socio-Environmental Synthesis learning goals**:

1. Describe a socio-environmental system, including the environmental and social components and their interactions.
 - *Related activity*: Students diagram the hydrological system that rice cultivation in Bali depends upon and the Water Temple System, and, in turn, discuss the linkages and interactions between the two systems.
2. Co-develop research questions and conceptual models in inter- or trans-disciplinary teams.
 - Value different ways of knowing and understand the value of different knowledge sources.
 - *Related activity*: Students examine the disagreements over how to continue cultivating rice that arose during the Green Revolution as a result of declining rice yields. Students discuss the difference between scientific knowledge and experiential or cultural knowledge, how they are valued, and the role they play in decision-making.
3. Find, analyze, and synthesize existing data.
 - Understand the different kinds of data and research methods used by relevant disciplines in the natural and social sciences.
 - *Related activity*: Students examine a simulation model that integrates ecological data and social data to predict rice yields. Students are also introduced to ethnographic studies, a common research method in anthropology.
4. Consider the importance of scale and context in addressing socio-environmental problems.
 - Understand that ecological and social processes often vary across differing contexts, including space, time, and conditions (e.g. economic or political).
 - *Related activity*: Students examine the impacts of coordinating cropping schedules at different spatial scales. Management of both pests and water availability was only achieved at the intermediate scale of coordination, which corresponded with the traditional water temple system

Learning Objectives:

At the end of this case, students should be able to:

1. Describe an example of socio-environmental system (Bali rice cultivation), including the component parts of the system and the relationships between the social and biophysical components of the system.
2. Explain how ecological and social factors interact in the Bali rice cultivation system.
3. Describe the different kinds of knowledge used to make decisions about rice cultivation in this case and how they are valued.
4. Explain how modeling was used to analyze the problem of declining rice yields in this case.
5. Explain how different types of data were synthesized to understand the role of the subak system described in this case.
6. Explain why integration of ecological data and social data is necessary to predict rice yields in this case.
7. Explain why it is important to consider sources of data from several disciplines.
8. Explain why it is important to consider ecological and social processes and system behavior across different scales (i.e. spatial).

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Introduction/Background:

This case study highlights the critical importance of considering the socio-cultural aspects of an environmental issue. In this example, the complex socio-environmental (S-E) system is that of the Balinese wet rice cultivation system. Management of rice production has evolved over centuries into complex, cooperative water management systems, called “subaks”, involving weirs (dams), canals, and temples. Subaks are governed by social practices and rituals centered on the water temples. These social practices, it turns out, are critical for productive rice cultivation, and the ancient Balinese system turns out to be better at sustaining rice cultivation than the new policies implemented during the Green Revolution. Based on classic anthropological research by Dr. Steven Lansing, this case study illustrates a synthesis of ecological, hydrological, economic, and ethnographic data. Lansing was able to demonstrate that water temples played an important role in this system by determining the irrigation schedules for the farmers in those watersheds. This is also a great example of communal resource management.

Before the Green Revolution, the global movement in agriculture that encouraged use of high yield crop varieties to increase food production, farmers followed a cropping calendar set by “water temples” and local “subaks” that staggered the planting and harvesting schedules for the different farmers in a given watershed. The subaks, which are associations of farmers, canals, and weirs sharing a single water source, serve both practical and religious functions and are governed by social practices and rituals centered on the water temples.¹ Remarkably, this system enabled Bali’s rice terraces to produce grain for over a millennium with no decrease in yields as is seen in other systems of irrigated agriculture due to salinization and loss of soil fertility. With the Green Revolution, the temples ceased to control cropping schedules, but continued to serve religious purposes.

The Green Revolution agricultural policies intended to increase crop yields and combat food shortages spread quickly across Asia in the 1960s and 70s, but were met with varying success. On the island of Bali, in Indonesia, Green Revolution policies involved the replacement of native rice with specially bred high-yielding varieties (HYVs), the use of new chemical fertilizers and pesticides, construction of new weirs and irrigation works, and the institution of continuous cropping schedules.

These mandated changes represented a major departure from the practices associated with the traditional Balinese system of wet rice cultivation, and had significant, unforeseen consequences. In the traditional system, rice fields experienced an alternation of wet and dry phases, which are essential to the basic biochemical processes of the rice terrace ecosystem. The cycle of wet and dry phases created “pulses” that affect soil pH levels, mineral cycles, soil oxygen levels, soil microbe activity, growth of nitrogen-fixing algae, phosphorus levels, and formation of a hard layer of clay that prevents nutrients from leaching out of the water and into the subsoil.

When rice farmers abandoned the traditional Balinese cropping calendar, they experienced a short-term, yet dramatic increase in yields. Within a few years, however, the situation turned disastrous due to severe water shortages and unprecedented explosions of pest populations. Consequently, thousands of tons of rice crops

¹ S. Lansing (1994) *The Balinese*. Cengage Learning

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were lost and famine threatened the island's inhabitants. In response, a number of farmers called for a return to the traditional wet rice cultivation system that had functioned so well for centuries. However, the experts at the Bali Irrigation Project dismissed their requests, interpreting their reasoning as religious conservatism or resistance to change. Anthropologist J. Stephen Lansing sought to resolve this conflict by creating a computer model to test the practical value of the traditional Balinese rice cultivation system. By synthesizing ecological, hydrological, economic, and ethnographic data, Lansing was able to demonstrate that water temples played an important role in this system by determining optimal irrigation schedules for farmers and, in the process, maximizing rice yields over time.

Classroom Management Summary:

TOTAL ESTIMATED TIME: Approximately 4.5- 5 hours (without modifications for upper level courses)

NOTE: This case has not yet been tested, so time estimates are guesses.

Tip: If this case will be conducted over several class periods, one technique to shorten the in-class time is to assign some parts of the case as homework. For example, for Part 3, students could read Part 3 and try to answer Questions 1 and 2 in advance to reduce 10-15 mins of in-class time.

PART 1: Green Revolution Policies in Bali – Problem or Solution?

Total time estimate: 35-45 mins.

- Students read Part 1 (5 mins)
- Students discuss Questions 1-3 in small groups (10 mins)
- Instructor-led discussion of Questions 1-3 (5-10 mins)
- Students discuss Question 4 (10 mins).
- Instructor-led discussion of Question 4 (5-10 mins)

PART 2: Temples, Terraces, and Rice Farmers- A Socio-Environmental System

Total time estimate: 50 mins.

- Students read Part 2 (5 mins)
- Students discuss Questions 1 and 2 in small groups (10 mins)
- Representative from each group draws diagram from Question 1 on a board (5 mins)
- Instructor-led discussion of diagrams, and Questions 1- 2; show slide 1 from the Supplementary Materials; brief discussion of Question 3 (10 mins)
- Students discuss Question 4; they can create a new diagram or build upon the diagram created for Questions 1 and 2. (10 mins)
- Instructor-led discussion of Question 4 (10 mins)

PART 3: Water, Pests, and Neighbors

Total time estimate: 50 mins.- 1 hr.

- Students read Part 3 and discuss Question 1 in small groups (10 mins)
- Instructor-led discussion of Question 1 (10 mins)- Ask students: "What incentives do farmer have for cooperating with each other to coordinate cropping patterns?"

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- Students continue reading Part 3 and discuss Question 2 in small groups. Students then draw predictions on the board (10-15 mins)
- Instructor-led discussion of Question 2, including student explanation of predications (5-10 mins); show Slide 2 from Supplementary Materials.
- Students discuss Question 3 (10 mins) (Question 3 can be skipped if time is limited)
- Students report out ideas for Question 3 (5 mins)

PART 4: Is the Water Temple System Necessary for Cultivating Rice? Testing a Hypothesis

Total Time Estimate: 2 hrs.- 2 hrs. 15 mins.

- Students read Part 4 and discuss Question 1 (5 mins)
- Instructor-led discussion of Question 1 (5 mins)
- Students discuss Question 2 (5 mins)
- Instructor-led discussion of Question 2 (5 mins)
- Students study figures and discuss Questions 3 and 4 (5-10 mins)
- Instructor-led discussion of Question 3 and 4 (5-10 mins)
- Students continue reading and examine figure of simulation runs; students discuss Question 5 in small groups, and one representative from each group draws a diagram on the board (10 mins)
- Instructor-led discussion of Question 5 (5 mins)
- Students answer Question 6 in small groups; one representative writes answers up on board (10 mins)
- Instructor-led discussion of Question 6 (5-10 mins)
- Students discuss Question 7 in small groups; one representative from each group writes answers up on board (10 mins)
- Instructor-led discussion of Question 7 (5-10 mins); Show Slide 3 from Supplementary materials; Conclude this discussion by asking students to articulate the implications of these results (i.e. answer Question 8)
- Instructor-led discussion of Question 8 (5 mins).
- Students discuss Questions 9 and 10, which ask them to step back and revisit questions from Part 1 (15 mins).
- Instructor-led discussion of Questions 9 and 10 (10-15 mins)
- Instructor Debrief case (5 mins).

PART 1: Green Revolution Policies in Bali – Problem or Solution?

Total time estimate: 35-40 mins.

Following a brief introduction to the problem presented in this case, students work in small groups to discuss various facets of the issue. Part 1 serves as an introduction to the case and challenges students to consider the various dimensions of the issue.

1) Students first read Part 1 (see Student Handout), which describes the situation that occurred when the Indonesian government implemented Green Revolution agricultural policies: rice farmers experienced a dramatic decline in productivity due to water shortages and pest outbreaks. This can be assigned as homework or can be done at the start of class.

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2) After reading Part 1, assign students to small groups (2-4 people) to discuss the following questions. Emphasize that they are not expected to know the answers here. Rather, ask them to imagine the perspectives of each party. After 5-10 mins., interrupt the discussions and ask for some thoughts on questions 1, 2, and 3:

1. *Imagine you are a Balinese rice farmer arguing for a return to traditional cultivation practices. What might some of your arguments be?*
2. *Imagine you are an Indonesian government official in charge of agricultural policies. What might your response to these farmers be?*
3. *What sources of knowledge are likely to be valued by each of these groups?*

These questions are meant to prompt reflection on cultural differences between these groups, and in particular, to highlight the differences in what kind of information is most valued. In particular, the goal is for students to realize that research-based knowledge and experiential knowledge are both important sources of information that are valued differently by different people (In this case, the rice farmers value experiential information more heavily, while government officials value scientific information more heavily. This will become apparent later in the case, so no need to explain this here.) The answers to questions 1 and 2 will likely underscore the response to 3. At this point, students do not have much information with which to answer questions 1 and 2, so the point here is to gather thoughts rather than to search for a correct answer. The instructor-led discussion is meant to ensure that all students understand the basic differences in perspectives between rice farmers and government officials. Some instructors may wish to hold a more in-depth discussion or to develop a modification. Keep in mind that Questions 1-3 are meant to raise awareness of the issue rather than to explore it in depth. Students will revisit this issue at the end of the case.

3) In the same groups, students will now discuss question 4 (~ 10 mins). Then, ask for some thoughts from the groups and discuss the question as a class (5-10 mins)

4. *What kind of information might help inform the government official's decision of whether to continue the Green Revolution agricultural policies or to return to traditional practices?*

This question will prompt students to consider what kind of scientific information might be useful for informing agricultural policies in this case. Answers can be quite varied, and at this stage, students may not be able to come up with many answers. That's OK. Again, the point here is to get students thinking about the nature of evidence, not to provide answers. The answers will become more apparent as the case continues. Responses might include:

- Information about how traditional agricultural practices manage the use of water.
- How do rice yields change as a result of different cropping schedules?
- What is the cause of the severe water shortages?
- What was the pattern of pest outbreaks over time following implementation of Green Revolution policies?
- How does the pattern of water flow into rice terraces influence rice production?

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PART 2 Temples, Terraces, and Rice Farmers- A Socio-Environmental System

Total time estimate: 50- 60 mins.

Part 2 explores the socio-environmental system at the heart of the rice cultivation problem presented in this case. Students are now given a more detailed explanation of the water temple system and the rice terrace ecosystem. The focus of this section is to develop understanding of what a socio-environmental system is using Bali rice cultivation as an example.

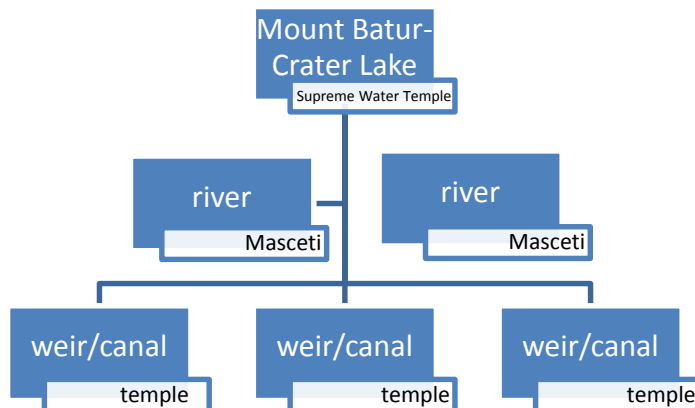
1) Students first read Part 2 (see Student Handout). Again, this can be assigned in advance as homework.

2) In small groups (2-4 students), students will discuss questions 1 and 2 for approximately 10-15 mins. Each group should create one diagram.

1. Based on the description you just read, create a hierarchical diagram (flow chart or picture) of the rice ecosystem including the following parts: Mount Batur, rivers, streams, Crater Lake, and rice terraces.
2. Now, add the Balinese network of temples on this same diagram, including the following parts: weirs/dams, the Supreme Water Temple, Regional Temples (Masceti), Subak Temples, Shrines.

These diagrams may be pictorial diagrams or flow charts.

Here is a hypothetical example:



3) Ask a representative of each group to recreate their diagram of the Balinese temple network on a chalk board or white board. Then ask each group to explain their diagram. In leading the discussion of these questions (see notes below), the key points to highlight are the spatial relationships between the structures of the social system (temples, weirs, canals, subaks) and the ecological system (lakes, rivers, streams, terraces). (15 mins)

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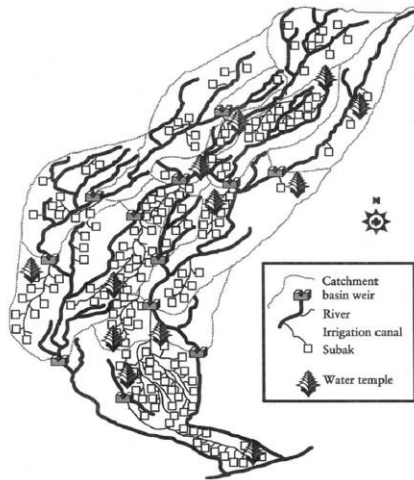


Figure 1- The Oos and Petanu rivers in south-central Bali. From Lansing and Kremer 1993: 103

Looking at the diagrams the students created and this map created by Dr. Lansing, point out how the hierarchical temple networks replicate the hierarchical networks of water channels -rivers, streams, and canals. An interesting observation is that this system is also non-hierarchical in that, although decisions are made at “higher levels (water temples),” cooperative patterns of water sharing emerge without top-down planning (the decisions of the temple priests effectively reflect the collective wisdom of the farmers).

In this map on the left, Lansing and Kremer (1993) first diagrammed all of the subaks, water temples, rivers, and weirs between two rivers in a region in south-central Bali. Note that the subaks, or farmer’s associations, are like leaves of a tree, while the temples sit at branch points of the canal system above a group of fields, next to the weir diverting water to them. The congregation of a given temple is the group of farmers whose fields are downstream from it. This map is attached in the Supplementary Materials powerpoint. You may want to show this to your students at this point.

4) After you have discussed the diagrams, ask students Question 3. A short discussion of Question 3 should follow (5 mins)

3. *How does this social system interact with the rice terrace ecosystem?*

The social system determines the flow of water into the terraces and the planting schedules, and hence the productivity of the fields.

Some students may make the connection that the irrigation actions (e.g. opening or closing dam gates) of farmers upstream will affect farmers downstream during times of water shortage. But this does not need to be explicitly pointed out here as it will be discussed further in the next section.

5) In their small groups, students now create a diagram of a socio-environmental system (10-15 mins).

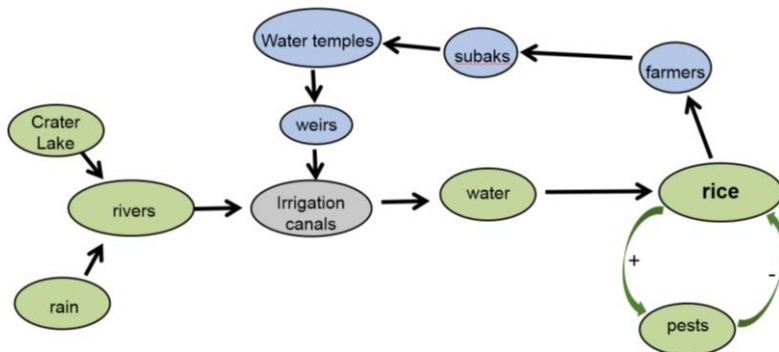
4. *Socio-environmental systems are tightly linked social and biophysical subsystems that mutually influence one another. Describe and/or diagram how the Bali rice cultivation system is an example of a socio-environmental system; include the parts of the system and indicate how they interact.*

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Balinese rice socio-environmental system:
tightly linked **social** and **environmental** subsystems that mutually influence one another



This diagram is a first draft, and students will return to revise it once they have gone through the rest of the case and have a better understanding of this socio-environmental system. During the small group discussions, point out that their diagrams in question 1 can serve as a starting point for this question. Some of the interactions between the parts of this S-E system include:

- Rice yields feed back positively to reinforce pest populations and pest damage.
- Pest damage feeds back to reinforce water stress by stimulating water temples to restrict water flow to blocks of subaks to deprive pests of food (farmers also sometimes choose to flood fields to kill pests).
- Water stress downstream feeds back to increase water flow from upstream.
- Farmers interact with water through subaks and water temples, which ultimately set irrigation and cropping schedules.
- The temples coordinate cropping schedules such that water is pulsed through the system (in continuous cropping, this would not happen). Pulses of water create pulses in important biogeochemical cycles, affecting mineral cycling, soil temperature, and soil microbe activity and enhancing productivity. Coordinated decreases in water flow also regulate pest populations by decreasing plant food availability over an area of many farmers' fields.

Note: remind students to hang on to these diagrams as they will be used in later parts.

PART 3: Water, Pests, and Neighbors

Total time estimate: 50-60 mins.

Here, students learn more about pest management and water scarcity issues. This section facilitates understanding of the trade-offs inherent in this S-E system between an individual farmer or subak's need for water and the threat of pests.

1) Ask students to read the first paragraph of Part 3 in the Student Handout.

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2) For approximately 10 mins., students will discuss Question 1 in small groups. Then, interrupt the discussion and examine the question together (10 mins):

1. Think about pest management: what do you think might happen over the period of a few years under the following scenarios? Assume that Subaks A, B, C and D are all neighbors, and that there are no other subaks nearby.

- a. Farmers in Subaks A and B follow the same cropping pattern, while their neighbors in Subak C and D follow a different cropping pattern such that they plant rice at different times than Subaks A and B.*
 - b. Farmers in Subaks A, B, C, and D plant rice year round.*
 - c. Farmers in Subaks A, B, C, and D all follow the same cropping patterns and leave their terraces fallow during the same time.*
-

A key concept for this question is that pests can migrate, and the pest problems of one Subak can become the problem of their neighbors. If nearby Subaks do not coordinate their fallow periods, pest populations can persist by migrating between rice fields. If Subaks coordinate their fallow periods, then pests in a wide area will not have rice plants to feed on, so their population levels will decline.

Depending on the course and students, a discussion of population dynamics can also be added. Ask the students to consider how the pest problems change over time. In scenario A, because pest populations can survive by migrating between fields, the populations will probably increase gradually or stay the same. In scenario B, the pest population will grow dramatically over time because there is no fallow period to starve the pests. In scenario C, the pest populations would be kept low because of the coordinated fallow periods that repeatedly depress pest populations. During discussion, this fact can be introduced:

“Field data indicate that synchronized [i.e., coordinated] harvests result in pest losses of around 1% compared with losses upwards of 50% during continual cropping.” (Lansing and Miller 2005)

Before moving on, ask the students: “What incentives do the farmers have for coordinating their cropping patterns?” You can get a few quick answers or just let the students mull over the question. This will become apparent later in the case.

3) Students now continue to read the section about water scarcity, and then make predictions about the results of the survey based on what they know so far. Give students approximately 10 mins. to discuss this question 2 in small groups:

2. Predict what the survey responses might have been (focus on relative values of the responses):

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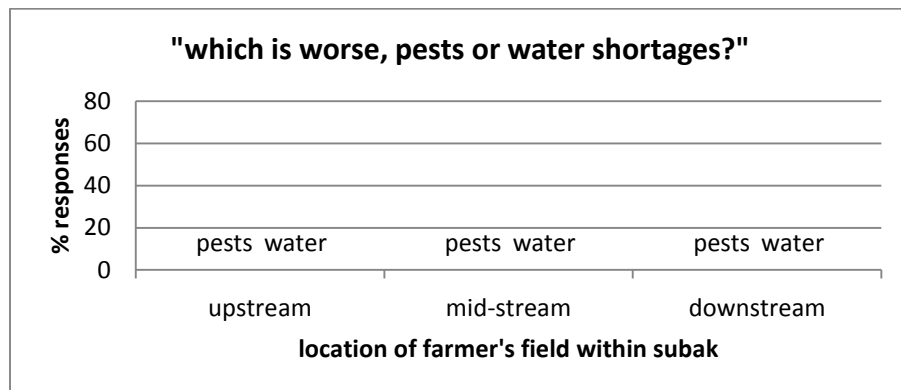


Fig. 2. Survey responses about major concerns of farmers stratified by field location (relative to water supply) within a given subak.

3) Ask representatives from each group sketch their results and explain their logic. Instruct students to focus on the relative values rather than worrying about what the absolute numbers might be. The key points here are that pests are a bigger concern for upstream farmers than water scarcity, whereas the reverse is true for downstream farmers.

4) Following their brief presentations, show them this figure from Lansing and Miller 2005 (see Supplementary Materials)

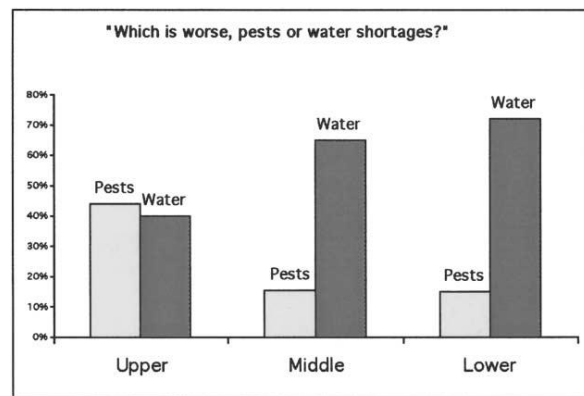


Figure 4. Survey responses about major concerns of farmers stratified by field location (relative to water supply) within a given subak (N=150)

Looking at the results of the survey, ask the students to articulate what incentives the upstream farmers have to cooperate with downstream farmers in sharing water. Based on the pest discussion above, and the survey results, the answer should be apparent. If everyone plants and harvests at the same time, fields will be fallow at the same time, and pests in a wide area will be deprived of food and habitat. However, if everyone plants at the same time to control pests, then irrigation demands are not staggered and water shortages will occur. Thus, these two constraints must be balanced.

5) Finally, students discuss question 3 and generate hypotheses. This should take about 10-15 mins.

3. *Given what you now know about the Balinese way of cultivating rice, can you think of a hypothesis that might explain the problems the Bali rice farmers were encountering during the Green Revolution?*

Ask students for hypotheses, but do not spend too much time discussing the relative merits of each. The next section will explore one hypothesis put forth by Stephen Lansing.

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PART 4: Is the Water Temple System Necessary for Cultivating Rice? Testing a Hypothesis

Total Time Estimate: 2 hrs. or more

1) Students now receive information about Lansing's approach to testing the hypothesis that the coordinated cropping and irrigation patterns controlled by the water temple system are critical for allocating water and managing pests. Ask students to read the first paragraph in Part 4 of the Student Handout. Then, ask them to discuss the first question, which is intended to challenge students to think about what kind of scientific approaches one could possibly take to test this hypothesis. After students discuss this question in their groups for 5 mins., ask for some answers to be shared.

1. What are some ways that this hypothesis might be tested? What kind of information could help inform the government planners' decisions about whether or not to continue the Green Revolution agricultural policies?

If computer modeling is brought up, a quick discussion about the advantages of this approach might naturally follow, but this discussion should be fairly short, as the remainder of this section will examine a modeling approach taken by Lansing and his colleague, James Kremer.

2) Building this model requires data, and this next question challenges students to think about what data are important in this context. Give students approximately 5 mins. to read the next paragraph and then discuss question 2 in their small groups. Then, ask for ideas to be shared with the whole class. Again, this section does not require much discussion, as the next section reveals what data Lansing and Kremer used for their model.

2. What kind of data might be important to obtain for this model?

- Example answers: rainfall patterns over time, cropping patterns for various subaks, actual rice harvest yields, groundwater flows, types of pests and their migration patterns

MODIFICATION: Modeling the Water Temple System

For advanced students, a modification could be developed that challenges them to explore the actual model that Kremer created; there is a replication of this model available at http://www.slansing.org/Lansing_Website/Bali_Model.html . The model uses the NetLogo program from Northwestern University (<http://ccl.northwestern.edu/netlogo/download.shtml>)

3) Next, students study the following figure that correlates actual and predicted rice harvests to assess the accuracy of the model's predictions. After students discuss this figure and the two associated questions (3 & 4) for about 5-10 mins., ask individual students to give their thoughts, and discuss the questions as a class.

MODIFICATION: More advanced students may be asked to discuss how they might test the validity of this model before revealing what Lansing and Kremer did.

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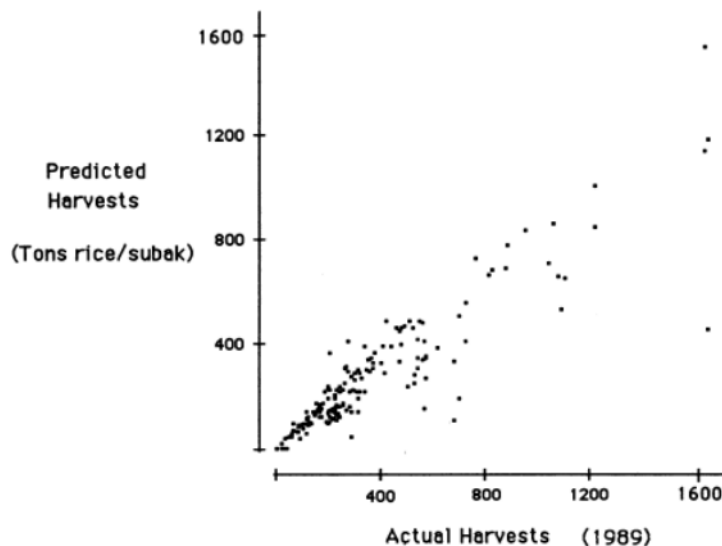


Fig 4: Predicted harvests, from the computer simulation, versus actual rice harvests. (from Lansing and Kremer, 1993)

3. *Based on the results in Fig. 3, do you think the model Lansing and Kremer built accurately predicts rice yields? In other words, does this model work as they intended?*

The short answer is, “yes”. Some students might need a bit of guidance to interpret the graph. Start with asking what each dot represents, and proceed with a discussion of correlations and, if appropriate, regression lines and slopes. For a greater challenge, you could provide students with a blank graph and ask them to draw the predicted relationship if the model makes accurate predictions about rice yields.

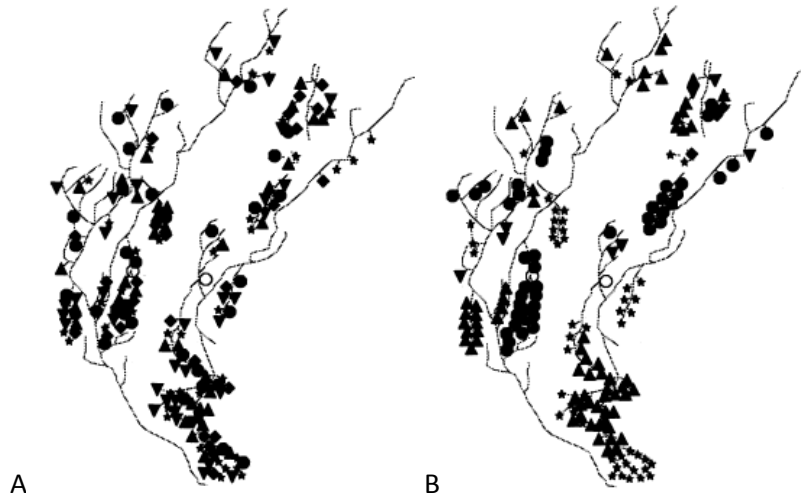
4. *If we assume the model does a very poor job of predicting actual rice harvests, would the results be different from what you see in Fig. 3? If so, how?*

Students may have a variety of answers, but one case indicating no relationship would show a flat slope on the regression line (i.e. slope = 0). Depending on the students, you may want to use the terms “regression line” and “slopes” in discussing these figures.

5) Next, students examine the results of simulation runs exploring the effect of different levels of social coordination of cropping schedules on rice yields. After students spend approximately 5 mins. discussing the figure and question 5, ask for a volunteer to diagram the watershed level of coordination.

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5. Draw a diagram similar to the two above that reflects a pattern where all subaks in the entire watershed follow the same cropping schedule. In the Lansing-Kremer model, this is the watershed level of coordination. Diagram A represents the subak level, and Diagram B represents the temple level.

The diagram should show the same symbol for all subaks, indicating that all subaks in the watershed follow the same cropping pattern.

6) Next, students use these diagrams to consider how the cropping patterns of neighboring Subaks affect pest populations and water availability. After approximately 10 mins. discussing Question 6, ask students to report and explain their answers. Discuss the question as a group.

6. Looking at the three diagrams, discuss how the coordination of cropping patterns might affect the two critical issues in rice cultivation: water availability and pest management. Use the chart below to summarize what you think might be the degree of severity (high, medium, low) of the two problems at each level of coordination.

	Subak level	Temple level	Watershed level
Pest outbreaks	med or high	low	low
Water shortages	med or High	med or low	high

The focus here is on relative degrees of problems when compared between the three levels of coordination. The estimates are derived by examining the spatial patterns of the subaks in relation to their cropping schedules and by considering how neighbors interact with regards to pest control and water management. At the Subak level, neighbors are not coordinating their fallow periods, and thus pest outbreaks are likely to be a problem (as discussed in Part 3). Moreover, because there is no coordination of schedules, upstream farmers are cropping with no regard to downstream farmer needs,

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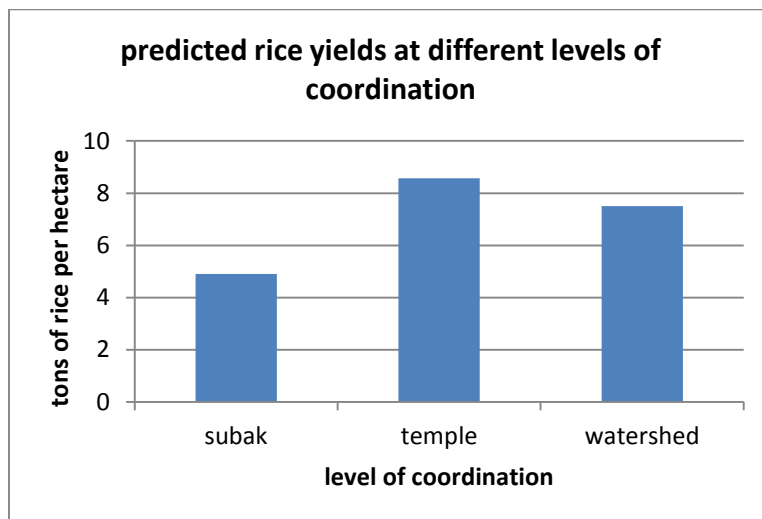
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and thus water shortages will be a problem for many of the Subaks. At the Temple level, clusters of neighboring Subaks are coordinating their cropping patterns such that immediate neighbors will have synchronized fallow periods. However, adjacent clusters of Subaks are following different cropping patterns, which means that they are not all using water at the same time. This pattern will reduce both water shortage and pest problems. Finally, at the Watershed level, all Subaks are following the same cropping pattern. While this means that pests are controlled due to synchronized fallow periods, water availability becomes a problem because all the Subaks use water at the same time.

7) Based on this graph, students now think about how pests and water availability impact rice yields, and make predictions in Question 7 about the rice yields for each level of coordination. Emphasize that what is important is the *relative* rice yields from the three different levels of coordination (which produces highest yields versus middle versus lowest), not the numerical values. After students discuss this for about 5-10 mins, ask students to draw their predictions up on a board. Then discuss their results.

7. In the figure below, estimate what you think the rice yields were for each level of coordination. As a starting point, the Lansing-Kremer model predicted a rice yield of 4.9 tons of rice per hectare. What are the relative rice yields for the temple and watershed levels?



Then show students Lansing and Kremer's results (see Supplementary Figures in the accompanying Powerpoint). This figure was created based on results reported in Lansing and Kremer 1993. The values for the watershed level are estimated based on Fig. 6 from that paper.

8) Students should recognize here that the Temple level of coordination produces the highest rice yields. Ask students to articulate the implications of these results by posing Question 8 to the group and discussing the responses.

8. Explain how this finding supports or refutes Lansing's hypothesis about the role of water temples.

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This finding supports Lansing's hypothesis because it demonstrates how the coordination of cropping patterns at the level of the water temples results in the highest rice yields, whereas the Subak-level control (i.e. no coordination, which is what was seen during the Green Revolution (i.e. no coordination amongst Subaks) results in low rice yields caused by pest and water problems.

9) Allow students to discuss the final two questions (9 & 10) for about 15 mins., and then ask for volunteers to present their answers.

9. Revisit the diagram you created of the Bali rice cultivation system as the socio-environmental system and revise it given what you now know.

To reemphasize the tightly linked nature of the social and ecological components of the Bali water temple system, you might end this case by revisiting the diagrams illustrating the interactions and feedback dynamics between the various parts of this socio-environmental system.

10. Returning to the first question you answered in this case study, what information can you now add to the arguments of the rice farmers discussed earlier? Imagine that you have a meeting with the Indonesian government officials in charge of agricultural policies to explain the new information that Lansing and Kremer found through their simulation model. What would you say?

This question is intended to be open ended, and to allow students to revisit some of the points made during the discussions in Part 1. In particular, you may want to revisit the discussion about how the farmers and priests on the one hand, and government officials on the other, may differ in how they value different kinds of knowledge and information. Now, with Lansing and Kramer's scientific studies, the farmers have knowledge in a form that the officials value. At the same time, the scientific studies help to explain why the Balinese water temple system works, and lends greater credibility to experiential, social knowledge.

10) Following the discussion of Questions 9 & 10, debrief this case by describing how Lansing and Kremer actually presented the results of their model to Indonesian officials, and what has now happened with the water temples in Bali. Details for the debriefing are provided below.

DEBRIEF:

How the model was used to inform policy:

In order to promote the use of their model for decision-making, Kremer and Lansing set up a meeting at the Batur temple with the high priest Jero Gede and two representatives for the Balinese irrigation project from the capital city, Denpasar. After seeing a demonstration of the model, both the priest and the government officials agreed the model was useful but suggested the scientists should validate the model results by conferring with regional irrigation offices and farmers of the subaks. The officials also agreed that the computer program could be installed at the Irrigation Control Board and the regional irrigation offices to help determine irrigation schedules. They reasoned that the program was too technical for farmers to use directly and that ultimately

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their offices controlled the dams. Although the scientists hoped that their model would help empower the farmers, they felt this would still be a good use of their model.

UNESCO World Heritage Site Designation:

Dr. Lansing was also involved in efforts to designate the Bali water temples as a UNESCO world heritage site, and the five watersheds in Bali with their water temples and rice terraces were listed as a world heritage site in 2012. The subak system was chosen because it met four of the ten World Heritage selection criteria, including the unique cultural tradition of the water temple rituals and its aim to sustain a harmonious relationship between the natural and spiritual world. The World Heritage Site status confers protections for the subak system, including legal protection of the property and the development of a management plan by the Bali government.

This short video of Dr. Lansing's presentation at PopTech provides a good summary, as well as a discussion of plans to design the Bali world heritage site:

http://poptech.org/popcasts/lansing_and_watson_water_temples_forever

MODIFICATION for Part 4: Evolution of the Water Temple System

Advanced students can explore how Lansing and Kremer's model was used to examine how the water temple system could have arisen based on ecological dynamics. In this experiment using the simulation model, individual subaks start with a specified level of rice production, which changes over time. Each "time step" in the model corresponds to one year, at which point the rice production of a subak is updated to its new value. How are these values determined? At the beginning of a year, each simulated subak checks whether any of its neighbors got higher yields last year. If so, it copies the cropping pattern/irrigation schedule of its most productive neighbor. Then the model simulates another year and recalculates rice yields for all of the subaks. Figure 6 below demonstrates the changes in mean yields as the subaks change their cropping schedules. These changes occur as subaks follow a behavioral rule where during each year, they determine their cropping schedules by copying the neighbor who had the best rice yields in the previous year. Over time, the percentage of Subaks that are copying neighbors (changing) decreases as Subaks converge on optimal cropping patterns. For the final simulation run, the cropping patterns of the subaks bears striking similarity to the actual cropping patterns of the subaks as set by the water temples. This is shown in Figure 7.

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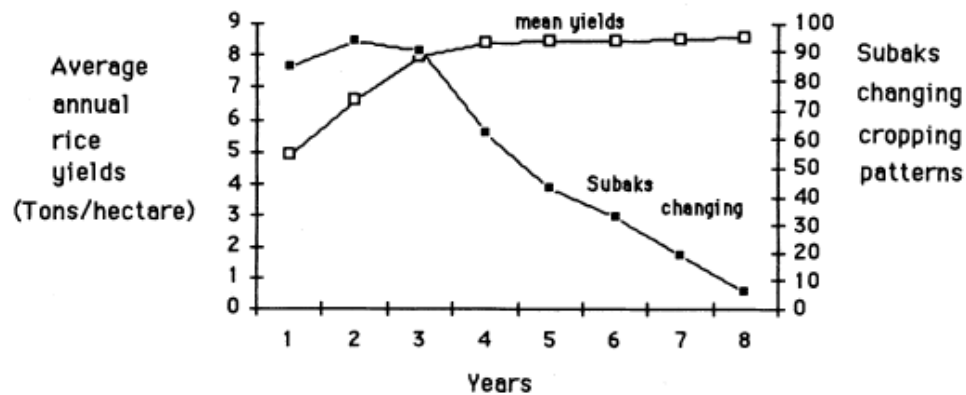


Fig. 6: Mean rice yields rise to a plateau as subaks converge on an enduring cropping pattern, shown in the right-hand image in Figure 7 (from Lansing and Kremer, 1993)

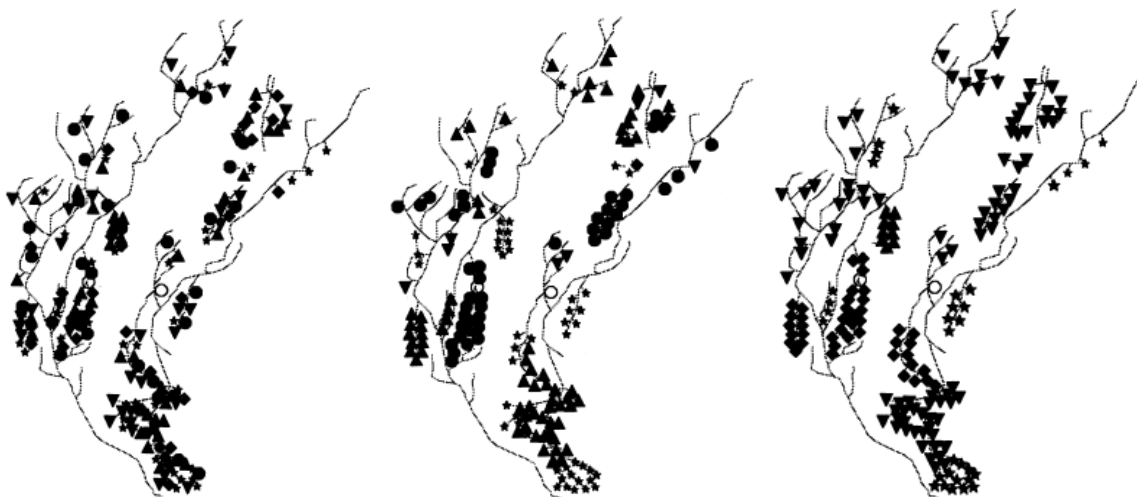


Fig. 7: First run of the phase three model (left), last run (middle), and the actual traditional cropping pattern (right). From the first run to the last run of the model, average rice harvests rose from 4.9 tons/ha to 8.6 tons/ha. (from Lansing and Kremer, 1993)

Assessments

At the end of each part, students can be asked to turn in written responses to the questions discussed during class, or these can be assigned as homework. The act of writing responses after the small group and class discussions serves to help students review what they have learned, and allows the instructor to assess how well students understood the lessons of each section.

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The learning objectives can also be used as assessment questions either interspersed throughout the case as appropriate, or as a summative evaluation at the end of the case. Students will answer the following, which are the stated learning objectives:

1. Describe an example of socio-environmental system (Bali rice cultivation), including the component parts of the system and the relationships between the social and biophysical components of the system.
2. Explain how ecological and social factors interact in the Bali rice cultivation system.
3. Describe the different kinds of knowledge used to make decisions about rice cultivation in this case and how they are valued.
4. Explain how modeling was used to analyze the problem of declining rice yields in this case.
5. Explain how different types of data were synthesized to understand the role of the subak system described in this case.
6. Explain why integration of ecological data and social data is necessary to predict rice yields in this case.
7. Explain why it is important to consider sources of data from several disciplines.
8. Explain why it is important to consider ecological and social processes and system behavior across different scales (i.e. spatial).

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