Title
Land Use Planning to Promote Marine Conservation of Coral reef Ecosystems in Moorea, French Polynesia

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Land Use Planning to promote Marine Conservation

of Coral Reef Ecosystems in Moorea, French Polynesia

SHAY BOUTILLIER AND TIM DUANE

The importance of land-use and Marine interactions: Human activity on land results in a variety of inputs into the marine environment that would otherwise not occur in a natural setting. These inputs include sediment, nutrients, and other pollutants. The purpose of our research was to investigate inputs resulting from human activity on the small tropical island of Moorea, French Polynesia; what risk they pose to coral reefs; and what can be done to mitigate their effects in the face of rapid growth and development.

We live in a world increasingly without boundaries,

but our tools and institutions for determining how to live in this world—where we'll build, where we'll live, how we'll travel, how we'll meet our needs for food, energy, and how we'll entertain ourselves, are often poorly suited to this world. Instead, we have city, regional and environmental planning systems that emphasize political boundaries rather than the regional commutesheds, foodsheds, or watersheds that bind us. And so we make decisions in one place with consequences for another, rarely making the connections between them.

This is not possible on an island: what happens on an island largely stays on the island, at least within the boundaries of an enclosing lagoon. Islanders have had to live with their waste—there is no "away" to which waste can be "thrown away." Some island societies have, therefore, faced the challenges of sustainability more acutely than those mainland cultures and economies that could draw on a larger geography for resources and waste disposal. In some cases, facing that challenge led to collapse or abandonment; in others, resilient adaptations have allowed the societies to thrive. Even in the latter, however, urbanization and globalization now threaten sustainable modes of being.

The island of Moorea, where UC-Berkeley runs the Gump South Pacific Biological Field Station in French Polynesia, presents an interesting case study of these challenges. Shay Boutillier and I therefore established this research and education project on Land Use Planning and Marine Conservation in order to explore how to promote sustainability on islands where land use development threatens coral reef ecosystem health. The Gump Station has been the site of excellent research over the years, but most of it (with the notable exception of important archaeology and insect biology research) focused on what happened to ecological systems

in the marine environment. Virtually none of it was focused on the challenges confronting Polynesian society today in the face of urbanization and globalization. We therefore sought to study how knowledge of both social and ecological systems could be integrated through planning and research to mitigate the impacts of land use changes on coral reef systems.

The overall project consisted of the following elements: an independent master's thesis project by Shay Boutillier, a research project funded by the UC Pacific Rim Research Grant Program, two graduate Environmental Planning Studio courses (in 2003–2004 and 2004–2005), a field study trip to Moorea over spring break in 2005 and the presentation of our results in Moorea at a conference addressing the interaction between land use planning and marine conservation. The analysis in this publication was generated through all of these elements. Although we explored many other issues, our project team settled on the following themes:

- The existing conditions and planning policy context of the island.
- Impacts to coral reefs.
- How urbanization, road development, and changing agricultural practices affect sedimentation, stormwater runoff, and the transport of other pollutants into the lagoon;
- How poorly managed pig farming creates a major source of unwanted nutrients, and how the adoption of appropriate technologies and best management practices could mitigate negative effects from piggeries on Moorea; and
- How tourism development could shift from a mass tourism model to an ecotourism model that could better protect the cultural and ecological assets of Moorea (in particular, we analyzed how the development of a golf course near and on important wetlands are likely to threaten such assets at great cost).

Together, these themes suggest a tangible set of feasible actions that can be taken by the people and institutions of Moorea and French Polynesia that will enhance the sustainability of social, economic, and ecological values and practices on the island. We are not in a position to determine if these actions should be adopted; that is for the people of Moorea and French Polynesia to decide. We are confident, however, that the results of our research and education project can help them to make more sustainable decisions.

—Prof. Tim Duane, Environmental Planning and Policy

HISTORY

AD 800
Polynesian migration led to settlement of the Society Islands.

1767
Contact between Europeans and Polynesians established in Tahiti following the arrival of English explorer Samuel Wallis.

1842
Tahiti becomes a French Protectorate. It is the first island in the Pacific to come under the control of a foreign power.

End of the 19th century / beginning of the 20th century
Following the arrival of European settlers, subsistence agricultural production shifts to economically viable crops such as vanilla plantations and copra produced by coastal coconut palm plantations.[18]

1940's
Construction of a military base and runway on the island of Bora Bora to support American military efforts in the Pacific.

Site Description

Location: 17.57 degrees South and 150 degrees West in the South Pacific Ocean.[1]

Nationality: French Polynesia, an overseas country of France.

Area: 132km²

Age: 1.2 million years

Geography: High island of volcanic origin with steep slopes and vertical faces.

Coastline: 57.6km alternating between lagoon frontages white coral sand beaches.[2] Coral reefs line approximately 90% of the coast.[3]

Climate: wet-dry tropics averaging 26.5° C (80° F) in the rainy season and 24.5° C (76° F) in the dry season.[4]

Population: 14,226 individuals[5] with an annual growth rate of 3.2%.[6]

Settlement: Currently there are just over 5,000 buildings 500 ft² or larger on the island.

The Island of Moorea

The small tropical island of Moorea is part of the Society Islands, one of five archipelagos that constitute French Polynesia. It is located 15 km northwest of French Polynesia's main island of Tahiti and capital city of Papeete.[7] The island rises to 1207 meters from the ocean at its highest point on Mount Toheia and is surrounded by a well-developed coral reef and lagoon system made up of wide outlying barrier reefs and near-shore fringing reefs that hug the coastline. The reefs are intersected by twelve deep navigable passes resulting from freshwater outlets.[8] The island consists of forty-six watersheds, with the dominant two being the Pao Pao and Opunohu river valleys to the north.

Coral Reef Ecology

Coral reefs form a biogenic structure that allow for a diverse ecosystem. These structures are made up of millions of tiny coral polyps and microscopic algae.[9] However, they can only tolerate a narrow range of environmental conditions and are thus very sensitive to environmental changes.[10]

1950's
Construction of the large-scale Club Med tourism resort on the island of Moorea.

Early 1960's
Copra and vanilla markets collapse.[19]

1962
France shifts its nuclear test program from the Sahara Desert to French Polynesia, establishing the Centre d'Experimentation du Pacifique (C.E.P.). Military spending rises from 4% of Gross Domestic Product (GDP) to 76% in just four years.[20]

1970's
France begins to phase out nuclear testing in French Polynesia. Growth of the tourism industry becomes the dominant industry.

1990
French Polynesia imports nearly 80% of all food items.[21]

1996
Final termination of French Polynesia's nuclear testing program.

Climate

Moorea's wet tropical climate is characterized by two distinct seasons: a warm, dry season from June through September and a hot, humid rainy season from October through April. The average annual precipitation reaches 109 inches per year, the majority of which falls during the rainy season.[11]

Population Growth

In the year 2000 French Polynesia's population was just under 250,000 individuals with approximately 75% of the population concentrated on the islands of Tahiti and Moorea.[12] Since 1960 Moorea's population has increased from 3,500[13] individuals to 14,226 [14] in 2002 and is currently experiencing an average annual growth rate of 3.2%.[15]

Ex-urban growth

With French Polynesia's economic activity centered adjacent to Moorea, in the sprawling capital city of Papeete, it has been easier to commute downtown on a ferry from Moorea than from the outlying subdivisions of Papeete. Because of this, more people are moving to enjoy the amenities and quality of life on Moorea while working in the city. Thus it is not an exaggeration to speak of Moorea as a suburb of Tahiti.[16] The daily commute to the city has been accelerated with the advent of fast reliable ferry transportation between Tahiti and Moorea and the intensive development of air services that make the island only 7 minutes away from Tahiti by air.[17]

Papette's sprawling urban center with Moorea in the distance

Existing Conditions and Planning Policy Context

Plan General D'Amenagement (PGA)

Plan Gestation D'Espace Maritime (PGEM)

Problem Statement

Land Use Planning and Marine Resource Management on the Island of Moorea In response to the growth and development pressures faced by Moorea, the French Polynesian Department of Urbanism and Moorea's Mayoral Office developed the Plan General D'Amenagement (PGA), a land-use plan to manage natural resources and development on the island. In addition, they developed the Plan Gestation D'Espace Maritime (PGEM), a marine management plan with eight marine protected areas (MPA's) surrounding the island. However, these plans were largely developed independently of each other. As a result, the potential impacts of land-based inputs draining into the MPAs, ensuing from implementing the PGA, remain unknown.

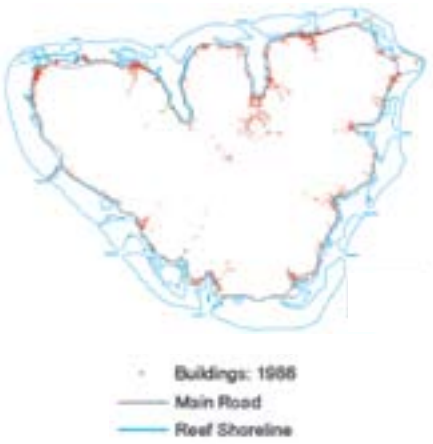
Objectives

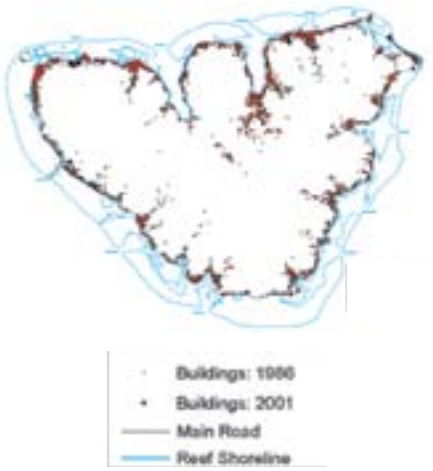
To understand the outcome of implementing the PGA we analyzed its anticipated build-out and evaluated the rate at which Moorea may reach this projected build-out.

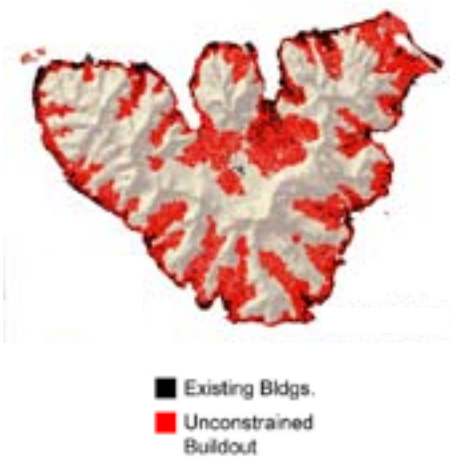
Methods

Using Geographic Information Systems (GIS) modeling software, we conducted spatial analyses of existing and projected development patterns on Moorea. Through build-out analysis, we compiled information on zoning types and their locations, the policies that permit building in these zones, the size and number of private lots that occur in each zone, and the amount of existing development on each lot. Each existing parcel was subdivided to the maximum extent allowable. We then projected the population density permitted by the PGA at build-out using the French Polynesian national average of 3.2 people per household.

GIS modeling was further employed to identify historic trends in growth and development patterns on the island. By comparing aerial photos over time it was possible to analyze the amount and location of development that occurred on Moorea over a roughly 20-year period.







Results

At present, there are just over 5000 buildings 500 ft² or larger on the island. Our analysis indicates that the PGA's land use policies would allow a build-out that could result in a ten-fold increase of existing development. With 51, 132 structures at build-out, Moorea's population density would resemble French Polynesia's capital city Papeete, with a density of approximately 3, 500 people/km².[22] Although there is no way to say that this increase will ultimately occur, it illustrates the maximum amount of development legally permitted by the PGA and therefore how effective the plan is at regulating growth and development on the island.

The majority of Moorea's population resides along the island's coastal areas, as the dramatic topography limits the amount of developable space inland. Coastal locations also reflect historical reliance on coastal lagoon resources and water-based travel routes. The examination of historic growth and development patterns on the island confirmed that most of the flat land along Moorea's coastline was built upon, with development creeping inland up river valleys. Currently, little of the remaining intact waterfront is public land, resulting in restricted physical and access to beaches and the ocean. Since 1986, our analysis revealed an increase of 2,542 structures. At this observed rate of development, Moorea may reach buildout in 50 years.

Public access to beach diminished with development

Impacts to Moorea's Coral Reef Ecosystem from Land-based Inputs

Problem Statement

Land use change within previously undisturbed watersheds leads to a range of new inputs into the marine environment, potentially causing significant harm to marine ecosystems. The outcome of our remote GIS analysis suggests the likelihood of significant land use change to occur on Moorea given the growth and development pressures faced by the island.

Objectives

Our goal in visiting the island was to observe existing conditions and land use practices in order to identify the various types of land-based inputs and assess their impacts to Moorea's coral reef ecosystem.

Methods

Field observation and analysis were conducted using non-participant observation methods outlined in John, Zeisel's *Inquiry by Design: Tools for Environment-Behavior Research* [23] and Reid and Dunne's *Rapid Evaluation of Sediment Budgets*.[24] Land use practices consisted of existing development, construction and agriculture.

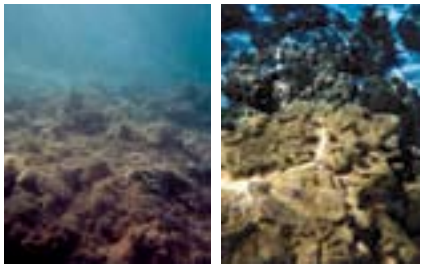
Results

STORM WATER RUNOFF

Increased impervious surfaces (such as roofs and roads) following development prevent infiltration of precipitation into the soil. This increases the volume and

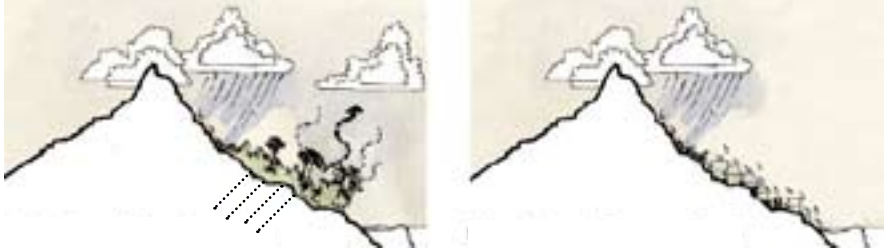
erosive force of runoff into nearby watercourses, resulting in channel erosion and sediment transport. Given Moorea's climate and geography, there is a high potential for sediment ladened storm water runoff, which we observed in action from a road development while on the island.

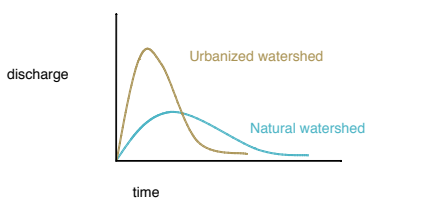
Moorea's storm water infrastructure enables pulses of fresh water and sediment to be transported directly to the lagoon where it can be deposited over near-shore coral reefs. Near-shore fringing reefs close to fresh water outflows are most at risk compared to barrier reefs beyond the reach of terrestrial runoff.



Left: *Near shore fringing reef close to fresh water outflow.* Right: *Barrier reef beyond sediment plume.*

Natural watershed allows for precipitation, evapotranspiration and infiltration. Urbanization increases impervious surfaces and storm water runoff.





SEDIMENT

Soil is exposed from construction and agricultural practices such as clearing, grading and cutting terraces into hillsides.

Development and agriculture occur on steep slopes, requiring steep roads to access sites.

Soil erosion evident on steep roads with incised roadside ditches, exposed parent material, and mass wasting of road cuts.

Even after development is established, soil exposure persists.

NUTRIENTS

Agricultural practices involve application of fertilizers and pesticides and generate livestock waste from domestic animals. Surface flow can carry nutrients to adjacent watercourses.

There is no central sewage treatment on the island. Household wastewater from existing development, including resorts and hotels, is treated on site by septic systems. Improperly functioning septic systems can leach untreated nutrients into groundwater.

ANALYSIS OF REGULATORY CONTEXT

Analysis of the PGA's policies reveals that current planning regulations fail to control inputs from reaching the marine environment:

- On Moorea, building permits are required for construction to occur. However the permits do not regulate how that construction occurs.
- Zoning designations control where agriculture occurs on the island, but nothing regulates how practices are carried out.
- The PGA requires that new development accommodate storm water runoff. However, conventional storm water infrastructure may actually exacerbate storm water impacts to coral reefs by increasing the peak flow of runoff and acting as a delivery mechanism for sediment.

GENERAL INPUTS AND IMPACTS TO CORAL REEFS

Sediment mobilized and transported in surface runoff

- Physically smothers coral polyp
- Inhibits reproduction
- Obstructs feeding
- Reduces light for photosynthesis
- Restricts larval settlement
- Lowers growth rate
- Limits recovery
- Provides substrate for algal growth

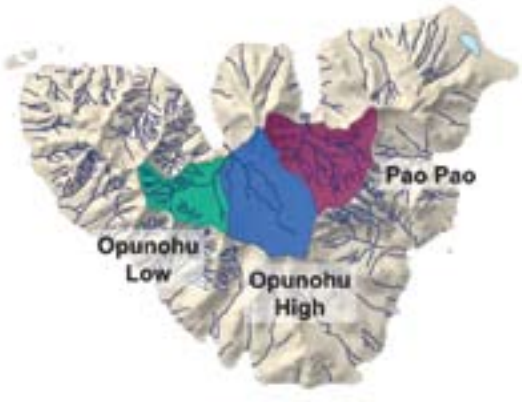
Pulses of freshwater from storm water runoff

- Reduce salinity levels necessary for coral growth.

Nutrient Loading

- Increased levels of nitrogen and phosphorous promote excessive algal growth which lowers the amount of dissolved oxygen in the water. This process is called eutrophication.

Major Sediment Sources on Moorea



Problem Statement

Given the prevalence of sediment sources initially observed on the island and the severity of risk that sediment poses for coral reefs, we undertook a more comprehensive investigation to understand which land use practices primarily contribute sediment to the marine environment. Our analysis was based on a study of suspended sediment loads and stream discharge from three Moorean watersheds conducted by Prof. John Harte and his students[25] during the 1993-1994 rainy season. The study found that sediment loss normalized by watershed area was approximately four times higher in the Pao Pao watershed than in the less developed Opunohu Low watershed. Although the study noted that the different land use patterns in the three watersheds may have contributed to these differences, the patterns had not been explored quantitatively.

Objectives

Quantitatively analyze patterns of sediment yield and land use in the three Moorean watersheds examined in the Harte study. Recommend mitigation measures for practices responsible for sediment loading to the marine environment.

Methods

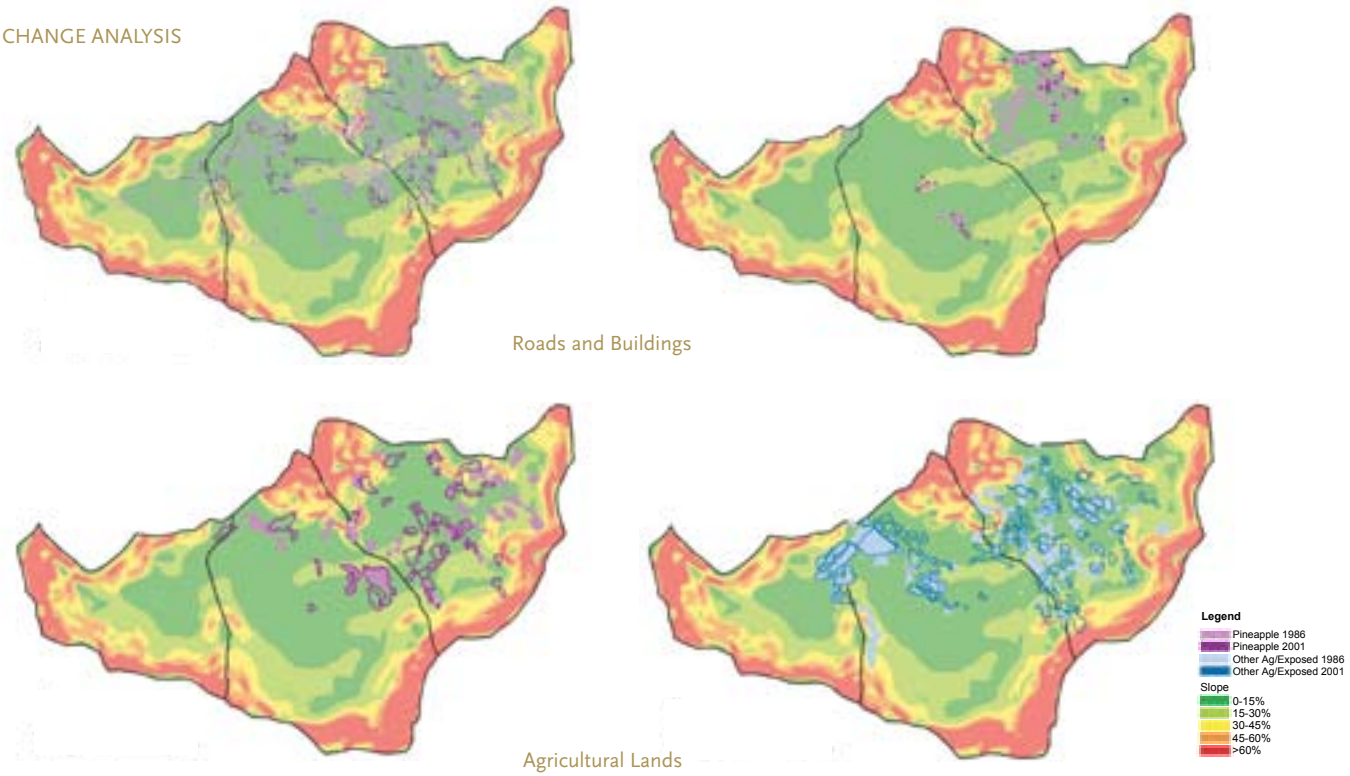
Using black and white aerial photos from 1986 and color aerial photos from 2001, we mapped roads, pineapple fields, pine, other agriculture (including exposed soils), and buildings in all three watersheds. We used GIS and Excel to analyze the location of these features across time (1986-2001), space (watersheds), and by slope. Based on regional population trends, we estimated the length and area of roads, number of buildings, and amount of each agriculture type during the 1993-1994 rainy season. Finally, we explored correlations between each land use variable (and combination of variables) and sediment yield.

Results

ANALYSIS OF LAND USE CHANGE

Agriculture In general agriculture is constant over time but shifts spatially from the Pao Pao watershed (Down 13%) to the Opunohu watershed (up 17%). Much of this increase was limited to 0-15% slopes in the Opunohu High watershed, indicating that as agriculture moves over from the Pao Pao watershed, it occupies the most accessible and easy to handle areas. This is further supported by the fact that across all three watersheds, a decrease in agriculture on slopes greater than 15% was observed.

Roads and Buildings We found that from 1986 to 2001, road length increased by 8% and building number increased by 35% in the three watersheds. Over 80% of the observed road length growth and building number increase occurred in the Pao Pao watershed. Of this increase, 80% of new road length and buildings in Pao Pao occurred on slopes less than 15%. Surprisingly, all three watersheds experienced a decrease in road length on land with slopes greater than 60%.



SEDIMENT SOURCES

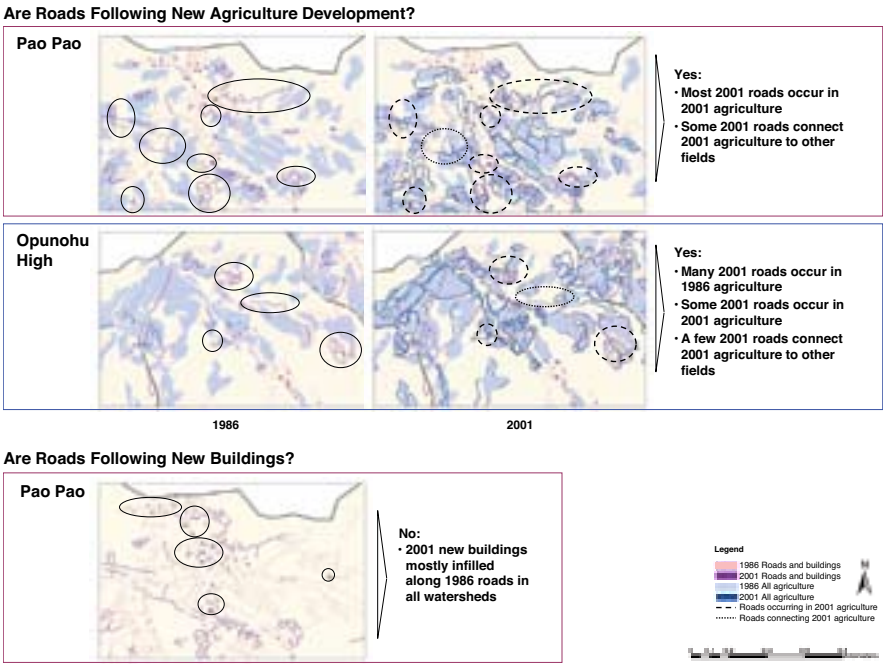
We conducted an exploratory analysis of the relationship between cumulative sediment discharge (for the entire rainy season), normalized by watershed area, and land use variables developed during our analysis of land use change in the watersheds. We found that sediment yield is most highly related to the surface area of roads ($R2 = 0.985$). We conclude that roads are most strongly associated with sediment yield from watersheds in Moorea.

Relationship Between Sediment Discharge and:	R^2
Area of Buildings	.576
Area of Roads and Buildings	.974
Area of Pineapple Fields	.759
Area of Roads and Pineapple	.902
Area of Roads Adjacent to/within Pineapple Fields	.860
Area of Agriculture/Exposed Soil	.957
Area of Roads	.985

RELATIONSHIP OF ROADS AND LAND USE

Because roads had the strongest association with sediment yield, it was important to examine potential land use causes of road length increase: Were new 2001 roads associated more with new 2001 buildings or new 2001 agriculture?

Using GIS, we visually analyzed new 2001 buildings and found that they mostly in-filled along existing roads rather than appearing along new roads. New roads were found to occur both within new 2001 and existing 1986 agriculture fields.



Stilt housing offers an alternative to terracing for hillside development

Local practices use palm fronds to manage sedimentation

Recommendations

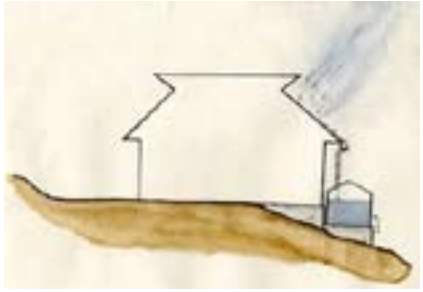
PROVISIONS TO MITIGATE THREATS TO CORAL REEFS FROM SEDIMENTATION.

Our analyses indicate that roads and exposed soils are the key sediment sources in Moorea. In order to protect the health and vitality of Moorea's coral reef, exposed soil must be reduced in agriculture, construction practices and road design. The following recommendations address implementing practices that minimize both the source as well as the transport of sediment.

- Educate landowners, farmers, and construction workers on Best Management Practices (BMPs). This can be done through the development of a BMP. demonstration project at the UC Berkeley GUMP Station.
- Create incentives to encourage the use of BMPs by landowners to keep disturbed sediment from moving off-site and to promote the collection, dissipation and infiltration of runoff.
- Establish temporal restrictions for when land-disturbing activities occur to avoid the presence of exposed soil during the rainy season.
- Encourage site design that minimizes the need for roads. Where roads are needed adopt design standards that conform to the natural topography of the site to minimize sediment loss and transport.
- Promote zero net runoff by reducing impervious surfaces to lessen the amount of runoff initially generated.
- Establish policies such as a grading ordinance or hillside development overlay that regulate how practices occur.

LOCALLY DERIVED MEASURES TO MANAGE SEDIMENTATION AND STORM WATER RUNOFF

1) Collect or infiltrate runoff generated from impervious surfaces. Runoff generated from roofs is of high enough quality to be used for domestic purposes.
2) Stabilize road banks and dissipate flow. Minimize exposed sediment using native plants. Divert runoff using cross cut culverts with boulders to dissipate flow
3) Stabilize slopes using palm trunks and fronds. Minimize exposed soil on steep slopes using palm frond mulch. Vegetated swales convey water off slopes with vegetation providing canopy interception.
4) Install check dams with palm trunks and crop taro in roadside ditches and low lands. Check dams slow runoff velocity allowing for infiltration. Taro grows well in inundated conditions and act as a sediment trap.



Piggeries on Moorea: Suggestions for Improved Environmental Management Practices

Problem Statement

Pigs have been an integral part of Tahitian culture for hundreds of years, and remain so today. If not treated properly, however, nutrients from pig waste runoff can degrade coral reefs by causing eutrophication. This process can lead to phase shifts in the marine environment from coral to algal dominance on the reef.

Objectives

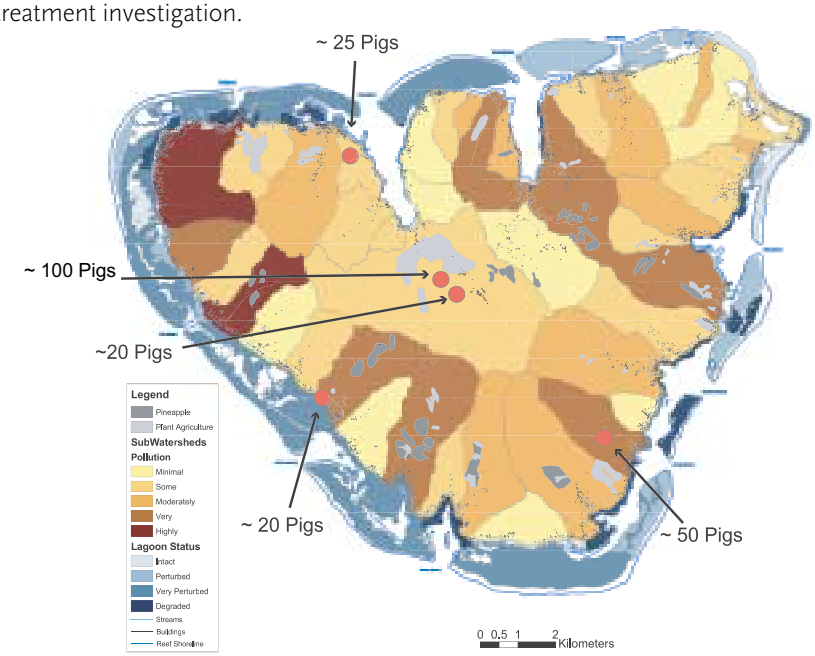
Understand the extent to which pig waste threatens Moorea's marine ecosystem; determine available treatment options and opportunities for successful implementation.

Methods

In this project, we synthesized available data related to piggeries and nutrient loading on the island, conducted site visits to assess local piggeries, tested water quality of adjacent streams above and below the site, and assembled information on physical design solutions suitable for small developing islands like Moorea. We further consider and report on potential institutional strategies for mitigating this environmental and cultural harm by assessing successful precedent case studies from other Pacific islands in which such measures have already begun.

Results

Currently on Moorea, pigs on farms, individual household pigs, and wild pigs total about eighteen hundred; more than one for every eight residents. The mass of nutrients in the total pig waste nearly equals the total mass of septic waste on the island, making these concentrated point sources ideal targets for treatment investigation.



Septic 14,000 residents
1 person .....189 l/day waste water
..... 2.8 kg Nitrogen/year
..... 0.7 kg Phosphorous/year

Pigs 1,800 pigs
1 pig..... 1.8 - 5.8 kg waste/day
.....13 kg Nitrogen/year
.....8 kg Phosphorous/year

Total nitrogen discharge into the environment:
Septic ..... ~39,000 kg/year
Pigs .....~23,000 kg/year

Total phosphorous discharge into the environment:
Septic ..... ~9,800 kg/year
Pigs .....~14,400 kg/year

OTHER HARMFUL COMPONENTS OF PIG WASTE

Pathogens Pigs can be infected with pathogens and parasites that are highly infectious to humans and can be readily transmitted to humans through direct exposure to fecal wastes or contaminated land, groundwater, or surface waters.

Biochemical Oxygen Demand (BOD) Organic waste in streams and lagoons cause oxygen in the water to be consumed, which reduces the oxygen available for fish and other organisms.

Hormones and Antibiotics Pig feed often includes hormones and antibiotics that may cause harm to aquatic ecosystems; the effect of these inputs is an emerging research area.

ANALYSIS OF REGULATORY CONTEXT

In French Polynesia, piggeries with over 20 pigs of 30 kilos or more are required to meet environmental standards set by the Ministry of the Environment. To become authorized, operations must obtain a Classified Installation for the Protection of the Environment (CIPE), which is a difficult process and existing piggeries often go unregulated. On Moorea, three of the five piggeries with over 20 pigs of 30 kilos or more have no authorization.

SITE VISITS AND NUTRIENT TESTING

Opunohu Agricultural College

- Authorized operation of roughly 200 pigs
- 3-stage treatment system in place and functional
- Solid waste separated and directly applied to land.
- Anaerobic tank and aerobic pond not cleaned as often as recommended.
- Some nutrient loading detected

Livestock curriculum taught at Agricultural College

Rural Development Service

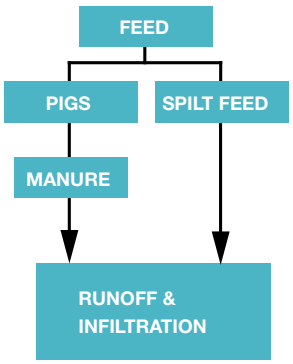
- Unauthorized operation of roughly 55 pigs
- 2-stage treatment system in place but effectiveness questioned.
- System lacks maintenance and is filled over capacity.
- Some nutrient loading detected

Effluent solid settling pond

Tuaiva

- Unauthorized operation of roughly 300 pigs
- Treatment system in place but not functional
- Direct waste effluent into the adjacent Tiori River
- High levels of phosphorous found.

Nutrient testing of runoff



Recommendations

Upon visiting the sites it was apparent that money had been invested into advanced waste-treatment equipment, however the majority of these systems were either out of use or not working properly. Because of this, we examined both simple, easily implemented solutions that could lessen the likelihood of nutrient loading as well as higher-level options that could treat greater loads more efficiently and effectively. In both cases recommendations include best management practices (BMPs) and involve a whole systems approach, resulting in the reuse of pig waste as a natural resource.

MINIMUM STANDARD PRACTICES, LOW-COST OPTIONS

Manage Feed Change feed content: Excess nitrogen and phosphorous in pig feed get excreted in pig waste, loading nutrients into ground and surface waters if not treated properly

Minimize spilt feed Feeding pigs in an enclosed location avoids direct nutrient loading from uneaten spilt feed. Store feed in secure, dry locations so spilt feed will not be affected by runoff and enter surface waters.

Select Location Setbacks from stream: Locating pigs away from streams minimizes the possibility for pig feed or pig waste to run off directly into streams, polluting downstream locations.

Flatter slopes Placing pigs on flatter slopes reduces runoff potential and increases infiltration of pig feed and waste, allowing nutrients and pathogens greater treatment capacity in the soil. However, nitrogen can still pollute groundwater on larger piggeries where nitrogen loading is too great for soil treatment.

Portable pens If pigs are located in small outdoor pens, their rooting and hoofing action can mix their manure with the soil and create a rich soil layer. If these pens are located around trees, the trees can use the nutrients from the manure. These pens can be relocated every three to six months.

Dry litter Bulky plant material lining pens can absorb liquids and manure. Pigs' rooting and hoofing action mix the plant and manure material, creating rich compost that can be used for growing crops.

Manage Solids Compost: Pig waste and carcasses can be composted to provide rich nutrients when applied directly to agricultural practices.

MULTI-STEP TREATMENT SYSTEMS, HIGHER LEVEL OPTIONS

For larger scale pig operations, higher-level treatment options may be more efficient and necessary. Advanced systems have been built on the island, but they are often not maintained properly. By building systems that create a resource from the waste, there is a greater incentive to observe and maintain a system regularly.

Multi-step systems typically begin by separating solids and sending the wastewater to an anaerobic tank or pond. That water can then move to aerobic ponds, a leach field or drip irrigation.

Biogas

Wetland

Compost

WASTE INTO RESOURCE

Anaerobic biogas tank Anaerobic ponds or tanks can capture biogas resulting from the degradation process. Biogas is produced in many countries for cook-stoves or small-scale electricity generation.

Subsurface wetland Wastewater gardens can produce useful plants such as high-protein hyacinth, fast growing bamboo or Makaloa reeds used for materials such as mats.

Compost Solid waste from the solid separator and sludge from anaerobic tank or pond can be composted and used or sold as a rich soil amendment.

INTEGRATIVE PLANNING SOLUTIONS

Although environmental standards exist for piggeries, many are out of compliance or lack authorization due to deficient monitoring or enforcement. Because of this our recommendations address policy incentives to improve environmental compliance.

PUBLIC POLICY

Active support Reference materials outlining best management practices and assessment tools such as an Environmental Piggery Checklist can assist operations with compliance.

Low-interest credit programs are an opportunity for piggeries to improve operations.

Monitoring system Initial baseline analysis with routine measurement is necessary to ensure standards are being met.

Point of sale tax Increased sales tax to pork sales may fund these policy incentives.

THE AGRICULTURAL COLLEGE AS AN EDUCATION AND INSTITUTIONAL CATALYST

Education for farm owners Providing these links to active support and detailed management advice in educational sessions will stimulate incentives for compliance and cultivate positive relations with farm owners.

Institutional catalyst For larger operations like the Agricultural College, new technologies and waste management curriculum can be displayed as part of a larger demonstration facility. Market development for the products from pig waste, such as compost, bamboo or other products with sustainable labeling, can increase the value of the resources provided.

Sustainable Tourism in Moorea: Opportunities for Ecological and Cultural Preservation & Education

Problem Statement

Tourism is one of the world's largest industries, accounting for more than 10% of the global economy.[26] Today, tourism accounts for approximately one-fourth of French Polynesia's GDP and is a primary source of hard currency earnings.[27] In French Polynesia, mass tourism is a major component of tourist ventures including large hotel and resort developments as well as cruise ship operations. Although mass tourism brings in more tourists and gross revenue than any other tourism scenario, negative impacts can occur when the level of visitor use exceeds the environment's ability to cope with this use. With its white coral sand beaches, diversity of marine life, and dramatic topography, Moorea is a premier tourist destination. However, increased demands on local services such as water, sewage, solid waste, fuel, power, roads, and medical services could ultimately destroy the very natural resources that attract visitors to Moorea in the first place.[28]

In addition to the typical tourist vacation there is a market for tourism emphasizing ecological and cultural experiences. Much of this type of tourism is termed ecotourism, defined by the International Ecotourism Society as "...responsible travel to natural areas that conserve the environment and sustain the well being of local people".[29] Ecotourism is appropriate in places where main attractions are ecological, cultural and scenic resources that can be degraded by the impacts of intensive tourism expansion.[30] Today, ecotourism comprises up to 20% of the overall worldwide tourism industry with annual growth rate ranging between 10-30%.[31]

Objectives

As an alternative to typical tourism, we assessed the potential for ecotourism on Moorea to attract international visitors, support local businesses and products, preserve local customs and practices, raise awareness of natural resource issues and finance their protection.

Methods

Using criteria developed by University of California, Berkeley Professor Randy Hester and Mark Hampton of University of Portsmouth, UK, we evaluated the potential for ecotourism on the island of Moorea and suggested means for implementation. Information gathered was organized into five main principles of ecotourism.

Results

PRINCIPLES OF ECOTOURISM

Preserve nature and local culture

Ecotourists travel long distances to see endangered species, especially large charismatic mega fauna, like endemic mammals and birds.[32] Moorea's coral reef ecosystem provides the big attraction needed to draw ecotourists. In addition to this large attraction, ecotourists will want to experience multiple aspects of local ecology and culture and learn about ecosystem processes.[33] This experience should be in an environmentally friendly way such as kayaking rather than via motorized boats.

Unspoiled Landscape Ecotourists want an unspoiled natural landscape and insensitive development can have adverse visual impacts.[34] Urbanization should not blemish the dramatically beautiful natural landscape but rather occur in accordance with the environment.

Unique Character Ecotourists are interested in experiencing what is distinctive about a place[35] over conventional suburban sprawl development that is not unique. Modernization on Moorea should occur in a way that preserves the unique character of Polynesian architecture.

Knowledgeable Hosts Ecotourists appreciate hosts who can provide local information and details about ecology, history, and culture.[36]

Insider Events Ecotourists want to experience things that other mass tourists do not get to see. This can include actively participating in habitat restoration, local ecology and culture. Ecotourists can participate in and be part of everyday occurrences and learn first hand what local people do. This includes participating in active duties of local vocations to experience "real work".[37]

Recommendations

INTEGRATIVE PLANNING SOLUTIONS

- Link tourism strategies to broader planning initiatives such as the PGA and PGEM.
- Incorporate broad-based community input and public participation.
- Respect carrying capacity through environmental review.
- Provide quality employment opportunities that reflect local knowledge and trade.

PLANNING IMPLICATIONS

Preserve nature and local culture

- Protect habitat. Currently, the disconnection between the terrestrial zoning plan (PGA) and the marine management plan (PGEM) does not allow for adequate protection of coral reefs. Investment must be placed on coral reef protection to ensure ecotourists will continue to visit.
- Identify environmental and cultural education opportunities

Unspoiled Landscape

- Development should limit road construction and encourage pedestrian access.
- If constructing on a hillside, stilt housing should be used over terracing
- To protect visual access and view sheds, property divisions should be kept vegetated, as specified in Moorea's previous terrestrial zoning plan (PGA), rather than divided with tall concrete walls.
- Incorporate Best Management Practices (BMPs) during construction and restore landscape after construction.
- Concentrate development in existing urban areas so large tracts of open space remain intact.
- Integrate "green" golf course practices. *See section on Moorea Golf Course Development*

Unique Character

- Currently, Moorea's terrestrial zoning plan (PGA) has design guidelines that encourages island-style development. However, landscaping guidelines using culturally distinctive and native plants can also be incorporated.
- Land-use plans and zoning laws for new development can protect waterfront property and maintain the regional aesthetic of the area.

Knowledgeable Hosts

- Local people should be trained to be professional and knowledgeable in this regard. Here local people with local knowledge can obtain well paying professional jobs doing the things they enjoy.
- Development of the Tahitian Cultural Center on the UC Berkeley property offers an excellent opportunity to circulate traditional knowledge.

Insider Events

- Identify and inventory local festivals, authentic places, traditional work, and arts and crafts that ecotourists would want to experience.
- Provide job training opportunities to local individuals and management training to local companies so experience can be professional yet unique.[38]

Evaluation of Moorea's Lake Temae Golf Course Development

Problem Statement

Lake Temae, on the northeast corner of the Island of Moorea in French Polynesia, is one of the best remaining representatives of the coastal wetland, an increasingly rare eco-system in the South Pacific. Listed by the United Nations Environmental Programme (UNEP) as a proposed protected area, Lake Temae's health and vitality are threatened by the construction of a golf course in the wetlands along its northern shore. In addition to severing Lake Temae's sole outlet to the sea, development of this golf course will also introduce a significant amount of chemicals into this sensitive coastal region, threatening several vulnerable species as well as the local islanders who depend on the ocean and the lake for subsistence.

Estimated Golf Course development boundaries based on area, parcelization, and description of course layout.

Objectives

Given the sensitive nature of the development site, more careful study and planning are necessary to re-evaluate whether a golf course in this location is the best decision for Moorea's future.

Methods

Evaluation of Moorea's Lake Temae Golf Course Development occurred through literature review, site analysis, comparison with precedent case studies and golf course practices, and review of existing policies and environmental standards.

Results

TEMAE GOLF COURSE, A NICKLAUS DESIGN

Founder and famous golfer Jack Nicklaus states: "I'm proud of the fact that even when we work in countries with less restrictive rules, we voluntarily apply United States rules to all Nicklaus Design work."[39]

UNDER U.S. STANDARDS, NICKLAUS DESIGN SHOULD:

Comply with Section 404 of the Federal Clean Water Act, which protects wetlands. Through this act developers must demonstrate that there are no feasible alternative upland sites for the project, redesign the course to avoid existing wetlands as much as possible and mitigate for wetlands that are destroyed on-site.

Comply with the Coastal Zone Management Act This act ensures protection of coastal resources including coral reefs, Lake Temae and wetlands. It limits development in coastal area, beaches and dunes and maintains public beach access.

Follow Hazardous Substances Regulations Here developers must limit pesticide use, certify personnel with restrictions on handling, storage, application and disposal of materials and eliminate use of chemicals banned in the United States.

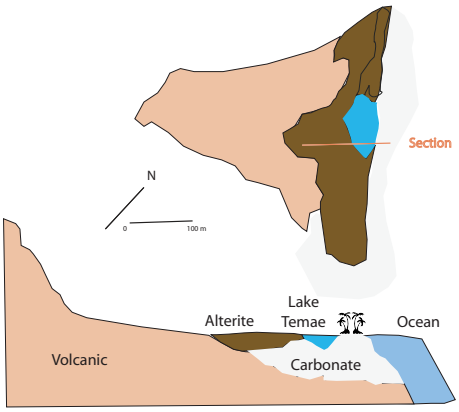
Protect aquifers To protect ground water developers must control non-point source pollution such as irrigation and storm water runoff, monitor groundwater conditions and avoid chemical migration towards sensitive coral reefs.

GOLF COURSE IMPACTS

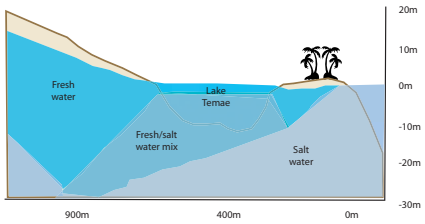
Lake Temae's geology originates from both volcanic and coral sources. Underlain by a very porous layer of limestone where inland fresh water mixes with ocean salt water, Temae forms a single connected hydrologic unit between the land and the sea.[40] No documented plan currently exists to manage the golf course in an environmentally sensitive manner. Under conventional golf course practices, chemical leaching from the addition of significant amounts of pesticides and fertilizers threatens the unique ecology of the lake, the health of the surrounding reef and the adjacent premier snorkeling and tourist site Temae Beach.

Estimated Environmental Impacts of Temae Golf Course Development

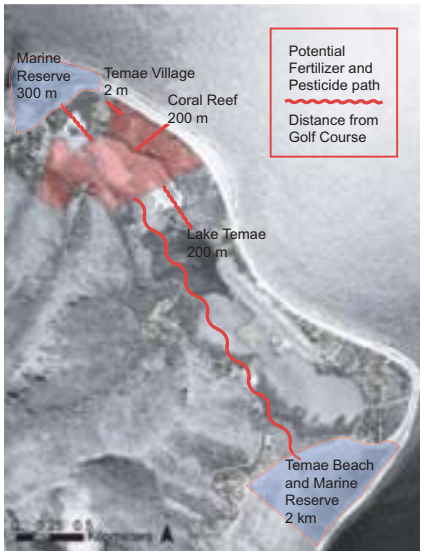
GOLF COURSE INPUTS	EFFECTS	ESTIMATED QUANTITY/ YEAR
Land		
	Wetland fill; hill side excavation	**50 Hectares**
Water		
	Draws down aquifers, runoff pollutes groundwater, carries pollutants into surrounding ecosystem	**400,000 to > 2 million liters**
Pesticides include herbicides, fungicides, and insecticides (sample) All of the following can be acutely toxic when airborne		
Chlorpyrifos	Impairs nervous system function	
Atrazine	Highly toxic to aquatic plants	
Benfluralin	Decreases red blood cell count	
Dicamba	Toxic to fetus	
Thiophanate-methyl	Decreases sperm formation, causes hyperthyroidism	
Diquat	Causes cataracts	
Pendimethalin	Toxic to liver	
Disulfoton	Causes optic nerve degeneration	
Total pesticide use		**>2 Tons**
Fertilizers		
Nitrogen	Contributes to eutrophication of lakes; contaminates drinking water causing a threat to health of infants	**10 Tons**
Phosphorus	Increases algal growth which blocks sunlight and kills coral; in inland lakes eutrophies water, a process which removes oxygen, killing aquatic organisms	**5 Tons**
Wetland fill		
	Eliminates wetland function as a pollution filter; major contribution to sediment runoff, leading cause of coral death	**55,000 Tons** **500,000 cubic meters or 50,000 dump truck loads calculation:** 25 hectares filled to a 2 meter depth; 100 kilograms/ cubic meter of soil; fill removed from hillside and placed in Lake Temae wetland



Moorea was born as an undersea volcano, the source of the volcanic base rock. Alterite is soil which eroded off the volcano. This is the primary area where the golf course will be developed. Carbonate is from the coral reef which formed offshore.



Lake Temae lies at an intersection between freshwater and saltwater. Underlain by a very porous layer of carbonate where inland fresh water mixes with ocean salt water, Temae forms a single connected hydrologic unit between the land and the sea. (Burlot et al.)



LAKE TEMAE SPECIES AT RISK:

In addition to introduction of pesticides and fertilizers, filling of the wetlands to facilitate development will destroy habitat for the locally rare Pacific

Black Duck *Anas superciliosa*, the Wandering Tattler *Heteroscelus incanus*, the Pacific Golden Plover *Pluvialis fulva* and the Little Heron *Butorides striatus*.

ANALYSIS OF REGULATORY CONTEXT

Analysis of Moorea's terrestrial zoning plan (PGA) policies reveal that current planning regulations for tourism zones are inconsistent with the goals of the Marine Management Plan (PGEM) as they encourage large scale tourism development in the vicinity of important marine protected areas (MPAs) and fail to control inputs from reaching the marine environment that potentially could cause significant harm to marine ecosystems.

Marine Protected Area Locations	Coral Characteristics	Existing Development	Allowable Future Development
Teaharoa	Coral reef completely intact (Category 1)	Low density development (area largely undeveloped)	High-end residential 'villas' Golf-course
Paopao Commune		Industrial activities, municipal structures	Luxury hotels (building size up to 7000m²)
		Agriculture fields	Agricultural activities not needing additional infrastructure/construction
		Soil saturation; filled in motus	Agricultural and industrial exploitation
		Land fill and dump site	Theme parks
Paaruiti	Coral reef intact on outer rim, slightly disturbed nearest coast (Categories 1 and 2)	Medium density development	Additional residential
Teavaro Commune		New exurban gated community	Luxury hotels (building size up to 2000m²)
		Luxury hotels	Agricultural activities not needing additional infrastructure/construction
		Municipal structures (airport)	Theme parks

Recommendations

Our analysis suggests that development of the golf course is a risky venture for the island. Current terracing of the hillside and filling of the wetlands point to discrepancies between the stated design standards and observed construction practices, yet the development of the golf course at lake Temae continues. Despite this, implementing the following management practices can help circumvent further damage.

GREEN GOLF PRINCIPLES

- Limit fertilizer applications, and use slow release fertilizers to avoid "pulses"
- Design and operate irrigation to prevent movement of water into wetlands and to reduce chemical transport and disruption of the natural hydrologic cycle.
- Consider chemical properties such as solubility, leaching potential, half-life, and degradation products when selecting chemicals for application.
- Establish Integrated Pest Management (IPM) as an alternative to pesticide application.
- Select turf appropriate for climate/environment to reduce need for irrigation.
- Establish buffer strips along wetland perimeter.
- Store chemicals such as pesticides, fertilizers, and fuel in a location where their spill will not result in their transport to wetlands.
- Avoid wetlands in course design routing.
- Collect and re-use drainage water from the golf course, creating a closed water system.
- Choose a course aesthetic that lowers maintenance standards such as promoting a scruffier and seasonal appearance over constant greenness. This minimizes nutrient and irrigation applications, which controls disease and lessens the need for costly pesticide and fungicide applications.
- Allow dynamic natural processes to function within the course.

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Conference Presentation to Mayor of Moorea

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