Report as of FY2006 for 2005HI125G: "Coastal Groundwater Management in the Presence of Positive Stock Externalities"

Publications

- Articles in Refereed Scientific Journals:
  - Pongkijvorasin, Sittidaj, and James Roumasset. 2007. "Optimal conjunctive use of surface and groundwater with recharge and return flows: Dynamic and spatial patterns." Review of Agricultural Economics 29(3) (forthcoming)
- Dissertations:
  - Pongkijvorasin, Sittidaj. 2007. Stock-tostock Externalities and multiple Resources in renewable resource economics: Watersheds, conjunctive water use, reefs, and mud. "Ph.D. Dissertation, Department of Economics, University of Hawaii at Manoa (forthcoming), Honolulu, Hawaii, x+117 pp.

Report Follows

Problem and Research Objectives

Hawaii's nearshore marine environment, which is a major recreational and ecological resource, is dependent on fresh groundwater discharge. Freshwater discharges from the groundwater aquifer into the ocean and mixes with the seawater, creating a nearshore ecological system that has evolved with less than seawater salinity and which supports indigenous fish and marine vegetation. Thus, the state of the groundwater aquifer directly affects the cultural, recreational, and economic values of the community. As water is extracted from the groundwater aquifer to meet demand, lower aquifer head levels will decrease freshwater discharge into the ocean, thus increasing salinity and damaging the balance of the nearshore marine ecosystem. Traditionally, models of optimal groundwater extraction do not include such environmental effects. The problem, therefore, is to govern groundwater extraction based on considerations of environmental consequences as well as present and future benefits of water consumption.

In order to assess the economic, biological, and cultural significance of varied levels of submarine groundwater discharge on the nearshore environment, we develop a botanical research activity for studying the effects of aquifer-induced freshwater discharge on native marine algae. Since native algae play a key role as the primary producers that support a unique food web of endemic organisms, the overall health of the nearshore marine environment is of great concern. By monitoring the response of marine algae to varied levels of nutrients and salinity in a controlled laboratory environment, we will gain a better understanding of the physiological effects of variable amounts submarine groundwater on marine algae species and the nearshore marine environment as a whole. The physiological parameters measured in this investigation include growth rate, branch development, and light absorbance.

Methodology

This research has two phases, which will be melded in the third year. The first involves an integrated bio-hydro-economic model to search for optimal levels of groundwater use and limu (Hawaiian seaweed) production. The second is a laboratory phase designed to provide understanding of the relationship between salinity and biological productivity of freshwater-impacted ocean areas.

Integrated Bio-hydro-economic Model

The model structure applied here closely follows that of D.L. Krulce, J.A. Roumasset, and T. Wilson (1997, Optimal management of a renewable and replaceable resource: The case of coastal groundwater, *American Journal of Agricultural Economics* 79:1218–1228), whose model in turn is an application of optimal control mathematics. The objective is to choose a path over time for extraction of groundwater and production of desalinated water in order to maximize the present value of net social surplus from water. The social surplus covers both traditional water uses and external benefits from production of indigenous fish and marine vegetation in nearshore waters affected by the discharge of freshwater from aquifers. We are particularly interested in limu as a nearshore resource that is affected by groundwater discharge. However, the model is general and can be applied to other nearshore resources.

The social planner's problem is to choose the paths of groundwater extraction and desalinated water over time in order to maximize the social net benefit, which includes the benefits from water and limu consumption minus the costs of supplying water and harvesting limu, i.e.:

$$\max_{q_t, b_t} \int_0^{\infty} e^{-rt} \left[\int_0^{q_t + b_t} p(x)dx - c(h_t)q_t - \bar{p}b_t + \int_0^{m_t} p_m(y)dy - c_m(S_t)m_t \right] dt$$

$$s.t. \quad \dot{h}_t = a[R - l(h_t) - q_t]$$

$$\dot{S}_t = g(S_t, h_t) - m_t$$

The Hamiltonian has two constraints, one for head level (which gives the shadow price of water in situ) and one for limu stock. First-order conditions for this problem yield the price path:

$$p = c(h) + \frac{\dot{p} - a(R - l(h))c'(h)}{r + al'(h)} + \frac{ag_h(S,h)\lambda}{r + al'(h)}$$

If the desalination technology is used, p is also equal to the cost of desalination.

Botanical Research

In this study, the endemic edible species *Gracilaria coronopifolia* was chosen for investigation. To accurately measure the physiological response of this marine alga to isolated variables, a digital growth chamber was modified to support a unidirectional flow-through saltwater system. Growth conditions are fully controlled.

In order to quantify changes in wet weight and morphology, three variables were calculated. The specific growth rate was calculated as follows: [(final wet mass – initial wet mass) / initial wet mass] / 16 days. The percent change in apical tip number relative to initial tip number was calculated in a similar manner: 100 * [(final apical tip number – initial apical tip number) / initial apical tip number] / 16 days. In order to quantify the number of apical tips in reference to initial weight, apical tip number / mass is calculated as the tip score. The change in tip score can then be calculated as follows: [(final tip score – initial tip score) / initial tip score] / 16 days.

Principal Findings and Significance

Integrated Bio-hydro-economic Model

From the integrated model, we show that accounting for limu value increases the optimal groundwater steady state whether or not desalination technology is used. We analyze four possible patterns of water use, including the use of desalinated water as a backstop and "frontstop."

Numerically, using data from the Kukio area, located along the North Kona coast of the island of Hawaii, we solve for optimal groundwater management considering its nearshore externalities. Two different approaches to incorporate the limu consideration are discussed. The first approach is to include the market value of limu in the model. The other approach is to impose a "safe minimum standard" level for limu stock as a constraint. Results show that, taking into account the market value of limu, the water extraction rate should be lower than when limu value is ignored. However, the difference is small because the value of limu is relatively insignificant compared to the value of water. However, it should be emphasized that the value of limu in this example accounts only for the consumption value and ignores other possible values, e.g., cultural or ecological value. When the model incorporates a minimum limu stock as a constraint, the paths over time of water extraction, head level, and water price are non-monotonic. It is optimal to deplete the aquifer below the steady-state level, followed by a conservation period in which the head level is increased to the steady-state level.

For the final year of this project, we plan to incorporate the laboratory results discussed below into the model. For example, nitrogen will be included as another water quality indicator determining the growth of limu. Also, we will explore imposing a constraint on limu growth or on water quality indicators such as salinity.

Botanical Research

Four levels of salinity were investigated: 11‰, 19‰, 27‰, and 35‰. The mean growth rate, percent change in apical tip number, and apical tip number / mass were calculated for each salinity level. The 11‰ treatment differed significantly from the other three in mean specific growth rates. About half of the samples in the 11‰ treatment died and rapidly lost their initial mass and pigments, while the rest increased in mass at rates similar to other treatments. Thus, it is likely that the lower threshold of the salinity concentration for *G. coronopifolia* viability is close to 11‰. The 27‰ treatment had a significantly higher percentage of new apical tips per day than all other treatments. A similar result holds for the apical tip number / mass variable. In vivo absorbance on day 16 of the trial showed a similar pattern: no difference among the 19‰, 27‰, and 35‰ treatments, but a significantly higher value for the 11‰ treatment.

This study may be the first to show that the calculation of tip scores as well as percentage of new apical tips is a valid and useful method for quantifying changes in morphology of marine algae. Since most growth occurs at the apical tips of marine algae, it is clear that those samples with more tips per mass will have higher growth rates.

A nitrogen trial using variable concentrations of ammonium is ongoing. Future trials will include variable amounts of phosphate and nitrate. Also, a synergistic trial where nutrients and salinity are varied together in a manner consistent with hydrodynamics of submarine ground water discharge in the field will be conducted. The combined effect of increased nutrients and decreased salinity should increase growth rates and apical tip development; it could alter pigment absorbance in some treatments as well. This trial should give the most insight to the biological response of marine algae to submarine groundwater discharge in the field.