Environmental Valuation and the Hawaiian Economy:

Introduction and Executive Summary*

THE PROBLEM

Economic planning and policy analysis are commonly criticized for their failure to properly account for adverse effects of economic development on the environment and other interactions between nature and the market economy. The limited and piecemeal curbs on land development projects, e.g. as provided by environmental impact requirements, fail to diagnose the major negative impacts of the economy on development and to direct available resources to the most serious environmental problems in a cost-effective manner.

The present report overviews existing measures of economic performance and alternative statistical devices used to incorporate environmental concerns into economic planning and the analysis of public policy. Ultimately, assessments of both aggregate economic performance and specific projects and policies must incorporate valuation of impacts on the environment, environmental services, and degradation of environmental resources. To this end, the report includes case studies that illustrate economic valuation of threatened environmental resources in Hawai‘i.

ECONOMIC ACCOUNTING FOR SUSTAINABLE DEVELOPMENT

Chapter 1 provides an introduction to the concepts and methods of environmental valuation and an overview of the interlinkages between natural capital and the market economy. Conventional methods of economic accounting, e.g. gross and net domestic product (GDP and NDP) focus on quantifying the value of the market economy. It has long been known that existing accounts may be a somewhat inaccurate measure of human welfare due to the neglect of nonmarket goods and services (e.g. parental childcare, household food preparation, leisure and recreation. Measures of aggregate national or state income may be particularly misleading when economic development comes at the expense of environmental degradation. Pollution, for example, is a nonmarket good (albeit one with a negative value), and its omission from income accounts places too much value on production activities that, say, degrade drinking water or accelerate the spread of noxious exotic species. Moreover, while NDP nets out depreciation of buildings and capital equipment to get a more accurate measure of income, depreciation of natural capital is ignored, even when depletion of resource stocks is for commercial purposes, e.g. the sale of timber or fish.

* This report was prepared by Brooks Kaiser, Nancy Krause, Dee Mecham, Jessica Wooley and James Roumasset, Principal Investigator, and is still in draft form. Comments and suggestions are welcome.

VALUING HAWAI‘I’S NATURAL CAPITAL

The examples in this report fall mainly into three categories of positive natural capital — forest resources, shoreline resources, and water resources — and a fourth category, alien species that degrade natural capital. Chapter 2 is devoted to the first three categories and begins with a discussion of the Ko‘olau forested watershed. Since the value of a resource system is not typically well defined in isolation, one must first define a benchmark level of degradation against which the value of the current system can be compared. In the case of the Ko‘olau forests, we consider a hypothetical major disturbance by a substantially increased population of pigs combined with a major forest conversion from native trees to the non-indigenous *Miconea calvescens* and a continuation of urban “creep.” This disturbance is assumed to reduce recharge to the Pearl Harbor Aquifer by 31% of the 133 million gallons per day that is currently attributable to the Ko‘olau’s. This implies that water use would have to decline and that O‘ahu would have to resort to desalination as a water source more than 35 years earlier than if the forests were to remain intact. The present value of the resulting cost increases varies from $1.4 to $2.6 billion, depending on the discount rate. If there were a complete deforestation, e.g. due to a devastating fire, the value of the lost recharge would be from $4.6 to 8.5 billion.

Another valuable ecological service provided by the Ko‘olau forests is maintaining water quality. Replacing the water filtration effects of the forests would be extremely expensive. The 31% decrease in recharge described above would lead to a corresponding increase in water runoff, increasing sedimentation of coral reefs and of the Ala Wai Canal, decreasing the carrying capacity of streams, and increasing the turbidity of streams and neighboring ocean areas. Replacement costs of natural filtration can be estimated as the costs of artificial filtration or as the costs of dredging. Using the lower of these two estimates, we find that a decrease in recharge and corresponding increase of runoff of 31mgd would increase sedimentation by 28,217 tons at a cost of $.75 to 1.2 million per year for land and ocean disposal respectively, implying a present value cost of $26 to $123 million.

A substantial amount of forest disturbance would also threaten species habitat both in streams and in the forest. Taking the case of sufficient disturbance to render one endangered fish species and one endangered bird species extinct and using (Mainland) contingent valuation estimates of $7 and $35.50 per household per year for fish and bird species respectively, we obtain an estimated value of $17 million per year for the 400,000 households in Hawai‘i or an estimated present value (using a 3% discount rate) of $567 million.

The Ko‘olau forests are also an essential part of O‘ahu’s image as a tourist destination and an important amenity to residents. These aesthetic values can be roughly evaluated by reference to a contingent valuation study of additional open space on O‘ahu. If one takes just half of that value per acre and applies it to half of the acreage on Leeward O‘ahu, the resulting value is $66/acre/household/yr. Or $18 million per year for O‘ahu residents alone. This implies a present value of $0.6 to 1.8 billion.

Forests are also a major part of ecotourism. Starting with actual expenditures on ecotourism of $413 million per year, we can conclude that the value of the Ko‘olau ecotourism capital is at least

$1 billion, provided that at least one-fifteenth of ecosystem expenditures are based on Ko‘olau assets, even without allowing for the estimated annual growth potential of 20%.

Even without exploring Hawai‘i’s other forested watersheds in comparable depth, we found *prima facie* reasons for concluding that the East Maui forested watershed area is at least as valuable as that of the Ko‘olau’s. First, Maui relies to a greater extent on surface water. Thus while O‘ahu enjoys the natural buffering of underground storage, Maui’s forests are more critical for converting irregular rainfall patterns into a smoother flow of surface water, in effect conserving water for use in relatively dry periods. Moreover, the Windward East-Maui watershed protects the State’s largest concentration of endangered bird species and some of the largest concentrations of native forests.

There is a similar situation facing Hawai‘i’s beaches. O‘ahu’s beaches alone are estimated to provide recreational services valued at roughly $700 million/yr, including $32 million for Hanauma Bay. The value estimates are based on demand for beach visits and exclude such values as sight-seeing, natural protection of shoreline property, and existence. Yet beaches in certain hot spots are threatened by a combination of natural shoreline movement, sea-level rise and coastal armoring (aimed primarily at preventing property loss). Clearly, substantial maintenance expenditures are warranted, yet policy guidelines on how to effectively combine the regulation of armoring and sand replacement have not yet emerged.

Coastal and marine resources are also shown to be important to Hawaii’s economy, yet face risks of overfishing and pollution.

MITIGATING AGAINST THE SILENT INVASION

Another threat to Hawai‘i’s environment and natural resources is the “silent invasion” and spread of alien species. As already noted, activities of pigs and other feral animals and the spread of plants such as *Miconea calvescens* result in the loss of ecosystem services, including groundwater recharge and water purification. The extensive habitat modification associated with the spread of these exotics results in a corresponding reduction of native species. Accordingly, Hawai‘i has both the highest proportion of non-indigenous species in the U.S. and the greatest concentration of threatened and endangered species. Other species can directly impact consumption and increase other costs.

The population of each such alien species can be considered as a public bad and its effects are analogous to pollution. Whereas some non-indigenous species have already been introduced, however, others remain as potential threats. Thus analogous to pollution abatement costs, the costs of alien species can be reckoned as the sum of prevention, control, and repair costs and the cost of residual damages. The efficient level of prevention and control costs is that which minimizes the total expected cost of a particular species. A particular prevention strategy will be welfare improving if its cost is less than the expected increase in the total of the other cost components in the absence of said strategy. A control strategy will likewise be justified if its cost is less than its expected benefits, i.e. the expected reduction in repair and residual costs that the strategy would afford. A number of case studies are provided to both illustrate methodologies that could be used somewhat more intensively and to provide *prima facie* evidence of under-investment in prevention and early control in Hawai‘i.

POLICY RECOMMENDATIONS

1. The State of Hawai‘i should provide for “green accounting” that measures the contribution and depletion of its environmental resources and a system of integrated economic accounts that includes such measures. In particular, “nature sector” accounts would help to establish priorities for environmental policy and spending by highlighting at-risk environmental services that are especially valuable to the full economic system.

2. Economic planning should be similarly extended to incorporate the health of the environment and the sustainability of economic growth. Using the Land Use Commission as a mere check on environmentally unsound development policy is not a sufficient instrument for environmental planning. Most of the threats to the environment reviewed in the present document are not associated with new development projects but by the “normal” activities of species already present in Hawai‘i (including humans). The State can no longer afford to take a passive approach to the environment. Rather a more active approach to conservation and risk management is urgently needed.

3. To the extent that the State and its various agencies are involved in the management and pricing of water and other natural resources, such management and pricing should reflect the true values of the resources and resource interdependencies. Since the Ko‘olau forests enhance the recharge to the Pearl Harbor Aquifer, for example, the cost of maintaining those forests should be partially reflected in the true cost of water. One mechanism for putting this principle into practice would be to attach a surcharge to water use over some minimal amount (e.g. 160 gallons/day/household) and to use the resulting revenues to help maintain the forests and the ecological services which they provide.

4. The indicative and prima-facie cost-benefit analyses regarding preventing and controlling the spread of alien species should be conducted in-depth and applied to several alternative pest-management proposals.

CHAPTER 1: CONCEPTS & MEASUREMENT OF ECONOMIC VALUE AND AGGREGATE STATE INCOME

1.1 INTRODUCTION

Economic planning and policy analysis in Hawai‘i—as in most other states—are to a large extent separate from environmental management. To explore the possibilities for a more integrated approach, this report describes the relationship between nature and the market economy, provides alternative methods of environmental valuation that facilitate integrated planning, and offers illustrative Hawaiian examples. The present chapter focuses on the augmentation of nonmarket (environmental) capital and income with traditional measures of income. The objective is to illustrate alternative methods to more accurately reflect economic performance and the interrelatedness of the economy and natural capital.

1.2 CONCEPTUAL FRAMEWORK OF ANALYSIS

To understand the reasons why environmental values tend to be omitted from measures of income it is necessary to examine the traditional description of the economy. The economy is usually depicted as a circular flow in order to highlight the ways that the separate parts of the economy relate to each other. At its most basic level the economy is divided into two sectors, production and consumption.[1] These two sectors interact through two kinds of markets: (1) goods and services produced by firms flow to consumption through output markets; and (2) factors of production (including land, labor and capital) flow through the input market to the production sector.

The circular flow model is based on the idea that wherever expenditures are made on national product an equivalent amount of national income is generated. As a result, there are two distinct ways of measuring national income—income can be calculated by determining the value of what is produced, or it can be determined by the value of the income generated by production. Both of these methods will yield the same result.

Market prices provide an accurate measure of the value of some goods and services. The price of certain goods, such as timber or commercial fish catches, are easy to determine. **Unfortunately, for other goods and services, such as clean air and water, various factors (referred to as market failures) prevent markets from operating and determining their value via price**. An example of an unpriced environmental service is the disposal of auto emissions into the atmosphere. These two categories of goods are classified as market and nonmarket goods respectively. **Basing economic decisions on observed market prices (if they exist at all) will in most cases result in an inefficient allocation of resources if adjustments are not made for the presence of market failures.**

[1] Government taxing and spending, investment and foreign trade are being omitted here for the sake of simplicity.

Many of the benefits of natural resources, such as recreational, ecological, or biological values, are subject to market failures, which are often the result of the nonexclusive or nonrival nature of the particular good or service. When one person's consumption of a good (e.g., viewing the O'ahu creeper—an extremely rare bird species—in the wild) does not diminish another's consumption (nonrival use) or it is not feasible to exclude anyone else from consuming the good (nonexclusive use), then the market process cannot establish a monetary value.

In some situations a voluntary action by an individual may be necessary to protect an environmental resource. A problem may arise if the individual believes that other people may not contribute their 'fair share' (because they are not required to). For example, in some forested watersheds in Hawai'i wild pigs are destroying the forests and causing sedimentation by rooting and trampling vegetation. One of the results is a major deterioration in water quality. The individuals who own the land in the forested area may think it unfair if they spend their own time and money trying to control the pigs when the entire population that uses the watershed will ultimately benefit. As a result, the land owners may be discouraged from taking the actions necessary to protect this valuable resource.

As suggested above, there are two separate problems associated with environmental values. The first problem involves developing techniques that are capable of estimating these values in economic terms. Valuation techniques have been developing for at least two decades and significant progress has already been made. Some of these techniques are described below. However, since many environmental values are not owned or controlled by property owners, the benefits associated with the values are often times difficult to capture. This leads to the second major problem. Mechanisms must be developed that will encourage private land owners to recognize these values even though they cannot directly capture the full economic value of these resources.

As indicated above, when future development paths and public policy formulation are based on incomplete measures of economic value, decision-making is likely to be flawed. Specifically, misleading or nonexistent price signals are likely to result in the overuse and degradation of natural assets. In order to more accurately estimate the total economic value of the economy, it is necessary to broaden the circular flow concept described above to include both market and nonmarket values.

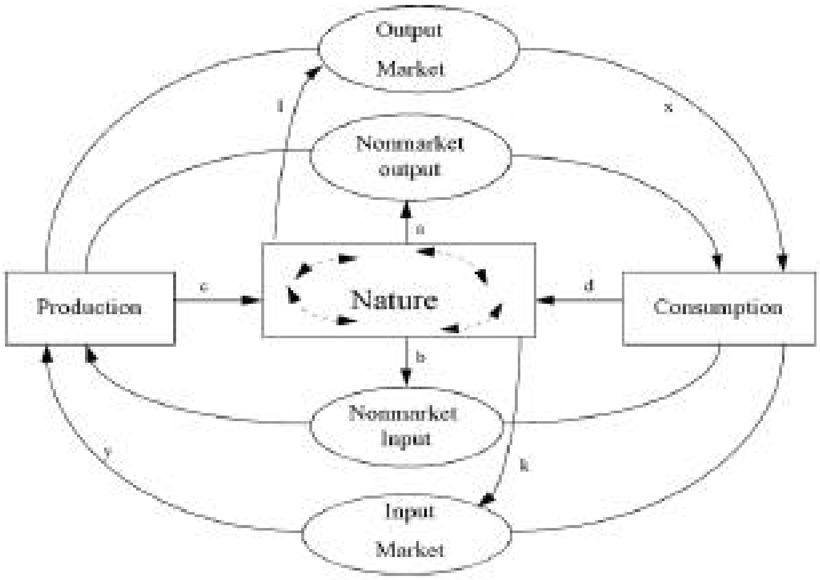
1.3 EXPANDED CONCEPTION OF THE ECONOMY

1.3.1 INCOMPLETE MARKETS

Market and nonmarket goods and services provided by nature flow to the economy through four separate linkages, illustrated in Figure 1.1 below. **The environmental goods and services flowing through the linkages from the nature sector can be more generally grouped into three basic categories: (1) those that provide inputs to production; (2) those that provide direct utility to households; and (3) those aspects of the environment that act as a 'waste sink' to absorb and recycle wastes resulting from production and consumption.** An assessment of total economic value should include all categories of environmental goods and services. For example, an attempt to value a forest located in an important watershed could include the following values:

- linkage (k): timber, maile leaves;
- linkage (l): expenditures on nature based tourism (ecotourism, park entrance fees);
- linkage (b): increase in the quantity and quality of water supplies that are eventually used in agricultural or commercial production;
- linkage (a): hiking, photography, & bird watching (with no associated fees).

Figure 1.1: Expanded View of the Circular Flow of the Economy



<u>Key</u>

(x)= *goods & services flowing from production to consumption through output markets;*

(y)= *labor, land & capital flowing to production through input markets;*

(a)= *nonmarket direct output from nature to consumption (e.g., scenic views, bird watching)*

(b)= *nonmarket direct inputs from nature to production (e.g., unpriced water, assimilative capacity)*

(l)= *market outputs from unprocessed nature (e.g., user fees, park fees, ecotourism)*

(k)= *market inputs to production (e.g., forests for timber, commercial fisheries)*

(c)*= *wastes resulting from production (e.g., organic wastes, cumulative pollutants, solid wastes)*

(d)*= *wastes resulting from consumption (e.g., auto emissions)*

Dashed arrows in nature sector represent the numerous interdependencies working in nature which provide indirect life support functions (water filtration, flood control, erosion control).

* *The environment has assimilative capacity to absorb wastes up to a certain point. As the assimilative capacity limit is reached, the levels of (a) and (b) will likely decrease.*

1.3.2 INSTITUTIONAL EFFECTS

Governmental programs and public policies can have a major impact on the relative size of the two main dimensions (the market and nonmarket loops illustrated in Figure 1.1) of the economy. As discussed above, environmental goods are often negatively affected by various market failures. **There are many examples of the federal and state governments taking actions that, in effect, move a particular environmental resource from the nonmarket loop of the economy to the market loop.** For example, in many cases a user fee system (assigning a price to an environmental resource) can be effectively implemented in order to alleviate environmental pressures on important environmental resources. **A well-known Hawaiian example of this is the implementation of the user fee system at Hanauma Bay that was first instated by the City of Honolulu in July of 1995.** These fee systems often meet with public outcry because individuals are charged for use of a resource that they consider should be "free." Hanauma Bay was no exception, as the fees were repealed from January 1, 1996 to April 25, 1996.[2] The implementation of these valuable policies is vital to both the economy and the maintenance of the resource capital. Successful implementation ultimately depends on public education, input and acceptance.

Placing a price on aspects of environmental resources has two general effects. First, pricing encourages the efficient allocation of resources. Specifically, individuals are encouraged to internalize the environmental costs of their actions into their decision-making so that scarce resources are allocated to those individuals who value them the most.[3] **Second, calculations of national or state income are improved when important assets are assigned a price reflecting their true economic value.** This is particularly the case if an accurate picture of the contributions made by the natural environment is to be obtained. The importance of this is discussed further below.

1.3.3 COMPONENTS OF TOTAL ECONOMIC VALUE

The expanded view of the economy illustrated in Figure 1.1 is a result of the evolving conception of total economic value. **As the values associated with the environment have become more obvious, economists have broadened the concept of total economic value to include both market and nonmarket values.** The expanded definition recognizes that many of the most significant values associated with the environment are not traded in markets and therefore have no market price. **A fundamental step in properly valuing environmental resources is recognizing and, wherever possible, quantifying the resource's total economic value (TEV). The total economic value of an environmental resource has been defined in several different ways by various economists.**[4] However, the differences in definition are usually just a matter of semantics; the general idea of TEV remains consistent.

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[2] Fees enacted July 1, 1995. Fee structure repealed by Ordinance 96-01, effective January 1, 1996. Fee structure newly instated April 25, 1996 by Ordinance 96-19 (Municipal reference Library, personal communication).

[3] In public policy, economic efficiency may not be the primary goal, particularly when there are important equity considerations involved. However, this issue is beyond the scope of this report.

[4] For insightful discussion of the total economic value concept see: Freeman III, 1993: 691; Pearce, 1990: 669.

At the most general level, the total economic value of an environmental resource consists of its use value and its passive use value. Direct use value derives from the actual use of the environment. This includes both extractive uses of the environment (such as the logging of koa or fishing) and nonextractive uses (such as bird watching or scenic vistas). The environment also provides services that individuals use in a less direct way. For example, the environment provides services in the form of erosion control, water recharge, and waste treatment. Both households and firms depend on the environment to provide these **indirect use values**.

There is also a component of TEV that is based on the value people place on environmental goods and services that is unrelated to direct or indirect use. This category of value, called **passive use value**, refers to the value associated with something that is captured by people through their preferences. In this sense, values are taken to be entities that reflect people's preferences and include the following motivations: **altruism**; concern for other people (**gift**) and future generations (**bequest**); **sympathy** towards nonhuman species; and feelings of **stewardship**. For example, people may place a value on the existence of the ʻōʻū (a critically endangered Hawaiian bird species) because they wish for other people (gift) or future generations (bequest) to be able to experience a beautiful bird species. Similarly, people may place value on the remote Alakaʻi Swamp on Kauaʻi because they feel an obligation to protect this unique biological area (stewardship).

All of the dimensions of value described above are considered to be legitimate components of total economic value. A particular environmental resource can be a source of one or all of these values. An example of TEV for a forested watershed is illustrated in Table 1.1

Table 1.1: Total Economic Value of a Forested Watershed

Direct Use Value	**Indirect Use Value**	**Passive Use Value**
timber production	recharge of underground aquifers	knowledge of the existence of forested watersheds for other people and/or future generations; (gift and/or bequest)
non-extractive recreation (hiking, bird watching)	erosion & flood control through absorption of rain	value obtained from knowing that a 'duty' to protect ecosystems has been fulfilled (stewardship)
extractive recreation (hunting)	water purification	critical habitat for threatened/endangered forest species (gift, bequest, altruism, sympathy, and/or stewardship)
indigenous/cultural uses	climate control	

The above framework is useful because it distinguishes between environmental goods and services that people directly use and those that, while less obvious, provide the foundation for a healthy economy and human welfare.

1.4 OVERVIEW OF INCOME ACCOUNTING

1.4.1 CURRENT MEASUREMENT OF INCOME

When the standardized national accounts (SNA) were developed by the United Nations in 1942, natural and environmental resources were not on the agenda of most economists. Not surprisingly, the Great Depression and the business cycle were the priorities. The standardized national accounts developed in 1942 and now used by most countries in the world still reflect societal priorities that—while perhaps appropriate several decades ago—may not fully capture today's societal preferences.

Within the United States, income measures such as net national product and net state product are used at both the national and state level to track the value of goods and services produced in an economy, as well as income received. These economic measures are of course very useful tools for economic analyses. They can indicate, among other things, the level of economic activity, its variations from year to year, the size of savings and investment, and the limits society can consume out of its current receipts. However, although these measures may be useful for short to medium-term gauges of economic activity, **they are less useful for gauging long-term economic growth. This is in large part due to the fact that natural resource depletion and degradation are not entered into these calculations.** Furthermore, although GDP is often used as an indicator of welfare, it is important to remember that the concept of welfare is much broader than a monetary measure of income. Welfare involves many dimensions of subjective well being other than those involving market transactions.

Due to the focus of the national accounts on income, it is important to understand the concept of income. **In any economy there is both natural capital and produced capital, both of which are capable of generating income.** Decisions to use one form of capital over another are based on assessments of the future income expected to be generated by the use of the capital. A major cause behind environmental degradation is the frequent under-valuation of the income generating potential of leaving the natural asset *in situ.*

There are thus three fundamental components that need to be considered in assessing income: the level of consumption, the amount of natural capital, and the amount of produced capital.[5] In order for income to be considered sustainable, natural capital must be increasing, or, alternatively, if natural capital is decreasing, produced capital must be increasing. If one of these two conditions is not met, income cannot be considered sustainable.

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[5] Here, sustainable income = consumption + the net value of capital appreciation (both natural and produced capital). In other words, sustainable income is what is left for prospective consumption after all capital stocks have been maintained intact.

Despite an increase in awareness that both natural and produced capital are capable of generating income, the majority of commonly used income measurements neglect the contributions made by natural capital. There are generally three ways of valuing national or state income, all of which generate the same measure:

1 determining the value of what is produced in an economy (these calculations include market goods only);
2 determining the value of the incomes generated by production (these calculations include market goods only);
3 and determining the increase in value added by all the firms in the economy in order to obtain the total value of all final products.

The most glaring inadequacies with respect to environmental and natural resources that are commonly associated with methods (1) and (2) are discussed below. There is another issue, usually referred to as double counting, which must also be considered in calculating measures of income. Double counting occurs when both intermediate goods (outputs that are in turn inputs for other goods) and final goods (goods that are not, in the period of time under consideration, used as inputs by other firms) are included in measures of income. When this happens, income calculations are greatly exaggerated. The first two methods mentioned above avoid double counting by only including in calculations final goods (and not intermediate goods).[6]

In some situations, the distinction between intermediate and final goods may be quite fuzzy. In such cases, the value added concept is considered particularly useful in avoiding double counting. If income is measured by the sum of the values added, it is not necessary to make distinctions between intermediate and final goods. Using this method, every purchase of a new good or service counts, but the entire selling price is not counted—only the part that represents value added. The value added calculations assess only part of a transaction in order to count only the contribution to the value of the ultimate final product that is made at each step (excluding the values of the items produced at earlier steps).

When the contributions made to the economy by specific natural resource categories or a specific ecosystem are of particular interest, the value-added approach may be appropriate. However, in order for this method to produce meaningful results, it is critical that environmental goods and services are accurately valued. Efforts that focus on value added typically examine the use of products and (produced as well as natural) assets as inputs of domestic production or as components of final demand. These data are typically supplemented with information on the value added of the different production activities in the economy. In order to implement this type of approach, it is necessary to estimate some of the nonmarket economic values of natural and environmental resources using the total economic value concept described in Section 1.3.3.

[6] An example of an intermediate good is wheat that is sold to a cereal company. If both the wheat (the intermediate good) and the cereal made from that wheat (the final good) were counted, the value of the wheat would be double counted and final output would be overstated.

1.4.2 DEFICIENCIES IN CURRENT MEASURES OF INCOME

Economists have been pointing out for years several controversial issues concerning national income accounting as it is currently practiced. These issues include the treatment of leisure, household and subsistence production, other nonmarket transactions, and the services of long-lived consumer durables. While not discounting the importance of these concerns, the focus of this report is on environmental and natural resource issues as they relate to the proper measurement of income and variations in assets. **The consensus amongst economists is that measures of income, such as GDP or GSP, do not adequately represent true, sustainable income because of three shortcomings: (1) the depletion and degradation of natural resources; (2) the treatment of defensive expenditures; and (3) the residual effects of pollution.**

1.4.2.1 Depletion and Degradation of Natural Resources

It is customary accounting practice to depreciate buildings, equipment and other manufactured assets. This depreciation represents the reduction in the income generating potential of an asset due to its deterioration or use. Natural assets are equally susceptible to the forces of degredation and depreciation. Just as a tractor depreciates due to use and decay, so does soil depreciate due to excessive agricultural practices. As these soils depreciate, the same crop yield can only be produced at a higher cost – this is in effect a loss in income.

Despite the fact that degradation affects natural assets in the same way it affects produced assets, **the depreciation practices and calculations routinely applied to produced capital are seldom applied to natural capital. This is despite the fact that** the use or degradation of these natural assets may result in significant decreases in future economic production. **The current treatment of natural capital with respect to depreciation perpetuates a belief that natural capital has no economic value, or is a 'free gift' from nature. Such a view ignores the fact that the true value of an asset is not its investment cost, but the value of its income generating potential.**

The obvious disparity in the treatment of man-made and natural capital provides false signals to policymakers. By ignoring the depletion of valuable resources, it is sometimes difficult to distinguish between capital depletion and the generation of income. The idea that rapid economic growth can be obtained by exploiting a resource base that may be rapidly diminishing is therefore promoted. **The problem is that the apparent gain in income may hide a permanent loss in wealth resulting from natural capital depletion.**[7]

In the case of marketed goods, net domestic product (NDP) is considered to be a better measure of economic activity than GDP because it recognizes the reality of depreciation (for market goods

[7] For an illustrative example of the effect of *not* depreciating natural resources, see Appendix 1.1, which documents briefly the Costa Rican experience.

only). The depreciation of produced capital is subtracted from GDP in order to get a more accurate measure of economic activity. Referring back to Figure 1.1, when the market loop of the economy is calculated, NDP tends in most cases to be lower than GDP because the costs associated with using produced capital are included. For those assets in the nonmarket dimension of the economy, there is no such adjustment to reflect the costs associated with using capital. As a result, decisions involving environmental and natural resources may be based on a mistaken belief that a particular action will increase income, while in actuality it may result in a decrease in natural capital and a reduction in future income generating potential.

1.4.2.2 Defensive Expenditures

Expenditures made to reduce the negative effects of environmental degradation and pollution are classified as defensive. Many of these expenditures are already included in the conventional accounts, although they are seldom identified as such. In the national accounts, defensive expenditures are treated differently depending on the sector from which they originate. Defensive expenditures made by firms are considered to be 'intermediate expenditures' and as a result are excluded from GNP. However, defensive expenditures made by governments and households are included in GNP. As a result, **for private firms, increased defensive expenditures mean less value added, while for households and governments national output increases as a result of defensive expenditures.**

There is a general consensus that all defensive expenditures, regardless of the source, should be labeled as costs of production and excluded from measures of income since they are not welfare increasing expenditures. For example, an individual living within a watershed may experience water quality problems due to high levels of sedimentation resulting from a particular land-use activity, such as urban sprawl or construction. As a result, the individual may purchase a water filtration system to restore drinking water to its previous level of quality. The purchase of water filtration equipment does not increase the individual's welfare. Instead, the purchase allows them to return to the level of welfare they were at before the water quality problem. As it is currently measured, national income increases when this type of expenditure is made. **Due to the current treatment of defensive expenditures, national income is higher when environmental damage is incurred and some type of restoration is undertaken than it would be if the harm were altogether avoided by taking preventative actions in the first place.**

In Hawai'i a large proportion of defensive expenditures is directed at problems associated with introduced species. For example, some communities on Maui have spent millions of dollars for water filtration systems to deal with the contamination, siltation and discoloration of water due to the increased erosion caused by wild pigs (HNIS in the US, 1992). Similarly, millions of dollars have been spent in Hawai'i national parks to install and maintain fencing to keep introduced species out of sensitive native habitats.[8] **Because Hawai'i faces a much greater threat from introduced species than anywhere else in the United States, it is no**

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[8] Ron Nagata, Chief of Resource Management at Haleakalā National Park, estimates the cost of fencing (from preparation to completion, including maintenance) to be: $60,000–120,000 per mile in rain forests; and $25,000 to $50,000 in drier areas. The actual costs range considerably due to variable helicopter costs. The aim of the fencing project at Haleakalā National Park is to protect the watershed from sedimentation caused by feral pigs (personal communication, June 19, 1998).

surprise the a large proportion of national parks' budgets can be classified as defensive expenditures. Other straightforward examples of expenditures in Hawai'i include the dredging of the Ala Wai canal, at an estimated cost of $10 million every 10 years (Dashiell, 1997) and household and business termite treatments and damage repair.

1.4.2.3 Residual Damages

Defensive expenditures do not necessarily eliminate all the adverse effects of environmental degradation. The damages remaining after defensive expenditures have been made are classified as residual. An example of residual damages involves an uncompensated, environmentally related property damage. This type of damage is likely to occur in cases associated with contaminated sites affecting residential homes. Federal statutes may provide for compensation to homeowners for the loss of their homes and the cost of relocation (e.g. Superfund). However, evacuation from homes is likely to cause damages in the form of social and psychological hardships for which compensation is not received. These uncompensated damages are a residual damage. Since residual damages clearly have an effect of welfare it is often argued that they should be incorporated into the national accounts. Again, **the Ala Wai canal provides an example for Hawai'i, since the canal is not suitable for fishing or swimming due to contamination from the sediment influxes.**

This problem is receiving increasing attention and, along with other problems associated with current measures of income, has acted as a catalyst for the development of alternative approaches for improving measures of income.

1.5 NATURAL RESOURCE ACCOUNTING – AN INTRODUCTION

Despite the more inclusive definition of total economic value and the increase in awareness of the contributions of natural capital to the economy described in earlier sections, many values associated with the environment continue to be omitted from measures of income. As indicated, this type of omission often occurs when environmental management is left to the devices of the market. This is mainly due to the characteristics associated with many environmental goods, in particular their nonmarket, public goods nature, and the existence of externalities. As a result, environmental goods and services are often over-used and under-valued. Not only does this have a negative effect on current human welfare, but it undermines the future income generating potential of a region or country.

Efforts to improve income accounting and decision-making are occurring at all levels of decision-making in countries throughout the world. These efforts are not limited to national efforts. **Many individual states within the United States, as well as many regions within states, are currently working with and developing improved measures of economic and environmental progress.** Similarly, efforts to more fully incorporate environmental values into project appraisal have been occurring for decades. These efforts are based on the idea that environmental goods and services are a form of capital that must be managed effectively and efficiently. **This section will examine some of theses efforts, including those efforts**

pertaining to natural resource accounting, and also the various methodologies available for valuing particular environmental goods and services.

As a review of the literature reflects, there are no standard definitions of environmental and natural resource accounting. However, for the sake of discussion, it is useful to conceptually divide suggested approaches for improving measures of income. Specifically, **approaches can be divided into methods that attempt to achieve full income accounting (e.g., measurement of the entire economy, including nonmarket goods and services) and methods that are concerned with measuring only certain contributions of the natural environment to the economy (e.g., market and nonmarket values associated with a particular ecosystem, such as a tropical forest).** Referring back to Figure 1.1, full income accounting would include attempts to measure both the outer and inner loops (e.g., all market and nonmarket production and consumption in the economy).[9] Physical and satellite accounts, on the other hand, are usually only concerned with estimating the contributions to the economy from particular ecosystem types or geographic areas. In Figure 1.1, these types of contributions are represented by the linkages flowing from the nature sector to the input and output markets.

Alternatives for improving measures of income generally strive to achieve all, or a subset of, the following objectives:

- **improve the measure of "true income";**
- **better represent environmental services;**
- **account for the depreciation of both produced and natural capital;**
- **exclude relevant categories of defensive expenditures;**
- **estimate environmental damages resulting from economic activities.**

1.5.1 FULL INCOME ACCOUNTING

Initiatives at full income accounting are based on the premise that income aggregates, such as GNP and NNP, give a distorted view of economic progress. Such distortion is thought to result from the inappropriate or lack of treatment of defensive expenditures, depletion in resource capacity and residual pollution damages. The aim behind these accounts is to incorporate the corrected elements into national income accounts in order to yield a resource-inclusive measure that can be used to determine whether or not the economy is developing in a sustainable manner.

Although the valuation of natural and environmental resources and degradation is a complex, and often controversial, endeavor, it has a distinct advantage over physical accounts (which collect and present data in physical units). Since values are expressed in a common numeraire (e.g., dollars) it is straightforward to compare different environmental categories. Similarly, it is also relatively easy to compare monetary estimates of environmental values with other economic categories and objectives. This type of comparison is fundamental to policy-making and economic decision-making.

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[9] For an example of full income accounting see Appendix 1.2.

1.5.2 PHYSICAL ACCOUNTS

Physical accounts, which were introduced by the Norwegian government in 1974 and subsequently adopted by the French and Canadian governments, are by necessity the basis of the income accounts described above. **Since it is not possible to undertake valuation without data in physical units, physical accounts are a fundamental step in assessing a particular region's natural capital.** Physical accounts of natural and environmental resources enumerate changes in resource quantity or quality in physical units such as barrels of oil or tons of carbon dioxide emissions.

In some cases, physical data is considered to be more suitable than monetary data. This is particularly true for the description of the flow of materials and nutrients within the natural environment, and from the natural environment to the economy and back to the environment as residuals. The concepts of material/energy balances and input-output analysis are frequently used to analyze the material flows between the environment and the economy.

In many cases natural resource accounts are linked with environmental statistics and quality indicators. Such approaches provide an overall framework for monitoring the natural environment and can be used not only to attempt to measure the short-term economic exploitation of the environment, but also to assess aspects of sustaining the natural environment for future generations. The French *patrimoine naturel* (natural heritage or natural patrimony) accounts were developed with such concerns in mind.

The development of physical data are necessary for describing environmental-economic linkages, but in many cases they are not sufficient. The main problem associated with using physical units lies in the development of huge data sets without reaching general conclusions on their economic significance. It is often difficult to obtain a more condensed description of the relevant linkages when it is not possible to aggregate the various units (for example, tons and cubic meters) or determine their relative importance. It remains to be seen to what extent weighting procedures can be devised that are capable of overcoming these difficulties. In many cases, the only way to obtain comparable results is to use a valuation in monetary units.

1.5.3 SATELLITE ACCOUNTS

A third method of dealing with deficiencies in income accounts is to utilize satellite accounts. **Satellite accounts, which can be in physical or monetary unites, are natural resource accounts that are consistent with the existing core national accounts, but are kept separate from them.** Both the World Bank and the United Nations encourage and/or use satellite accounts in income measures.[10] The World Bank has actively encouraged the use of satellite accounts as an interim measure to provide for the inclusion of environmental concerns in revisions of the SNA.

[10] The UN's satellite accounts only include marketed natural resources which are located on privately owned land. As a result they are obviously incomplete since a large proportion of environmental assets are not privately owned.

While the use of satellite accounts is frequently endorsed as a way to track the effect of economic growth on natural resources, most countries only use the traditional national income accounts. In the United States, the Bureau of Economic Analysis in the U.S. Department of Commerce has developed a set of satellite accounts, and a set of integrated accounts for oil and minerals.

1.6 A BRIEF COMPARISON OF THE ACCOUNTS

Placing a monetary value on natural resources can be a complex and controversial endeavor. While physical accounts avoid this problem, the lack of monetary value means that there is no common unit of measurement that can be used to compare the relative importance of the physical accounts. **The greatest advantage full income and satellite accounts have over the physical accounts is that measures of different categories of environmental goods and services are comparable with each other and with other economic measurements. This tends to make these two types of accounts of greater use in economic decision-making and public policy making.**

Despite the usefulness of valuation, there may be some bias associated with monetary valuation. This bias may occur because valuation is often more focused on environmental costs, leaving environmental benefits frequently under-represented. The main reason for this is that measurement of costs is often less complex and controversial than the measurement of benefits. This is in large part due to the nontangible nature of many types of environmental benefits (for example, estimating the value to individuals of an endangered species or biodiversity). **While in many cases environmental costs can be estimated by measuring the cost of repairing environmental damage, many environmental benefits can only be estimated by rigorous survey methodologies (which are often controversial).**

As a result of these measurement issues, valuation exercises may under-represent environmental benefits. As long as the valuation effort makes explicit this possibility, efforts that focus on the cost side still provide valuable information and are an important step in improved accounting for the environment.

Although physical data is a necessary precursor to monetary valuation, it also serves important purposes on its own accord. Indeed, in some cases physical data is preferred over monetary data. This is often true for the description of the flow of materials and nutrients within the natural environment, and from the natural environment to the economy and back to the environment as residuals. **Physical data is also useful in its ability to effectively illustrate trends in environmental assets and land uses over time.**

As indicated by the above discussion, when deciding which approach is most useful in a particular context (physical or monetary data) there is a fundamental trade-off that should be considered. Valuation in monetary terms is often desirable from a policy-making and decision-making point of view. However, methodologies for monetary valuation are demanding and have large data demands. The inherent complexities associated with ecosystems sometimes means that the desired knowledge is not yet available. For example, due to many scientific unknowns and uncertainties, it may not be possible to predict the decline in a particular environmental value (such as commercial fisheries) resulting from some environmental change (such as cumulative water pollution).

The choice of evaluation method is affected by all of the above considerations, as well as many others. Methodology selection will likely depend on some balancing of policy goals against the costs of obtaining these goals. Some factors to be considered when choosing an appropriate methodology are summarized in Table 1.2.

Table 1.2: Summary of Accounts by Type

	Full Income	***Satellite***	***Physical***
Main Aim	replace existing measures of economic activity with resource-inclusive measures that can be used to determine whether or not the economy is developing in a sustainable manner	allow for the evaluation of environmental aspects of the economy and to adjust selected traditional income aggregates accordingly	describe the flows of resources, materials and energy underlying economic activity
Unit of Measurement	Monetary (based on physical)	Monetary (based on physical)	Physical
Relationship to Convention Accounts	replace conventional economic measures	separate from, but consistent with, conventional accounts	separate from conventional accounts
Data Requirements	detailed knowledge of consumer preferences in order to assign correct prices to environmental values environmental data in physical units	data that is already available (for example, reclassification of defensive expenditures) environmental data in physical units	data regarding stocks and flows of environmental & natural resources and pollution output by sector
Strengths	since values are expressed in a common unit (dollars) it is straightforward to compare environmental categories with each other and with other types of economic measures	designed to be compatible with traditional economic measures data requirements are not prohibitive	credited with documenting important linkages between the environment and the economy.

Weaknesses	very high data requirements philosophical and ethical questions sometimes associated with monetary valuation	typically the focus is on the cost side of economic-environmental interactions, as a result some of the benefits flowing from the environment to the economy may be ignored	not expressed in monetary unit so cannot be compared with other economic measures can get large and unwieldy when many measures are collected

As indicated above, despite the usefulness of economic valuation, it is not always the preferred method for accounting for the environment. There are various reasons why economic valuation may not be appropriate in a given situation. **Data limitations, the particular functions the accounting system is meant to fulfill, limited resources, and even ethical and/or philosophical considerations are all factors which must be considered when developing an accounting approach for a particular context.** Given the usefulness of monetary valuation, and the associated complexities and data demands, a compromise seems warranted. Specifically, **economic valuation should be applied when the necessary data and resources are available and the environmental attribute in question is deemed important enough to warrant the expenditure of resources required.** At the same time, it must be recognized that at present not all environmental attributes are amenable to valuation. Such attributes should be tracked through alternative methodologies, such as physical accounts and/or environmental indicators.

1.7 NATURAL RESOURCE ACCOUTING IN THE U.S. – GENERAL

Within the United States, efforts to incorporate environmental and natural resource considerations into economic measures (e.g., gross state product) are still in the initial stages of development and use. There are only a few studies that attempt even a loose interpretation of full income accounting. In fact, most of the official environmental accounting in the United States has been restricted to the assembly of data on pollution abatement expenditures. Within the context of Table 1.2, this type of effort can be considered a step towards the development of satellite accounts.

Within individual states in the United States, there are numerous state and regional level initiatives aimed at more fully incorporating environmental data into state planning. Although satellite or full income accounting may not be the aim of these particular initiatives, they are adding to the knowledge base on which future efforts at full income accounting and satellite accounting depend. These types of initiatives can loosely be categorized in the physical account category described in Table 1.2. Often the focus of these initiatives is on the development of environmental indicators and/or more meaningful measurements of financial, social and natural capital. There is also a wealth of research throughout the country aimed at estimating the economic values associated with particular environmental goods and services. These methods are discussed briefly below.

As a result of the trade-offs discussed above, it is logical for an initial assessment of a region's natural capital to place a large emphasis on physical data. Monetary valuation should be undertaken for those assets that are considered high on the public agenda and for which data are available or can be readily obtained. In the initial stages it is important to determine where data gaps may be and where future research priorities should be placed.

1.8 NATURAL RESOURCE ACCOUNTING – CURRENT INITIATIVES

1.8.1 CHESAPEAKA

One of the few initiatives undertaken in the United States that makes an initial attempt at full income accounting is a study examining the Chesapeake Bay region (Grambsch, 1993). This study utilizes an environmental accounting framework that adds a new sector—nature—to the traditional industry, government, and household sectors. Some of the main findings of the study are described below.

The Chesapeaka study is particularly relevant to the Hawai'i situation because it focuses on nonmarketed environmental services. Many efforts at improving accounting for the environment have focused on marketed services, such as timber output, fish harvest, and crop production. While these types of values are no doubt important to both the Chesapeaka and Hawai'i contexts, due to the uniqueness of the environments and a high reliance on the environment for various recreational and tourists uses, it is likely that nonmarket values may be more significant than market values to the economy. Indeed, a key finding of the Chesapeaka study is that environmental priorities should be less aligned with correcting environmental damages (e.g., pollution control), than with protecting environmental services to households (e.g., protecting habitats and biodiversity).

The Chesapeaka study is a good example of how, with the proper analysis, data that already exists can be integrated and re-examined to produce new and meaningful results that have relevance to public policy. All of the data utilized in the study was obtained from pre-existing sources. Gross Chesapeaka product is derived from data on gross state product obtained from the Bureau of Economic Analysis and data from the Bureau of the Census. Specifically, county employment as a percentage of total state employment is multiplied by gross state product to obtain a gross county product. Finally, gross county product for the counties in Chesapeaka is summed to obtain gross Chesapeaka product.

Environmental concerns (e.g., air and water quality) are represented by physical measures derived from a variety of sources. For example, information on point and nonpoint source discharges of nitrogen and phosphorous are obtained from the Resources for the Future Environmental Data Inventory database. Point, area and natural source air emissions are obtained from the National Acid Precipitation Assessment Program emissions inventory. Also, survey data on participation in various recreational activities are also used extensively.

The measurements described above are incorporated into the conventional accounting entries to obtain a modified Gross Chesapeaka Product (GCP). The results are considered preliminary and many environmental problems (including solid and hazardous wastes, the contamination of sediments and living organisms by toxic chemicals and the loss of biodiversity) are not presently included. **While the modified GCP is not significantly different than the conventional GCP, examining the various components of the economy (including environmental linkages) allows for the formulation of recommendations and priorities for environmental policy that more accurately reflect those environmental sectors that provide significant values to the economy.**

Examining initiatives being undertaken in other states, such as the Chesapeaka study, serves an additional purpose. In order to undertake efforts at full income accounting, various types of data are required. In places that have not yet included environmental concerns on the public agenda, much of the required data may not yet be available. Economic and environmental research priorities can be reassessed in light of experiences like the Chesapeaka study so that research can focus on collecting the most relevant and useful data.

1.8.2 SYSTEM OF INTEGRATED ENVIRONMENTAL AND ECONOMIC ACCOUNTS

In the *Handbook of National Accounting* (United Nations, 1993) a satellite System of Integrated Environmental and Economic Accounts (SEEA) is developed to compute "environmentally adjusted net domestic product." The handbook includes recommendations on methods to achieve compatibility between physical and monetary accounts. It also identifies those parameters that could be valued in monetary terms to obtain the figures required in (monetary) environmental accounts.

Although physical accounts are considered to be an integral part of the SEEA, the emphasis is on stocks and flows that can be assessed in monetary terms. This is achieved by segregating all flows and stocks of assets in national accounts that are environmentally related to establish the total expenditures required for the protection or restoration of the environment. This allows for the identification of conventional accounts that reflect the direct costs of compensating for the negative impacts of economic growth (e.g., defensive expenditures). The general aim of satellite accounts¾ i.e., to provide an accounting of environmental costs and benefits *as far as possible* given the current state of knowledge and available data ¾ is similar to full income accounting, but the ambition is not as high.

1.8.3 IDENTIFICATION AND RECLASSIFICATION OF ENVIRONMENTAL EXPENDITURES

Most of the official environmental accounting efforts at the federal level in the United States have been mainly concerned with compiling data on pollution-abatement expenditures by industry.[11] As discussed earlier, this type of information can be used to adjust measures of economic activity (such as gross domestic produce or gross state product) to include environmental effects (particularly environmental damages resulting from economic production). Both the Bureau of the Census and the Bureau of Economic Analysis (BEA) have been assembling expenditure data for manufacturing establishments since about 1972. However,

[11] France, Japan, Germany and the Netherlands have all implemented similar efforts.

due to budget restrictions the BEA survey was shifted to the Census Bureau in 1989 and greatly reduced in scope.

The modification of the conventional national accounts by incorporating pollution control costs is considered the least radical of the available alternatives to "correct" economic measures. However, unlike most other countries that track these costs, it has not been the intention of the United States to employ these data to generate a downward-adjusted GDP. Furthermore, no future plans in this regard have been made. **However, both the BEA and the U.S. Environmental Protection Agency have been investigating the feasibility of developing more extensive resource and environmental accounts (which could *conceivably* include GDP adjustments). It is quite likely that such efforts would be viewed as supplements to, rather than substitutes for, the conventional accounts**.

Some attempts at estimating environmental damages by identifying defensive expenditures compare defensive expenditures with some level of environmental standard (for example, demand curves based on societal preferences consistent with environmental standards goals). Often the losses in environmental functions are measured by the costs of restoring the functions to a level consistent with environmental standards. The choice of standard therefore becomes a critical factor in determining the level of environmental damages. For this reason, it is important that environmental standards are appropriately set, given the current state of knowledge. Caution must be taken since the level of environmental damage can be manipulated by changing the environmental standard.

1.8.4 PHYSICAL ACCOUNTS

Of the three general types of accounts, physical accounts have received the most attention, particularly in European countries. Generally, there are two types of physical accounts (Lutz, 1993). The first is a stock account, which typically indicates an opening stock, any additions (through discoveries or growth) and subtractions (due to exploitation or natural destruction) to the stock, and a closing stock. This type of account can be applied to depletable resources (e.g., minerals) or to renewable resources (e.g., forests). The second type of physical account applies to pollutants. These accounts usually describe the generation of air and water pollution by polluting source. **This type of data is already routinely collected in many countries, including the United States, as part of national and international efforts to generate environmental quality reports**.

1.8.4.1 Norway

In 1974 the Norwegian government became the first government to use physical accounts to track natural resources. The focus of these accounts is on aspects of the environment that are particularly important to the economy. The Norwegian system classifies resources into two broad categories. The categories and their components are listed in Table 1.3.Table 1.3 : Norwegian Classification System

Resource	**Physical Classification**
Material	Minerals (oil & gas) hydrocarbons (coal & forests)

	stone, gravel, sand Biological resources (occurring in air, water & land) Inflowing resources (solar radiation, hydrological cycle, wind & ocean currents)
Environmental	Status resources (air, water & soil resources)

The units of measurement for each component vary according to the particular resource. The basic accounting framework relies on a distinction between stocks and flows. Material resources are reported in stock and flow (use) accounts. Stock accounts for minerals include developed reserves, undeveloped reserves, new fields and revaluation (revised estimates of reserves) and extraction. Flow accounts monitor extraction and imports by households, industry and government. Biological stocks include reserves, recruitment (new additions), revaluation and natural mortality.

The environmental resource accounts keep track of the status of air, water and soil reserves and includes two accounts. The emissions account records total emissions of waste products into the air, water and land. These emissions are recorded by emission sector (agriculture, manufacturing, transportation, and households) and region. The state account describes the state of the environment at different points in time and changes in the environment.

The physical accounts developed in Norway have been used for various purposes. The Norwegian accounts have been used as a basis for forecasting future uses of resources. They have also been used to predict the associated changes in environmental quality resulting from changes in resource use. **However, the scope of the Norway system is limited to those resources that are considered particularly important to the economy. Due to this focus, the Norway accounts may ignore many nonmarket environmental attributes that, although not obviously important to the economy, are highly valued by households and individuals. The extent to which this is a problem depends on the stated aims of the system.** In the Norwegian case, the aims of the accounting program are limited, partly due to the costs of data development. As long as the limitations associated with a particular system are made explicit, programs with limited aims can still be useful for fulfilling certain specified functions.

1.8.4.2 France

The French system was developed in 1978 and is considered to be one of the most ambitious resource and environmental accounting systems. There are two primary objectives of the French accounts. The first objective is to include the entire "natural patrimony."[12] The second objective is that each element in the "natural patrimony" is to be described or analyzed in terms of its three basic functions: economic, ecological, and social. **The**

[12] Define as "the collection of the natural elements and of the system which they form and which are capable of being transmitted to future generations or of being transformed."

"natural patrimony" accounts are intended to support both environmental and economic models. These accounts are intended to be part of a multilevel data system with raw statistics and data summaries at the lowest levels and aggregate indices of general welfare at the highest level. As a result, the system includes a number of separate sub-accounts that may be related to each other:

- Physical accounts - similar to the Norwegian resource accounts in content but with different presentation.
- Geographical accounts - assemble data related either to ecosystems (e.g., forests) or to some other definition such as geographical region (e.g., coastal lands), political territories, or "abstract" concepts such as an imposed grid network.
- Agent accounts - refer to all accounting for those activities that link human activity to the natural environment and can cover a wide range of stock or flow accounts. Their distinguishing feature is that they identify human owners and users. These accounts can be expressed in either physical or monetary terms.

It is easiest to see how the entire system of accounts works by considering as an example the French water accounts. The central account for water tabulates changes in the stock of water from various supply sources (including ground water, lakes, reservoirs, rivers, and glaciers). The peripheral account for water is essentially a water balance that identifies where water originates (evapotranspiration sources) and its destination (run-off, percolation and interception), plus consumptive use of water in human activities (urban, industry, agriculture, hydropower). The agent account for water shows expenditures made and income earned on water-related activities such as water treatment, drainage, development of drinking water supplies, irrigation and flood control.

The French system is more comprehensive than the Norwegian system, and is considered to be very inclusive both in terms of the elements of the environment and natural resources covered and also in accounting concepts. Almost all the natural resource accounting methods could be incorporated into the French system. The French system can best be classified as a combination of satellite and physical accounts.

The French system is still under development and, not surprisingly, the developers of the system aimed to incorporate pragmatism and flexibility into the system in order to reflect changing data supplies and the needs of policy-makers. The categories incorporated in the accounts were initially based on choosing priority sectors (forest, water, soil, land use and wildlife) and a few basic interactions. These priority sectors were largely determined by the "present knowledge," the "willingness of policy makers" and the availability of "reliable, comprehensive, consistent, and regularly updated data sets" (Peskin, 1993).

Due to the above considerations, the patrimony accounts themselves do not play a role in the setting of priorities. This is important to note because one main purpose of most any accounting system is to help determine which environmental and resource sectors are relatively more important with respect to the effect on the economy. It is quite likely that the French accounts are not ready to serve this function because important links between the environment and the economy are missing. **The extent to which budgetary constraints will**

ultimately limit the development and usefulness of the French accounts remains to be seen. However, it is likely that the system will be limited to some extent by budgetary constraints. It is important that any attempts at initiating accounting schemes be cognizant of such practicalities from the initial stages of development.

1.8.5 ENVIRONMENTAL INDICATORS

Many states within the U.S., as well as many regions within particular states, rely increasingly on the use of environmental indicators as a complementary tool in environmental management and decision-making. While some of these initiatives are strictly limited to environmental indicators, many of them combine economic, environmental, social, and financial indicators in an effort to better understand the relationships between the various components of the economy. Environmental indicators can be direct or indirect measures of environmental quality. They are used to assess and communicate the status and trends of environmental conditions and are usually geared toward both decision-makers and the general public.

Within the United States, the use of indicators has become widespread. Many of these initiatives are coordinated by the State Environmental Goals and Indicators Project. This project is a cooperative agreement between the U.S. E.P.A. and the Florida Center for Public Management. **It was developed to assist state environmental agencies in improving their environmental management capabilities by providing procedural, technical and limited financial assistance for the development and use of environmental goals and indicators.** At least seventeen states are currently associated with this project. Regional projects within states, which also tend to focus on economic, social and environmental assets, are also increasing in number.

There are various reasons behind the popularity of indicator programs. The economic valuation of environmental goods and services is a demanding exercise that requires large amounts of information. In many cases the resources required to carry out quality valuation exercises are not available, or the information available may be inadequate. Developing indicators of natural capital services provides useful data to decision-makers and the public about the status of important forms of capital in the region/state. At the same time, indicator programs encourage the collection of data that can be used as the basis for future attempts at improved accounting for the environment.

Although indicators can be useful for a wide range of purposes, they do not necessarily support all uses equally well. For this reason, the specific uses and the primary audiences must be defined before a good set of indicators can be developed. Most indicator data sets consist of both the current state of selected areas of concern as well as the most relevant pressures on them. Target levels are often incorporated into the analysis to determine whether trends are moving away or towards stated goals and objectives. **A common element of most of these initiatives is the move away from reactive methods of setting and implementing public policy to a pro-active approach.**

1.9 METHODOLOGY FOR THE ECONOMIC VALUATION OF ENVIRONMENTAL GOODS & SERVICES

The economic valuation of environmental goods and services is necessary for both macro-analysis (e.g., natural resource accounting) and micro-analysis (e.g., project appraisal). As discussed in ealier sections, economic values include passive use values as well as direct and indirect use values. **Although it is not always possible, or even desirable, to express everything in monetary units, quantifying as many values as possible provides a clearer picture of the trade-offs involved in economic decision-making**.

Environmental valuation methodologies can be divided into two general categories: indirect approaches and direct approaches. Indirect approaches rely on observed behavior to infer environmental values. Direct approaches use survey-based techniques to directly elicit preferences for non-market goods and services. Both categories of approaches rely on the foundations of welfare economics and use measures of willingness-to-pay and willingness-to-accept-compensation in order to assess the costs and benefits of environmental change. **Each of these approaches has associated strengths and weaknesses and some are more suitable for various categories of environmental goods and services than others. The appropriate technique therefore depends on the particular valuation context.**

1.9.1 INDIRECT VALUATION APPROACHES

Indirect valuation approaches, also called revealed preferences approaches, look at decisions that people make regarding activities that utilize or are affected by an environmental amenity in order to reveal the value of the amenity. These techniques focus on measuring use values and are not capable of measuring passive use values.

1.9.1.1 Defensive Expenditures

The defensive expenditure approach examines behavior and expenditures aimed at mitigating adverse impacts or environmental changes. Households and firms may undertake averting actions to protect individuals from exposure to environmental degradation. These actions typically occur in one of three ways: buying durable goods (e.g., pollution treatment equipment); buying nondurables (e.g., bottled water); and changing daily routines to avoid exposure to the contaminant (Council, 1997: 668). Under certain conditions, t**hese types of expenditures indicate that individuals, firms or governments consider the resultant environmental benefits to be greater than the costs of the associated expenditure**.

The defensive expenditures **approach has the advantage of relying on existing market prices. On the other hand, the approach is limited to cases where markets do exist in which to observe averting behavior. Also, this approach does not account for the residual damages of environmental degradation (damages occurring even after averting behavior is taken). Therefore, it does not estimate the full costs associated with environmental degradation.** Also, some expenditures made by households include both a preventative element and a non-preventative element and it is sometimes difficult to distinguish between the two. An example of such an expenditure might be a baseball cap—it may provide aesthetic pleasure as well as being a defensive expenditure against the increased probability of skin cancer due to ozone depletion.

Examples of averting behavior include: buying bottled water due to contamination of local drinking water supply; the purchase of air purifiers to reduce indoor air pollution; the consumption of organic vegetables to reduce intake of pesticides; and the installation of insulating material to reduce noise pollution.

Potential Uses In Hawai'i:

Assessing the costs/benefits of water and air pollution control. Assessing damages associated with introduced species such as termites and mosquitoes and the potentiality of the introduction of the brown tree snake.

1.9.1.2 Derived Demand Techniques (Change in Productivity)

When an environmental resource is an input to production for some economic activity, a change in the environmental resource can be estimated by the resulting change in revenues and costs. For example, where water is an important component of a production process and a firm's cost structure is known, the value of the water can be estimated by measuring water's contribution to the firm's profit. If the supply of water is unrestricted, a firm will continue to use units of water up to the point where the contribution to revenue of the last unit is just equal to its cost to the firm. Even where there is no cost for the water itself, there will usually be costs to the firm associated with water use (e.g., pumping and delivery costs). If water supply is restricted (e.g., by quotas or water rights), the firm may cease use of water before the equality is met. The level of water use at varying prices to the firm defines a "derived" demand relationship.

Potential Uses in Hawai'i:

Municipal water delivery, land conservation, forest management and watershed management.

1.9.1.3 Replacement Cost Technique

The replacement cost technique identifies the expenditure required to replace an environmental resource. **The expenditure is a measure of the willingness to pay to continue to receive the environmental benefit**. If the expenditure has actually been incurred than it is considered to be a lower bound estimate, since more may have been spent if necessary to keep the benefit. The estimate is not a measure of the benefit of avoiding the damage in the first place, since the replacement cost may be higher or lower than the damage cost.

In valuing environmental and resource changes with this approach, prices and costs for close substitutes are examined and used as a proxy for changes in the value of resource quantity or quality. This technique is frequently used to assess the change in environmental values associated with development of a wetland area. In such cases, the cost of replacing the wetland (and the services provided by that wetland) lost by development, either by restoration or purchase of wetlands elsewhere, is considered to reflect a lower bound estimate of the economic value of the wetland.

Potential Uses in Hawai‘i:
Estimating value of groundwater for various uses. Estimation of benefits of environmental resources negatively affected by land degradation and development. For example, estimating the benefits of erosion prevention measures by calculating the value of fertilizer required to replace nutrients lost through soil erosion.

1.9.1.4 Hedonic Price Method

The hedonic price method is based on the premise that people value a good because of the attributes associated with that good. House prices are often used in hedonic pricing because the decision to purchase a particular house is based on the attributes of that house (e.g., number of bedrooms and bathrooms, square footage, the safety of the neighborhood, the view). If one of the attributes is some aspect of environmental quality, such as proximity to a forest preserve, comparison of the price consumers pay for houses in areas near the forest preserve (assuming all the other attributes of the house are equal) may provide information on the value of the forest preserve.

The main advantage of the hedonic price method is that market data on property sales and associated characteristics are readily available from county or municipal sources, as well as from private real estate services. Data obtain from these sources can usually be linked to other sources of data for the same geographical area (e.g., data on air and water quality, proximity to wildlife). However, there are some disadvantages that limit the use of this technique. One problem is that the effect in price resulting from the characteristic in question may be small or difficult to determine relative the all the other characteristics. There are also some statistical problems that must be dealt with in order to design a valid hedonic study.

Potential Uses in Hawai‘i:
Aesthetic values, proximity to unique habitats (such as coastal areas and forests reserves).

1.9.1.5 Travel Cost Method

The basic premise behind the travel cost method is that travel costs incurred in travelling to a site can be regarded as the price of access to the site. Changes in the travel costs to a site can then be viewed as having the same effect on visits to the site as a price change in an access fee. Using the travel cost method, the area surrounding a site is divided into concentric zones of increasing distance. A survey of users at the site determines the zone of origin, visitation rates, travel costs and various socioeconomic characteristics. Users closer to the site are expected to make more use of it since their travel costs are lower than those for distant users. The survey results are used to construct a demand curve to determine visitation rates at various prices.

The travel cost method has been particularly important in estimating recreational values associated with environmental resources. This is in large part due to its flexibility, and also because it does not rely on entry fees. This latter consideration is important because many important environmental resources do not have associated entry fees. **This method can only estimate a lower bound of environmental value since it does not include nonuse values**. Nonetheless, it remains an important tool for measuring the benefits of improving environmental quality at recreation sites. (See the discussion of beach values in Chapter 2.)

1.9.1.6 Proxy-Good Technique

A good or service with a market price may be a substitute for the unpriced environmental resource of interest. The market price can be taken as an approximation for the value of the effect. **For example, funds spent by private environmental organizations to acquire unique habitat areas could be used as a proxy for the value of that resource**. Similarly, the revenues earned by the state from selling hunting licenses could serve as a proxy of the value an area as a place for hunting. In order for this technique to produce meaningful results it is important that the proxy provide the same kind of satisfaction in similar amounts to people (see also the discussion of entrance fees at Hanauma Bay, in Chapter 2)

1.10 DIRECT VALUATION APPROACHES

In contrast to the above approaches, which rely on observed behavior, direct approaches use survey-based techniques to directly elicit preferences. **Since there is not an existing market for many environmental goods, this approach constructs hypothetical markets**. The most common of these techniques is the contingent valuation method (CVM). This method provides respondents with background information regarding the available choices regarding a specific environmental good (for example, visibility in the Grand Canyon, which may be threatened by air pollution). The choice involves either an increase or a decrease in the supply of the environmental good in question. Respondents are asked either how much they are willing to pay for an increase in the good, or how much they are willing to accept in compensation if the good is decreased. Contingent valuation is the only technique currently capable of estimating both use and nonuse values associated with environmental resources.

Due to its hypothetical nature and certain reported biases associated with CVM studies, the degree to which CVM results will ultimately be incorporated in decision-making remains to be seen. Much care must be taken in developing and implementing CVM studies if they are to produce meaningful results. Even a survey that is carefully crafted and implemented can experience problems as a result of respondents who refuse to answer willingness to pay questions. Respondent refusals are somewhat common since some people feel that they should not have to pay for certain environmental services, or because they feel that the money might not be spent efficiently by the government (for example, in situations where the payment vehicle is a tax).

Potential Uses in Hawai'i:
Applicable to a wide variety of passive use values, including endangered species, unique habitats, and the value of clean air and water.

1.11 CAVEATS TO ECONOMIC VALUATION

Many services of the environment are considered by some to be too socially important to be determined by consumer preference theory. One reason for this is that these techniques favor the rich over the poor (since consumers are constrained by their budgets). Furthermore, there may be services of the environment whose long-term value to society is under-appreciated by present-day consumers (for example, the long-term ecological value of certain species). Many people, including some economists, would argue that these types of environmental and natural resource services are better left to alternative valuation principles. Such arguments should be keep in mind when developing and implementing valuation programs. However, **despite difficulties and controversies associated with economic valuation, it is often the case that environmental attributes that are not estimated in economic terms are omitted from analysis and decision-making. For this reason, the argument that some number is better than no number is likely to hold true in the majority of cases. Therefore, economic valuation should be applied where possible, but the limitations and assumptions involved in any valuation exercise should be made explicit.**

1.12 SUMMARY / RECOMMENDATIONS

After surveying the available alternatives for improved accounting for the environment, it is evident that no one alternative or methodology will correct all the problems associated with current economic measurements. This is due to both the limitations and gaps in available data, as well as difficulties in rectifying various ethical/philosophical views reflected in the valuation debate. However, what is apparent is that some types of data are required for all possible approaches. Specifically, for physical accounts, satellite accounts and full income accounting, large amounts of environmental data are required. **As efforts move from physical accounts to satellite accounts to full income accounts, the use of economic valuation methodologies becomes increasingly necessary. As a result, it is not essential to make a firm commitment to a particular approach before initiating a program for improved environmental accounting. It is quite apparent from existing attempts that learning-by-doing is the best approach to developing an appropriate system, and any approach will require the collection of environmental data as a first step.**

A review of the current situation in Hawai‘i reflects the fact that environmental data—both in physical and monetary terms—is lacking in may key areas. Before a comprehensive and meaningful attempt can be made to improve natural resource and environmental accounting in Hawai‘i, research priorities must be focused on collecting physical environmental data and on integrating physical data into economic models and methodologies.

As discussed above, market and nonmarket goods and services provided by nature flow to the economy through many separate linkages. Public policies and decision-making must include these various dimensions of value in order to allocate scarce natural capital efficiently. An assessment of total economic value is critical in this regard. The following chapters examine and describe in detail some of the important natural capital of Hawai‘i and the vital goods and services flowing from the nature sector. Chapter 2 provides an in-depth analysis of the Ko'olau forest ecosystem that illustrates how economic valuation of the environment can be done, the nature of the interrelationships between the environment and the economy, and how important Hawaii's ecosystems are for its economy. The chapter also assembles more comprehensive, albeit indicative information about the value of diverse environmental resources in Hawaii and threats thereto, and provides prima facie evidence of the importance improved environmental management for sustainable economic growth in Hawaii. Chapter 3 discusses the threats to both Hawaii's environment and its economy posed by alien species and offers a *prima facie* benefit cost analysis for the Brown Tree Snake that illustrates how alternative prevention and control strategies can be evaluated. **These chapters are not meant to to provide authoritative scientific information on the exact status of and interlinkages between environmental resources; nor do afford precise dollar estimates of the values particular resources. They do, however, provide an overview of Hawaii's natural capital, its importance for the economy and insight into the need for further study along the lines described.**

CHAPTER 2: CASE STUDIES: EXAMPLES OF NATURAL CAPITAL AND THE ASSOCIATED ECOSYSTEM SERVICES

2.1 INTRODUCTION

This chapter will present case studies that focus on physical descriptions of several natural capital categories and many of their associated ecosystem services. These ecosystem services can sometimes be measured, qualitatively or quantitatively, for the islands as a whole or for specific areas, to provide indicators of their values. Threats to the continued availability of these services are described for each section. These case studies show how the economy depends on these selected examples of natural capital, and, at the same time, how decisions about economic activities threaten the future availability of ecosystem services. **The results of these case studies and others like them could be used to create an accounting system for Hawai'i which directly incorporates the many benefits derived from nature. Such accounting allows for improved decision making and social welfare.**

It is useful, however, to keep in mind some general caveats facing the valuation of ecosystems and their services, beyond their absence from the marketplace. These include high levels of scientific uncertainty, problems of inseparable joint provision of multiple goods and services, and problems of defining the relevant beneficiaries of the services and the values they may hold for them.

The scientific uncertainty that pervades ecology leads to difficulties in predicting the relationships between change in the environment and the human benefits derived from that environment. The complex interdependencies make the task of determining what changes are true threats to ecosystem services and what changes will simply provide services a little differently. For example, the introduction of one species, say the Brown tree snake, might throw an entire island's ecosystem out of whack, resulting in the loss of large numbers of native species, or threatening tourism dollars and human health. What would the simultaneous introduction of the snake and some predator do? Perhaps the predator would control the snake and no long lasting imbalance within the ecosystem would occur. Perhaps, though, the predator would find a more delectable prey, or be a vector for some disease, and the impact on the environment would be heightened further.

As the threat of the Brown tree snake reveals, one change in the environment can render impacts in multiple arenas. At the same time, the existing environment contains single elements that provide many services. For example, a wide, sandy beach provides an aesthetically pleasing view, a comfortable place to enjoy the ocean, a barrier for property protection, and a habitat for unique strand vegetation. Replacing this beach with a seawall might maintain one aspect, property protection, and might even provide a different though equally pleasing view to many eyes. However, it may no longer provide a nice place to enjoy a walk or start a swim. These intertwined services can only occasionally be successfully separated and measured independently. In this study, every attempt is made to quantify the various benefits within this context.

This study also must address the question of who one considers the beneficiaries. **One ecosystem, such as a coral reef, will provide benefits to local individuals, the state, the nation, and potentially the entire world population.** Locally and statewide, fisherman and consumers of fish would be one set of beneficiaries from a healthy reef. Citizens of the U.S. might benefit from a convenient place to spend a dive vacation or from the fish imported from Hawaiian waters. Globally, the biodiversity of the reefs may be highly valuable. Since these services may require different levels of reef quality or use according to different levels of the beneficiaries, conflicts could arise between the optimal levels of local use and global use. Since the question facing this report is what is the role of the Hawaiian environment in the Hawaiian economy, the main perspective will be the values accrued to citizens of the state. When relevant, such conflicts and their effects on value estimates and policy will be highlighted.

Three areas of the Hawaiian environment will be investigated in this chapter. These are forested watersheds, beaches, and ocean resources. Chapter 3 will analyze the problem of existing ecosystems threatened by introduced species. Values for the ecosystem services and amenities produced by these resources or threatened by alien species are valued here using the methodology discussed in Chapter 1. Both indirect and direct valuation techniques are used. Indirect, or revealed preference techniques, used include the travel cost method, replacement cost techniques, and proxy-good techniques. Contingent valuation is relied on to measure the values of several items. Once valued, these amenities could be included in full income accounting for the state, as discussed in Chapter 1.

2.2 CASE STUDY: FORESTS

2.2.1 INTRODUCTION

Hawai‘i has approximately 2.2 million acres of forested land. Hawai‘i’s forests generate a broad variety of important ecosystem services that include water supply, soil and water quality, recreation and aesthetic pleasure, subsistence activities and commercial harvests, erosion control and biodiversity. These services support economic activity such as scientific research, tourism, and agricultural and pharmaceutical industries. There are many threats to Hawai‘i's forests, particularly native forests, and their associated ecosystem services. Currently, the primary threats include grazing, browsing and rooting animals, alien weeds that displace native plants, urbanization, and fire (Stemmerman, 1989).

The exact value of forest ecosystem services may be impossible to determine because, in part, there are so many associated economic benefits. For example, net estimates of tropical non-timber benefits range from $1 to $420 per hectare per year (Godoy et al, 1993). Forests have complex interrelationships with other types of natural capital. The value of ecosystem services derived from the soil, the ocean, and beaches are all related to the forests and how they are utilized and managed. Thus one must interpret the economic benefits of forests with an understanding of the roles and values of these associated types of natural capital.

Despite these complicating factors, a description of forest generated ecosystem services with quantitative estimates and qualitative descriptions provides substantial insight into how Hawai‘i’s economy critically depends on the forests. This case study will attempt to describe and value these services by developing scenarios concerning deterioration or enhancement of the resource quality from these threats for the forested area of the Koʻolau range on Oʻahu. The most significant ecosystem services of this forest are groundwater and surface water collection and filtration and species habitat, and the majority of the focus will be on these values. The study will also briefly discuss the similarities and differences of the Koʻolau forested area with other Hawaiian forests, on East Maui and the island of Lānaʻi, to provide an indication of the relative values of these forests to the Hawaiian economy.

Non-indigenous has been defined as the condition of a species being beyond its natural range or natural zone of potential dispersal and includes all domesticated and feral species and all hybrids except for naturally occurring crosses between indigenous species (HNIS in the US: 53). **Alien**, or **non-native,** also means non-indigenous.

Native forests are defined here as areas with 60% or more native forest vegetative cover.[15]

2.2.2 THE KOʻOLAU CONSERVATION DISTRICT

The Koʻolau mountains include a large tract of forested lands which has not been developed since zoning as a conservation district began a century ago. Currently, forested watersheds that create and protect water supplies in the Koʻolau mountains of Oʻahu are relatively healthy.[16] This is no accident. Investments in forested watersheds, driven by private and public concern about water supply and quality, began in the 1900s.

Some similar efforts continue today, while several private and public landowners currently share the responsibility for managing these lands for the multiple uses described above. Since the social values for these lands are difficult to value and even more difficult to capture as landowners, incentives for management strategies that maximize the social benefits of the resource may be distorted in favor of strategies that maximize the private benefits of the resource. Furthermore, the production of non-market amenities from the forest may be competitive with one another for limited resource inputs. A more complete understanding of the social and non-market values of the forest should lead to improved decision capabilities and resource allocation for both private and public entities. These values are explored below.

2.2.2.1 Water Supply

Forested watersheds, whether native or non-native, provide water supply essential for drinking, cooking, other domestic needs, tourist-related services, fishing, agriculture and manufacturing. This water is appreciably undervalued in the marketplace. Forests store appreciably more water

[15] See NC table, appendix
[16] Mike Buck, DLNR, personal communication

than the same soils planted with agricultural crops or cleared land (Wood, 1977) for a variety of reasons, including the following:[17]

- Volcanic rock aquifers throughout Hawai‘i have excellent water yield properties. Forests allow for increased percolation rates (movement of water through the soil) which recharge underground aquifers.

- Tree leaves, branches, and understory plants in a forested watershed act as an umbrella and intercept rain before it reaches the ground. This reduces rain's erosive capacity and increases the infiltration of the rainwater into the ground.

- In wet areas, forested watersheds act as a sponge and soak up rainfall into the soil, roots, mosses, ferns, and leaves. When fully saturated, water is released slowly so that it is delivered consistently and dependably, available for use long after the rain fell to the ground. This even flow aspect of forests was much of the impetus for placing Hawaiian forests into reserves as early as the 1880s.

- Fog condensing on trees and other vegetation is an important component of water supply and evapotranspiration cycles in Hawai‘i and can result in an estimated 30% increase total annual precipitation. (Hamilton, Juvik and Scatena, 1994).

- Forests may act as a pump where plants use water that is released back into the atmosphere through evaporation and transpiration (ET). With dense forest cover, suppressed ET allows much of the rainfall and condensed fog to infiltrate into the ground, percolate through the soil, and appear as clean water in streams or ground water (Hamilton et al., 1994).

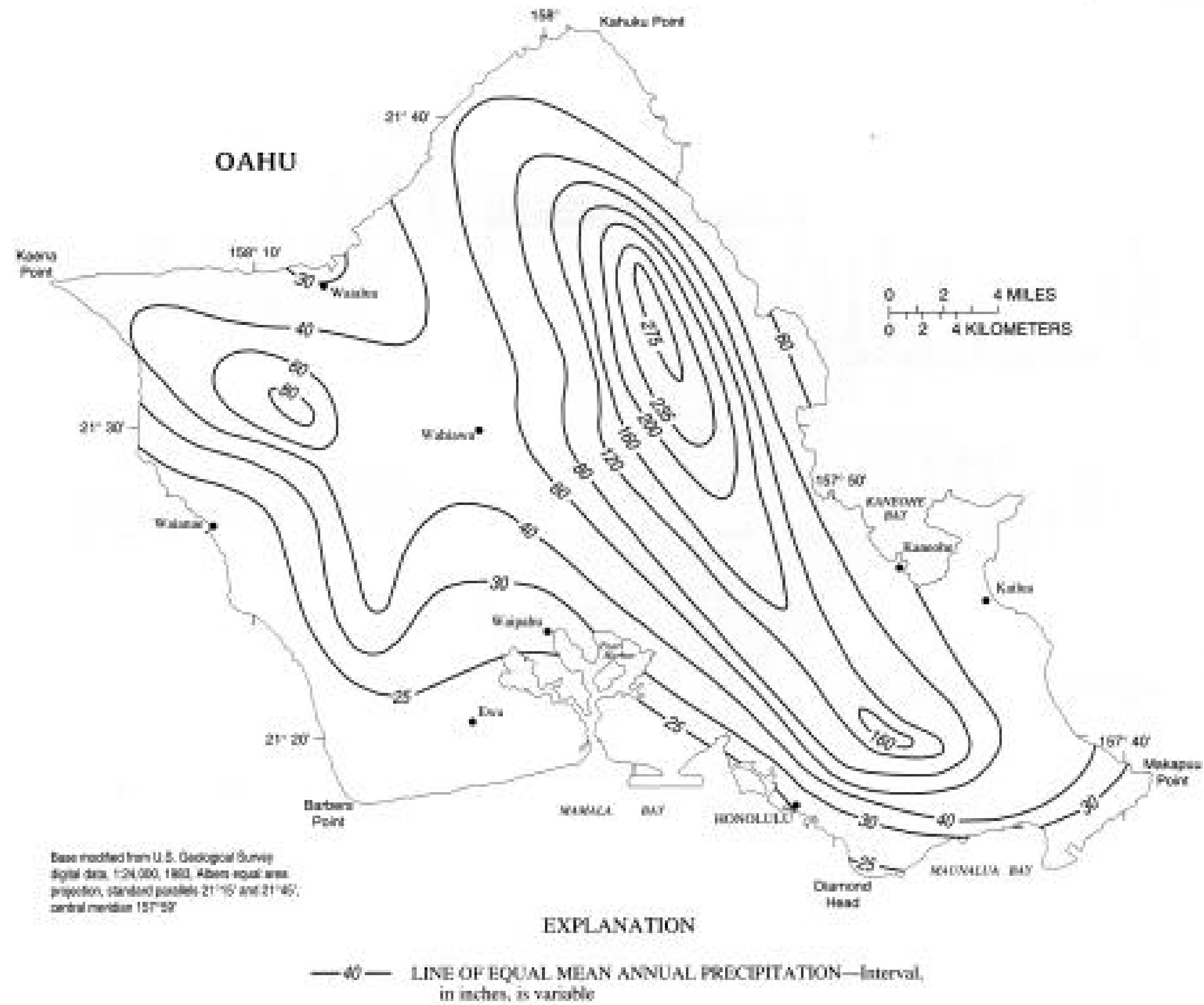
To estimate the full value of these services to the state, we develop a replacement cost model for the groundwater from the Ko‘olaus, and a combination of replacement cost and proxy good techniques to value the surface water quality for this area.

2.2.2.1.1 *Groundwater*

Figure 2.1 is a map showing isohytes (rainfall levels) for the island of O‘ahu. The Ko‘olau conservation district is a 97,760 acre area along the Ko‘olau mountain range running the entire windward (Eastern) side of the island. There are hundreds of inches of rain each year in some locations, and the general trend is for high levels of rainfall along the crest of the range declining with elevation. This rainfall can meet with several fates, discussed below. The form and composition of the forest in large part determines how much of the water will run off, how much sediment it will carry, and how much will recharge the aquifers from which O‘ahu draws its water supply

[17] Source: East Maui Watershed Plan, 1993

Figure 2.1: Rainfall levels for the island of O‘ahu



The Pearl Harbor Aquifer underlies much of O‘ahu and water flow on the leeward side of the Ko‘olaus contributes significantly to the recharge of this aquifer. Some officials of the State Water Commission believe that current withdrawal rates are such that all renewable island resources will be utilized fully in 25 years. **This means that any additional growth in water usage after that time will need to come from external sources such as desalination or depletion of aquifer water levels.**[18]

Water is a significant limiting factor for growth in the Hawaiian Islands, and concern for the water supply led to an early appreciation for the scarcity of the resource. From this recognition,

[18] Roy Hardy, Water Commission, personal comm., 7/24/98. Other studies (e.g. Krulce, et al., 1998) have shown that this does not have to be the case if water management is improved in the interim.

various institutional decisions (some scholars have argued that the word for law, *känäwai*, is derived from *wai*, water) concerning water and its use have evolved. First, cultural taboos were used to limit the use of surface water. Surface water diversion began early, for the purpose of growing taro. After the arrival of Europeans, ground water was discovered and surface water irrigation ditches developed to move surface water from places of high rainfall to agricultural areas. A few of the wells have shown signs of quality deterioration, and some wells have been abandoned due to saltwater infiltration. Restrictions have been placed on well usage.

To address these water problems and others, forest preserves were set aside at the turn of the century to protect the watershed and by the 1930s replanting occurred in deforested areas to restore the vital ecosystem services the forests could provide. These deforested areas were the result of cattle grazing and other forest degrading land use practices in the previous two centuries. Much of the need to protect water from these early days stemmed from the high levels of water needed to produce sugar, as it takes 1 million gallons to produce one ton of sugar (Wilcox, 1996: 1). Housing and other development projects on West Moloka‘i, for example, have been virtually halted due to water shortages (Wilcox, 1996: 1). With the importance of sugar dwindling, residential usage is quickly becoming the most important beneficiary of the Ko‘olau's water.

Groundwater and surface water can both meet the population's water needs. The benefits of groundwater over surface water are manifold: (1) the infiltration process provides a lengthy period (about 12–25 years for Hawaii's geology) during which sediments and other contaminants are filtered out, (2) the ground provides a convenient storage facility in which water can be kept clean for times of future demand, and (3) the ground does a better job of capturing the water for use than we could without drastic alternation to the forest environment and the other amenities it provides.[19] These benefits mean that changes in the ratio of runoff (surface water) to ground water infiltration will affect the overall quantity and quality of the water supply. This study will use this potential change to calculate the value of the forest in the production of ground water quantity as well as surface water quantity and quality.

2.2.2.1.2 *Water Quantity*

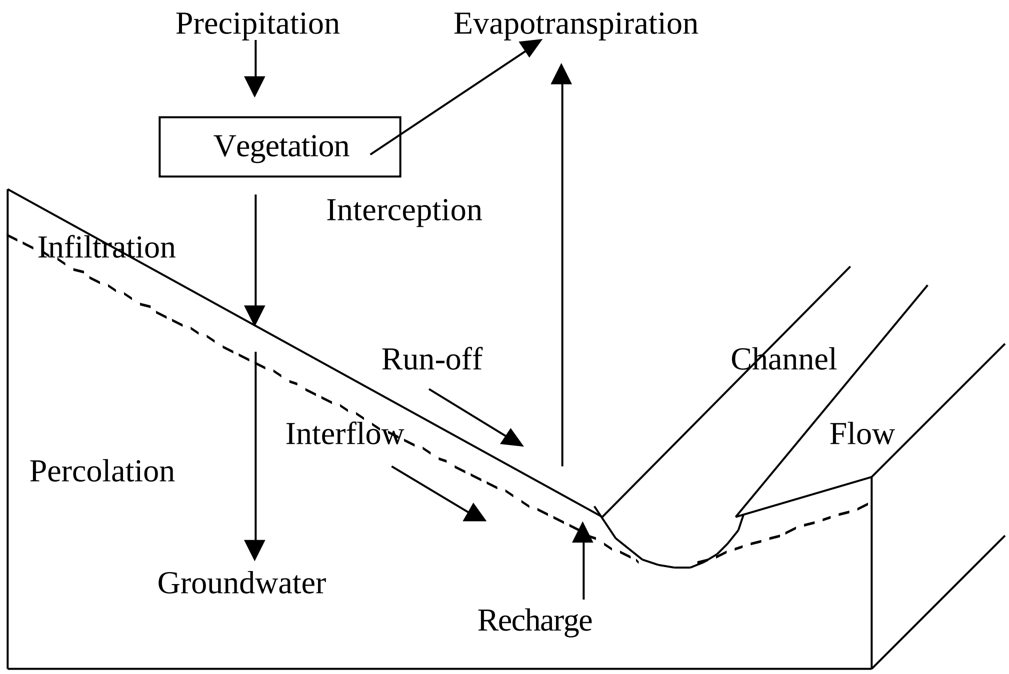
Ground and surface water come from precipitation. Principal hydrological pathways can be seen in the following chart from O'Callaghan (1996: 8). Here, rain falls and fog condenses onto the vegetation canopy. At this point, the water either evaporates, is absorbed into the plant and may transpire, infiltrates the ground and percolates through to the aquifer, runs off into a stream channel, or flows underground and discharges above ground at another point.

Each of these factors should be taken into account when creating a water balance model. Giambelluca's work provides most of the basis for subsequent investigation of water budgets for the Ko‘olaus. His dissertation investigated precipitation, runoff, evapotranspiration (ET, the total flux of water vapor from all surfaces through the processes of evaporation and transpiration), and recharge for areas affecting the Pearl-Harbor Honolulu basin, including the

[19] For instance, evaporation and transpiration losses could be eliminated by replacing the forest with large catchment and storage systems.

Ko‘olau range. While elevation has the most significant effect on rainfall, other factors such as vegetation cover, soil type and slope affect the levels of runoff and recharge. [20]

Figure 2.2: Hydrological Cycle

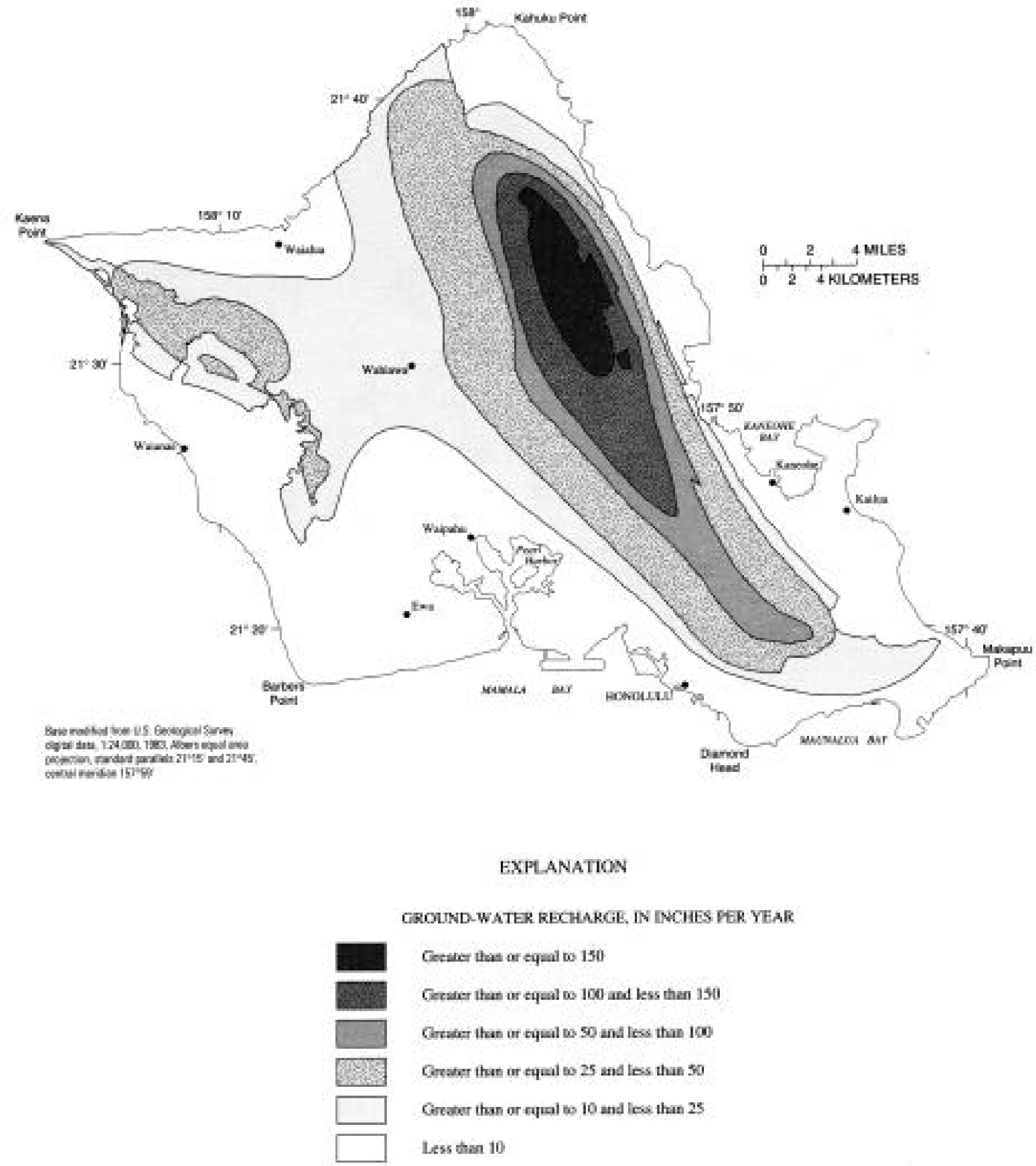


Current estimates of the total recharge to the aquifer vary somewhat; this analysis uses a recharge level of 281 million gallons per day (MGD) (Mink, 1980). Based on Giambelluca (1983,1986) and Shade and Nichols (1996, Table 22) we assume that approximately 133 MGD, or about 45% of the groundwater recharge to the Pearl Harbor Aquifer, comes from the Ko‘olaus.[21] Figure 2.3 shows estimated levels of recharge for the island, and it is apparent that the Ko‘olaus are significant contributors to recharge. **Maintaining high levels of recharge from the Ko‘olaus will lessen the need for alternative water sources. The upland forest plays an important role in this maintenance.**

[20] For example, in the upper portions of the Ko‘olaus it is believed that evapotranspiration rates may be suppressed because the forest virtually always is receiving some form of moisture, and because the elevation makes for cooler weather. Fog-drip, or moisture absorbed from the clouds does not return in large part to the atmosphere, and therefore may be a major source of water recharge in the hydrological cycle. Giambelluca (1983) estimates that the quantity of fog-drip for the leeward Ko‘olau slopes is about 6 inches per year for areas above the 2000 foot cloud base.

[21] From Giambelluca’s research on the Ko‘olau mountains, USGS researchers have estimated that for the leeward side of the mountain range, precipitation is divided very generally into approximately 45% recharge, 40% ET, and 15% runoff. Since these estimates may vary significantly, primarily with climatic zone, and there exists significant scientific uncertainty about the hydrological process in the Ko‘olaus, including incomplete soil surveys, rainfall and hydro-geological data, and evapotranspiration rates, these numbers should be interpreted as only a rough starting point for this analysis.

Figure 2.3: O'ahu Rainfall Recharge Estimates



The characteristics of the land cover determine to a large extent the rate of infiltration of groundwater. There are several characteristics of concern. The main factors are the geomorphology of the landscape, the soil type, and the vegetation cover.

Steep slopes will clearly have more runoff and less infiltration than flatter slopes. Streams that meander or pass over more rubbly and less smooth, or channeled waterways, will have higher infiltration rates. Intense rainfalls that may be experienced in severe storms, particularly as on the windward sides of the Koʻolaus, will tend to increase channelization and runoff. Layers of vegetation help slow this process by providing slope stability, more even stream flow, and fallen debris in the water, creating a mechanism to slow the flow and provide freshwater organisms with conducive habitat. In general, the windward side of the Koʻolaus, which is much steeper, should expect greater run-off and less recharge.

Second, the soil type will determine the permeability of the landscape below ground level. Compacted soil can prove quite impermeable if not broken up.[22] The soil types in Hawaiʻi generally have a high clay content and are permeable until disturbances occur. When these clay soils are packed, however, they can quickly form an impenetrable layer.

Finally, vegetation cover determines much of the process of ground water recharge. A healthy, multiple tiered forest will collect more raindrops through its leaves, protect the soil from both sheet and rill erosion,[23] and will keep the soil permeable through its roots systems. Each of these services increases groundwater recharge levels. These ecosystem services are highly valuable in Hawaii, where population demands for water are taxing supplies. **Threats to these ecosystem services, therefore, impose true economic costs on Hawaiʻi.** These costs are measured here by estimating the lost value (replacement cost) accrued from a deterioration in environmental quality. These estimates should then be used as guidelines for determining the most rewarding use of the resources for the people of Hawaiʻi.

The threats to forest quality and the associated ecosystem services could come from several types of disturbances. A large decrease in recharge could come from a variety of changes in the forest. The following describes perceived threats to the watershed which might cause this sort of change, the type of damage to ground water recharge, soils, and water quality through erosion and sedimentation, the potential level of impact, documentation from similar occurrences, and the probability of a problem in the Koʻolaus.[24]

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[22] Some of the early irrigation ditches were in fact made of packed soil. The soil base for the Koʻolaus is volcanic. The Natural Resources Conservation Service (NRCS) has conducted soil surveys for the islands (NRCS, 1972 (Island of HI, 1973)). Many of the original irrigation ditches were not lined, and were sufficiently watertight just through packing the soil tightly (NRCS, 1972 (Island of HI, 1973)).
[23] Sheet erosion is caused primarily by raindrop impact. Rill erosion is caused primarily by surface runoff.
[24] The additional value of the forest to water quality will be discussed below.

Perceived Threat:

Fire

Type of Damage:

Removal of vegetation cover, changes in soil capabilities, probable increased erosion.

Potential level of impact

Would reduce evapotranspiration and increase runoff significantly. Heat levels can reduce permeability of soils and reduce recharge levels. Higher levels of erosion due to lack of cover. Decrease in ET rates. The higher the intensity of the fire, the more drastic the impacts.

Documentation from similar threats

Hanalei fire in Kauaʻi, HI: found 86% of a transect line had vegetative cover of less than 50% 4 mos. after fire, but 10 mos. after 94% of transect had cover of 50% or greater. Fireweed was dominant species, uluhe regeneration low, no evidence of widespread erosion (Wood et al. 1969); Shoshone National Forest: 120,000 acres experienced high intensity burn. Soils became hydrophobic. Full recovery estimated at 350-400 years. Pre-disturbance water yield 3340 acre-feet/year and sediment yield of and 0.3 tons/year, erosion 56 tons/year. Post-fire water yield 5469 acre-feet/year and sediment yield 168 tons/year, erosion 4842 tons/year (Cathedral Fire EA, 1988.)

Probability of occurrence

Low probability due to rainfall levels as well as DLNR watchfulness and information campaigns of the past few decades. El Niño drought years have higher probabilities.

Road Construction

Type of Damage:

Removal of some vegetation cover; disturbance and compaction of soils; provision of faster runoff pathways. Increased human activity.

Potential level of impact

Would increase runoff, erosion and sedimentation, the intensity depending on road use and rainfall episode intensities. Mitigation procedures are possible.

Documentation from similar threats

Highway (H-3) construction increased suspended sediment loads by 56 to 76 percent from 1983–91 in North Hälawa, Haʻikü, and Kamoʻaliʻi Drainage Basins (1 to 4 sq. mi. basins) (Hill, 1996.)

Probability of occurrence

Low due to current conservation district zoning. Most of the district is privately owned, so changes in zoning could significantly increase probability.

Urban development
Type of Damage:
Removal of vegetation cover, road and other construction. Increased human activity.
Potential level of impact
Extensive decrease in soil permeability and infiltration rates and thus groundwater recharge; increase runoff and sedimentation. Enhanced transport system for sediments increasing the damage from existing and additional sedimentation.
Documentation from similar threats
Water yields become less even and more dependent on the magnitude of the precipitation event. Runoff from paved surfaces is nearly 100% of rainfall. Infiltration in unpaved portions of urban areas is reduced by as much as 83% compared with pre-urbanized conditions (Murabayashi & Fok, 1979). Changes in infiltration for agricultural and pasture land as compared to forest land in Hawai‘i may be more than 10 times lower for some soil and slope conditions, though under other conditions there may be little difference. In general, since rainfall intensities in Hawai‘i frequently exceed infiltration rates, the likelihood of surface water runoff will be less on a given soil under forest cover than one under sugarcane, pineapple, or pasture, and forest covered soils will accept water faster, have greater porosities, and larger, less erodible aggregates, decreasing the hazards of erosion, than others (Wood, 1977).
Probability of occurrence
Low due to current conservation district zoning. Most of the district is privately owned, so changes in zoning could significantly increase probability. Urban creep (e.g. along valley sides) might occur through easements and permits.

Ungulates (cattle and feral pigs)
Type of Damage:
Removal of understory and perhaps greater vegetative changes. Disturbance of soil. Increased dispersion of introduced species like Strawberry guava.
Potential level of impact
Probable increase in erosion and sedimentation. Potential decrease in infiltration rates due to soil disturbances. Groundwater recharge might decrease.
Documentation from similar threats
As much as 88% of the soil is bare in regions of HI inhabited by feral pigs (Kurdila, 1995). 27% of 37 field plots in DLNR sample of the Ko‘olaus showed slight surface erosion on steep slopes, while over half of the plots showing erosion had signs of impact by feral pigs or cattle (Buck et al, 1988).
Probability of occurrence
High probability of occurrence. Presently responsible for much of the disturbance in the Ko‘olaus. Hunting and fencing in small parts of the watershed has curbed recent damage levels. Reforestation in the 1930’s restored significant damage from cattle in previous centuries.

Logging operations
Type of Damage:
Removal of vegetation. Soil disturbance.
Potential level of impact
Increase soil disturbance, erosion, sedimentation and runoff. Decrease ET. Groundwater recharge likely to decrease.
Documentation from similar threats
Increase in erosion and surface water yields dependent on type of logging. Airborne (helicopter) will have fewest watershed impacts. Water yields become less even and more dependent on the magnitude of the precipitation event.
Probability of occurrence
Low due to conservation district zoning and lack of quality resource. Timber reserves account for approx. 14,000 acres in the conservation district, 10,000 of which are zoned resource which allows for some extraction (Buck et al., 1988). Koa retail prices range from $4.30 per board-foot to $29.30 per board-foot depending on quality (Winkler Wood Products, personal communication) with an average of 210 board-feet per tree (Carlson & Bryan, 1959).

Miconia calvescens
Type of Damage:
Significant change in forest structure to monoculture with virtually no understory.
Potential level of impact
Probable increase in soil erosion, sedimentation and runoff. Possible decrease in recharge.
Documentation from similar threats
Unknown; further studies in Tahiti, where currently 2/3 of forest cover is *Miconia*, may improve information. May simply be exchanging one type of cover for another with little effect on watershed qualities of forest.
Probability of occurrence
Low due to public awareness campaigns and concerted efforts at removal. However, Island of Hawai‘i is already infested with approx. 10,000 acres, and a 500,000 acre potential without eradication.

Other introduced species - leaf hoppers, pathogens, vines, the unknown, etc.
Type of Damage:
Significant change in forest cover and/or composition.
Potential level of impact
Leaf hoppers and some pathogens can reduce leaf area cover and may increase sheet erosion and change ET. Vines can reduce canopy cover and create forest openings with associated increase in "edge" effects – drier, more erosion-prone landscapes.
Documentation from similar threats
Watershed impacts and erosion will increase as the species lead(s) the forest away from "green" dense canopy to disturbed forest. Tahiti's *Miconia calvescens,* described above, provides an example of the devastation possible from one plant. Other examples exist throughout the world; the Brown Tree Snake has wreaked havoc on Guam's environment, Zebra mussels have significantly altered the ecological underpinnings of the Great Lakes, and so forth.
Probability of occurrence
The probability of new species' arrivals is high, but the probability that they will have high damages is relatively unknown. Rate of species introduction to the islands is extremely high, increasing the probability of damages. The probability of arrival of new species is also increasing as air and shipping traffic to the islands continues to grow. The unknown ecological properties of these new arrivals on the existing Hawaiian environment determines the probability they may inflict damages upon arrival. Current monitoring unlikely to be consistent enough to answer these questions until devastation has occurred.

To determine these costs for ground water recharge, we take a four-step approach to the problem. First, we determine what quantities of water would be used over time in an economically efficient system, allowing for modest economic growth. Second, we use these quantities to calculate the implied efficiency prices and scarcity rents.[25] Third, we recalculate these prices, quantities, and rents for a change in current forest conditions. Finally, we take the difference in the scarcity rents to represent the change in social welfare from a deterioration in forest conditions. This change in social welfare can thus be used as a value of the services provided by the initial level of forest quality which would be foregone by allowing a deterioration of that quality. With this relative value for forest quality, we extrapolate the findings to estimate an overall value for the ecosystem services provided for the forest as a whole.

For the first step, we realize that water is not bought and sold in a decentralized market without external costs and benefits, so that current water prices for O‘ahu do not result in optimal usage rates by the population. **Water prices tend to underestimate the cost of production and the social benefits of the water's uses, so the quantity used is likely to be higher than optimal and the price lower than optimal.** Furthermore, because the aquifer can be drained by human use more quickly than it can be refilled by nature, the resource must be considered exhaustible, and as the resource becomes scarcer over time, the price should rise. It is assumed that the water from the aquifer can be substituted for with desalinated water at a wholesale price of $3.48[26] per thousand gallons, which provides an upper limit to the price which can be charged for the water

[25] Scarcity rent is benefit gained from the production of the water at lower costs due to the ecosystem services provided by the forest which would otherwise have to be provided by a more costly substitute like desalination.
[26] Figure from Krulce, Roumasset, and Wilson (1998) was $3 per 1,000 gallons for 1991. $3.48 is inflation adjusted to 1997.

from the aquifer. Krulce, Roumasset and Wilson (1998) created a model which allows one to calculate these optimal prices given assumptions about the growth in demand for water and the cost structure for extracting water from the aquifer for the Pearl-Harbor Aquifer on Oʻahu. This model is used here to determine the current optimal wholesale (net of distribution charges) price path and quantity path for water usage from the Pearl Harbor aquifer, and then the optimal paths are recalculated under the assumption of a significant forest disturbance.

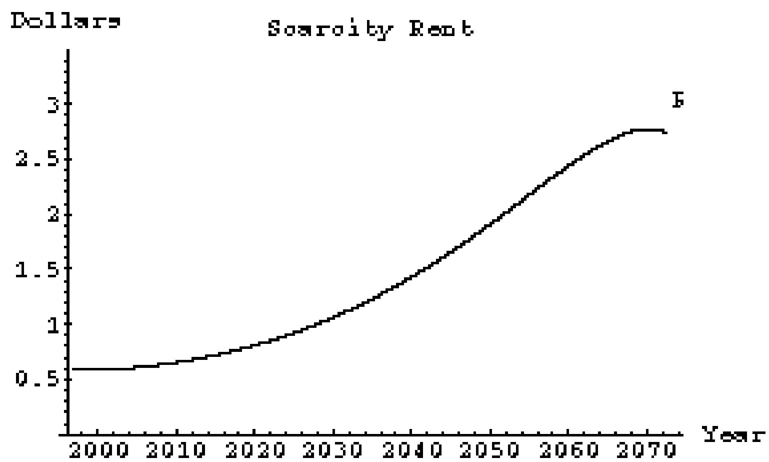
For the second step, the scarcity rent is measured as the amount above the cost of extraction the optimal price should be to account for foregone future usage times the amount of water used at that price. Thus, the scarcity rent for 1,000 gallons used today at a wholesale price of $1.01 and an extraction cost of $0.41 would be $0.60. This is shown as the y-intercept on Graph A of Figure 2.4. To approximate the total scarcity rent for all the water used in each time period one first multiplies the difference between each period's extraction cost and optimal price (the scarcity rent, shown in Figure 2.3) by the optimal quantity used in that time period (not shown, but for example in the first period of the current recharge level the optimal quantity extracted it is 149 MGD). Then one can calculate the net present value by summing up over the infinite future given assumptions about the growth in demand (to calculate the quantity) and the social discount rate for the water (to discount the value of the future water usage to today's market[27]).

The deterioration in forest quality anticipated in this analysis is a decrease in groundwater recharge of 41 MGD, or 31% of the current recharge level from the Koʻolaus. Figure 2.4 shows a visual representation of the scarcity rent for 1,000 gallons in each time period under current forest conditions (Graph A) and under a change in forest conditions which leads to this decrease in recharge (Graph B). **At the year 2072 under current conditions, and the year 2057 for this level of deterioration in water quality, the optimal wholesale price of water from the aquifer would be equivalent to the wholesale price of desalination.** At this point, the same amount of water should be extracted from the aquifer in each year, maintaining an optimal aquifer head level and extraction cost. Growth in demand for water should be supplied by desalination. **Thus, a significant benefit of the healthy forest is that the time until desalination is required is significantly greater. This will postpone any large capital expenditures for treatment facilities and decrease their present value cost as well.**[28]

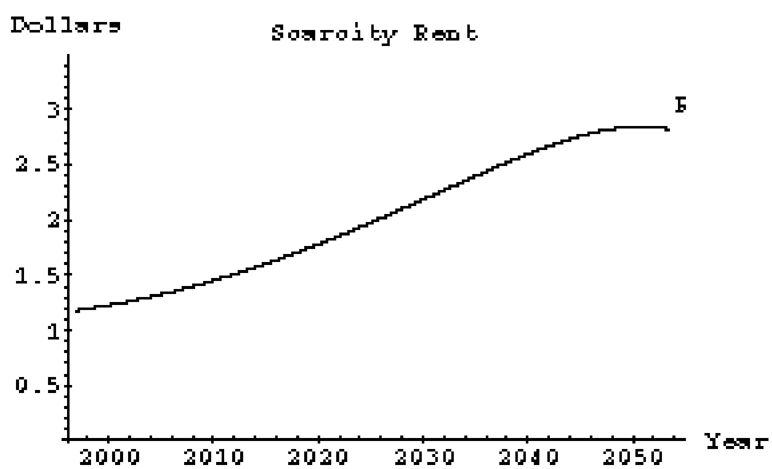
[27] For a lengthy discussion of scarcity rent, present value and social discount rates, see Tietenberg, Environmental and Natural Resource Economics, 4th edition, 1996.
[28] Such costs are not estimated in this analysis.

Figure 2.4: Scarcity rent for recharge to Pearl Harbor Aquifer

Graph A: Current, recharge of 281 MGD



Graph B: Post-forest quality change, recharge of 240 MGD



In brief, the perceived threats are any combination of fires, roads, logging, urban development, feral ungulates, and introduced species like *Miconia calvescens*. Given current forest zoning and threat levels, the most likely way in which such devastation could occur without a change in usage laws would be through a combination of extremely heavy *Miconia calvescens* and/or leaf hopper infestation changing the composition of the forest canopy, urban creep along the edges of the district removing key areas of streamside vegetation and adding pavement, and an increase in feral pigs causing lower rates of soil infiltration.[29]

Using the four-step technique outlined above, **we find that the net present value lost from a decrease in recharge of 41 MGD to the Pearl Harbor aquifer may be between $1.42 billion and $2.63 billion dollars**, depending on the assumptions made regarding the social discount rate. If one believes that society should have a low discount rate, which places almost as great a weight on future benefits as current ones, then the discount rate might be as low as 1%, which leads to the $2.63 billion sum. If society chooses to use a market rate for discounting, i.e. what one might be able to get as a long-term real interest rate (net of inflation) for a U.S. treasury bond, 3% might be more appropriate, which leads to the $1.42 billion figure. [30]

If recharge to the aquifer from the Ko‘olaus ceased altogether, the reduction of inflow to the Pearl Harbor aquifer would be approximately 133 MGD. The lost net present value from such a disruption would amount to $4.57 to $8.52 billion.

As a caveat, note that groundwater and surface water levels might actually be increased by similar changes in the forest quality to those described above. For instance, a reduction in vegetative cover could lead to decreases in ET which more than compensate for decreases in recharge due to lower levels of soil moisture storage and infiltration rates.[31] Before manipulating the forest cover for watershed purposes, the benefits of the additional water must be weighed against the costs of the changes in the forest to other amenities, such as water quality, wildlife habitat and aesthetic pleasure. These are further discussed below.

In summary, groundwater recharge is a valuable product of the Ko‘olau forest, with a net present value of at least $1.42 to $2.63 billion. O‘ahu gets about 90% of its fresh water supply from groundwater. Alternative production techniqques such as desalination are

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[29] While any of these threats might be capable of reducing groundwater recharge by 41 MGD, or 31% of the current recharge level from the Ko‘olaus, through the impacts described, there is a great deal of scientific uncertainty involved when discussing changes in vegetation cover, and there are many possible types of mitigation procedures which could allow for development such as road building or logging without negatively impacting groundwater quantity or even erosion and sedimentation. For this reason, given current restrictions which already place a social value on the resource quality, a combination of impacts is assumed necessary for such a significant change in recharge levels.

[30] The optimal social discount rate is a controversial topic within economics. Most government agencies use a 10% discount rate, but agencies like the USDA Forest Service are mandated to use a 4% discount rate because of the long-range social benefits they produce. James Kahn has suggested the use of 30-year U.S. Treasury bond rates because they are a low-risk, diversified investment, or the average real rate of growth of GDP, historically 2-3%, because any one part of the economy growing exponentially larger than the economy as a whole could not be sustained for long (Kahn, 1995).

[31] Giambelluca puts forward a scenario, though not directly for the Ko‘olaus, in which all of the 1975 sugarcane land is converted to vacant land, resulting in a net increase in groundwater supply to O‘ahu of 71 MGD, but only a 3 MGD increase in recharge if these same lands are changed to medium density residential land (1983:250). He makes the assumption that medium density residential land would have 25 persons per acre, with a maximum increase of population of 544,000 people.

costly and the postponement of their need is a valuable policy goal. Postponement can occur on the supply side by maintaining or potentially enhancing forest quality.

2.2.2.1.3 *Water Quality*

Ground and surface water quality are also extremely valuable to Hawai‘i, and again the forest can provide clean water through natural ecosystem functions rather than through technological innovations.[32] Several factors indicate that an increase in surface water run-off and higher levels of sedimentation would impose large costs that could warrant significant expenditures on purification. The flashy nature of flows means that significant levels of runoff reach the ocean within 5 days, leaving little opportunity for cleansing by stream beds. A 1981 study estimated that 90% of the sedimentation in O‘ahu waterways resulted from 2% of the time involved in all rainfall (Status of Forest Watershed Research in HI, 1981). The quick trip to the ocean combined with heavy episodic rains indicates that any man-made attempts to replicate forest services are more likely to fail; storm runoff drains flood and the sedimentation would still end up in the oceans without treatment. This results in large levels of increase of sediment to the reefs. Reef growth will slow measurably, although science cannot predict the relationship clearly, with increased sedimentation as the reef calcifiers must exert greater energy cleansing themselves rather than building up $CaCO_3$. The increased nutrient load may also favor algal production and in some cases enhance blooms of crown-of-thorns. These relationships are discussed in the section on ocean resources (Section 2.4).

The end result might be a die-off of the reef, leading to a drastic reduction in tourism to the reef, the direct cost of which is estimated by the contribution of dive tourism to the economy. Indirect impacts which may be even more costly would stem from the decreased production of nursery fishes and food for Hawaii’s important pelagic fisheries and from decreased sand production and large wave protection, leading to more rapid beach erosion. **A study of coral reefs in Indonesia indicates that sediment from logging may cause present value net losses from fisheries and tourism damages of $273,000 per square kilometer[33] of reef** (Cesar, 1996). Though this figure is not directly applicable to Hawai‘i because of differences in

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[32] Extremely successful water purification may now be possible for as little as a penny per gallon. Safe Water Systems of Honolulu is advertising Sol*Saver—a solar water pasteuriser that disinfects microbiologically contaminated drinking water by killing disease-causing bacteria, viruses and other micro-organisms, at an estimated cost of $0.01 per gallon. The unit is 99.999% effective, according to tests conducted at the University of Hawai‘i Water Resources Research, and works on dirty water as well as contaminated water (World Water, March 1997, p. 6).Suppose recharge from the Ko‘olaus decreased 41 MGD as above, with a corresponding increase in runoff of 41 MGD. This extra run-off does not benefit from the natural ground water soil filtration process, and any forest quality changes which would increase run-off so substantially would likely not allow for surface cleansing or moderation of the timing of the water flow. Thus damages can be estimated as the cost of cleaning this increased run-off, for an annual cost of $149.65 million, or a net present value range of $5.14 billion to $15.11 billion for discount rates of 3% and 1% respectively. Additionally, the water quality of the original levels of run-off would have deteriorated from the forest disturbance. Run-off from the Ko‘olau conservation district is estimated to be 150 MGD, so the additional damage estimates using the same technique amount to $547.5 million per year. The total net present value if one counts both the additional runoff damages and the existing runoff would be the net present value of $868.5 million per year, or $23.96 billion to $70.4 billion for discount rates of 3% and 1% respectively. Clean-up of every gallon of water to 99% purity, however, would increase the water quality above that which the forest provided, so this figure is higher than the benefit level accrued from the forest’s services.

[33] Present value calculations using a 10% discount rate and a 25 year time horizon.

reef diversity, fisheries resources and dive tourism levels, impacts on the reef from changes in forest quality must not be overlooked.

One way in which to estimate the costs of sedimentation to Hawai‘i is by using the clean-up of sedimentation in the Ala Wai canal as a proxy-good for the costs of cleaning up the water pollution throughout the district. The cleanup of the canal itself is a defensive expenditure and is itself thus an estimate of the value of the water quality. This canal serves as the destination for waters from three main streams: the Makiki, Mänoa, and Pälolo streams, covering about 16 square miles, with an annual average fresh water flow of 21.0 MGD. Approximately 10,000 cubic yards of sediments, or 18,739 tons per year, flow into the canal. Seventy-seven percent of this sediment, or 7,700 cubic yards per year, are estimated to originate in the conservation district of the Ko‘olau forested watershed. Dashiell has estimated the costs of dredging the Ala Wai canal to be $50 per cubic yard for ocean disposal or $80 per cubic yard for land disposal (Dashiell, 1997). These dredging costs are assumed to be the lower bound of damage costs elsewhere because the canal presents an opportunity to capture the sedimentation and remove it in one concentrated effort. Annual sedimentation costs for this small portion of the Ko‘olaus can be estimated as 77% of the cost of dredging the canal, or $385,000 to $560,000 per year.

Recall that run-off is currently estimated to be approximately 15% of precipitation.[34] Then, surface water run-off from the conservation district can be estimated at 150 MGD. If current stream flow of 21 MGD produces 7,700 cubic yards of sediments from the Ko‘olaus per year, then sediments from the Ko‘olaus can be very generally estimated at approximately 55,000 cubic yards per year. An increase of runoff for the area recharging the Pearl Harbor aquifer, from about 44 MGD to 85 MGD, which corresponds to a decrease in recharge of 31% with no net change in ET, would increase this sedimentation by 15,033 cubic yards, per year. Assuming a damage level equal to the costs of dredging, the damages from the change in forest conditions described above due to sedimentation would be $0.75–1.2 million per year, for ocean disposal or land disposal respectively, for a corresponding present value range of $25.8 million to $121.47 million, for discount rates of 3% and 1% respectively. If runoff were to increase by the full level of recharge to the Pearl harbor aquifer from the Ko‘olaus, or 133 MGD, then the minimum annual damages would be $2.44 to $3.90 million, for a net present value of $83.7 to $394 million.

Additionally, the canal itself has been a depository for sediments from the Ko‘olaus for the past 70 years and the resource is not suitable for many recreational activities, including swimming or consuming fish caught there due to high contaminant levels. Swimming in the streams could result in Leptospirosis, a bacterium resulting in painful, potentially fatal, illness, which is transmitted to the water by feral ungulates and rats. Staphylococcus infections have also been a recurring problem for outrigger canoe paddlers in the area while they are not a problem for a control group of paddlers which does not use the Canal for practice (Dashiell, 1997). Health costs associated with such diseases are not presented in this analysis but could be calculated by the frequency and cost of treatments as well as any opportunity costs associated with treatment for the patient.

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[34] More specifically, for the leeward Ko‘olaus, about 6.5 inches of rain per month is necessary to initiate overland flow and/or interflow, and approximately 31% of additional precipitation runs off (Giambelluca, 1983).

In summary, water quality is a highly valuable asset provided by the quality of the Ko‘olau forest. Using the most conservative estimates, a significant forest disturbance, capable of increasing runoff by 41 MGD, would lead to damages estimated at a net present value of between $25.8 and $121.47 million. A complete forest destruction could result in water quality deterioration damages of at least $83.7 to $394 million.

2.2.2.1.4 *In-stream Values*

In addition to providing water supply for extractive consumption purposes, forests protect stream flow and quality allowing for the production of in-stream ecosystem services. In-stream uses of stream waters are those uses that do not require withdrawal or diversion from the natural watercourse (DLNR 1981) and include habitat for freshwater fish and other aquatic organisms, water bird habitat, scientific and educational use, aesthetic enjoyment, water-based recreation, navigation, and waste assimilation. Using these categories of ecosystem services, about 127 square miles have been studied in Windward O‘ahu from Makapu‘u Point to beyond Kahuku Point (Ko‘olau Loa and Ko‘olau Poko Districts). Eighteen sub-areas were identified with 13 major perennial streams. Rainfall in this area is high, averaging 100 inches per year, streams are short with steep gradients and small drainage, and stream flows are flashy with high flood potential and very little base flow.[35]

Some streams are perennial and contain the rare native Hawaiian freshwater *‘o‘opu* as well as freshwater snails and other invertebrates. (Geologic Hydrology, 1996). Other similarly unfamiliar, small freshwater species have been valued at $7 per household per year using contingent valuation, or survey, methods (Loomis and White, 1996). **This would imply a yearly value for the preservation of a single such aquatic species by residents of Hawai‘i of $2.4 million and a range of net present values of $82.4 million to $242.4 million for 3% and 1% discount rates respectively.** This analysis will use this range as a low-end estimate of the value for in-stream uses.

2.2.2.2 Soils

Soils are economically important *in situ* because they:

- moderate the hydrological cycle,
- shelter seeds,
- provide physical support for seeds to grow (hydroponic alternatives cost about $55,000/hectare),
- retain and deliver nutrients to plants,
- are a buffer to the application of fertilizer,
- decompose organic and waste,
- render human pathogens harmless,
- detoxify industrial waste,
- regulate carbon, nitrogen, and sulfur cycles.

[35] Appendix 2.2 summarizes the O‘ahu study.

These soil ecosystem services disappear with soil erosion. In addition, forest deterioration that leads to erosion precipitates landslides, causes silt to disseminate into the ocean and Hawaiian fishponds, transforms coastal waters between the reefs and coral sand beaches into mud, and may pollute streams, destroy coral reefs, and degrade coastal fishing.

Erosion control benefits of forests are multifaceted. Forests prevent soils from eroding off of the land and into urban areas, streams, and the ocean. Erosion control in Hawaiʻi is especially important because the state's land area is relatively small. And while it takes many 100s to 1000s of years to build up soils naturally, it takes only a few years of human activity to erode them away.[36]

The use of soils in Hawaiʻi has changed markedly over time and has tended toward activities that increase soil erosion. General trends in soil use include the replacement of forests with Polynesian subsistence agriculture, the replacement of subsistence agriculture with cattle ranching and sugar and pineapple plantations, and all of these uses continue to be replaced by development such as suburban growth. These changes can alter the rate of erosion by many orders of magnitude. Soil scientists estimate that the erosion factor on developed areas is 10 times greater than on cropland, 200 times greater than on pasture, and 2000 times greater than forests (Maslow, 1977). Studies in the North Eastern United States showed that sediment yields of forested lands were about 50 tons per square mile per year while developing area sediment yields could reach 25,000 to 50,000 tons of sediment per square mile per year.

Soil erosion from various natural and human causes in Hawaiʻi has left several spots virtually bare. These include the island of Kahoʻolawe and the Waiʻanae mountains on Oʻahu. **While soil erosion in the Koʻolaus is currently minimal, the continued presence of feral ungulates, as well as disturbances that increase the rates of soil erosion, could lead rapidly to a decrease in soil quantity.**

While the species of vegetation cover may not have a great impact on the aesthetic value of a forest or even the short run water production capabilities, it may have a long run effect on the ability of the forest to maintain itself through its effect on soils. Tahiti's *Miconia calvescens* infestation is probably increasing the rate of landslides, leaving whole slopes barren. This sort of catastrophic soil loss could capitulate other rapid changes in the forest, leading to rapid deterioration of the forest. However, evidence from Kahoʻolawe suggests that even barren areas can regenerate soils and vegetation cover within a relatively short time span of a quarter century. On the island, soils have been built up by fencing off regions to protect them from goats and planting Australian salt brush that captures soil material from the air rapidly. These regions have seen a significant increase in vegetation cover and diversity in just a short span of 25 years or so.[37]

This rapid recovery indicates that even the most drastic changes in the forest are unlikely to be permanent, especially if quick management action is taken. Because massive soil loss occurs

[36] Note that the soils and the impacts of soil erosion in Hawaiʻi are very different from those in the continental United States. Soils in Hawaiʻi, John Street, Conservation Biology in Hawaiʻi.
[37] Bob Hobdy, personal communication, July 31, 1998.

episodically and unpredictably, and because the long term impacts have such a wide range and are so difficult to ascertain, this valuable indirect service is not valued in this preliminary survey of values for the Koʻolau region. Regardless of recoverability, however, the loss of the use of the natural capital in the interim is potentially costly, and certain changes, most recognizably the extinction of species, are irreversible.

2.2.2.3 Species Habitat

Another major ecosystem service the Koʻolau forested area and other forested regions of Hawaiʻi provide is species habitat. The threats to ground water described above are also threats to this natural capital in varying degrees. Forest disturbances tend to lead to conditions favorable to invasive species at the expense of native species, as shown in the discussion of the Hanalei fire above. The economic role of introduced and invasive species is discussed at length.

The level of threat may differ from that to groundwater, however. For instance, the exchange of one forested canopy for another may not have much impact on water quantity or quality, but could result in the loss of habitat for one or more rare species of flora or fauna. The protection of one species, scientists have learned, cannot take place in isolation. The entire community must function as a food web and provider of living space. Hawaiʻi's native ecosystems developed from an extremely limited number of species that managed to make the journey to the isolated islands. The celebrated 60+ species of Honey creepers (now only about 24 remaining) evolved from a single species, and other similar stories of evolution show that native Hawaiian ecosystems are very diverse but also very fragile. As a society, we do not yet know all the many assets this diversity could afford us, but we have some ideas based on the rates of discovery of medicinal purposes for tropical plants and marine organisms.

The Koʻolaus are home to 11 federally endangered plant species.[38] All but five of the taxa are or were endemic to the Koʻolaus, and the exceptions are or were only in Hawaiʻi. The plants and their habitats have been variously affected or are currently threatened by one or more of the following: habitat degradation by trampling and/or predation by feral, or domestic animals (pigs, goats, cattle, rats, slugs); competition for space, light, water, and nutrients by naturalized, introduced vegetation; habitat loss from fires; trampling due to military training exercises; and recreational activities. There are several endangered bird species in the Koʻolaus as well. These endangered species may not have a high direct economic value, like a wood product (koa) or a medicinal plant (e.g.) would, but they represent values that society has proclaimed high through the passage and implementation of the Endangered Species Act, which specifically requires that most decisions ignore economic costs and benefits[39]. Currently, the most utilized method for gauging the value of this sort of biodiversity is through surveys, or the contingent valuation method. Other methods may be possible under certain circumstances. Loomis and White have

[38] *Chamaesyce deppeana* (ʻakoko); *Cyanea truncata* (hähä); *Cyrtandra crenata* (haʻiwale); *Cyrtandra polyantha* (haʻiwale); *Eugenia koolauensis* (nïoi); *Hesperomannia arborescens* (no common name (NCN)); *Lobelia ohauensis* (NCN); *Lycopodium nutans* (wäwaeʻiole); *Melicope lydgatei* (alani); *Rollandia crispa* (NCN); and *Tetraplasandra gymnocarpa* (ʻoheʻohe).

[39] Sections 7 and 10, added later to the original act, do allow for the possibility of takings and other exemptions in extreme cases. However, the recent listings of several salmon species in the Pacific Northwest show that the listing process itself is still relatively independent of economic benefits and costs.

summarized household willingness to pay values from contingent valuation studies done for various species in isolation (see Loomis and White, 1996, for details of each study included).

These studies use some form of survey to elicit per household willingness-to-pay values for the preservation of the species. There is some indication that charismatic mega-fauna (whales, grizzly bears) are given preference over relatively unknown and unutilized (by humans) species like the striped shiner or the squawfish. When grouped by general taxonomic qualities, however, the birds in these studies have the highest average annual willingness-to-pay per household, at $35.50. Marine creatures (fish and mammals) have an average of $21.86. The studies do not include any plants or insects.

Endangered Hawaiian birds (31), turtles (5), and marine mammals would probably receive higher values than native plants (199) or invertebrates (including 41 snails) in contingent valuation. Plants and micro-fauna, however, are much more likely to have hidden economic values, such as medicinal cures or as bio-control agents for species determined to be pests. With at least 3 of 31 endangered birds present in the Koʻolaus, each with an estimated value of $35.50 per household per year, birds alone might be worth $42.6 million to 400,000 Hawaiian households each year, for an estimated net present value of about 1.46 billion dollars.[40]

This estimate is subject to several uncertainties. Contingent valuation can fall victim to many biases, especially the fact that payments by households are hypothetical. It is unlikely that if an individual came to every household's door collecting for endangered birds that he or she would receive $35.50 on average from each home, and almost certain that the second collector, coming for another bird, would get less than the first. These biases indicate that in this case the estimate is probably an upper bound. If we assume that households believe that their $35.50 per year should suffice for all birds in the region, then the net present value given the same assumptions would be $487 million.[41]

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[40] 3*35.50*400,000 households. Discount rate of 3% assumed for calculation of NPV. For 1% discount rate, $NPV = 3 billion. Standard deviation from the Loomis bird estimates is $24.69 per year per household, or $29.6 million per year for 400,000 Hawaiʻi households.

[41] Figure calculation: $35.50 per household * 400,000 households = $14.2 million, for a NPV of $487 million at 3% discount rate and $1.434 billion at 1% discount rate.

History's lessons: Endangered Species in Hawai'i

The status of forest plants, animals, and insects also provide an indicator of the status of Hawai'i's native forests. Of all the plants and birds known to have gone extinct in the United States, two-thirds are from Hawai'i. (HNIS in the US: 238) Recorded extinct species include twenty-four bird species, ninety-three plant species (55 definitely extinct, 38 possibly extinct), (Center for Plant Conservation, Hawai'i, May 1997), seventy-two snails, and seventy-three insects (USFWS-Pacific Office Hawaiian Dead List, 1994; IUCN Red List, 1996). There are also many non extinct Hawaiian species that are currently in danger of extinction. Hawai'i's birds represent 34% of the country's 75 listed endangered bird species while plants represent 42% of the country's 553 listed plant species (DOI Fish and Wildlife Service, Endangered Species Bulletin, As of December, 1997). Note that the extinction of a single species does not necessarily have a direct impact on the economy but threats to a single species may mean that there has been a significant degradation of an entire ecosystem that provides valuable ecosystem services. A serious threat of extinction of one insect, plant or animal species is an indicator that a whole environment, all associated life forms, and the interactions of varied species with each other, are in peril (Stemmermann, 1989).

Perhaps a better indicator of how households value species habitat is how much these households spend on accoutrements that allow them to benefit from the species. In its simplest form, as used here, this gives a ballpark value through the proxy-good technique described in Chapter 1. With more sophisticated data on the usage of these accoutrements, either the hedonic price method or travel cost method could be used to calculate more precise estimates.

In the Ko'olaus, these proxy-good expenditures can take many forms, including time spent hiking or hunting in the forest, or money spent on binoculars to search out the rare birds. In fact, spending on wildlife viewing has become a large portion of recreational dollars for the nation and for Hawai'i. Figures from the FWS indicate that, for Hawai'i, 123,000 residential and non-residential individuals participated in wildlife watching, 53% of whom neither fished nor hunted. **Expenditures in the U.S. by HI state residents on wildlife watching equipment and related expenditures reached $27,560,000 in 1996, with additional trip related expenditures of $42,814,000.** Table 2.1 provides the breakdown.[42] Since not all of these expenditures took place in Hawai'i, the figures are not a lower bound estimate of the value of the resources in Hawai'i, though they do indicate the values that state residents have for these activities. What portion of these expenditures is attributable to the Ko'olaus is unknown, although their proximity to the major population center of the state and comparative ease of access indicates it may be high.

[42] Trip related expenditures consist mainly of food, transportation and lodging expenditures incurred during wildlife-watching excursions. An example would be fees for boat excursions to watch dolphins or whales.

Table 2.1: Wildlife watching expenditures, 1996

Expenditure Item	Expenditures ($1000)	Avg. per participant ($)	Spenders		
			Number (1000's)	% of participants	Avg. per spender ($)
Total, all items	70,374	574	92	75	764
Total trip related	42,814	754	51	90	839
Total wildlife-watching equipment	13,567	111	76	62	178
Binoculars, spotting scopes*	1,077	9	12	9	93
Film and developing	2,111	17	30	24	71
Cameras, special lenses, video cameras, and other photographic equipment.*	5,666	46	11	9	501
Day packs, carrying cases, and special clothing*	1,065	9	10	8	106
Bird food	2,671	22	51	42	52
Food for other wildlife*	265	2	11	9	25
Nest boxes, bird houses, bird feeders, and bird baths	599	5	19	15	32
Other equipment*	114	1	7	6	17
Auxiliary equipment *†	634	5	12	10	54
Magazines and books	915	7	27	22	34
Membership dues and contributions	2,789	23	33	27	85
Plantings*	527	4	7	5	81
* Estimate based on small sample size					
† Includes tents, tarps, frame packs, and other backpacking equipment, and other camping equipment.					

In summary, the Ko‘olaus contribute significant value through the provision of species habitat. Conservative estimates of this value to Hawaiian citizens alone, based on the presence of a single endangered bird, range from $487 million to $1.434 billion in net present value.

2.2.2.4 Biodiversity

Biodiversity is simply a measure of the abundance of species of plants and animals in a given area and is defined as "the variety and variability among living organisms and the ecological complexes in which they occur" (HNIS in the US, 1992).

Some scientists believe that the primary benefits of native forests are related to their biodiversity (Reid and Miller, 1989: 88.). The primary ecosystem services derived from the biodiversity of species in forests may be biological and scientific research opportunities. Significant ecotourism benefits, as described above, and watershed benefits[43] are also likely to be important biodiversity driven services.

Scientific research on Hawai‘i's biodiversity contributes to the improved understanding of evolution and other central scientific concepts. Scientists emphasize that the Hawaiian archipelagoes, with their endemic biota, serve as crucial sites for modern evolutionary studies (Loope, 1989). The islands' biological diversity contains information and forms of life found only here, where the life forms have adapted to the climate and soils of the region over many millions of years.

Although Hawai‘i's species biodiversity has not been extensively studied yet,[44] the state has the highest biological diversity per unit area in the United States (Loope and Gon, 1989).

Hawaiian organisms also comprise a significant part of the natural and intellectual heritage of the United States and the world (Loope, 1989). Research into molecular genetics of Hawai‘i's native biota is likely to have a huge impact on medical science, genetic engineering, and biotechnology for agricultural commodities. These values are becoming increasingly obvious as genetic engineering advances. Pharmaceutical companies also are increasingly interested in the genes and chemicals that can be found in biologically rich areas because so many pharmaceuticals have been found by looking at biologically rich native forests. Companies now pay for the right to bioprospect for drugs and products in some countries, such as a Costa Rican deal for $1.35 million.

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[43] Native plant species are resistant to Hawai‘i's weather, drought, and flood conditions. East Maui Watershed Partnership Preliminary Plan.

[44] In many biological fields, there has been very little research on Hawaiian species. For example, the biology, ecology, and evolution of some terrestrial invertebrates, including small mollusks, nematodes, spiders, mites, and insects, is largely a vast unknown. Studies on the importance of Hawaiian invertebrates or pollination biology are similarly uninvestigated

It is estimated that one-fourth of all western prescription drugs contain elements of rainforest plants, generating about $43 million in revenues per year. Globally, medicines from wild products are worth about $40 billion a year (Kramer, et. al, 1995). Of the top 150 prescriptions used in the US, 118 are based on natural sources (Ecological Society of America,1996). Agricultural benefits are possible from genetic study of plants and animals as well. One gene from one Ethiopian barley plant is now protecting California's $160 million-a-year barley crop from yellow dwarf virus. A single hit from one of Hawai'i's native plants or animals could result in tremendous benefits. The NY Botanical Gardens has sponsored research on cancer and AIDS cures in Hawai'i for the past two years, testing up to thousands of compounds a month, with no success yet. Their continued persistence indicates the potential benefits of a single hit, no matter how unlikely.

Reduced biological diversity means that more species are endangered. The threats to Hawaiian species are acute because so many of them are localized endemic species (found in small ranges only in Hawai'i) that are generally more vulnerable to extinction than species with large ranges (Loope and Gon, 1989). The primary threats to biological diversity include the fragmentation of habitat (e.g., natural areas become islands surrounded by areas used for human purposes), the invasion of alien species, air pollution and climatic change (Loope and Gon, 1989).

One measure of the minimum value of biodiversity is the expense associated with protecting reduced biodiversity, or protecting endangered species which reflect biodiversity. Around 1989, it was estimated that "the average cost of listing an Endangered species is $60,000 (J. Faye, USFFWS, personal communication). This estimate is based on the ratio of annual person-hours to the number of species listed." The cost per listed species was perhaps as high as $500,000 during periods when the Federal administration appeared to actively oppose the ESA program. Using the lower estimate, over one million dollars was spent simply on Federal recognition of the rarity of a handful of Hawaiian plants (as of 1989 or so) (Stemmermann, 1989). For the eleven listed plants in the Ko'olaus, the cost of listing these species ranges between $660,000 and $5.5 million, and serves as a lower bound estimate of their expected value to society.

2.2.2.5 Subsistence Activities

Subsistence is a valuable ecosystem service that is not reflected in markets but provides significant economic benefits. Subsistence is defined as the customary and traditional use of "wild and cultivated renewable resources for direct personal or family consumption as food, shelter, fuel, clothing, tools, transportation, culture, religion, and medicine; for barter or sharing, for personal or family consumption and for customary trade" (Governor's Task Force on Moloka'i Fishpond Restoration, 1993). Subsistence has been identified as vital to families for economic, cultural, and social reasons. Forest-related subsistence activities include pig and deer hunting, gardening, protection of fresh water, fishpond, and ocean resources, and the collecting of maile. Particularly during rough economic times, subsistence fishing, hunting, gathering and cultivation provides a reliable means of support for communities. Historical opinions indicate that when agri-businesses close (e.g., sugar plantations), subsistence becomes a more vital aspect of the economy.

Subsistence may have health benefits as well. Subsistence activities require hard work and may result in healthier cardiovascular systems and could reduce health costs. Subsistence harvests can provide healthy alternatives to the junk food that is often otherwise consumed by low-income households; a diet of fish, taro, breadfruit, and sweet potato may reduce weight and the risk of heart disease, high blood pressure, and diabetes (Nä Pu‘uwai, 1982).

There are also significant cultural benefits for families and communities, particularly for native Hawaiians who learn about *Mälama ÿäina* (caring for the land) and how to harvest sustainably, *Mana‘o‘i‘o* (faith and respect for nature), genealogical ties to the land and cultural heritage, reproductive cycles of biological species, methods of fishing and gathering, and *‘ike* (knowledge) about natural resources. Subsistence activities are also linked to spiritual fulfillment for native Hawaiians.

Subsistence is important to Hawai‘i's economy simply because it is a viable alternative that at least partially compensates for the loss of jobs and revenues. Subsistence activities compensate for low income levels or high unemployment rates, such as the 20% rate in Moloka‘i where an estimated 28% of household food is acquired through subsistence activities and 51% of the population ranked subsistence "very important" to their family (based on random sample survey, 1993). In a 1982 study on subsistence activities by Puna Hawaiians in Puna Pähoa, the frequency of subsistence food gathering was 59%, gathering medicinal plants was 48%, gathering maile was 38% and hunting was 38% (Puna Hui ‘Öhana, 1982).

In the following section, the value of subsistence meat from pig hunting in the Ko‘olaus is estimated at $1.3 million using replacement cost techniques.

2.2.2.6 Hunting

While the value of subsistence activities from the Ko‘olaus is virtually impossible to ascertain without significant survey efforts to quantify usage of the resources, one area of subsistence activity which can be estimated is the value of pig hunting for food. Hunting has recreational value as well. In state expenditures by US residents for hunting totaled $16,436,000 in 1996. The primary game species are pigs, deer, and goats. In the Ko‘olaus pigs are the main species present and hunted. A 100–130 pound pig, the average size sold commercially, sells today for $1.48 per pound. With approximately 134,000 hunting days per year for feral pigs (USFWS, 1996) and only about 100 pigs sold per year by one of the larger meat providers (Suisan market), we might assume that most of the pigs caught are for consumption by the hunters. If every other hunting day is successful, then annual pig removal from the forests can be estimated at 67,000 per year. If we assume for exposition that 80% of the catch is consumed by the hunters and their ÿöhana, then the replacement value of the food from these pigs to the state's economy, assuming an average size of 115 pounds, is $9.1 million per year. If we then assume that one seventh of this harvest comes from the Ko‘olaus, then the value of subsistence meat from pig hunting in the Ko‘olaus is estimated at $1.3 million. **If one-seventh of the state-wide hunting occurs in the Ko‘olaus, then the estimated level of expenditures, and thus minimum value to recreationists, is one-seventh of $16,436,000, or $2,348,000 per year.**

Pigs contribute positively to the value of the forest for the recreational benefits of hunting and for the food value, but negatively contribute to the value of the forest through increased levels of soil erosion and the spread of introduced species like strawberry guava and insects conveying avian malaria. These values are explored in greater detail in the case study on introduced species.

2.2.2.7 Aesthetic Values

A significant source of benefits from the Ko‘olaus comes from the aesthetic pleasure received in viewing their beauty from homes, offices, or passing cars. The most successful tool for measuring these values uses differences in property values to elicit the higher willingness to pay for a view (hedonic price method). No such study has been undertaken for O‘ahu. Other estimates of aesthetic value might be derived from photographic sales of the area or its inhabitants, though this would significantly underestimate the number of people benefiting from the views (proxy-good technique). A third method, surveying or contingent valuation, recently has been used to value the benefits of open space on O‘ahu (Vieth et al, 1995).

The survey asked about values for currently unused sugarcane lands, but the results are relatively transferable to the aesthetic values of the Ko‘olaus. Based on a survey of 280 individuals living on O’ahu, the willingness to pay per additional acre of open-space land was 0.23 cents per household per year. The conservation district is 97,760 acres. If one half of this is readily visible from roads or homes, and is thus valued for its expansive, uninterrupted views, one can estimate a value of $112.50 per household per year for the view of the Ko‘olaus. With an estimated 270,000 households on O‘ahu, that amounts to an aesthetic value of $-30.4 million per year.[45] The net present values for 3% and 1% discount rates respectively will be $1.04 to $3.07 billion.[46]

2.2.2.8 Commercial Harvests.

Commercial forestry is $29 million industry in Hawai‘i. The value of some native trees, especially hardwoods, is high, although commercial harvests have declined over the years as native forests have disappeared. Significant harvests continue particularly on private land. In 1991, out of 100 surveyed respondents who own land with hardwoods, total revenue was $12.41 million; $5.45 million of this was from milled products and $6 million was from woodwork products. Koa revenues totaled $1.2 million, with $1.45 million from exported wood products. The total value of the koa logs was an estimated $.8 million.[47] These revenues may represent a depletion of natural capital if the native trees are not replaced.

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45 Because the respondents to the surveys may have other reasons besides aesthetic pleasure for desiring open space, such as the avoidance of urban sprawl, this survey cannot be used as a minimum value for aesthetic qualities of the land

46 Other studies outside of Hawai‘i have estimated the value of open space to be significantly lower, at between 0.01 to 0.09 cents per acre in the Continental U.S. and Canada. There could be several valid reasons for Hawai‘i’s higher values, particularly that the scarce land available on the island makes every land use more valuable.

47 Status of Forested Watershed Research in Hawai‘i, Hilton Wood, Institute of Pacific Islands Forestry, Unites States Fish and Wildlife Service, Landowners Survey.

Currently, no hardwoods are harvested in the conservation district, though such harvesting is legally possible with the appropriate permits. There are an estimated 14,000 acres of koa on leeward slopes (Buck et al, 1988). Much of this is on land unsuitable for timber harvest due to steep slopes or soil instability, however. Processed koa boards sell anywhere from $4.00 per board-foot (BF) to $30 per BF, depending on the quality (Winkler Woods, personal communication, 1998). Based on rough estimates of the productivity of koa forests from which we estimate that an acre of koa forest might produce 1000 BF (Soil conservation in the Pacific, 1961), at an average price of $17 per board-foot, the standing timber value of the koa in the Koʻolaus might be $238 million.

Since the removal of this koa would cause significant ecological change in the forest, many of the ecosystem services described above would be lost at least temporarily. If these trees were harvested and this $238 million invested for the benefit of the citizens of Hawaiʻi, it would still be less than the benefits accrued to residents in terms of water quantity, quality, and aesthetic pleasure, not to mention species habitat. The liquidation of the forest for this economic gain would not be an optimal use of the forest capital.

Ecologically intelligent harvest practices might result in a steady stream of benefits from timber harvest that is not currently realized, however. If only 1% of the potential 14,000 acres was on land suitable for harvest using even the most careful harvesting techniques, and if only one-one hundredth of that was harvested each year, benefits might still be $23,800 dollars a year, enough to provide for some monitoring of forest quality to ensure that the resource will be available for future uses.

A further benefit of selective timber harvest is that since the hardwoods of tropical forests are aesthetically pleasing to many people, increased availability of these woods may foster increased appreciation for their source and a greater interest in conserving the forest resource. The importance of this sort of secondary effect of awareness is evident in the increase of concern for tropical rainforests world-wide by individuals who will never set foot near one, but have been informed by the media of the benefits they might receive from such a forest one day, or of the beautiful birds or other unique flora and fauna of such forests.

In summary, the standing value of the koa timber forest may be $238 million. A potential stream of benefits from highly selective extraction could be $23,800 per year, for a net present value of $0.6 to $2.4 million.

2.2.2.9 Tourism and Eco-tourism Opportunities Including Recreation.

The opportunity to experience Hawaiʻi's forests, particularly the native forests, is an important ecosystem service supporting tourism, or more specifically, “ecotourism.” These opportunities include recreational activities that are valued and used by locals as well. For example, hiking with clubs in federal, state and roadside parks, with DOFAW or with private groups like Nature Conservancy of Hawaiʻi or the Sierra Club, is a popular recreational activity that attracts tourists and locals to many forested areas.

Ecotourism has been defined as nature-based travel to natural areas to experience and study Hawai‘i’s unique flora, fauna, and culture in a manner which is ecologically responsible, sustains the well-being of the local community, and is infused with the spirit of *aloha ÿäina* (love of the land).[48] In addition to rainforest hiking, examples of forest-related activities include: geology/vulcanology, astronomy tours, backpacking/trekking, mountain camping, bird watching (endangered), (ethno-)botany tours, research expeditions, nature centers, nature trails/walks, game viewing, elder hostels, bicycle tours, mule rides, Hawaiiana/lifestyles, outback 4-wheel drives, outdoor skills, high-altitude trekking, “eco” air tours. Expenditures in Hawai‘i increase as a result of these activities. For example, in addition to the decision to take a flight or stay in a hotel in an area near forested land in Hawai‘i, tourists purchase food to take on a hike or visit a forested area, pay park user fees, purchase books and outdoor equipment, rent cars, hire downhill bike companies, or go on mule rides.

In August, 1994, using surveys of nature-based operators, DBEDT estimated that a total of $413.2 million per year was received as direct expenditures to non-profit operators and organizations ($6.0 million/yr) and for-profit operators ($407.2 million/yr). This represents 4.8% of total visitor expenditures in Hawai‘i for 1993.[49] Note that this figure does not include parks or expenditures on products or food. If one-fifteenth of these expenditures are based on assets of the Ko‘olaus, then the net present value of direct revenues, even with no growth in such tourism, would be $1.0 billion dollars.

Ecotourism in Hawai‘i may not yet have reached its full potential. **The global growth rate for ecotourism is about 20% per year** (Sherman, 1990). The market for ecotourism is considered to be one of the fastest growing sectors in the tourism industry. Comparisons to Costa Rica’s economy, where eco-touring is now the number one earner of foreign capital and was already generating $700 million per year in 19xx, indicate that the potential for ecotourism in Hawai‘i could be big business. Similarly, the economy in the Galapagos islands in Ecuador, often compared to the Hawaiian Islands because of the unique evolution of distinct species in isolated archipelagos, (Loope et al., 1988) is almost entirely based on ecotourism.

2.2.2.10 Climate Control/Atmospheric Gas Regulation.

The buildup of several trace gases in the atmosphere, especially CO_2, is expected to lead to substantial warming over the next few decades and beyond. This warming will cause sea levels to rise and precipitation patterns to change (See Fankhauser). Deforestation, mostly tropical, is one of the primary causes of these emissions and is estimated to account for 1/5 to 1/2 as much as the burning of fossil fuels. (Postel and Heise, 1988; see Adler, Fisher, Hanemann article.)

Reforestation and maintaining existing forests are effective ways to offset CO_2 levels. Businesses have increasingly invested in carbon storage by purchasing land for protection from clearing as an alternative to installing pollution control devices. This is essentially a defensive expenditure reflecting the value of the forest as carbon storage. It is estimated that this may be a $5–10

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[48] Based on Ecotourism Society definition.
[49] Ecotourism Opportunities for Hawai‘i’s Visitor Industry, Prepared for DBEDT, Office of Tourism by the Center of Tourism Policy Studies, School of Travel Industry Management, UH at Mänoa, December, 1994.

billion per year industry in future, twenty-five current projects generated $45 million for conservation and reforestation (US World and News Report, xxx).

Though limited in land area, Hawai‘i’s role in climate control may be sizeable due to its reefs and tropical forests. With about 1,715 million hectares of natural forests in the tropics worldwide (Kramer et al, 1995), Hawai‘i’s 0.89 million hectares only represents 0.05% of the world’s tropical forests. **One study has estimated that replacing the carbon storage function of all tropical forests would cost an estimated $3.7 trillion dollars** (Panayotov and Ashton, 1992). Hawai‘i’s portion of this would be $1.85 billion**. The 97,760 acre Ko‘olau conservation district would account for $82.2 million of this total.** The emissions from the active volcanoes on Hawai‘i, however, are likely to make Hawai‘i a net contributor to atmospheric pollution, regardless. However, unless the rate of tropical deforestation in less developed countries slows, Hawai‘i’s contribution may continue to grow. A market estimate of the value of these benefits may be directly possible if global carbon trading emissions become a successful endeavor.

2.2.2.11 Additional Ecosystem Services and Forest Benefits

Several benefits derived from forest ecosystems are not directly valued in this study. They are described in Table 2.2, along with examples of how one might calculate estimates for Hawai‘i and examples of values from other places.

Table 2.2: Other Forest Ecosystem Services

Examples of Other Forest Ecosystem Services	Description of Services	Examples and Indicators of Value
Cultural and Spiritual Practices	*Hälau hula* (hula groups)/lei makers perpetrate Hawaiian traditions and educate others about cultural practices and how to use plants for medicinal or religious purposes. Trees such as ÿöhiÿa lehua and koa have *mana* (spiritual value)	Numbers of users. Collected plants feathers, nuts and oils.[50]
Cultural Commercial Goods	Native Hawaiians collect ornamental plants (e.g., use of palapalai, maile, liko) and feathers to sell	Lei industry and trade, nuts, oils, meat, and cloth.
Air quality and Urban Ecosystem Benefits[51]	The planting of trees reduces particulates in the air. Cleaner air reduces health care costs.	Planting 500,000 trees in Tucson is projected to save 1.4 million dollars in avoided costs on average each year
Pollination	Lands filled with plants and trees allows for insects and birds to act as pollinators for the plant species. Pollination induces flowering so that plants can reproduce.	Estimated to be worth $4-6 billion/year in the U.S.
Disturbance Regulation	Reduced water runoff during high rain events, flood control, expedited use of land covered with lava	Flood control costs

[50] Hawaiian Conservation Values and Practices, Burrows.
[51] Ecosystem Services: Benefits supplied to Human Societies by Natural Ecosystems, in the Issues of Ecology series. Contact Public Affairs Office 2010 Massachusetts Avenue, NW, Suite 400, Washington DC 20036, 202 8338773, esahq@esa.org.

Absorption of Particulates and Light	Forests absorb particulates and light so that activities, such as space research using telescopes, can be more effective	Telescope industry on Big Island
Pest control	Provide habitat for birds, insects and other life forms that control agricultural pests. In the U.S., 99% of potential crop pests are controlled by natural pest enemies (birds, spiders, parasitic wasps, flies, lady bugs, fungi, viral disease).	It is estimated that this saves U.S. farmers billions of dollars each year.

2.2.2.12 Ko'olau Area Summary and Conclusions

Table 2.3 summarizes the forest amenities given preliminary values in this study. Note that these are values for the entire supply of the environmental service. Net present values are calculated using 3% and 1% social discount rates respectively for the ranges. The lower bound estimate of the net present value of the resource is $7.444 to $14.032 billion. Several valuable amenities, as described in Table 2.2 above, are not even included in this study. When more than one method is used to value the same impact, the lowest value for Hawai'i is used. For the total valuation, only compatible services are summed. For example, the $238 million of standing koa is not added to the value of the forest amenities but provided as a comparative estimate.

Table 2.3: Estimated Net Present Value (NPV) for Ko'olau Forest Amenities

Amenity	Estimated Net Present Value (NPV) for Ko'olaus	Important limitations
Ground water quantity	$4.57 to $8.52 billion NPV	Optimal extraction assumed.
Water Quality	$83.7 to $394 million NPV	Using averted dredging cost estimates.
In-stream uses	$82.4 to $242.4 million NPV	Contingent valuation estimate for a single small fish species.
Species habitat	$487 to $1,434 million NPV	Contingent valuation estimate for a single bird.
Biodiversity	$660,000 to $5.5 million	Average cost of listing 11 species in Ko'olaus.
Subsistence	$34.7 to $131 million NPV	Based on replacement value of pigs hunted
Hunting	$62.8 to $237 million NPV	Based on fraction of hunting expenditures in state. Does not include damages from pigs to the other amenities.
Aesthetic Values	$1.04 to $3.07 billion NPV	Contingent valuation; Households value open space for aesthetic reasons.
Commercial harvests	$0.6 to $2.4 million NPV	Based on small sustainable extraction of koa
Ecotourism	$1.0 to $2.98 billion	Based on fraction of direct revenues to eco-tourism activities
Climate control	$82.2 million	Based on replacement costs of contribution of all tropical forests to carbon sequestration.
Estimated value of joint services:	**$7.444 to $14.032 billion**	

The net present value per acre for the conservation district is estimated at between $76,146 and $143,535.The annual stream of benefits from the conservation district is approximately $165.23 million, or $1,690 per acre.

2.2.2.13 Policy Implications

These calculations indicate that management expenditures of $1–2 million dollars, as suggested by the Department of Land and Natural Resources, Division of Forestry and Wildlife,[52] would represent only 0.6–1.2 %of the resource value per year. Should these management expenditures result in the prevention of scenarios such as the combination of urban creep, *Miconia calvescens* and feral ungulate activity described as resulting in an 41 MGD recharge loss, one would save an estimated $59.2 million. This $59.2 million figure is reached by assuming the following:

- Decrease in groundwater quantity value of $26 million per year;
- Decrease of water quality value of $750,000 per year;
- Decrease of species habitat resulting in a 75% chance of species extinction for one native stream species and one native bird, with an expected value of $12,450,000;
- No net measurable change in hunting, subsistence, carbon sequestration or aesthetic values;[53]
- Decrease of $23,800 of koa harvest due to habitat loss;
- Decrease of one-third in eco-tourism revenues due to loss of habitat diversity, with a value of $20 million.

Thus, the benefit-cost ratio for $1–2 million spent annually on the prevention of such deterioration in forest quality would be between 29.6 and 59.2, well above the social return for many public projects. **When the irreversibility of such changes are taken into account as well, the pay-off even from millions of dollars of expenditures in forest quality maintenance will still generate a significant return for the state of Hawai‘i.**

2.2.3 EAST MAUI

2.2.3.1 A Comparison of Resources

East Maui forests provide several important ecosystem services. The East Maui watershed is the single largest source of surface water in the state. Of Hawai‘i's rare, threatened and endangered species, one third are found only on the island of Maui. Some of the most intact and extensive native forests left in Hawai‘i today occur in the Windward East Maui watershed. The Windward East Maui watershed supports the State's largest concentration of endangered forest birds.

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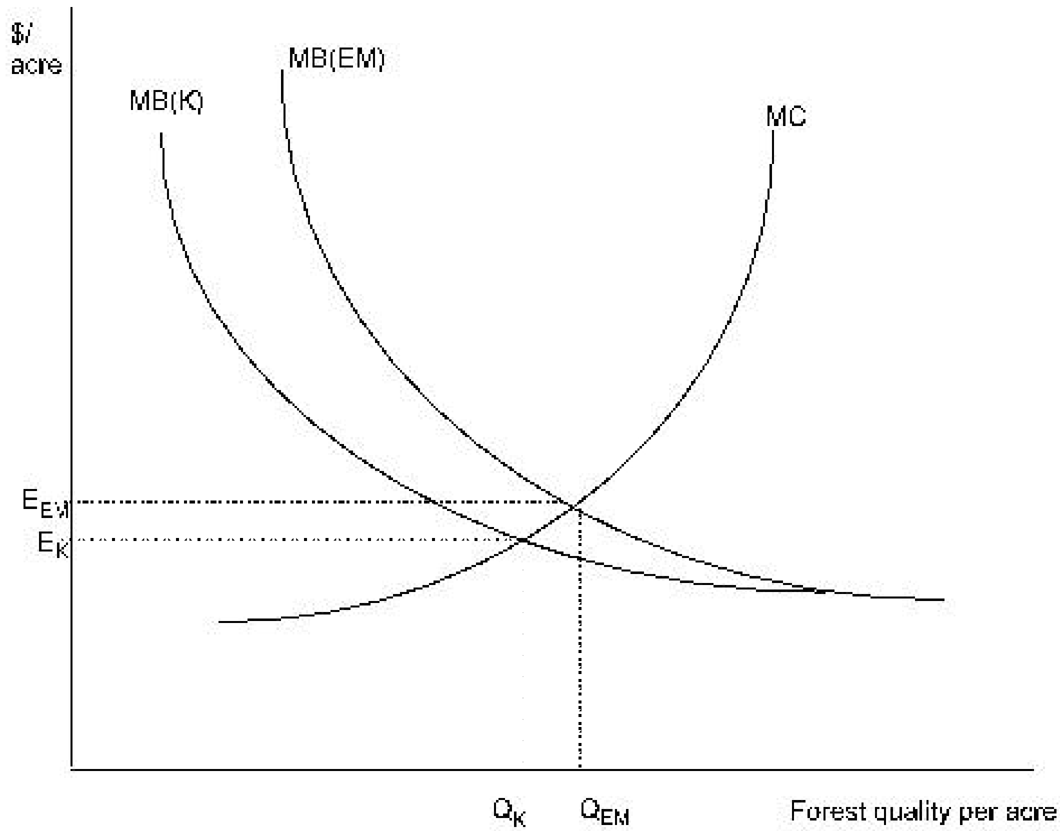
[52] Mike Buck, personal communication, Ko‘olau Watershed Partnership Meeting, July, 1998.

[53] While the increase in pigs might increase hunting and subsistence values somewhat, and the uniformity of *Miconia calvescens* stands might decrease aesthetic values somewhat, the net effect is assumed to be negligible. The replacement of current vegetation cover with *Miconia* is also assumed to have no impact on carbon sequestration.

In contrast to O‘ahu, Maui relies primarily on surface water supplies that are collected by ditch systems. While Maui receives a lot of rain, droughts are common and there is much less significant ground water storage area to draw on when surface supplies dry up (EMWP). Forty-eight streams originate in the East Maui watershed, 35 are perennial and 13 intermittent. This watershed produces an average of 60 billion gallons/year, or 164 MGD, of surface water. Only about 20% of Maui's water consumption is from groundwater, while on O‘ahu this figure is closer to 90%. Thus, the even flow of water from the forest, and the quality of that water, may be even more valuable per unit of water than they are on O‘ahu. Threats to these amenities may thus merit greater levels of expenditure for prevention or mitigation. Figure 2.5 shows this concept graphically.

Figure 2.5



MB(K) = Marginal Benefit of increasing/maintaining the forest quality in the Ko'olaus
MB(EM) = Marginal Benefit of increasing/maintaining the forest quality in the East Maui Watershed
MC = Marginal cost of increasing/maintaining the forest quality of Hawai'ian rainforest
E_{EM} = Efficient level of expenditure per acre on forest quality in East Maui Watershed
E_K = Efficient level of expenditure per acre on forest quality in Ko'olaus
Q_{EM} = Efficient level of forest quality in East Maui Watershed
Q_K – Efficient level of forest quality in Ko'olaus

Note that this graph explains forest quality benefits and costs from the perspective of water flow and water quality. For example, the marginal costs might be costs of fencing off an acre to keep out pigs or other ungulates. These fencing costs will increase as more and more difficult terrain is fenced. The marginal benefits stem from available, cleaner water in this case. As the potential limitations to the water supply from drought or the costs of treating water decreases with higher levels of forest quality, so do the marginal benefits from increasing forest quality further. In this case, though the water from the Ko‘olaus supports many more people than that in Maui, the marginal benefits could still be higher, as drawn in Figure 2.1, if groundwater supplies are not threatened on O‘ahu by the activities which threaten forest quality.

Forest quality is also very important for species habitat in East Maui; again, probably more so than the Koʻolaus because of the relatively undisturbed nature of much of the watershed. This watershed is home to 12 native birds as well as native insects, snails, and other invertebrates; many of these are endangered. Because benefits to species habitat accrue both locally and globally, higher expenditures per acre may again be warranted for the protection of species habitat in East Maui than in the Koʻolaus, regardless of local population levels. Figure 2.1 may then be interpreted in the same manner as it was for forest quality benefits to water.

The efforts and investments by private and public interests to preserve these demonstrate the extent of the value of the watershed to Maui. A group of six federal, state, county, and private landowners, was established in 1991 to manage 100,000 acres. A $2.4 million fencing project put in 50 miles of fence, keeping several thousand acres free of havoc-wreaking feral pigs.[54]

The introduction of non-indigenous plant species, such as the invasive plant *Miconia*, threatens ecosystem services in the East Maui watershed. The also causes forested watershed benefits to deteriorate. While *Miconia* has not yet taken over the forest, it can spread rapidly and kills maile, ÿöhiÿa lehua and most other plants by covering them in dense shade and thickets of seedlings. This single plant, *Miconia,* now infests over 70% of Tahiti's native forests though it was introduced only in 1937. There is great cause for alarm because species that are invasive elsewhere are likely to be invasive in Hawaiʻi.

Approximately 900 acres have been treated to eradicate *Miconia calvescens* in the East Maui watershed. This investment will be worth only a stay of a few years if it is not followed up by monitoring and further eradication because of the seed bank properties of the species.[55] Making investments now are especially important because there is a lag in time between the introduction of alien plant species, when the species can be controlled, and establishment of the species, when it is too late to control or prevent ecosystem destruction. Thus these current efforts allow water supply beneficiaries to avoid substantial costs in the future and will reduce the likelihood that non-native species will take hold and cause watershed deterioration.

2.2.3.2 Summary and Policy Implications

Roughly the same size, the East Maui watershed is perhaps of even higher value than the Koʻolau conservation district. In both cases, the most valuable aspects of the forested area are shown to be eco-tourism, aesthetic pleasure, species habitat, water quality and water quantity. Species diversity and native habitat are present on a greater scale in East Maui, indicating that the values may be greater as well. Water quality also may be more valuable since Maui uses significantly more surface water than Oʻahu.

In both, hunting, subsistence, and commercial harvests may have the most visible pay-offs to the local population but their overall values are dwarfed in comparison to the ecosystem services provided indirectly by the forest's health. The continued protection of these assets is worth

[54] See Chapter 5 for details.
[55] See Chapter 5 for details.

considerable public attention and expenditure. There are two levels of political conflict and human nature which make this task difficult. These are:

1) Conflicts between land owners and land users
2) Conflicts between types of users.

The first conflict is perhaps more clearly resolved in favor of both parties than the second. Providing land owners with a decentralized incentive mechanism to manage their land for the multiple uses from which society benefits requires an understanding of those assets and methods for protecting and enhancing them. For instance, since water quality is a valuable benefit from the forest, land owners should perhaps be rewarded financially for supplying clean water. This could be implemented through a monitoring system that either subsidized clean water or taxed water polluted above a certain level of acceptability, determined by setting the marginal cost of getting the water slightly cleaner equal to the marginal benefit of the slightly cleaner water.

The second conflict requires land users with differing levels of personal benefit from the resource to agree on the best use of the land. This is extremely difficult in part because it involves future generations who are not even able to come to the bargaining table at this time. This aspect of the controversy is shown in the large value discrepancy between a small difference in the choice of discount rate. A low discount rate like 1% will enhance the position of future generations.

History's lessons: Threats and Loss of Forested Land in Hawai'i

The decline in native forests began with the arrival of Polynesians about 1500 years ago. Many lowland forests were burned, cleared, and converted to agriculture or dwelling space. Environmental change accelerated after western contact and extended to highland forests. Trees were harvested as raw materials and were cleared to make room for agricultural, industrial, urban, and suburban areas. As observed in the early 1900s, "the rapidity with which the native Hawaiian forest can be absolutely destroyed is truly remarkable and peculiar to the islands." Dense forests were wiped out in 5–10 years (General Description of the Hawaiian Forests. A Report of U.S. forester E.M Griffith (Assistant Forester, Bureau of forestry, USDA) on Hawaiian Forests, presented at Yokohama, Japan, on March 5, 1902). It is estimated that only a few pockets of pristine native forests still exist (HNIS in the US, 1992).

Goats, cattle, sheep and other ungulates were introduced and multiplied rapidly after Captain Cook arrived in the islands in 1778. These animals root up, eat and trample forest undergrowth and cause erosion and forest deterioration, particularly in native forests. Feral animals also spread and create seedbeds for invasive weeds that diminish native animal habitat and survival, displace economically or culturally important plants, and change the quality of forested land.

As Hawai'i has become a major travel destination and shipping hub, many non-indigenous plants, insects, arthropods, and other biological species arrived by ship, aircraft, or by mail, both intentionally and accidentally. Native forests are particularly at risk once non-native plants are introduced because they are often unable to out-compete invasive plants. These impacts are described in more detail in section 3.4 below.

These land use changes have reduced forested land in Hawai'i—the acreage of all native forest ecosystems has declined dramatically since human contact. Reforestation has increased the total acreage of forested watershed areas and many of the associated forest ecosystem services. Yet replanting does not replace the benefits of native forests. In addition, even the prevention of further forest degradation would probably not be enough to preserve what exists now because grazing, browsing and rooting animals and invasive weeds, insects, and other non-native biological forces have become established and are able to spread themselves (Stemmerman, 1989).

These declining trends have long-term implications for the conservation of island biota and the associated ecosystem services. Conservation biologists have concluded that functioning forest systems cannot be preserved by creating a reserve around a forest that is healthy today because. Hawaiian rain forests have a cycle of dieback and regeneration. The dieback stage is a weak link in the life cycle of plants in some parts of Hawai'i. Thus "it is essential that a reserve include an area large enough to contain all the rain forest life cycle stages , and that there be reserves on all islands representing all the successional stages" (Gerrish, 1989).

2.2.4 LÄNA‘I

The forests of Läna‘i are significantly different from the other islands described in this analysis. They are mainly dry land forests, and even more rare than the rainforests discussed above. The smaller land area shows the effects of forest quality change even more rapidly than O‘ahu or Maui. The island has experienced a significant amount of land-use change through agriculture[56] which has already resulted in a decrease in the island's ability to provide fresh water for itself.

The island receives significantly less rainfall, around 30–40 inches per year versus highs of 250–400 inches for O‘ahu and Maui respectively. Fog-drip has played an extensive part in recharging both surface and ground water sources. The population growth of the island is already limited by the water supply. As a small island, it may also depend more upon the quality of its reefs for both subsistence and tourism values. Both Mänele Bay and Hulopo‘e Bay are designated as Marine Preserves and are highly valued for their recreational opportunities. Thus, water quality enhancement will have significant positive values.

Axis deer, purposefully introduced in the early 20th century, have created the kinds of disturbance to the forest that were discussed as hypothetical for the other areas, laying waste to forests and replacing them mainly with grasslands. The presence of goats, cattle, and Moulon sheep has exacerbated the problem. These changes in forest quality are perhaps similar to the changes experienced in the Ko‘olaus through the introduction of free-roaming cattle throughout the 18th and 19th centuries. The benefits from improving the forest quality on Läna‘i should be significant given that there are still several rare species present on the island, including the native gardenia and sandalwood which are only present on Läna‘i.

Läna‘i has a further advantage in location if it is to be used for the preservation of dry land forest habitat. Because population levels are lower,[57] trade is lower. Thus, the rate of species introduction is potentially more manageable. For example, of the 13 most problematic introduced plant species in Hawai‘i,[58] only 6 are deemed present and uncontrollable, while the figure is 9 for O‘ahu and 11 for Maui. The quick-spreading and destructive *Miconia calvescens* has not arrived. However, the destructive species currently present already have significantly altered Läna‘i's forest ecosystems. Dryland forest preservation on the island will require swift and thorough action in the immediate future.

The benefits of Läna‘i's forests accrue to a much smaller local population base, and the species habitat, while important, is unlikely to outweigh the diversity of East Maui. There are certainly significant global values to the forests of Läna‘i but the estimated benefits are unlikely to look as high as they are for the Ko‘olaus. The land may be one which can be developed for global values with little resistance from local values if a resolution to the positive local values accrued from deer hunting which conflict with the global values for species diversity, native habitat, and reef quality can be found. This should be the main focus of policy efforts on the island.

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[56] 16,000 of 89,000 acres in pineapple cultivation at one point
[57] Currently about 2,800 people.
[58] See Chapter 5 for details.

2.3 CASE STUDY: BEACHES

2.3.1 BACKGROUND

Sandy beaches provide many ecosystem services that support Hawai‘i’s economy. Beaches provide commercial, recreational, cultural and subsistence ecosystem services. Beaches also provide habitat for animals such as crabs or turtles, including the endangered hawksbill turtles that nest on beaches like south Maui, and habitat for about 25% indigenous, non-endemic Hawaiian plant species. Beaches also enhance property values, are critical for flood and erosion prevention, and protect property from storm waves. Beaches are primarily recognized as the backbone of the state’s $11 billion dollar tourist industry[59] and are perhaps the islands’ main tourist draw. Although it may appear that Hawai‘i has an abundance of sandy beaches, there are significant threats to their health, accessibility, and availability.

2.3.2 ECOSYSTEM SERVICES AND INDICATORS OF ECONOMIC VALUE

Among the six main islands, there are 24.4 miles of safe, clean, accessible and generally suitable-for-swimming sandy beaches and 184.9 additional miles of sandy shoreline (Databook, 1995, Table 7.42). Valuing these beaches is essential to the decision-making process, especially with regard to investment (in terms of protection, nourishment, etc.) to offset physical depreciation or degradation.

The value of Hawai‘i’s beaches cannot be easily nor directly calculated by any standard accounting procedures. Beaches of Hawai‘i are, with rare exception, freely accessible to the public and are not traded in markets. In addition, the value of each service provided by the beaches must be estimated by methods appropriate to the valuation of that service. The total economic value of the beach is the sum of all the recreational, commercial, cultural, ecological, and subsistence benefits. Estimating all of these values is a monumental task. At best we can estimate the values of the most important services provided by beaches with the understanding that the sum of these values will not accurately reflect the true value of the beach but will give an indication of the relative economic importance of this natural resource. This section will focus on the value of services associated with recreational uses—perhaps the easiest value to estimate.

Examples of recreational ecosystem services, which are often related to commercial activities and attract many tourists, often can be described qualitatively and/or quantitatively. Hawai‘i’s recreational beach opportunities are myriad and include sun bathing, walking, bird watching, whale watching, and running. Beaches also support and provide easy access to the ocean for swimming, surfing, diving, snorkeling, scuba diving, parasailing, windsurfing, sailing, kayaking, and canoeing. Hawai‘i’s recreational beach opportunities are unique because they are complemented by Hawai‘i’s warm climate and water temperatures as well as the unique biological communities, such as dolphins that can be seen year round or humpback whales that can usually be seen for several months each year.

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[59] HVCB reports show total visitor spending to have been 10.77, 10.685, and 11.444 billion dollars in 1997, 1996 and 1995 , respectively. 1997 marked the all time high for visitor spending in Hawai‘i.

One indicator of the importance of beaches to the economy is simply the number of users. Table 2.4 lists the attendance for various Honolulu beach parks in 1997.

Using beach attendance as an indicator tells us only half of what we need to be able to determine the market value, the quantity multiplied by the market price. Using the market value as the indicator of the value of the beach is no better, even worse, since a zero price would mean beaches are worth nothing. Knowing that 20 million people went to the beach last year and incurred some expenses in order to do so tells us that the true value of a beach visit cannot possibly be zero. This is widely recognized as a reason why GDP, or GSP, estimates do not provide exact measures of a society's economic welfare (see discussion in preceding sections). In interpreting such indicators, it is imperative that one be aware that there is a difference between GDP and the true social welfare and that difference is going to be greater the more that unpriced goods and resources are significant to that economy.

Table 2.4: City And County of Honolulu Estimated Beach Attendance

1997 Beach Attendance			
Ala Moana	1,601,313		744,768
	9,536,234	Ke Waena	344,628
Hanauma	2,207,953	Waimea	884,776
Sandy	514,349	Ali‘i	440,497
Makapu‘u	198,115		513,673
Bellows	101,829		408,269
Kailua	579,719		605,453
Kualoa	115,506		574,024
	231,500	Yokohama	230,476
Sunset	716,912	Depots	107,700
Total: 20,658,804			

Source: City & County of Honolulu, Dept. of Emergency Services, Ocean Safety Division. Attendance based on headcounts taken at about 2-hour intervals by Water Safety Officers over an 8-hour work-day at guarded O‘ahu beaches.

The true economic value of any good or service, including beach recreation, is what one would be willing to pay. Of course, one need not always pay what he is willing to pay and will happily pay a lower market price. The willingness to pay shows us the true value of a good. The difference between what individuals are willing to pay and what they actually pay is referred to as consumer surplus. For recreational beach services at public beaches, the entire economic value of the beach recreation is consumer surplus.

Determining the willingness to pay for a good or service is usually done by considering how quantities consumed vary with changes in the prices since consumers reveal their preferences in their reactions to price changes. For public beaches, where the price is fixed at zero, the willingness to pay must be estimated by alternative methods. One may consider the costs of going to the beach and see how beach attendance varies with those travel costs. Or one may simply ask beach goers how much they would be willing to pay.

Two alternative methods have been used to estimate the value of O‘ahu’s beaches. But before discussing them it should be noted that the values presented are measures of consumer surplus that are not directly comparable to market values. Nonetheless, these measures of value are just as real as market values.

A 1972 study by James Moncur estimated the recreational value of each of 11 “super park” areas on O‘ahu.[60] A survey of local residents collected respondent zip codes and the number of visits to each recreational area.[61] The travel cost, or ‘price,’ of going to the beach was approximated by using a constant cost per mile multiplied by the distance between the respondent’s zip code area and the park which they visited. With this information, Moncur derived demand functions for each beach to arrive at an average willingness to pay per visitor occasion. The values ranged from $1.36 per day at Ala Moana Beach Park to $5.34 per day at Kailua Beach Park.[62]

There was, and still is, some debate about the use of a travel cost method for valuation of recreational sites when the distances are very short.[63] Moncur, though, demonstrated that methods used for estimating distances for longer trips had to be redefined to capture the variability of the distances traveled by resident beach-goers.

The U.S. Army Corps of Engineers estimated the value of Waikïkï Beach at $5.48 per day visit in its September 1991 report. This result was obtained by using the Corps’ unit day value (UDV) methodology. The UDV method relies on expert opinion to assess the value of a recreational site according to the Guidelines for Assigning Points for General Recreation (Table 6-29, ER 1105-2-100, attatched as Appendix 2.6). The experts assign points according to the criteria in Table 6-29 and assign a point total for which there is a corresponding average willingness to pay for the recreational benefits of a given recreational area.

Waikïkï received a score of 53 out of 100 from a panel of four experts.[64] The generality of the guidelines, though, makes the point assignment entirely subjective and the expertise of the panel seems to be irrelevant to some of the criteria. Even more, the importance of each site characteristic is likely to vary with the particular type of recreation area but the distribution of points does not. The Corps itself is wary of the UDV method and recommends its use as a last resort. This criticism of the UDV method is not to entirely dismiss the estimate provided but to see what value the measure fails to capture.

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60 The “super-park” areas were Ala Moana, Waikïkï to Hawai‘i Kai, Hanauma Bay, Sandy Beach & Makapu‘u, Waimänalo & Bellows, Kailua, Kane‘ohe to Lä‘ie, Püpükea to Mokulë‘ia, Yokohama to Nänäkuli, Barber’s Pt. To Sand Island, and Keäiwa Heiau.

61 The survey question asked only about the beach visits in the two weeks prior to the survey.

62 All of the values from earlier studies have been adjusted to 1998 dollars.

63 See Penning-Rowsell, Edmund C., C. Green, P. Thompson, A. Coker, S. Tunstall, C. Richards, and D. Parker (1992), *The Economics of Coastal Management: A Manual of Benefit Assessment Techniques*.

64 The 4 experts were a coastal engineer, a civil engineer technician, an environmentalist and an economist.

While $5.48 is greater than the day use values estimated by Moncur, it may understate the value by not considering differences in the types of recreationists. (Moncur's survey only estimated residents' average willingness to pay.) The total recreational value of the beach would be the sum of all beach goers' individual valuations, which are certain to differ across persons, some of whom are residents and others tourists. The subjective nature of the criteria in the Army Corps of Engineers' guidelines would be certain to elicit different scores when assessed from a visitor's perspective versus that of a resident. The guidelines include criteria for recreation experience, availability of opportunity, carrying capacity, accessibility, and environment.[65] The criterion for recreation experience assigns more points for areas with high quality activities and defines high quality activities as those not common in the region. While the beach experience is common to residents, for the tourist it represents a high quality activity since it is less common to her. The availability of opportunity is a characteristic that gives individual beaches on O‘ahu zero points since there are many other beaches and they are all within a one hour travel time. Travel time to alternative destinations is valued differently by tourists and locals since tourists spend a limited amount of time on the island; time which they are less likely to spend in searching for and traveling to alternative beaches on the island. The environmental criteria which allots points according to aesthetic quality is likely to be judged more favorably by tourists who are less familiar with the less visible environmental amenities of the beach.

The UDV value ought then to be thought of as a lower bound estimate, one which seems to approximate the resident values estimated by Moncur. For tourists, the day use value of the beach can be expected to be significantly higher than that of a resident.

Using the day use values estimated in the two studies of O‘ahu beaches and the beach attendance data above, we can calculate **the 1997 flow of value generated by the beaches of O‘ahu.** Using Moncur's estimates, the value was **$86.6 million**; the Corps' UDV shows a value of **$113.2 million**.

Studies of recreational value elsewhere provide us with some estimates to which we can compare the above estimates and also introduce some different methodologies with which we can attempt to evaluate the difference in tourist and resident demands.

Bell & Leeworthy (1991) used a travel cost method to estimate the willingness to pay for tourists who had visited beaches in Florida. The methodology was similar to that used by Moncur but focused on tourists who face costs much higher than the actual transportation costs so the total trip cost, including transportation & lodging are included as travel costs. It is obvious that this will lead to much higher estimates but is clearly justified by the fact the beach-goer reveals this preference by their willingness to incur the additional expenses associated with getting to the beach.

The Florida study was much more comprehensive than either of the studies on O‘ahu's beaches. The study surveyed 826 tourists over the course of a year. Each respondent was asked about the beaches they visited during their most recent visit and other visits in the previous 12 months.

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65 Table 6-29 is attached as Appendix 2.6.

Besides providing the number of times they visited each beach mentioned, respondents rated each beach on a variety of beach characteristics, including congestion, water quality, and appearance. The survey also collected data for various categories of expenditure related to the beach trip. Age and income characteristics were also collected to be included as determinants of demand.

In the estimation of the willingness to pay, accounting for the effects of all relevant variables is necessary in order to come to an unbiased estimate. Bell & Leeworthy estimated an average tourist's willingness to pay at $53.20.[66]

Using the Bell & Leeworthy estimate for tourist beach days and the Moncur or Army Corps estimates for residents, the annual recreational value of the beach becomes **$694.1 million** or **$704.7 million**.[67]

In another paper the same year, Bell & Leeworthy[68] estimated the value of beach use for residents and nonresidents. The methodology was similar, following a travel cost method. The results were day use values of $16.74 and $47.98 for residents and nonresidents, respectively. Using these values the total annual value of O'ahu beaches is **$733.1 million**.[69] The authors compare their values to those obtained by a contingent value method used in another Florida study by Curtis and Shows. The day use values of Curtis and Shows are more comparable to the resident values previously mentioned. They explain that the differences can be accounted for by the bias associated with the contingent value approach used by Curtis and Shows. The contingent value method uses survey data in which respondents are asked hypothetically how much they would be willing to pay. The bias is obvious as respondents refuse to reveal their willingness to pay out of suspicion that such information might lead to usage fees being imposed.

And in a third paper that year, Leeworthy and Wiley (1991) estimated day use values for Island State Park in Central New Jersey; their estimate of consumer surplus per day ranged from $29.61 to $105.52. Here the authors were careful to note that the extreme measures were a result of sensitivity to functional form.

While there are other alternatives, all of the beach studies surveyed in this research have used either the travel cost method or the contingent value method in the determination of recreational value.[70]

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66 A value associated with a price elasticity of -0.15 and income elasticity of 0.37.

67 These values assume a 60/40 split for tourist/resident beach attendance. While this figure may not be reasonable for beaches like Waimänalo, it is clear that the most attended beaches are those dominated by tourist visits (Waikïkï, Hanauma Bay and Ala Moana). Those beaches account for 65% of all beach attendance at O'ahu's guarded beaches. Hanauma Bay turnstile records show resident attendance accounting for less than 15% of the beach attendance there. The split seems reasonable but is subject to debate which emphasizes the need to collect more data on beach attendance with respect to the tourist/resident split.

68 Bell & Leeworthy, 1991, An Economic Analysis of the Importance of Saltwater Beaches in Florida.

69 Given the same assumptions regarding the percentage of tourist and resident attendance.

70 The Australian Environmental Evaluation Handbook lists other possible methods of evaluation. One of the methods was a proxy value method, where the market value of a close substitute is used to approximate the value of the unpriced good or service. Private beaches charging a day use fee are an easy choice but there are few when one disregards clothing-optional beaches. Another alternative to the beach experience is to experience The Beach, a

Admittedly, using the values generated by studies on Florida or New Jersey beaches is less than ideal for determining the value of Hawai‘i’s beaches but it does give us an idea of the magnitude of the value that we might expect to find through the application of similar methodologies. Expecting higher values for Hawai‘i’s beaches seems justifiable given tourists’ image of beach characteristics here and elsewhere. According to a 1997 Longwoods International survey, Hawai‘i’s beach image versus all other beach destinations is the leader in every respect except affordability and uniqueness where it is second only to Tahiti.[71]

Much of the data necessary to proceed with the travel cost and contingent value methodologies is not publicly available although summary information is available through Hawai‘i State Data Books and Hawai‘i Visitor and Convention Bureau research reports. Summary information, though, is not sufficient for these methods of estimation; individual observations would be required. Even more, there are critical pieces of information that are not available. The number of beach days is absolutely essential and, for the contingent value method, survey respondents would have to be asked about their willingness to pay for the beach visit. The absence of these key elements would require a new survey design that incorporated these questions.

In the spirit of the travel cost method, one might simply determine the number of beach days per trip divided by the average length of stay to find the percent of the trip that is attributable to the beach days and multiple by the average tourist spending.[72] Doing this gives a day use value of the beach of $421.30 with certain assumptions regarding average number of beach days.[73] Even when we assume minimum beach days, just one beach visit per beach-going tourist, the day use value is $186.97. These estimates are clearly very rough. **As mentioned, a more thorough and complete assessment would require that data be collected on the number of beach days for visitors.** Without that information it is unlikely that we can be very confident in the figures that we calculate. The data that is available simply tells if they participated in a beach activity or not and multiple activities could be included in a single trip. Either a revision of present visitor surveys or new surveys to find out how many times the beach was visited would lead to better estimates. **Finding out which beaches were visited and how many times each would allow**

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water park in Ohio. Using an average water park entrance fee as a proxy value for determining the value of the beach, the average for 23 U.S. water parks was $21.42.

[71] Longwoods International, “U.S. 1997 Emergency Fund Advertising Evaluation Benchmark Report,” March 16, 1998. The report listed Tahiti, Jamaica, Bahamas, Florida, and Mexico as beach destination competitors.

[72] Average length of stay and average tourist spending figures from Hawai‘i Visitors and Convention Bureau, “HVCB 1997 Annual Research Report.” By using the averages, these calculations ignore any distributional effects that may exist. Individual observations from the HVCB survey or another survey would be necessary to assess those impacts and arrive at a more precise measure.

[73] This estimate assumes an average number of beach visits is 2.25. This is reasonable considering that Longwoods International survey showed that 26% of Hawai‘i’s visitors designated their trip as a beach trip. We attribute their spending to beach demand. In HVCB’s “1996 Visitor Satisfaction Report,” 88% of U.S. visitors and 77% of Japanese visitors participated in water activities. The survey question only asked if the visitor participated in an activity so the number of visits is unknown. The average number of beach days conservatively assumes that those visitors who need not designate their trip as a beach trip but participated in a beach activity did so only once. The Longwoods study included touring as a trip purpose which could include visiting beaches and part of that demand for touring trips to Hawai‘i would then be attributable to beaches. Assessing the impact of Hawai‘i’s beaches in the decision to travel here is difficult. One might start by first determining what percent of visitors would visit Hawai‘i in the absence of beaches.

for more precise estimates and allow for beach specific estimates which would be valuable in allocation of resources in efforts to preserve and/or improve the quality of beaches.

Reliance on alternative methodologies is necessary given the public good nature of beaches; however, park entrance fees collected at Hanauma Bay Nature Preserve provide explicit cost data along with turnstile attendance figures allowing for an estimate of demand without the assumptions or biases inherent in the alternative methods. Park officials began charging an admission fee of $5 in July of 1995. The fee schedule was rescinded in January 1996 and no fees were assessed until March 1997 when a new fee of $3 was instituted. The design and redesign of the fee schedule was greatly influenced by local politics resulting in residents not having been subject to the admission fees with resident identification.[74] For estimation purposes, this means that alternative methodologies must be used to estimate value by resident beach-goers.

Even though we have price data, the model of non-resident demand for Hanauma Bay beach days is limited by the lack of other determining factors including characteristics of the beach-goer and the park conditions on the day of the visit.[75] The model estimated below uses beach days per month (DAYS) as the dependent variable which is determined by park admission fees (PRICE) and a dummy variable for peak seasons (PEAK).[76] The following demand equation was estimated by OLS regression techniques.[77]

$$\begin{aligned} DAYS = \underset{(17.9)}{70476} - \underset{(-1.2)}{1344}\ PRICE + \underset{(5.3)}{23875}\ PEAK \end{aligned}$$

The price coefficient shows that a one-dollar increase in the admission fee leads to a decrease of 1344 visitors per month. The price coefficient is statistically insignificant though. As discussed, the model is subject to omitted variable bias. The introduction of other determining factors is likely to improve the estimates of the model. There is also some question as to how long it takes visitors to become aware of the price schedule and incorporate that in the decision to visit Hanauma Bay.

Using the present estimates, the price elasticity of demand is –0.033, very close to zero meaning that visitors demonstrate very little responsiveness to increases in admissions fees. This elasticity is calculated at the mean price and only relevant in that price range and is likely to differ at higher prices. This means that the measure of value, consumer surplus, is sensitive to the functional form that is assumed to exist at values not included in the data set.

This demand equation above gives a cut-off price (price at which beach attendance would fall to zero) of $52.43 in non-peak months and $70.20 in peak months.[78] At a zero price, consumer

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[74] See Mak & Moncur.
[75] In Bell & Leeworthy (1991), survey respondents were asked to rate the beach with respect to a variety of beach characteristics such as congestion, cleanliness of coastal waters, adequacy of parking, and physical appearance.
[76] Data is from the Hanauma Bay Nature Preserve Daily Attendance Summaries from July 1995 to December 1997. March to September were designated as peak months.
[77] Numbers in parentheses are t-ratios.
[78] Assuming a linear functional form.

surplus is calculated to be $1.8 million per nonpeak month and $3.3 million per peak months giving an **annual total value of $32.4 million at Hanauma Bay alone**.

While we can determine the beach-specific demand for Hanauma Bay, we must still rely on alternative measures for the value of the open-access beaches. To launch an effort to estimate the value of each of Hawai‘i’s beaches would require a massive effort and the results may be held in question due to perceived biases in the alternative measures.

Improving the estimates for Hanauma Bay would be an important starting point. Since demographic characteristics of visitors and various beach characteristics are needed, a survey be designed not only to get that information but also the information necessary to estimate demand by the travel cost and contingent valuation methods. Comparing the estimates from each methodology will allow for a greater understanding of the biases involved in the alternative methods and allow for better application and understanding when used to determine the values of open-access beaches.

Up to this point, all of the estimates of beach value have focused on *only the recreational value*. Beaches generate a wide variety of services and the value of each recreational, commercial, cultural, ecological, and economic benefit should be included in an estimate of total economic value.[79] Some examples of these benefits have already been mentioned. The omission of estimates of the value of ecological and cultural benefits in this section should in no way be interpreted as an indication of their economic insignificance. Rather those values are much more difficult to determine since additional forms of bias are introduced through scientific uncertainty or subjective bias with respect to culture. Estimates then would be extremely sensitive to subjective assessments of how much of the value of each species or the local culture can be attributed to the beach.

There are reasonable approaches for estimating the value of the beach’s contribution to property protection. Using hedonic regressions, one estimates the portion of the property value that is attributable to the beach and its characteristics, particularly its width. The hedonic regression method, though, does not separate the types of value contributed by the beach to the property owner. That is, some of the increased property value would be due to the protective service provided by the beach and some would be due to recreational or commercial value. Therefore attempting to estimate the beach value created by its protective services by such a method would lead to double counting the recreational or commercial value of beachfront property owners. Alternatively, the value of beach protective services could be isolated by considering the property owners’ insurance expenditures to see how they varied with beach characteristics.

Given the problems associated with the estimation of the value each benefit provided by the beach, even the best case scenario is that the estimate of total economic value will only capture a portion of the true value of the beach. While the estimates are imperfect, they provide an assessment that more reasonably approximates the true value. E**stimates of beach value allow for the rationalization of policy considerations with respect to policies affecting the use**

[79] Existence value should also be included. See Silberman, et al (1992) for estimates of existence value of New Jersey beaches. Existence values are estimated by a contingent value approach.

and preservation of Hawai‘i’s beaches. This is of critical importance when considering the deterioration of Hawai‘i’s beaches and the economic impact that is sure to have on the state economy.

2.3.3 THREATS AND LOSS

Despite Hawai‘i’s numerous sandy beaches, there are threats to this important natural capital that jeopardize the associated flow of ecosystem services. The primary threat to beaches today is that they are eroding and disappearing. This beach loss has been linked to the building of seawalls and revetments. Coastal zone authorities and landowners build walls and revetments along shorelines to mitigate **coastal land loss**. While this technique preserves coastal land property, at least temporarily, recent assessments reveal extensive and negative impacts on adjoining beaches. (Journal of Coastal Research, Fort Lauderdale, Florida, Vol. 13, No. 1, Winter 1997, 209–215: Beach Loss Along Armored Shorelines on O‘ahu, Hawaiian Islands, Charles H. Fletcher, Robert A. Mullane, Bruce M. Richmond.)

Coastal land loss is caused by sea level rises, which may be due to natural or human activities (e.g., global warming due to CO_2 emissions[80]). Sea level rises, measured to be approximately 0.6 inches per decade in O‘ahu (Coyne et al,1996), often cause coastal erosion because beaches naturally migrate landward by eroding coastal upland and releasing sand that is stored in dunes or fossil shorelines to maintain a constant sand supply for beaches. The building of sea walls and revetments interfere with these natural land and sand profile adjustments because dunes on land can no longer share sand with the beach; consequently, beaches erode, narrow, and disappear (Coyne et al, 1996). So attempts to preserve eroding coastal land, which is often valuable private property, can lead to beach loss, which is often a valuable public resource. The private property values are generally accounted for in markets, the public values generally are not.

[80] As discussed in the Forested land case study below, global warming has been caused primarily by human activities.

MAUI: Out of a total of 254 kilometers of shoreline, about 52 kilometers is now sandy beach (Databook 1995). supporting Maui's local economy. Yet sandy beaches are disappearing due to the building of seawalls and revetments. In response to coastal erosion, seawall and revetments have been constructed to protect property. Thirteen kilometers of shoreline are now lined with seawalls. These attempts to stabilize receding shorelines have degraded adjacent beaches and beaches in front of the constructed walls and preconditioned much of the coast to accelerated beach loss in the future (MOESE, 1991 report). During the last 50-80 years, Maui has experienced extensive beach loss and narrowing especially along the west Mäÿalaea Bay coast and the area of north Kïhei to south Kam‘aole. Kahului coast and Lahaina and Kapalua areas face similar problems. Studies indicate that 62% of the beaches are eroding, 24.5% are accreting, and the remainder has stabilized (MOESE, 1991 report).

The building of sea walls to stabilize coastal property lines over long stretches of beachless coast can result in the complete termination of sand supply. In Honoköwai, there is a mile of private property with stabilized shoreline and no beach. North of this area is Honoköwai Beach Park, which is not stabilized but experiences erosion. The building of sea walls at Honoköwai prevents sand deposition at the beach park because former sand sources have been replaced by seawalls. Without this sand, the beach at Honoköwai has no natural replenishment and has eroded away over time. The shoreline at Honoköwai Beach Park contains coral rubble, cinder blocks, and dirt rather than beach. (MOESE, 1991 report).

There are also sites where beach loss has occurred on stabilized shorelines that do not protect any upland development. Three thousand feet of stone revetment fronts Kalama Beach Park, which led to the total loss of the beach, where the nearest upland development is nearly 1,000 feet away from the revetment in some areas. Studies show that the building of additional seawalls and revetments near this area may have a domino effect that is likely to result in the loss of Kihae beaches as well (MOESE, 1991 report).

Another important beach area, Punahoa, has deteriorated due to shoreline stabilization along the Honoapi‘ilani Highway. Beach recession threatens to undermine the highway, so a set of concrete barriers and a revetment have been installed. A wide and healthy beach has been lost in the process. Research shows that in the future, the continuing strategy to protect the highway will reduce sand delivery to neighboring beaches and erosion will accelerate north of the site (MOESE, 1991 report).

Beach values may be threatened by debris, pollution or sedimentation as well. For instance, some of Hawai‘i's beaches, at times, are littered with debris. This may reduce the aesthetic enjoyment that residents and tourists derive from the beaches; debris may also reduce ecosystem services associated with marine organisms—though the effects are not fully known. For example, between April and July, over 5,000 pounds of old fishing nets were pulled in during two community cleanups. (These nets present a danger to marine life like turtles.) Yet debris leftover from ocean activities represent only a small portion of the total debris that washes ashore; an estimated 80% of this debris can be traced to activities on land. During a one day annual Coastal Cleanup in Hawaiʻi, 204,278 pounds were collected; over 63% of this was plastic (it is illegal to dump plastics into the ocean) and almost 30% was cigarette butts. The Coast Guard is the enforcement agency for ocean dumping. Stronger enforcement of laws the prohibit most ocean dumping, education for the resident and tourist populations on the importance of using trash cans, and increased community policing of beaches are among the recommended methods to reduce these problems (*Star Bulletin,* 1998: A-1).

Pollluted runoff in coastal areas, considered the state's worst water quality problem, may also reduce the ecosystem services that are derived from Hawaiʻi's beaches; it also threatens federal funding provided to the state to clean polluted coastal waters. Currently, EPA gave the state one to five years to implement its program to comply with federal requirements. Most coastal pollution is runoff from agricultural lands, urban areas, and dumping sites that deposit fertilizers, pesticide, oils and animal waste into the ocean (*Star Bulletin*, July 9, 1998: A-1).

A California report demonstrates the potential importance of clean oceans and healthy estuarine wetlands to robust economies. It was estimated that 56% of California's $700 billion GSP in 1992 was linked to coastal business endeavors including coastal community tourism business, bird watching, recreational boating, and commercial fishing. The report estimated that 86% of the $32 billion generated by tourists in California was spent in coastal counties; in addition, coastal recreation, port operations, and commercial fishing accounted for 370,000 jobs in the state. Similar to Hawaiʻi, development and nonpoint source pollution, such as runoff from streets, farms and suburban lawns, were identified as the major threats to coastal environments because petrochemicals, fertilizers, pesticides, and coliform bacteria cause beaches to close and fisheries to deteriorate (San Francisco Chronicle, June 28, 1995, citing a Coastal Alliance in Washington, D.C. report).

Pollution and sedimentation also threaten beaches because the may damage the marine organisms that create sand. As discussed in the ocean case study below, coral, coralline algae, and other creatures create calcium carbonate ($CaCO_3$) which gets ground up in the churning of waves and creates sand particles. If growth is slower due to eutrophication, often caused by pollution or sedimentation, there will be less sand over time because fast growing algae soaks up nutrients and shades out light that corals need to grow (Flora, 1994). Note that this threat to beaches demonstrates how different types of natural capital cannot be examined in isolation; the prevention of sedimentation and pollution depends on ecosystem services provided by forests, as described in the case study below, and oceans, also discussed below.

O‘AHU: Generally, inadequate setbacks for development along the coast have resulted in the building of structures that lead to beach narrowing and loss in adjoining beaches. For Lanikai/Waimänalo/Kailua and Mokulë‘ia areas, “greater building setbacks for coastal lots would have reduced the need for shoreline structures and prevented beach narrowing and loss.” For example, before 1971, southeast Lanikai was an accreting beach (it was getting wider). Accreted lands were claimed as private property and development advanced to the legally permitted 40 foot setback. The accretion trend reversed in the late 1970s and property owners armored the coast to maintain their property line. Now, the beaches adjoining the areas with coastal armoring are gradually narrowing and disappearing.

Beach area, O‘ahu	Narrowed beach	Lost beach
Mokulë‘ia (North Shore)	2.1 ± .2 km	.2 km
Ka‘a‘awa Headland (Windward coast)	3.2 ± .3 km	.8 km
Kailua/Waimänalo (Windward coast)	.9 ± .1 km	1.6 km
Mä‘ili-Mäkaha (Leeward coast)	1.3 ± .1 km	.2 km
Overall O‘ahu	17.3 ± 1.5 km	l0.4 ± .9 km

The overall loss of sandy beaches in O‘ahu represents 24% of the original sandy shoreline (there is a total of 115.6 km ± 9.8 km of sandy beach shoreline) (Beach Loss Along Armored Shorelines on O‘ahu, Hawaiian Islands, Charles H. Fletcher, Robert A. Mullane, and Bruce M. Richmond).

2.4 CASE STUDY: OCEAN RESOURCES

2.4.1 INTRODUCTION TO THE SERVICES

Hawai‘i’s marine resources are an extremely valuable portion of its livelihood. Ocean resources are used directly and indirectly, for everything from tourism to subsistence. These uses are listed here according to whether they are commodity (extractive) uses or non-extractive uses.

2.4.1.1 Current and Potential Commodity Uses:

1. Commercial Fishing
2. Sport Fishing
3. Limu, ogo, and other seaweeds
4. ‘Opihi and other cultural gathering
5. Aquaculture and biotech
6. Aquarium fishes and invertebrates
7. Energy Production (OTEC)
8. Coral Jewelry
9. Reef products for medical purposes

2.4.1.2 Current and Potential Non-extractive Uses:

1. Sport diving and snorkeling (See tables)
2. Other boating activities
3. Sand production for beaches
4. Property protection from large swells, tropical storms and hurricanes.

2.4.1.3 Inshore waters

Scuba diving and snorkeling are significant tourist draws to Hawaiian waters, particularly on Maui and Hawai‘i. **Just the night dives to view the Manta rays at Keahou Bay on Hawai‘i may bring as much as $660,000 profit[81] to the dive shops in West Hawai‘i.** The health and quality of the reefs provides the natural capital necessary to sustain this profitable industry.

Hawaiian reefs are unique for several reasons. Brian N. Tissot at the Kalākaua Marine Education Center of the University of Hawai‘i at Hilo has summarized the key qualities that make Hawai‘i’s reefs different.

They are geologically young and therefore not as well developed as other reefs. They are less diverse than other reefs due to the geographic isolation. With smaller reef areas and the absence of lagoons that trap and retain both coastal and terrestrial runoff, Hawaiian reefs are generally more nutrient poor and therefore lack a high abundance of filter feeding animals such as soft corals, sponges, tunicates, and bivalves. As a result, Hawaiian reefs are more clearly dominated by stony corals. The combination of youth and isolation have meant that Hawaiian reefs generally produce less growth in biomass and the species which are present serve more generalized ecological roles. The ecosystem is therefore simpler, and potentially more vulnerable to diseases or other stresses.

The stresses which damage reefs are often highly visible and directly impact tourist satisfaction as well as creating long term impacts which reduce the value of Hawai‘i’s natural capital. Natural stresses occur from wave action, runoff and storms. The combination of these factors has resulted in reefs on Hawai'i, Maui, O'ahu and Kaua'i that are small and occur relatively close to shore. They are generally fringing reefs (exceptions are the barrier reefs of Kaneohe Bay on O'ahu and reefs on the south shore of Moloka‘i). There is a general westward trend towards greater reef development that coincides with the geologic ages of the islands. The effects of wave exposure are that in general more sheltered leeward coasts have reefs with greater coral cover than wave-pounded windward coasts.

Further stresses include reduced salinity and thermal changes from the introduction of fresh water, and siltation and increased turbidity from runoff which has increased significantly, particularly from golf courses which utilize fresh water and chemical treatments to care for the courses. These impacts generally slow coral growth by diverting energy to the removal of sediments or by blocking out the sunlight required for forming $CaCO_3$. A recent study here

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[81] This estimate is based on a phone survey requesting information on the frequency of trips per week, the maximum number of passengers possible, and the price per passenger. From this, estimated revenues were calculated to be $1.6 million assuming operations run at 85% capacity. Boat trips are generally not considered profitable unless the boat is half full, so annual operating costs of the night dives are estimated at $940,000.

showed that highway construction increased suspended sediment loads by 56 to 76 percent in three small (1 to 4 sq. mi.) basins (Hill, 1996). An earlier study determined that sediment yields from construction areas can be as much as 500 times the levels detected in rural areas (National Association of Counties Research Foundation, 1970).

With the steep slopes of many portions of Hawai‘i’s islands, even natural erosion from forests may contribute significant levels of deterioration in water quality. The connections between the quality of the reef and activity on land are immediately visible in Hawai‘i by comparing the reef at Molokini to reefs elsewhere. Molokini has no soil to erode into the water and water quality is pristine. Not only is visibility greater and more consistent at Molokini, but also species appear to grow larger (Flora, 1994). Molokini is an extremely popular dive site, with dozens of boats and hundreds of people visiting virtually every day, even at higher prices than for other boat dives in the islands. Moorings have been installed at an expense of about $600 each to prevent damage to the reefs from anchors. These moorings also have been installed privately at many dive sites in West Hawai‘i by the Mälama Kai Foundation.

The following is a summary of zonation patterns typical of Hawai‘i. (Brian Tissot).

Table 2.5: Zonation Patterns Typical of Hawai‘i

Reef Zonation	Corals	Invertebrates
Reef flat zone (0-2 m)	Corals are generally sparse here and dominated by cauliflower coral intermixed with boulders	This area has numerous boring urchins in holes.
Reef bench zone (2-10 m)	Lobe coral is abundant along with some cauliflower coral, other uncommon corals (e.g., Leptastrea & Pavona) and sand.	Boring urchins, sea cucumbers, numerous snails and Christmas tree worms are common.
Reef slope zone (10-30 m)	Finger coral is the most common species along with lobe coral.	Wana, slate-pencil urchins, sea cucumbers and christmas tree worms are common.
Rubble zone (30-40 m)	This area usually consists of lobe and finger coral rubble sloping into sand.	Sea cucumbers occur here.

As runoff from land activities affects the reefs, the reefs affect the quality of the shore. **Reefs produce the sand that creates beaches and they provide barrier protection from storms and high waves.** White or coral sand is produced by the decomposition of calcium carbonate ($CaCO_3$) that many creatures create in shells, colony structures, or through chemical transformations. In Hawai‘i, stony corals are significantly aided in their production of sand by Halimeda spp., an alga whose leaves calcify into chips about the size of oatmeal flakes, as well as snail shells, foraminifera and other calcifiers. As shown above, both of these tasks are more challenging for Hawaiian reefs that have not had the millennia to develop that many reefs have had. For this reason, man's interactions are likely to have more noticeable effects on the reef and the land environments dependent on the reef. This fragility makes these natural processes more valuable as there is less room for errors which nature could correct independently.

Reefs have extractive commodity values as well. The calcium carbonate structures that coral colonies create as homes are ideal for creating artificial bone for medical purposes. The connective tissue of these colonies contains natural sunscreens that Australian scientists have successfully begun to adapt for human use. Tropical fishes that live amidst the corals are collected and sold for home aquariums. Tropical fish collection removes approximately 225,000 yellow tang from Hawaiian waters each year. Several other species of fish and invertebrates are also harvested, mostly from the island of Hawai'i. The average price paid to the collector per fish removed is about $2, though these fish will sell for much higher prices on the mainland. About 75% of these Hawaiian fishes are directly exported out of state, and local sales include fish sold to exporters, so the true export level is likely higher.

Significant areas for the collection of tropical fishes are: Mäkua, Wai'anae, and Käne'ohe on O'ahu, with 10–25,000 specimens collected from these areas annually; Kona and Miloli'i on Hawai'i, with more than 50,000 specimens collected in each area; and Kawaihae on Hawai'i, with 10–25,000 specimens collected per annum, and southwest Maui, with 25–50,000 specimens collected each year. **Long time divers of the Kona Coast claim significant, visibly noticeable reductions in the levels of tropical fishes in the waters of West Hawai'i.** Whether these are due to unsustainable harvest rates by aquarium collectors or some biological process, natural or not, is unknown. The benefits of tropical collection accrue beyond their financial gain; aquariums and their viewers generate a greater awareness of the marine environment and this awareness may generate greater tourism interest as well as conservation interest. The costs are also higher than depletion of the actual species; tropical collectors often use techniques that damage the reefs in one form or another to collect the fishes. In Hawai'i, the most damaging techniques, such as stunning fish with bleach or cyanide, or dynamiting, are not generally used, but frequently coral heads will be shattered in order to more easily remove species hiding within the branches. These fishes are also food for larger pelagics and other ocean dwellers which we in turn use for food.

Table 2.6 shows data from the DLNR, Division of Aquatic resources, for fiscal year 1994–5. Interestingly, the price per fish collected is significantly higher on Maui than for the other islands. The reason(s) for this anomaly are unknown. The price differences among species indicate that Achilles tang and Potter's angels in particular are either more difficult to capture and keep alive to market or are in higher demand by collectors or both.

Table 2.6: Aquarium Fish Species

List of top 5 species of aquarium fishes/invertebrates collected for the State of Hawai‘i and select islands

	All Islands		Hawai‘i		O‘ahu		Maui	
Species	Number sold	Value per fish($)	Number sold	Value per fish($)	Number sold	Value per fish($)	Number sold	Value per fish($)
Yellow Tang	218830	1.60	176598	1.30			36388	2.99
Kole	22136	1.38	15188	0.95			3298	3.08
Achilles Tang	15856	4.31	11072	3.22			4210	6.89
Feather Duster Worm	12555	1.03			12553	1.03		
Clown tang	11995	3.66	6788	2.94			2172	5.79
Long-nosed butterflyfish			4553	1.95			2282	3.89
Potter's Angel					7061	3.06		
Green Shrimp					5100	0.97		
Hermit Crabs					4877	1.02		
Lemon Butterflyfish					4761	1.03		
Percentage of catch and total value represented by top 5 species	67%	60%	88%	77%	31%	22%	78%	75%

2.4.2 COMMERCIAL FISHERIES

Commercial Fisheries in Hawai‘i contribute about $50 million directly to the Hawaiian economy through the quantity of fish sold. Support for the fishing vessels and their crews will multiply that contribution significantly.

Table 2.7: Commercial Sea Landings, HI, and by island

Commercial Sea Landings, 1995

	Pounds Landed	Pounds Sold	Value (Dollars)	Value ($/ lb. sold)	Percent of catch sold
All Islands	22,989,104	22,077,700	53,528,754	2.42	96
Kaua‘i & Ni‘ihau	841,350	681,666	1,703,643	2.50	81
O‘ahu	17,717,767	17,307,864	44,014,093	2.54	98
	19,373	15,126	35,419	2.34	78
Moloka‘i	64,686	58,853	149,757	2.54	91
Maui	650,077	512,820	1,403,839	2.74	79
Hawai‘i	3,695,851	3,501,371	6,222,003	1.78	95

Commercial Sea Landings, 1996

	Pounds Landed	Pounds Sold	Value (Dollars)	Value ($/ lb. sold)	Percent of catch sold
All Islands	21,875,982	21,061,148	47,772,279	2.27	96
Kaua‘i & Ni‘ihau	684,795	583,224	1,440,763	2.47	85
O‘ahu	16,483,231	16,180,378	38,526,884	2.38	98
	13,378	9,287	21,634	2.33	69
Moloka‘i	71,104	65,944	185,330	2.81	93
Maui	669,048	519,528	1,286,530	2.48	78
Hawai‘i	3,884,762	3,668,240	6,216,580	1.69	94

Source: Division of Aquatic Resources, DLNR, State of Hawai‘i.

Maintenance of these fishery stocks is thus an extremely valuable enterprise. The Western Pacific Fishery Management Council (WestPac), under the authority of the Magnuson Fishery Conservation and Management Act, oversees decision-making regarding Hawai‘i’s fisheries. Limited entry to the fisheries has been introduced to curb over-fishing on certain stocks of pelagics, bottom and ground fish, and precious corals (NMFS 15 CFR Part 902; 50 CFR Part 660, et al. Fisheries off West Coast States and in the Western Pacific; Final Rule).[82]

Hawaiian waters also harbor several species of marine mammals. These marine mammals are protected under the Marine Mammal Act of 1972. Bycatch (species caught or killed along with the main harvest but not generally sold in markets) from fishing for the commercial species such as tuna may only include small quantities of these marine mammals. Though there are many marine mammals in Hawaiian waters, reports of interactions between commercial fishing and these creatures have so far remained low.

[82] See Appendix 2.4 for details on Bottomfish and Pelagics.

Continued care will allow both commercial fisheries and marine mammal stock populations to remain healthy, or, in the case of endangered animals like the Hawaiian monk seal or the Humpback whale, to recover. The following table shows Hawai'i's commercial fisheries along with the estimated number of vessels partaking in the fishery and the species of marine mammals which have reported kills or injuries. The numbers of kills are sufficiently low that all Hawaiian fisheries are classified as Category III, meaning that casualties to all marine mammal stocks from all fisheries are lower than 10% of the Potential Biological Removal (PBR) level as determined by the National Marine Fisheries Service (NMFS).

Table 2.8: Conflicts between Hawaiian fisheries and endangered marine mammals

Commercial Fisheries in Hawai‘i

Fishery description	Estimated No. of vessels/ persons	Marine mammal species/ stocks incidentally injured/ killed
Gillnet fisheries:		
Hawai‘i gillnet	115	Bottlenose dolphin, Hawaiian; Spinner dolphin, Hawaiian.
Purse seine, beach seine, round haul and throw net fisheries:		
HI purse seine	18	None documented.
HI opelu/akule net	16	None documented.
HI throw net, cast net	47	None documented.
Troll fisheries:		
HI trolling, rod and reel	1795	None documented.
HI net unclassified	106	None documented.
Longline/set line fisheries:		
HI swordfish, tuna, billfish, mahi mahi, wahoo, oceanic sharks longline/set line.	140	Hawaiian monk seal, HI*+; Humpback whale, Central North Pacific*+; Risso's dolphin, Hawaiian; Bottlenose dolphin, Hawaiian; Spinner Dolphin, Hawaiian; Short-finned pilot whale, Hawaiian.
Pot, ring net, and trap fisheries:		
HI lobster trap	15	Hawaiian monk seal, HI*+.
HI crab trap	22	None documented.
HI fish trap	19	None documented.
HI shrimp trap	5	None documented.
Handline and jig fisheries:		
HI aku boat, pole and line	54	None documented.
HI inshore handline	650	Bottlenose dolphin, HI.
HI deep sea bottomfish	434	Hawaiian monk seal, HI*+.
HI tuna	144	Rough-toothed dolphin, HI;Bottlenose dolphin,HI; Hawaiian monk seal, HI*+.
Dive, hand/mechanical collection fisheries:		
HI squiding, spear	267	None documented.
HI lobster diving	6	None documented.
HI coral diving	2	None documented.

The potential tradeoff of marine mammal protection for food supply can be used to estimate the value of these marine mammals to society. If citizens of Hawai‘i or the world are willing to pay higher prices for the fish they consume from Hawaiian waters in order to fund expensive fishing technology which allows fewer interactions between fishing vessels and marine mammals, then the sum across consumers of the differences in price between “dolphin-safe” tuna and other tuna, for instance, would provide an estimate of society’s total willingness to pay for conservation of the dolphins.

Certain corals found in Hawaiian waters are another valuable commodity. Precious corals are used primarily for jewelry. They are generally found at depths of greater than 100 feet and are thus difficult to harvest. They grow slowly and would be harvested above levels capable of self-replacement without intervention. They do not contribute significantly to reef-building or to sand production, so their harvest does not cause significant damage to the underwater environment as long as it is done in a reasonable manner, such as hand-picking. See Appendix 2.5 for the definition of precious corals and their associated quotas.

2.4.3 AQUACULTURE

The extent of the value of marine resources and their projected importance in the world economy as well as that of Hawai‘i is evident in the amounts of research and investment that are going into various aquaculture projects. On Hawai‘i, the Natural Energy Lab of Hawai‘i (NELHA) has contracted out land and resources to several companies involved in raising shrimp, various algae, black pearl oysters, tridachna (giant clams), tropical aquarium fishes and even abalone. Fish ponds have served Hawaiians for centuries as a form of aquaculture. Several other species are being raised in Hawaiian waters, including various shrimps, mullet, and finfish. The predicted increases in demand for food around the world require such investments in aquaculture if we are to use ocean resources to best advantage.

2.4.4 POLICY IMPLICATIONS

The rise of aquaculture, in spite of the scientific and other difficulties, shows how the world has begun to realize that its abundant resources are still not infinite. Decisions about resource use must be made according to the principle that scarcity is a limiting factor for air, water, forests, reefs and other ecosystem resources as well as for gold, oil, and other extractive products of the environment. **The human race will be entering a period of population growth that will tax our ingenuity and the resources of the planet. Hawai‘i, because of its small land size yet diverse human and natural environments, will be a good indicator of the success we might see on a global scale.**

Restrictions on resource use of the sort being developed for ocean resources do not currently address these issues as well as they might. Limited entry fisheries are the most successful way to use the resource optimally, and individual transferable quotas (ITQ’s) are the most efficient method within the group of limited entry management techniques because they allow for cost effective harvesting. Restricting harvest mechanisms or specific days fishing are only appropriate if external ecosystem services are threatened without them, because otherwise these methods artificially raise the cost of harvest. If, however, coral harvesting with a machine tears up the substrate and inhibits the ability of future corals or other species to grow, then requiring hand harvesting will impose the true costs of the harvest and result in a more efficient harvest level.

2.4.5 CONCLUSIONS

This section has discussed several of the valuable extractive and non-extractive uses of Hawai‘i’s ocean resources. While it does not place estimated values on most of these resources, it is included to show another dimension of Hawai‘i’s economic dependence on its environment. This section may be considered similar to a physical accounting, as it shows the quantities associated with resource use. Since most of these resources are extracted and sold in the marketplace, it is easily transferred from a physical account to a monetary account.

Commercial fisheries, worth $50 million in direct revenues and perhaps substantially more in indirect support expenditures, are probably the most valuable asset. This asset is also in great danger of disappearing. Fisheries around the world have been collapsing over the last decade and Western Pacific resources are not immune. A significant reduction in catch levels might mean only 10% of the catch rates of previous years. At the same time, market demand for fish is growing tremendously as consumers change their diets to consist of more fish and less red meat. This increases the value per fish but also the pressure to increase harvest levels. Careful management which uses economic incentives to control harvest levels, with additional support for aquaculture activities, are potentially the most valuable tools to protect the value from these assets.

Other ocean resources provide a significant return to the economy as well. Reefs provide direct tourism benefits and indirectly property values will depend on reefs for shoreline protection. Marine organisms, particularly invertebrates, are perhaps the fastest growing area of resource development for bio-technological and pharmaceutical qualities. This is in part due to the complicated biological strategies adopted by tropical marine organisms to compete fiercely for limited resources of light, substrate, and nutrients. Our understanding of these scientific processes is extremely limited and is probably the best avenue for quick advances from further research. The maintenance of reef diversity is simultaneously important as this diversity increases the probability that one or more species may provide significant benefits. Already, the stony corals which dominate Hawaiian reefs have been found capable of producing such diverse products as bone replacements and sunscreen.

2.5 CONCLUSIONS

This chapter has given preliminary estimates for several ecosystem services from forests, beaches, and the marine environment. All three provide significant value to the Hawaiian economy, most of which is not currently valued or significantly undervalued. Scientific uncertainty plays a large role in our inability to calculate the values of several of these assets, in particular those drawn from complicated ecosystems. These include some of the more potentially valuable assets such as species habitat, biodiversity, and property value protection. Currently, rather simple actions can be taken that provide large benefits to Hawai‘i. The single most profitable action may well be successful control of feral ungulates from native habitat and important watershed areas. This action can help eliminate water quality problems, human health problems, reef quality deterioration, and loss of native habitat and endangered species. Chapter 3 addresses the threats to these services in greater detail and the costs they impose on Hawai‘i.

Appendix 2.1: Groundwater Analysis Assumptions and Results

The groundwater valuation is based on the model presented in Krulce, Roumasset, and Wilson, 1998. Important assumptions in their paper include:

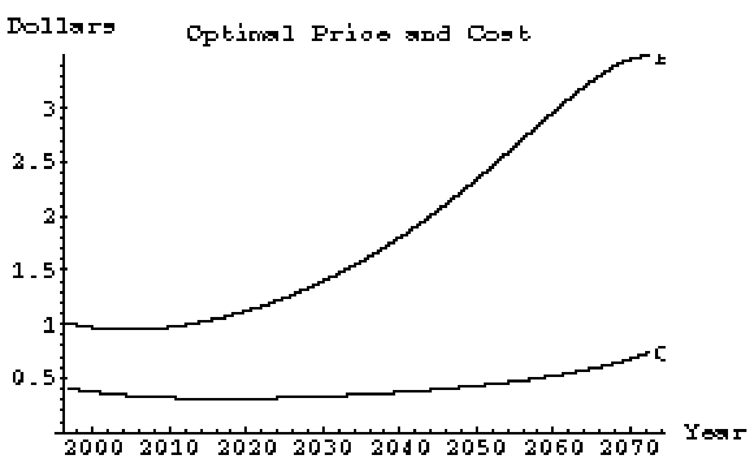
Demand is represented by a log-linear function of price,
The aquifer leaks according to a quadratic equation based on the head level,
The initial head level of the aquifer is 15 feet,
Extraction costs are an increasing function of head level,
The discount rate is 3%, and
Desalination is a viable alternative for the production of fresh water.

Additional assumptions made here in order to implement this model include:

The aquifer receives an original inflow of 281 MGD of water,
Extraction costs grow as an exponential function of head level,
The wholesale price of desalination is $3.48 per 1,000 gallons, and
The annual growth rate of demand for water is 1%.

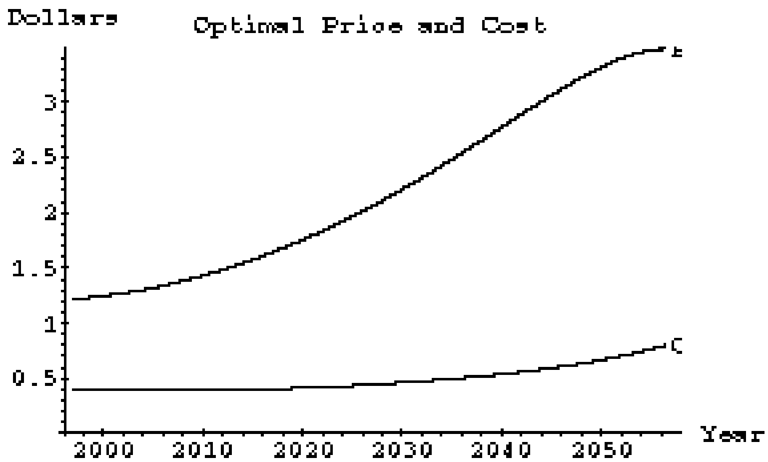
The model first estimates the optimal quantities extracted for an inflow of 281 MGD and then derives the optimal wholesale price and the extraction cost for these quantities over time until a steady state level of extraction is reached. This results in the price and cost paths shown in Figure A2.1.1:

Figure A2.1.1: Optimal Price and Cost for Pearl Harbor Aquifer Groundwater, Current Forest Quality



The analysis then assumes that a sufficient amount of damage occurs to the forest that groundwater recharge to the aquifer is reduced by 41 MGD, to 240 MGD. This results in the price and cost paths shown in Figure A2.1.2.

Figure A2.1.2: Optimal Price and Cost for Pearl Harbor Aquifer Groundwater, Deteriorated Forest Quality



Notice that not only does the lower level of groundwater intake lead to higher optimal prices, but the time at which it becomes necessary to use desalination is 15 years earlier with the deteriorated water quality than without.

Appendix 2.2: In-stream Uses Study of Windward O‘ahu

This appendix summarizes the findings of a DLNR study of in-stream uses for Windward O‘ahu streams (DLNR, 1981). This study investigated 13 major streams in terms of their potential for in-stream uses including:

- Stream fauna habitat;
- Waterbird habitat;
- Scientific/educational research;
- Aesthetic enjoyment;
- Water-based recreation;
- Navigation; and
- Waste assimilation.

The streams (each with several reaches, shown here in parentheses) investigated in detail were Waimänalo (4), Maunawili (7), Käne‘ohe-Kamo‘oali‘i (4), He‘eia (5), ‘Ähuimanu (3), Kahalu‘u (4), Waihe‘e (2), Waiähole (2), Waikäne (2), Kahana (2), Punalu‘u (Waiono) (2), Kaluanui (2), and Mälaekahana (3). At least 5 streams had at least one reach known to have native fauna species present. Only three areas were thought to be important waterbird habitat: Kawai Nui marsh and Ka‘elepulu Pond as parts of Maunawili stream, and the natural part of He‘eia stream. Recreational opportunities and aesthetic values ranged in potential significantly.

General findings indicate that:

(1) Stream fauna habitat is generally found in areas with rural or natural land uses and vegetative cover and natural channel conditions. The value of this ecosystem service depends on its potential to host stream fauna and fisheries that ensure native species survival. Channel alteration favors the replacement of native species with less unique, less valuable non-native species. Activities which will accelerate channel alteration include removal of streamside vegetation, such as might occur through logging, feral ungulate activities, or change in vegetation cover to a single story canopy like *Miconia calvescens* from a multi-tiered canopy.

(2) Water bird habitat is generally found in areas with rural or natural land uses and vegetative cover and natural channel conditions. The value of this ecosystem service depends on its potential to host water birds. Water birds are not prevalent in the windward Ko‘olaus.

(3) Scientific and educational values include the potential for streams to serve as field laboratories for research and educational activities, such as biological, microbiological, physicochemical, and hydraulic studies. The value of high quality reaches was treated as relevant and just as valuable as research in pristine areas since the purpose of research may be to examine the environmental aspects of low quality as well as pristine streams. The northern streams are of significantly higher quality than those farther south on the windward side of the Ko‘olaus, so that experiments requiring comparisons of similar situations, differing by only a few characteristics such as the presence of urban development in the Kaneohe bay area, are quite feasible.

(4) Though aesthetic values are highly subjective and difficult to quantify in absolute terms, there are elements that contribute to an observer's assessment and assumptions that can be made about these elements to allow for an evaluation of whether there is high, moderate, or poor aesthetic value. Field observations were made to obtain these values. The assumptions used in the windward Koʻolau study were that the surrounding vegetation type was relevant in that density and size are significant elements, the stream is the focal point of the setting, man-made impacts detract from aesthetic quality, lighting enhances aesthetics, the stream should stimulate visual and audio sense, and the stream environment should draw the observer in, not turn them away.

(5) In-stream recreation activities, such as wading, fishing, swimming, and boating, depend directly on stream flow (picnicking, hiking, and camping are recreational activities associated with streams but they are not considered directly dependent on stream flow). Relevant parameters include stream turbidity, channel modification and channel bottom roughness. Where a stream was found suitable for recreation, this study evaluated the stream depth and velocity to describe the value of the recreational activities.

(6) Navigational values were found to be limited to channels that were at least 50 feet wide and six feet deep since big boats need about this much water volume to avoid conflict with other activities. Thus navigation for Windward Oʻahu is limited to the lower reaches of streams that experience tidal influences, only a very small portion of stream flow for the area.

(7) Waste assimilation is the ability of streams to convey discharges downstream and depends on stream flow. Discharges may include treated wastewater, storm runoff, or discharge of agricultural waters. Five wastewater treatment facilities discharge into inland waters. The values for waste assimilation in Windward Oʻahu is considered low since water quality standards set by Public Health Regulations require water treatment prior to discharge.

(8) Potential hydroelectric power values were based on USGS flow duration data and were found to be limited due to the small watershed areas, low available heads and extensive stream diversions for irrigation and domestic purposes.

Appendix 2.3: Summary of Willingness to Pay Studies for Endangered Species Preservation

Summary of Per Household Economic values of rare and T/E Species ($1993) (Loomis and White, 1993)			
	Low value	High value	Average of all studies
Studies reporting annual WTP			
Northern spotted owl	$44	$95	$70
Pacific salmon/Steelhead	$31	$88	$63
Grizzly bears			$46
Whooping cranes			$35
Red-cockaded woodpecker	$10	$15	$13
Sea Otter			$29
Gray whales	$17	$33	$26
Bald eagles	$15	$33	$24
Bighorn sheep	$12	$30	$21
Sea turtle			$13
Atlantic salmon	$7	$8	$8
Squawfish			$8
Striped shiner			$6
Studies reporting lump sum WTP			
Bald eagles	$178	$254	$216
Humpback whale			$173
Monk seal			$120
Gray wolf	$16	$118	$67
Arctic grayling/Cutthroat trout	$13	$17	$15

Appendix 2.4: Definitions of Hawai‘i Fish Management Unit Species

Bottomfish management unit species means the following fish:

Common name	Local name	Scientific name
Snappers:		
Silver jaw jobfish	Lehi (H); palu-gustusilvia (S).	Aphareus rutilans.
Gray jobfish	Uku (H); asoama (S).	Aprion virescens.
Squirrelfish snapper	Ehu (H); palu-malau (S).	Etelis carbunculus.
Longtail snapper	Onaga, ‘ula‘ula (H); palu-loa (S).	Etelis coruscans.
Blue stripe snapper	Ta‘ape (H); savane (S); funai (G).	Lutjanus kasmira.
Yellowtail snapper	Palu-i‘usama (S); yellowtail kalekale.	Pristipomoides auricilla.
Pink snapper	(H); palu-‘ena‘ena (S); gadao (G).	Pristipomoides.
Yelloweye snapper	Palusina (S); yelloweye opakapaka.	Pristipomoides flavipinnis.
Snapper	Kalekale (H)	Pristipomoides sieboldii.
Snapper	Gindai (H,G); palu-sega (S).	Pristipomoides zonatus.
Jacks:		
Giant trevally	White ulua (H); tarakito (G); sapo-anae (S).	Caranx ignoblis.
Black jack	Black ulua (H);tarakito (G);tafauli (S).	Caranx lugubris.
Thick lipped trevally	Pig ulua (H);butaguchi (H).	Pseudocaranx dentex.
Amberjack	(H)	Seriola dumerili.
Groupers:		
Blacktip grouper	Fausi (S); gadau (G).	Epinephelus fasciatus.
Sea bass	(H)	Epinephelus fasciatus.
Lunartail grouper	Papa (S)	Variola louti.
Emperor fishes:		
Ambon emperor	Filoa-gutumumu (S)	Lethrinus amboinensis.
Redgill emperor	Filoa-pa'lo'omumu (S); mafuti (G).	Lethrinus rubrioperculatus.

Notes: G--Guam; H--Hawaii; S--American Samoa.

Pacific pelagic management unit species means the following fish:

Pacific pelagic management unit species

Common name	Scientific name
Mahimahi (dolphin fish)	Coryphaena spp.
Marlin and spearfish	Makaira spp.
	Tetrapturus spp.
Oceanic sharks	Family Alopiidae.
	Family Carcharhinidae.
	Family Lamnidae.
	Family Sphyrnidae.
Sailfish	Istiophorus platypterus.
Swordfish	Xiphias gladius.
Tuna and related species	Allothunnus spp., Auxis spp.
	Euthynnus spp.,
	Gymnosarda spp.
	Katsuwonus spp., Scomber spp.
	Thunnus spp.
Wahoo	Acanthocybium solandri.

Appendix 2.5: Precious Corals

Precious coral means any coral of the genus Corallium in addition to the following species of corals:

Precious Corals

Common name	Scientific name
Pink coral (also known as red coral)	Corallium secundum
Pink coral (also known as red coral)	Corallium regale
Pink coral (also known as red coral)	Corallium laauense
Gold coral	Gerardia spp
Gold coral	Callogorgia gilberti
Gold coral	Narella spp
Gold coral	Calyptrophora spp
Bamboo coral	Lepidisis olapa
Bamboo coral	Acanella spp
Black coral	Antipathes dichotoma
Black coral	Antipathes grandis
Black coral	Antipathes ulex

These corals are protected by quotas and harvest is restricted both in location and in technique of harvest. following chart shows coral regulations for Hawaiian waters.

Quotas for Precious Corals Permit Areas

Name of coral bed	Type of bed	Harvest quota	Number of years	Gear restriction
Makapu‘u	E	P--2,000 kg	2	S
		G--600 kg	2	S
		B--600 kg	2	S
	C	P--67 kg	1	
		G--20 kg	1	S
		B--17 kg	1	S
Ka‘ena Point	C	P--67 kg	1	S
		G--20 kg	1	S
		B--17 kg	1	S
Brooks Bank	C	P--17 kg	1	N
		G--133 kg	1	N
		B--111 kg	1	N
180 Fathom Bank	C	P--222 kg	1	N
		G--67 kg	1	N
		B--56 kg	1	N
Westpac Bed	R	Zero (0 kg)	--	--
Hawai‘i, American Samoa, Guam, US Pacific Island possessions		X--1,000 kg (all species combined except black corals)	1	N

Notes:

1. Types of corals: P=Pink G=Gold B=Bamboo

submission requirements (Sec 660.3). State regulations on black coral harvesting are not

nonselective harvest will be multiplied by 5 and counted against the quota. If both

south and east of a line midway between Nihoa and Ni‘ihau Islands. Nonselective gear or

5. S=Selective gear only; N=Nonselective or selective gear

6. No authorized fishing for coral in refugia

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Appendix 2.6: Guidelines for Assigning Points for General Recreation

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Table 6-29
Guidelines for Assigning Points for General Recreation

Criteria	Judgement Factors				
(a) Recreation experience[1]	Two general activities[2]	Several general activities	Several general activities; one high quality value activity[3]	Several general activities; more than one high quality value activity	Numerous high quality value activities; som general activities
Total Points: 30					
Point value:	0-4	5-10	11-16	17-23	24-30
(b) Availability of opportunity[4]	Several within 1 hr. travel time; a few within 30 min. travel time	Several within 1 hr. travel time; none within 30 min. travel time	One or two within 1 hr. time; none within 45 min. travel time	None within 1 hr. travel time	None within 2 hr. travel time
Total Points: 18					
Point value:	0-3	4-6	7-10	11-14	15-18
(c) Carrying capacity[5]	Minimum facility for development for public health and safety	Basic facility to conduct activity(ies)	Adequate facilities to conduct without deterioration of the resource or activity experience	Optimum facilities to conduct activity at site potential	Ultimate facilities to achieve intent of selecte alternative
Total Points: 14					
Point value:	0-2	3-5	6-8	9-11	12-14
(d) Accessibility	Limited access by any means to site or within site	Fair access, poor quality roads to site; limited access within site	Fair access, fair road to site; fair access; good roads within site	Good access, good roads to site; fair access, good roads within site	Good access, high standard road to site; good access within site
Total Points: 18					
Point value:	0-3	4-6	7-10	11-14	15-18
(e) Environmental	Low esthetic factors[6] that significantly lower quality[7]	Average esthetic quality; factors exist that lower quality to minor degree	Above average esthetic quality; any limiting factors can be reasonably rectified	High esthetic quality; no factors exist that lower quality	Outstanding esthetic quality; no factors exist that lower quality
Total Points: 20					
Point value:	0-2	3-6	7-10	11-15	16-20

[1] Value for water-oriented activities should be adjusted if significant seasonal water level changes occur.

[2] General activities include those that are common to the region and that are usually of normal quality. This includes picnicking, camping, hiking, riding, cycling, and fishing and hunting of normal quality.

[3] High quality value activities include those that are not common to the region and/or nation and that are usually of high quality.

[4] Likelihood of success at fishing or hunting

[5] Value should be adjusted for overuse.

[6] Major esthetic qualities to be considered include geology and topography, water, and vegetation.

[7] Factors to be considered to lowering quality include air and water pollution, pests, poor climate, and unsightly adjacent areas.

CHAPTER 3: ALIEN SPECIES AND THE ECONOMY

3.1 INTRODUCTION

Hawai‘i, the state that may have the nation's most unique biological species, also likely has the Nation's biggest introduced non-indigenous species problem. Though the islands may appear to be a tropical paradise with lush trees, flowers and birds, "except in a few pockets (i.e., only at higher elevations), most of the trees, foliage, flowers and birds are non-indigenous" (HNIS in the US, 1992: 234). **At least half of the wild species in Hawai‘i today are non-indigenous—a proportion that is higher than any other area in the United States.** In addition, no other area in the United States receives as many new species annually (HNIS in the US, 1992: 234). Table 3.1 summarizes the situation by showing the number of threatened and endangered species alongside the number of introduced species.

Table 3.1: Introduced and threatened/endangered species in Hawai‘i

	Threatened or Endangered species	**Estimated Introduced, Non-indigenous species**	**Estimated Total number of species**
Mammals	4	18	19
Birds	31	38	95
Reptiles	5	13	13
Invertebrates	67*	2,009	10,000
Plants	283	861	1,817
Additional animals "species of concern"	363		
Additional plants "species of concern"	317		

* Includes candidate species
Figures from USFWS and L. Loope, *Island Ecosystems*, in Stone and Stone, 1989.

To understand the role that these species play in the Hawaiian economy, one must appreciate the manner in which the situation has arisen. The complex series of events which led to the islands' current status stem from a combination of biological evolution and human attempts to better their standards of living. Prior to the arrival of man, Hawai‘i was populated by chance. Its great distance from other land masses mean that independent species arrival and establishment was extremely slow. Those species that did arrive tended to evolve into many new species by adaptive radiation, so that the genetic diversity of the islands stems from the arrival of a very limited number of creatures or seeds. For example, 272 plants established before man's arrival adapted and diversified into 1,729 species and varieties, 95% of which are endemic (Fosberg 1948).

Most new species arrive in association with human activities or transport, both intentionally and accidentally (HNIS in the US, 1992: 77–78). With the arrival of Polynesians, new species became established at a rate of three or four every 100 years compared to the natural rate of one new species every 50,000 years (HNIS in the US, 1992: 326). With the arrival of Europeans in 1778, the rate jumped to hundreds of thousands of times the natural rate. For the 50 year period from 1937 to 1987, Hawaiʻi received an average of 18 new insect and other arthropod species each year, more than a million times the natural rate (HNIS in the US, 1992: 238).

Today, Hawaiʻi is a major transportation hub, which allows alien species to arrive by ship, aircraft, or by mail. For example, agricultural imports that are shipped in may provide a pathway for alien insects; individuals who are not conscious of Hawaiʻi's fragile and unique environment, such as military personnel, tourists from the mainland, or locals returning home, may not be aware that there is dirt with alien seeds on their shoes; or individuals may order plants by mail or purchase them at the nursery to plant in their back yard without realizing the plants are invasive, can spread quickly, and destroy native habitat.

Many of the species that are of concern today were introduced to Hawaiʻi because they held positive economic values for residents. In formulating any successful plan to control alien species, or even to evaluate their impact on Hawaiʻi's economy, this fact must be kept in mind. The uncertainty about what sustenance travelers might find meant that travelers brought their own supplies which could be self sustaining if any reasonable landscape conditions were found. Taro, feral pigs and other plants and animals were brought by both Polynesians and westerners for food. Axis deer were brought as a gift to King Kamehameha V. Sugar cane was introduced as an agricultural crop. Along with the financial prosperity this brought, it changed the islands' ecosystems dramatically by requiring shifts in water allocations, water quality, and by taking up land for agriculture and providing food for rats and other pests. Bio-control agents that now eat all sorts of vegetation were introduced to protect sugar crops. *Miconia calvescens* and other plants were brought to the islands as ornamentals, valued for their appearance. Former cane lands are now prime lands for the spread of new invasive weeds, as they are disrupted ecosystems.

The problems of purposefully introducing new species to Hawaiʻi were either not fully understood, were expected to be less expensive than the benefits, or were dismissed as unimportant to the individual responsible. The problems of islands, and Hawaiʻi in particular, have been underestimated by their human inhabitants. The island ecosystems are interdependent in critical ways that are not as obvious in ecosystems on larger landmasses. Insects at 13,000 feet on the top of Mauna Kea depend on the health of lowland ecosystems for food (NG, Sept. 1995). The health of fishes and corals at 60 feet underwater depend critically on the sediment levels from upland forests. Most of the species present were derived from a few plant and animal settlers, so threats to one species are likely to include several similar species as well. This heightened susceptibility enhances the risk that an introduced species will become a pest in the existing ecosystem.

Many alien species prey upon and destroy native habitat, compete with them for food and habitat, spread foreign disease, and alter environmental conditions. For example, ecological processes for indigenous plants have been compromised by molasses grass or wheatgrass, which increase the frequency of brush fires. Molasses grass now comprises 80% of plant cover in parts of Hawaiʻi Volcanoes National Park (HNIS in the US, 1992: 73, 75). Birds in Hawaiʻi are similarly threatened by changing plant habitats and insects. Hawaiʻi has lost half of its native birds to extinction; avian malaria, spread by introduced mosquitoes, has devastated many populations.

Clearly not all alien species cause economic loss or threaten native species. However, each introduced species may have the potential to cause such devastation due to unforeseen consequences. Several bio-control agents, including the mongoose, the African snail, and several insects released over the past century attest to the damage well-intentioned introductions can do. Any policy formulated regarding the introduction of alien species must take into account these scientific uncertainties.

To analyze policy choices for alien species, it is worthwhile to separate species into several categories. The first division is between accidentally introduced vs. purposefully introduced species. Accidentally introduced species call for increased public awareness of the dangers of species introduction, the main vectors for introduction, and the steps individuals can take to avoid introduction. Using questionnaires and inspections at ports of entry will reduce both accidentally and purposefully introduced species. To maximize the economic return on preventative expenditures, they should be made up until the point that the expected marginal benefit of another dollar spent is equal to the expected marginal cost of failing to prevent an introduction. **Since preventative measures can easily target more than one species at a time, even the expected costs of the greatest potential threat are likely an underestimate of the potential damage levels and thus efficient levels of preventative expenditures.**

Purposefully introduced species, such as nursery plants, agricultural crops, or bio-control agents, are brought on to the islands because there is some expected gain from their introduction. In these situations, liability for losses caused by the species introduction (much like liability for oil spills rests on the oil companies) should serve as both a deterrent for casual introductions and a mechanism for collecting funds in the case of the establishment of a pest needing attention. Currently, importers are liable for costs through the approval procedure, but once given admittance for a species they are not responsible for damages. Unlawful importations that result in the escape or establishment of a species that "caused the [D]epartment [of Agriculture] to initiate a program to capture, control, or eradicate that pest" (Hawaii Revised Statutes, §150A-14(d)) require the court to impose liability payments to the state general fund based on the cost of the development and implementation of the program. Such a requirement for legally introduced species would internalize the potential costs of the threat onto the individual(s) who stand to gain directly from the introduction as potential importers would need to carefully determine the expected damages to the islands and weigh these damages against their expected profits. This could even lead to the creation of insurance policies for species introductions, a market could be created to determine a more efficient trade-off between the risk and the potential gain from a new introduction.

Once a species has been introduced, policy decisions must focus on expenditures for control and remediation. These expenditures should be spent as long as the marginal benefit of doing so is greater than the marginal cost. For example, if one *Miconia calvescens* tree or *Myrica faya* tree can easily spawn an entire stand, then the marginal cost of controlling the last standing tree is likely lower than the marginal benefit of doing so, regardless of the need for expensive technology and/or helicopters to aid in the process. On the other hand, if we tried to control the rat population to the last rat, the benefits would be unlikely to outweigh the expense.

The discussion that follows shows how some of the worst pests in Hawai‘i, as well as those with high probabilities of successful introduction and establishment, might fare in terms of economic costs to the state. When possible, marginal analyses will be used. Otherwise, the known costs of introduction will be balanced against the benefits and the potential for marginal study evaluated.

3.2 LOSS OF ECOSYSTEM SERVICES AND COSTS

Harmful introduced species can have serious and multifaceted consequences on Hawai‘i’s economy. One of the primary consequences is the reduction of ecosystem services. For example, feral animals in the forests have negative impacts on economic activities that range from the ecosystem services benefiting recreational hiking opportunities to those benefiting marine resources – such as fisheries. Other species might influence the economy more directly. For example, Brown tree snakes can cause economy-halting power outages, and insects can devastate crop productivity.

Ecosystem services related to Hawai‘i’s biodiversity, such as scientific research or ecotourism, are particularly threatened by introduced competitors, diseases, and predators, since the isolated Hawaiian species did not co-evolve with such threats.

The magnitude of these threats is dramatic. Hawai‘i has the greatest concentration of threatened and endangered species in the U.S. and the greatest number of extinct species. While destruction of habitat continues to be a major cause, harmful introduced species have been identified as an important, if not the most important, current threat (HNIS in the US, 1992: 234). A section of a National case study that focused on Hawai‘i found that the introduction and spread of “[n]ew species have played a significant role in the extinction of indigenous species in the past and continue to do so” and concluded that “Hawaii, the nation, and the world lose something valuable as the indigenous flora and fauna decline” (HNIS in the US, 1992: 234).

There are also significant economic costs associated with the introduction and spread of many non-indigenous species because they draw resources away from activities that improve the quality of life. Money and resources must be spent to (1) prevent the establishment of harmful species (e.g., fencing out of feral animals), (2) control populations (e.g. the application of pesticides) and (3) remediate damages caused by harmful pests (e.g. replacement of wood structures due to termite damage). In addition, the Hawai‘i economy is negatively impacted by alien pests that cause (4) residual damages (those that are leftover after control and remediation efforts) such as lower property values or decreased agricultural production. The reduction in ecosystem services, like water supplies that are protected by forested watersheds, would also fall into the residual damages category.

3.3 THE CAUSES OF ALIEN SPECIES PROLIFERATION

Introduced species must first have adequate climate to become established. With almost every climatic zone present within a short distance in the islands, this first hurdle is easily overcome for many species. Proliferation will then depend on the genetic qualities that the species has brought with it that determine how the species competes for food and space. Species that have different mechanisms or adaptations for competition and survival may change the ecosystems into which they are introduced to favor their genetic strong points. For example, broomsedge (*Andropogon virginicus*) has significantly increased both the area and intensity of fires where it has spread, and the fires aid the further spread of this invasive grass.

Once introduced, agriculture, fire, and urbanization create ideal conditions for the establishment of invasive weeds. Non-indigenous species move with human populations as they expand in places such as Kōkeʻe (Kauaʻi), Kula (Maui) and Volcano, Kona mauka, and Kohala (Hawaiʻi). Once established, these harmful plants can inhibit growth of native plants and act as hosts to invertebrate pests and disease. For example, strawberry guava, a non-indigenous thicket-forming tree, creates shade so deep that few native plant seedlings can survive. It may also release chemicals that inhibit other species when fallen leaves decompose. Strawberry guava is spread by feral pigs and introduced birds which eat their fruit (Smith, 1989). Natural disasters provide new opportunities for non-native plants to become established as well. For instance, in 1992, Hurricane ʻIniki provided new opportunities for banana poka to expand in Kauaʻi.

3.4 CASE STUDIES

3.4.1 THREATS TO HAWAIʻI

3.4.1.1 The Brown Tree Snake

Brown tree snakes were accidentally introduced to Guam in 1940s. They cause an average of one power outage every four days. If Oʻahu faced similar conditions, the expense of power outages would be dramatic. A conservative estimate of the cost for one major Oʻahu power outage triggered by a fallen tree branch in 1991 was $13 million (Fritts, 1994). Brown tree snakes also devastated Guam's native bird population, wiping out 9 of Guam's 11 native land bird species. Hawaiʻi's remaining bird populations could be similarly decimated. There are also health costs associated with these snakes—200 people in Guam have been treated for bites from this aggressive, venomous snake (SI, TNCH). Brown tree snakes could also threaten the tourist industry. For example, many residents and visitors are comforted by the absence of snakes here in Hawaiʻi (the only native snake is a small, earthworm-like blind snake).

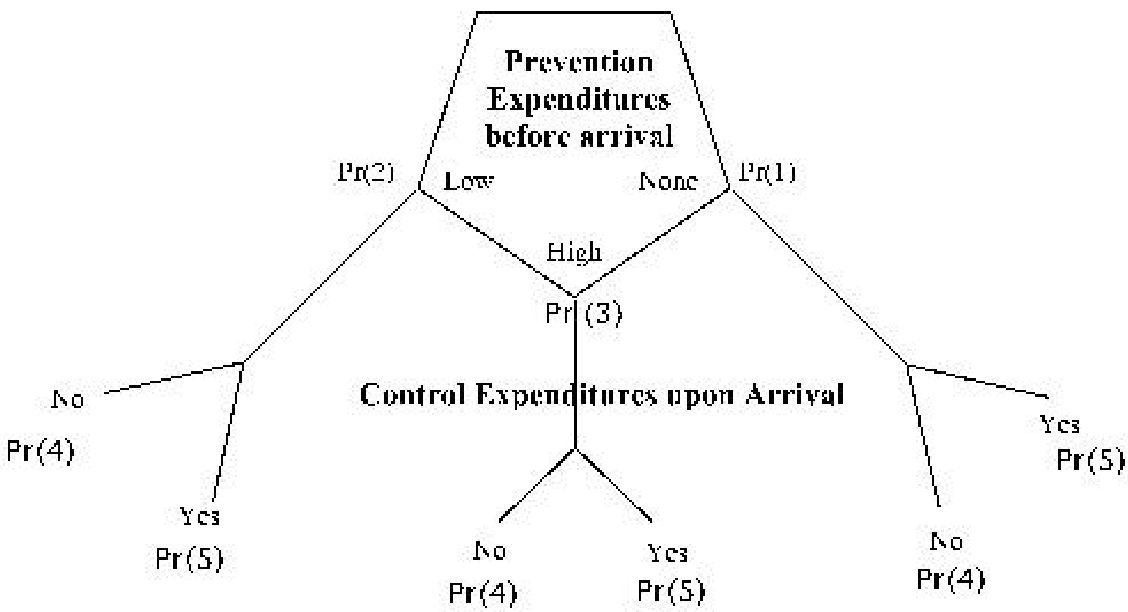
Could it survive in Hawaiʻi?

The brown tree snake feeds on birds and lizards, of which Hawaiʻi has densities in line with Guam's. It has no known predators in the islands. **The threat of Brown tree snake introduction is imminent, and at least seven already have been caught in Hawaiʻi.** The specifics of its reproductive system are still being studies but it is believed that, like many other snakes, a female can store fertilized eggs long enough that the threat of a gravid snake arriving in Hawai‘i is real. There are an estimated 1000 other snake species in the world that could pose a similar threat (SI, TNCH).

What might it do once it arrived?

For concreteness, we will investigate a simplified world in which we know several facts about the Brown tree snake. This will allow us to examine the expected damage levels from a successful introduction of the snake and the expected costs the state might choose to incur to avoid them. Figure 3.1 shows the decision tree which leads to the various expected damage levels described in this section. Note that there are two stages at which policy must be made: the prevention level and the control level. Both levels will impact the expected levels of damages through their impacts on the probabilities of those damages occurring.

Figure 3.1: Decision Tree for Prevention and Control of the Brown tree snake, Boiga Irregularis***.***



Pr(1) = Probability that Brown tree snake(BTS) arrives, given no prevention expenditures
Pr (2) Probability that BTS arrives, given low prevention expenditures
Pr (3) Probability that BTS arrives, given high prevention expenditures

$Pr(3) \le Pr(2) \le Pr(1)$

Pr (4) = Probability that BTS causes high damages, given arrival and no control exp.
Pr (5) = Probability that BTS causes high damages, given arrival and control exp.

$Pr(5) < Pr(4)$.

For this analysis, we will first assume that there are two possibilities which could occur if the snake reached Hawai‘i. The first is that the snake will have the same sort of impacts as it did on Guam, a high damage level, or D_H. The second is that the impacts will be much less severe, or a low damage level, D_L. Then, we will assume that there are two discrete levels of expenditure the state could make to influence the probabilities associated with the occurrence of D_H and D_L. First, the government could spend nothing, a low level, or a high level on preventing entry of the snake. Thus there are two levels of prevention costs, high (C_{PH}) and low (C_{PL}), which could be spent now, before the snake has arrived. Second, control costs, Cc, could be spent in the case that the snake becomes established. Both sets of expenditure choices will influence the probability of the creature's arrival. The table below indicates the impact and its estimated cost in Hawai‘i for high damage levels and low damage levels. The figures are extrapolations based on the impacts in Guam adjusted for population.

Table 3.2: Potential damage estimates for Brown tree snakes in Hawai‘i

Impact	**Premise for estimate**	**D_H , High Damage Estimate (annual)**	**D_L , Low Damage Estimate (annual)**
Power outages	1643 power outages from 1978–1997 directly attributable to snakes. $13 million loss in productivity to 8 hour O‘ahu power outage.	$112 million (based on $1.2 million per outage* in lost productivity and damages, with same frequency as Guam)	$15.6 million (based on $1.2 million per outage* in lost productivity and damages, occurring monthly)
Bites requiring medical treatment	Bite frequency average of 3 per month. $70 dollars per doctor visit.	$16,800 Population adjusted to 20 bites per month.	$0 No bites.
Lost bird species	75% of native birds extinct. Average bird value to state population of $31 per household per year.	$288 million. (75% of threatened or endangered birds extinct)†.	$12.4 million.† (1 bird extinct.)
Poultry industry declines	Snakes known to prey on poultry, Extent unknown.	$158,000 (1% reduction in egg production, a $15.8 million value in 1993)	$15,800 (0.1% reduction in egg production.)
Agricultural productivity	May reduce natural insectivores, with associated decline in agricultural	$5 million. (1% reduction in agricultural productivity, $505	$0.5 million (0.1% reduction in agricultural productivity)

	productivity.	million value in 1993)	
Seed dispersal	Removal of birds and lizards may reduce seed dispersal rates of both alien and native species.	Not Estimated	Not Estimated
Total:		$405,174,800 per year	$28,515,800 per year

*$1.2 million is used based on average power outages closer to 1 hour than 8 hours.
† See previous chapter for discussion of estimates. They are calculated based on Contingent Valuation studies of household values for endangered bird species.

The expenditures on prevention and/or control are assumed to affect the probabilities of arrival and high damage levels versus low damage levels are shown in Table 3.3. They should be interpreted in the following manner: assume with no prevention, the probability of arrival is 90%, and with no control, the probability of high damages given the snake's arrival is 80%.

Table 3.3: Effects of prevention and control expenditures on the expected damages from Brown tree snakes

Type of activity	**Probability of arrival**	**Probability of high damages given arrival**	**Expected value of damages**
No prevention, no control	90%	80%	$296,858,700
Low prevention, no control	60%	80%	$197,905,800 + C_{PL}
High prevention, no control	30%	80%	$98,952,900 + C_{PH}
No prevention, control	90%	50%	$195,160,770 + C_C
Low prevention, control	60%	50%	$130,107,180 + C_{PL} + C_C
High prevention, control	30%	50%	$65,053,590 + C_{PH} + C_C

Assume further that low prevention costs, C_{PL}, are the $1.6 million dollars currently allocated to Brown Tree Snake prevention, and that high prevention costs, C_{PH}, are 10 times that, or $16 million per year. Control costs are set based on the $450,000 available for direct Brown tree snake control in FY98 from the Department of the Interior under Section 6 of the Endangered Species Act (ESA) and adjusted by the difference in waterborne shipping tonnage for Guam and Hawaii. Guam's 1996 shipping tonnage was 437,000 tons while Hawai'i's was almost 49 times that, at 21.25 million tons. Thus, control costs are assumed to be $21.9 million dollars per year.

Actual control costs might be significantly higher, as the funds for Guam currently only allow careful inspection of high risk cargo and the manning of traps around the high risk ports of entry.

Table 3.4 shows the expected value of the damages given the above cost structure, the net benefits of these expenditures, and the benefit/cost ratio. Clearly the benefit-cost ratio depends on the effect that preventative expenditures have on the probability of arrival of a species, so that the 60.8 benefit-cost ratio for low preventative expenditures compared to the 11.4 ratio for high expenditures may be unrealistic since a 10-fold increase in expenditures is shown to reduce the probability of arrival only twice as much (from 90% to 30%) as the low level of preventative expenditures does (from 90% to 60%). Though diminishing returns to prevention expenditures should be expected, they may not be this extreme. Note further that high prevention expenditures will return a higher net benefit than low (though not necessarily a higher benefit-cost ratio) as long as the reduction in the probability of arrival is greater than 4% in the case of no control expenditures or 6% in the case of control expenditures.

Table 3.4: Benefit-cost analysis of prevention and control expenditures for BTS

	Expected value of damages evaluated at C_C = \$21.9 million, C_{PL}= \$1.6 million C_{PH} = \$16 million	**Net benefit of expenditures**	**Benefit/Cost ratio of preventative and/or control actions**
No prevention, no control	$296,858,700	$0	
Low prevention, no control	$199,505,800	$97,352,900	60.8
High prevention, no control	$114,952,900	$181,905,800	11.4
No prevention, control	$217,060,770	$ 79,797,930	3.6
Low prevention, control	$153,607,180	$143,251,520	6.1
High prevention, control	$102,953,590	$193,905,110	5.1

How much do these results depend on the expenditures' ability to change the probability of arrival? Under the above circumstances, there will be a positive return on the high prevention expenditures in the case of no control expenditures as long as the reduction in the probability of arrival is greater than 4.9%, and in the case of control expenditures, as long as the reduction in the probability of arrival is greater than 6.7%. The low prevention expenditures are even more likely to result in a positive return: a reduction of only 0.5% is needed in the case of no control, and 0.7% in the case of control expenditures.[83]

Note that improved scientific understanding of the snake and its biological needs, as well as improved technology for controlling the pests, will reduce costs of control and prevention as well as increase the effect of preventative and control expenditures on the probabilities of arrival and high damages. For this reason, funds spent on research can be seen to clearly decrease the expected costs of the snake. On Guam, studies between trap types, bait types, and trap distances (Rodda et al, forthcoming) have already increased the capture rates and reduced the escape rates of traps to an extent that the highest returns to further expenditures may be on controlling feral dog destruction of traps rather than increasing the numbers of traps.[84]

This point is an important result of analyzing the alien species problems. As the costs of species such as the Brown tree snake on Guam, the Zebra mussel throughout the mainland United States, the meleleuca tree in Florida, and *Miconia calvescens* in French Polynesia, continue to mount, a greater respect is developing for the ability of one single introduction to have long lasting and extremely costly economic and ecological impacts. These potential impacts are likely to deserve much greater study and greater preventative measures, as the expected benefits of preventative measures may be significantly higher than those of control measures once a species has arrived.

3.4.2 SPECIES WHICH ALREADY HAVE ESTABLISHED A PRESENCE IN HAWAI'I

3.4.2.1 Mammals

3.4.2.1.1 *Feral Pigs*

The only mammals in Hawai'i were one (or possibly two) native bat(s) prior to the arrival of humans Polynesians brought pigs for food, and Europeans introduced another breed of pig and other hoofed animals. The general effects of their grazing and predation on the forests and their biota are well documented. The most damaging activities include destruction of native habitat through trampling, eating, and digging; creating soil disturbance, degradation, erosion, and sedimentation; increasing the rate of establishment of other non-indigenous species including plants, insects, bacteria, algae and fungi; direct predation on crops and bird or invertebrate species; and acting as vectors for human diseases including plague and leptospirosis. The ecosystems did not evolve in such a way that they have defenses against the arrival of so many animals This lack of biological defenses within the ecosystems increases the potential levels of impact further for Hawai'i over other locations.

While feral ungulates and rodents impose great costs on the Hawaiian ecosystems and economy, some also provide significant benefits. In particular, hunting is a source of both recreation and sustenance. Table 3.5 summarizes hunting data for the state.

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[83] This threshold is calculated by determining the point at which the change in expected damages is equal to the prevention and control expenditures.
[84] This is the recommendation of the USDA, USDOD, USDOI, and Government of Guam presented in a joint 1997 Environmental Assessment for expanding Brown tree snake control activities on Guam.

Table 3.5: Hunters and hunting days

Type of Game	Hunters, state residents and non-residents		Days of hunting	
	Number	**Percent of Total**	**Number**	**Percent of Total**
Deer	11,000	48	49,000	19
Wild Sheep	10,000	43	49,000	19
Feral Pig	12,000	51	134,000	52
Big game, total	20,000	86	193,000	75
Small game, total	9,000	37	86,000	33
Total, all types	23000	100	258,000	100

Notes: 1. Individual species and small game data based on small sample size; 2. Population 16 years and older; 3. Data from USFWS 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

The US Fish and Wildlife Service estimates that U.S. residents spent a total of 16.4 million dollars on hunting trips and equipment in Hawaiʻi, or an average expenditure per hunter of $715 dollars (USFWS, 1998). Assume that one of every two hunting days results in a pig caught. With 134,000 hunting days per year, that amounts to 67,000 pigs. The market price for pigs is $1.48 per pound for an average pig of 100–130 pounds.[85] Thus the market value if these pigs are 115 pounds each would be $11,403,400 per year, or $950.28 per hunter. There are two possible ways to regard the value of hunting to each hunter, then. First, the hunter could be offsetting the costs by the expected benefits of the hunt, meaning that the value to the hunter is $950.28 - $715, or $235.28. On the other hand, one might assume that the hunter gets satisfaction out of hunting regardless of the success of the hunt, so that the value to the hunter is $950.28 + $715, or $1,665.28. The reality undoubtedly involves some of both, so that the range of values for hunters is $235.28 to $1,665.28 per pig.

Estimating the expected damages per pig in the forest is a more difficult task. While we know it is possible for a single pig to so significant damage, such as roto-tilling a 15 square yard patch in a day, we do not know how frequently a pig might do this.[86] In the section of this document describing impacts to the Koʻolau Conservation district, we note that 88% of soil is bare in regions inhabited by pigs (Kurdila, 1995). This will potentially increase erosion and sedimentation in streams and on reefs, for which we have estimated costs of $50 to $80 per cubic yard of sedimentation.

If the relationship between pig activity and soil erosion and sedimentation were better quantified, we could use these costs as a lower bound estimate of pig damages to water quality, ignoring the other impacts of pigs on the native ecosystems. If we assume that currently, due to restrictions on human activities like logging and road building in the conservation districts, sedimentation rates above the natural rate of approximately 0.3 tons/acre (Stone, 1989) are due to feral ungulates, then current damages to water quality from their activities are approximately 0.7 tons/acre,[87] or $1,925,000 dollars for the Koʻolau conservation district alone. If the 150 MGD of surface water run-off from the Koʻolaus represents one fifteenth of the surface water flow from

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[85] Market price obtained from Suisan market, Hilo, Hawai'i, personal communication.
[86] Personal communication, Mark White and Stephen Anderson.
[87] This estimate is calculated from the data on sedimentation flows to that Ala Wai canal. (Dashiell, 1997)

all Hawai‘i conservation districts,[88] and we assume similar levels of damages throughout the state, then damages to water quality from feral ungulates are estimated to be $28,875,000 per year. Net of the total value of hunting per year, a low estimate of damages from pigs amounts to $1,035,600 to $23,842,400. Recall that this estimate ignores damages to native ecosystems, which are generally estimated to have quite high values by the methods available (e.g. contingent valuation).

For the purposes of estimating control costs, we examine fencing as the appropriate control strategy. It is generally accepted that fencing an area and removing the pigs within the fenced area is a successful method of preventing damages from these animals. Fencing costs will vary significantly with the type of landscape that must be fenced. Examples of fencing costs already taken are shown in Table 3.6.

Table 3.6: Examples of fencing costs for pig removal

Location	**Area Fenced[89]**	**Costs of fencing**
Haleakalä National Park	50 miles of fence, maximum area = 199 sq. miles	$2.4 million, minimum of $12,057 per square mile.
Külani Prison (Hawai‘i)		$36,000 to $50,000 per mile.
Pöhakuloa Training Area	7.56 miles of fence; 2.5 square miles	$276,000. $36,000 to $40,000 per mile, or $108,500 per square mile.
Pälalai Gulch, O‘ahu	90 acres	$75,000, or $533,333 per square mile.

If we assume $40,000 per mile of fencing, anywhere from 25.9 miles to 596 miles of fence could be installed simply for water quality purposes and retain a positive benefit-cost ratio.[90] If the values for species habitat found in Chapter 2 are taken as lower bound estimates, adding species habitat benefits to watershed benefits will increase the level of fencing which returns a positive benefit-cost ratio significantly. For instance, if we assume that there are thirty-one endangered birds in the state and pigs jeopardize just one that can be saved with fencing, (or, alternatively, substantially increase the probability of some number of them surviving) then the damages from pigs should also include the $14.2 million per year estimated value to Hawaiian households of preserving a bird. In that case, a positive benefit-cost ratio for fencing would allow for another 355 miles of fence per year. That substantial investment in fencing would have a positive sum of net benefits does not imply that fencing with removal of the pigs enclosed in the fenced area

[88] One fifteenth is an approximate guess based on visual comparison of forested land areas, and is meant for illustrative purposes only.

[89] With the exception of Pöhakuloa, where dimensions are known to the author, costs per square mile are based on circle-shaped enclosures and on the theorem that a circle will have the greatest area ($A=P^2 / 4\pi$) for a given perimeter. Smaller enclosed areas will cost more per square mile as the ratio of the perimeter to the area is lower.

[90] Numbers reached by dividing damage levels of $1.035 million and $23.8 million by 40,000. This is assuming that a mile of fence will serve to decrease pig impacts by at least $40,000.

should be the only instrument of control. Even more cost-effective control may be achieved through a combination of fencing with removal and targeted population control outside fenced areas, e.g. hunting.

3.4.2.1.2 *Rats*

In Hawaiʻi, rats were causing $6–10 million dollars a year damage to sugar cane in the early 1990's. This number has decreased due to decreases in sugar cane harvests, not rats. Rats now cause an estimated reduction in the Macadamia nut harvest of 5–10%, which for 1995 would account for 1.8 to 3.6 million dollars in direct agricultural damages (APHIS, personal communication). Rats are also vectors for human and animal diseases. They are a known vector for plaque, which has been present in Hawaiʻi in the last half century. Rats are also known to have dramatic impacts on native bird, invertebrate, and plant populations. The specific impacts beyond the scope of this study, but could be calculated in a similar fashion to those documented here.

3.4.2.2 Plants

Hawai'i has seen the arrival of over 4,600 plant species in the last 200 years. Of these, 86 are established as known pests to native ecosystems. The worst dozen offenders are listed in Table 3.7 below, along with their predicted level of controllability as established by the Hawaiian Ecosystems at Risk (HEAR) project of the University of Hawaiʻi.

Table 3.7: Controllability index for plant pests in Hawaiʻi

Plant species (common name)	Controllability index for Hawaiian islands. Code 1 = absent (no habitat), 2 = absent, potentially present, 3 = Present, controllable (island wide), 4 = Present, controllability unknown, 5 = No info available, 6 = Present, uncontrollable (island wide) ; (1 = best, 6 = worst.)							
	Niʻihau	Kauaʻi	Oʻahu	Molokaʻi	Länaʻi	Kahoʻolawe	Maui	Hawaiʻi
Andropogon virginicus (broomsedge)	5	2	6	6	2	2	6	6
Clidemia hirta (Koster's curse)	1	6	6	6	4	1	6	6
Lantana camara (lantana)	6	6	6	6	6	6	6	6
Leucaena leucocephala (koa haole)	6	6	6	6	6	6	6	6
Melinis minutiflora (molasses grass)	2	6	6	6	6	4	6	6
Miconia calvescens (purple velvet leaf)	1	3	3	2	2	1	3	3
Myrica faya (Faya tree)	1	6	4	2	6	1	6	6
Passiflora mollissima (banana poka)	2	6	2	2	2	2	6	6

Pennisetum clandestinum (kikuyu grass)	6	6	6	6	6	2	6	6
P. setaceum (fountain grass)	2	3	4	3	3	3	3	6
Psidium cattleianum (strawberry guava)	1	6	6	6	6	1	6	6
Rubus argutus (prickly Fla. blackberry)	1	6	6	6	2	1	6	6
Schinus terebinthifolius (Christmas berry)	2	6	6	6	6	2	6	6

Table 3.8 shows generalized characteristics of the plants which present threats to the Hawaiian ecosystems and economy, as well as the locations of major infestations. Though each plant is likely to have specific qualities that render it a pest, costs associated with these problems should be approached generally in order to maximize transferability of information among species. The levels of scientific uncertainty are significant enough to render such first-run approximations as best guesses adaptable to several species. For example, if a species promotes fire, such as broomsedge or fountain grass, estimates of potential damage to the direct human economy could be reached by determining the increase in probability of a fire and using that to determine the increase in expected damages to homes from fire.

The cost of replacement of native habitat with introduced species is extremely difficult to quantify because though we know biodiversity has positive values, methods for measuring this biodiversity are not well developed. Judgement about the levels of control expended to avoid such ecosystem damages or to remediate such damages after they occur must be decided by society in a manner which weighs the costs of such actions against the present and future uses of the land as native habitat and as disturbed habitat. Currently, these expenditures are probably lower than they would be because of inadequate incentives to maximize the net benefit of the resources to society. These inadequate incentives include a lack of concern over the available resources for other individuals or future generations, which will lead to unilateral decisions like the release of a bio-control agent for the good of an agricultural crop which might lead to the demise of a noncommercial plant or animal or even another type of crop. Lack of information about the present and future ecosystem services provided by a species or set of species within a habitat are likely to also lead to lower levels of protection for the resource. The pubic good nature of much of the land and ecosystem services like water quality and quantity provided by the land also indicates that lower than optimal levels of protection are likely.

Table 3.8: Plant pests and characteristics

Plant species (common name); major areas of infestation	**Plant characteristics that lead to classification as pest.**				
	Form	Range	Fire	Other problems	Agricultural / economic use.
Andropogon virginicus (Broomsedge); O‘ahu: windward plain and Püpükea E. Moloka‘i: overgrazed ridges Hawai‘i Island: Puna and Ka‘ü	Perennial bunchgrass	Boggy, open mesic and dry forests; 0–1600 m	Fire stimulated	Dormant during rainy season; erosion; alleopathic	No
Clidemia hirta (Koster’s curse); O‘ahu	Noxious weedy shrub to 2 m.	All	Not fire resistant; is pioneering	Shades competition; aggressive invader	No. May be spread in conjunction with marijuana growing.
Lantana camara (lantana)	Thorny shrub	0–600 m, dry areas	Survives all but hottest fires	Forms impenetrable thickets; allelopathic	No
Leucaena leucocephala (koa haole) all islands	Thornless tree	0–700 m	Regenerates rapidly, fire may flush new seedlings; mature stands are fire suppressing	Dense thickets exclude others	Used for fodder. Deliberately introduced on wide scale.
Melinis minutiflora (molasses grass)	Perennial mat grass	0–1500 m in dry and mesic environments	Fire adapted	Smothers competitors, spreads quickly	Good forage grass
Miconia calvescens (purple velvet leaf) 11,300 acres in East Hawai‘i and Hononau.	Tree to 15 meters	Mesic to wet habitats.		Creates dense monotypic stands. Seed dispersal frequent and large. 10,000 ac. On Hawai‘i infested, 500,000 ac potential range.	Brought in for ornamental purposes. Average cost per acre of removal is $200.
Myrica faya (Faya tree) 85,900 acres on Hawai‘i Kaua‘i: Kōke‘e; O‘ahu: Wai‘anae range; Maui: lower Kula; Läna‘i: Kolele; Hawai‘i: Hämäkua, Hualälai, Volcanoes National Park	Noxious evergreen, to 15 meters.	300–1700 m, invades mesic and wet habitats	Not fire adapted	Forms dense monotypic stands. Nitrogen fixer.	No. Average cost per acre of removal is $250.

Passiflora mollissima (Banana Poka) Hawaiʻi: Hualālai, Laupāhoehoe, Volcano Kauaʻi: Kōkeʻe; Maui: Waiakoa.	Light-loving vine.		Unknown	Smothers forest canopy following sub canopy disturbances. 70,000 ac of native forest in HI smothered.	No.
Pennisetum clandestinum (Kikuyu grass) All islands	Rhizomatous plant	500–2000 m in dry and mesic habitats and wet disturbed habitats.	Slow burning. Fire retardant	Noxious weed classification every state but HI. Strong allelopathic releases, shading.	Favored rangeland grass.
P. setaceum (fountain grass) Hawaiʻi: Kona and Kohala	Noxious weed, bunchgrass.	Dry habitats	Fire stimulated. Carries intense fires throughout range.	Crowds out others.	Bio-control opposed by sugar interests.
Psidium cattleianum (strawberry guava) All islands.	Medium size tree.	Mesic and wet habitats.	Unknown.	Dense monotypic thickets. Found in conjunction with pig disturbances.	No.
Rubus argutus (prickly Fla. blackberry)	Thorny scrambler. Noxious weed.	600–1700 m	Quick recovery though destroyed by fire.	Impenetrable thickets expand by rooting of aerial shoots.	No.
Schinus terebinthifolius (Christmas berry)	Low growing evergreen deciduous tree.	Most mesic to wet lowland habitats.	Killed by high intensity fire but regenerates rapidly.	Shades out others and releases allelopathic substances.	Bio-control opposed by bee keepers.

One plant species that has garnered a great deal of attention is *Miconia calvescens*, or Velvet purple leaf. This attractive plant was brought to Hawaiʻi as an ornamental and planted in East Hawaiʻi. Hawaiʻi now has about 11,000 acres infested with *Miconia,* centered mainly at Onomea near Hilo.

Miconia is an interesting study in alien species for several reasons. First, the potential threat level is high. Second, its biological capacity may indeed call for complete eradication, a surprising finding when discussing both economics and ecology. Third, the type of forest created by *Miconia* infestations is structurally quite different from most multi-layered tropical forests and may have costly impacts on watershed properties. This combination of factors is explored below.

The potential threat level is very high, as Tahiti's *Miconia* problem provides a potential scenario similar to Guam and the Brown tree snake. Sixty-five to seventy percent of Tahiti's forests has been replaced with monotypic stands of *Miconia*. These stands have little if any understory and no diversity. Their establishment was probably aided by a set of two hurricanes in the 1980's, but it does seem capable of invading undisturbed or only slightly disturbed areas of forest.

Since one tree is capable of producing several million seeds per year, and seed banks are known to last at least 6 years after removal of all flowering trees, eradication is a wasted expenditure unless it is followed up with repeated sweeps over the next 6–10 years. *Myrica faya* may be another example of this sort of growth potential and subsequent eradication problem: there was one known tree in Volcanoes National Park in 1961, by 1978, 609 hectares were infested, and by 1985, 12,000 hectares were infested.

This geometric growth pattern indicates that early control and eradication is essential to avoiding significant ecological change and potential economic damages, but prevention will have significantly higher returns than any attempts at eradication and is worth significant investment. Continuous and careful monitoring of new species is thus a potentially good way of maximizing return to prevention expenditures or any aspect of controlling introduced plant species. **Plants will not necessarily behave as they did in their native environments; *Miconia calvescens* is just one part of healthy forests in its native Central and South American ranges** (Bob Hobdy, personal communication). We have learned to be this cautious with purposefully introduced species, establishing quarantines and study periods for bio-control agents that have significantly increased the success rate of such introductions. These efforts must be continued and accidental introductions (or illegal purposeful introductions) must receive considerable efforts.

Because the trees grow tall and do not permit enough light for understory, rainfall effects on soil are likely to be impacted. For stands taller than 6 meters, increases in erosion are expected because the leaves no longer act to slow the raindrops, and in fact, may allow for the formation of larger drops that hit with the same velocity that they would if there were no canopy. The potential costs of sedimentation have been discussed in the sections on the Ko'olau forested watershed and feral ungulates above. In addition, landslides may become more common, and will reduce the soil capabilities of the land. Included in these effects may be a reduction in groundwater infiltration rates, which could lead to lower amounts of groundwater, increased water scarcity and thus greater costs to society. We cannot gain much information from the Tahiti experience about groundwater changes because fortunately the main watershed is located in the 30% of the forest that has not been invaded.

***Miconia* in Hawai'i's stream beds**: Quick research potential in Hawai'i on this issue may be possible in the near future. The Hawai'i stream research center at the University of Hawai'i conducted a thorough study of the Onomea and Alakahi streams on the island of Hawai'i in 1997 (Kido et al, 1997). This study was intended to create a baseline for observations of the stream quality as impacted by human actions. However, the Onomea stream is located amidst the heaviest infestation of *Miconia calvescens* in Hawai'i. Continued monitoring of the stream should allow for quick identification of *Miconia* related water and soil quality problems.

A bio-control agent, a defoliating fungus, has been released on Hawaiʻi to attempt to slow the expansion rate of the trees sufficiently to allow for complete eradication of the plant before it spreads further. This bio-control agent cannot be released in Tahiti because Tahiti has certain rare endemic plants that would be affected by the fungus. *Miconia* control efforts also include trials to determine the best herbicide to kill the trees.

On the island of Hawaiʻi, *Miconia calvescens* eradication costs are currently estimated at $200 per acre. This eradication treatment is expected to have 90–95% success at killing the existing trees (Nelson, personal communication). Treatment is expected to be necessary after no longer than 2 years, and then again after 4 years. Monitoring will likely need to extend beyond this period. Thus, we assume that at a 4% discount rate, an acre of *Miconia* infestation will cost $542.94 for eradication over the next six years plus some monitoring costs after that time. The clearest benefit of keeping *Miconia calvescens* out of Hawaiian forests is the preservation of species habitat. If one species worth $14.2 million to Hawaiian households per year is preserved, then the present value of expenditures on the 11,360 acres in Hawaiʻi need to be less than $1,250 per acre for the benefit-cost ratio to be positive. So far, then, treatment remains cost effective, as long as commitment to the necessary re-treatments is made. However, if the species expands to its 500,000 acre potential, and still only threatens one species, then the costs per acre must be less than $28.4 per acre to return a positive benefit-cost ratio.

Since hunting down the last *Miconia* sapling 6 years after the last known tree is removed will cost significantly more than $200 per acre, the relationship between the expected benefits and expected costs will change as the control efforts reap success. It is unlikely that hunting down *Miconia* would be more profitable than adopting a more wide-scale monitoring program that would allow the quick control of newly introduced threats.

Miconia costs in Hawaiʻi:
The Hawaiʻi Tropical Botanical Gardens is located on 37 acres on the island of Hawaiʻi in Onomea, the heartland of the estimated 11,300 acres of *Miconia* infestation on the island. The non-profit organization has an annual budget of about $1 million, collected from entrance fees and donations. They currently estimate *Miconia* control expenditures of $25,000 per year, down from $40,000 a year when direct eradication was underway on several acres of the gardens (Lucas, pers. comm). This amounts to current expenditures of $675 an acre to keep the land *Miconia*-free. *Miconia*'s quick shading canopy and aggressive nature could devastate the gardens if left unchecked.

3.4.2.3 Insects

Each year an average of 20 new alien insects make their way to Hawaiʻi; half are known pests. Included here is a discussion of the known effects of a few of these species.

3.4.2.3.1 *Formosan Ground Termite*

There are 4 known species of termites present in Hawaiʻi. The most damaging of these termites is the Formosan subterranean termite, *Coptotermes formosanus.* This species is particularly aggressive and can cause major structural damage to an unprotected home in 6 months, with complete destruction in 2 year's time (Tamashiro, 1984). Besides threatening homes, they will attack more than 50 species of live trees, including crop trees such as Macadamia and Papaya (Tamashiro and Su, 1987). These potential costs have never been included in damage estimates. The potential costs of pesticide use to contamination of the water supply have also been omitted.

The termite does not spread rapidly on its own, perhaps only a few hundred meters in 5 years. However, man's movements have spread the termite to all main islands in Hawaiʻi. The most serious populations are on Oʻahu and Kauaʻi, with other islands mainly limited to ports of entry (Tamashiro, 1990).

Formosan termites were first recorded in Hawaiʻi in 1908 when they were collected by entomologists, but the first reports of "white ants" causing such types of damage were in 1860s. Though uncertain, it is likely that they have been here since the mid-1800s, probably arriving from China on wooden boats. This termite now is well established in Louisiana and other Gulf states as well.

The costs of damages from this termite to man made structures have been estimated for different locations and at different times over the past thirty years. For Hawai'i, the most recent formal attempt to measure the costs directly was a 1984 paper which estimated that about $60 million is spent by consumers on control and repair. This estimate was derived by surveying the 80 pest control companies in Hawaiʻi and estimating the costs based on chemicals sold, since the companies were not forthcoming with many details. This number was inflation adjusted to $100 million in 1990 and then inflation adjusted again to $150 million in 1997.

More informally, Dr. Ken Grace has spoken to Pest Control Distributors and based on marketing surveys, found that termite control costs are $30 million for 1997. Insecticide treatment for soil is $25 million and chemical concentrate costs $5 million. This does not include depreciation or repairs costs, which could be significant as the median home price in Oʻahu was $307,000 for single family homes in 1997 (Honolulu Board of Realtors, 1998).

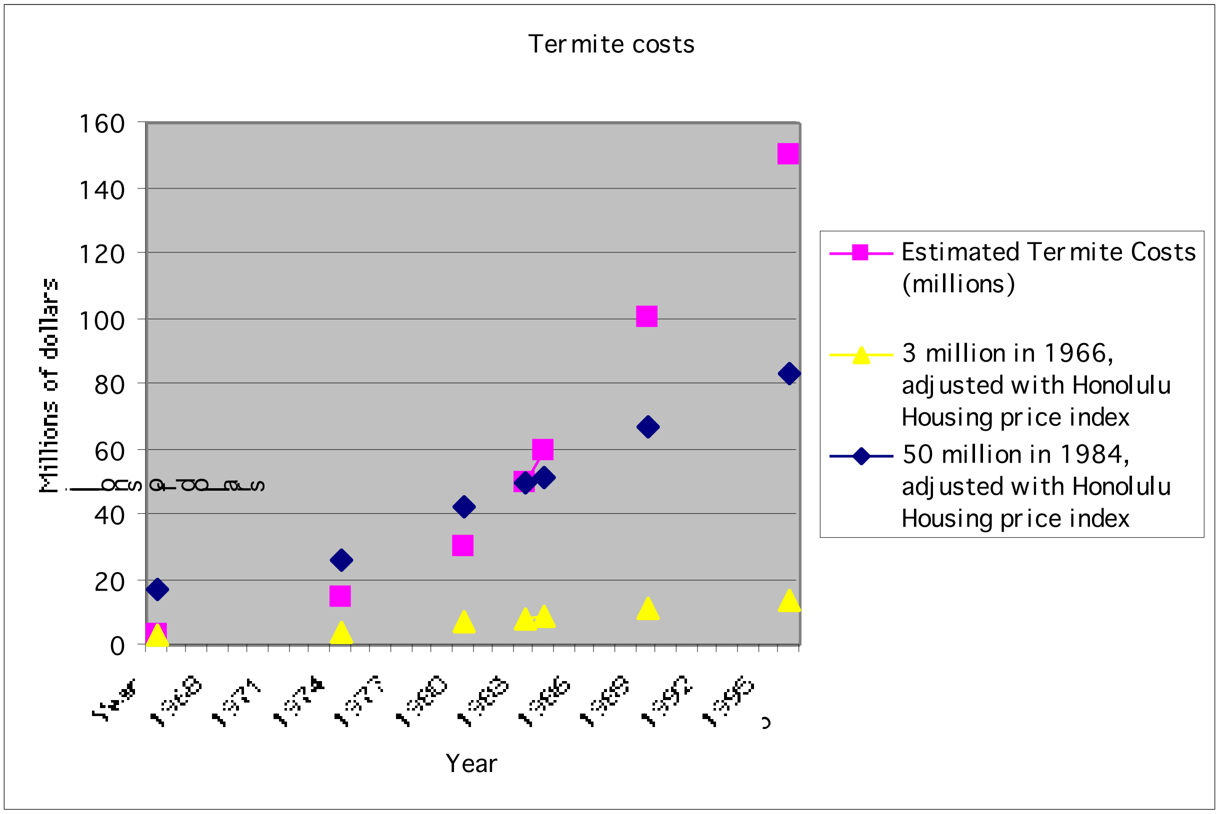
Since Oʻahu gets about 90% of its household water from ground water aquifers, contamination from pesticides is a costly risk. The present value of this water may be $4.57 to 8.52 billion (see Chapter 2 for details). Low contamination levels due to pesticides used for sugarcane over the last half-century may already be appearing in the groundwater, suggesting that the threat is real and a lag time may make it difficult to associate the cause with the effect. The potential extent of the damage is also hard to quantify, since there are likely to be different levels of contamination depending on the soils and geological properties of an area.

Figure 3.1 shows the estimated termite damage for years that estimates are available against two possible levels of costs in real dollars. These are the $3 million per year estimate from 1966 and the $50 million per year estimate in 1984. Taking these figures and converting them to nominal dollars for the same years as nominal estimates are shown, one sees that housing costs have not risen as rapidly as estimated termite control costs, indicating a belief that the problem continues to grow in costliness even as expenditures advance rapidly.

Table 3.9: Estimated Termite Costs in Hawai‘i

Year	Estimated Termite Costs ($ million)	Honolulu Housing Cost Index (1967 =100)	3 million in 1966, inflation adjusted	50 million in 1984, inflation adjusted	Source for termite costs
1966	3	95.6	2.9	16.8	Anonymous (Tamashiro, 1987)
1975	15	147.3	4.4	25.9	Fujii
1981	30	240.3	7.2	42.2	Higa
1984	50	284.8	8.5	50.0	Tamashiro
1985	60	294.1	8.8	51.6	Tamashiro
1990	100	380.3	11.4	66.8	Tamashiro
1997	150	473.4	14.2	83.1	Grace

Figure 3.1



Termite control research in Hawai‘i is conducted at the University of Hawai‘i and the current budget is $350,000 each year, primarily federal funds, with some private, and a little state. The 1999 budget will increase to $450,000. The combined budget of all government pest prevention programs is only $25 million**.** There are more than 2000 termite species in the world, many of these destructive species could thrive in Hawai‘i’s tropical climate.

History’s lessons: Termites vying for Hawai‘i’s throne?
The Iolani Palace, completed in 1845, was damaged to such an extent by subterranean termites that it was leveled in 1875 and then rebuilt in following years. Termites devoured the Palace Coronation Pavilion in 1905 and 1913. Another massive and costly renovation that installed a steel frame and repaired the foundation, came after further damage in the 1920s. Damages continued to mount until 1969, when a massive chlordane treatment was used to cleanse the structure. Termite problems have resurfaced since 1995, and chlordane’s detrimental effects on groundwater quality have everyone searching for safer, more efficient eradication tools. (Silvestri, 1997)

3.4.3.2.2 *Biting Sand Flies*

Biting sand flies could be introduced by aircraft or ships and infest Hawai‘i’s beaches. Hawai‘i is the primary shipping link between the mainland, Asia, and other Pacific Rim ports. It is also the 17th busiest airport in the world. Once here, poisoning and re-engineering of beaches to minimize breading habitat would be needed in order to avoid losses in tourism revenue and currently unquantified benefits to visitors at Hawai‘i's beaches.

3.4.2.4 Alien insect pests and agricultural production

Non-indigenous weeds, insects, mollusks, birds, and pathogens reduce crop and livestock production, increase production costs, and cause post harvest crop losses. Management of agricultural pests requires costly research, development, and control technology application such as pesticides (HNIS in the US, 1992: 65).

Hawai‘i farmers have a difficult time coping with the ever increasing number alien insects. Farmers must respond to the threats from these pests with an increase in the use of pesticides, changes in crops, or they must quit farming. The agricultural industry estimates that it **loses $300 million per year in revenue** from potential markets that now refuse Hawai‘i’s exports because of alien fruit flies that infest many island crops. Agriculture constitutes a large portion of Hawai‘i’s economy, grossing nearly $500 million in crop revenues per year.[91] New pests threaten Hawai‘i’s diversified agricultural hopes in particular.

Fruit flies exemplify how insects limit the potential of Hawai‘i's agricultural economy. For example, Hawai‘i's papaya industry now exports $19 million worth of papaya per year to the U.S. mainland, after having adopted the double-dip hot water treatment method of control for the fruit fly. This represents 15% of the U.S. market. Assuming Hawai‘i's next two most promising tropical fruits, mangos and avocados, could also capture15% of the U.S. market, were fruit flies no longer a problem, this could increase export revenues by another $22 million per year.

Export revenues forgone, however, are not the same as economic benefits forgone. A more detailed study would assess market potentials of the most promising fruits, subtract expenditures for labor and other inputs, as well as the opportunity cost of the land employed, and add the estimated value of consumer surplus. One should also add in the current expenditures on fruit fly control as an additional cost of fruit fly damages. These calculations would likely exceed $50 million per year but would be less than the $300 million estimate put forth in lobbying efforts seeking the approval of fruit irradiation.

Alien snails, insects, viruses, and other pests threaten Hawai‘i’s taro production (already **a $2.79 million industry statewide** in 1996[92]). Taro root aphids have caused a 90% crop loss in dryland taro. The only treatment is removal of all taro from the infested field for at least one year. Many other crops face similar threats, such as bacterial blights on anthurium and ginger

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[91] A University of Hawai‘i study estimates its overall contribution to the economy at $2.9 billion for 1995. (Statistics of Hawaiian Agriculture).

[92] Figure from Statistics of Hawaiian Agriculture found at http://www.nass.usda.gov/hi/stats/stat-11.htm on August 15, 1998.

root, a papaya ringspot virus that weakens and ruins papaya, and a root aphid that reduces vegetable crops.

3.5 CONCLUSIONS

Hawai‘i’s many valuable natural resources and ecosystem services are extremely vulnerable to threats of introduced species. The native flora and fauna developed in relative isolation with sufficient lack of competition for most species to have developed through adaptive radiation rather than competitive behavior. The lack of defenses leaves room for aggressive introduced species to create major changes in the ecosystem. Frequently with plants, for example, complex ecosystems may be replaced by monotypic tree stands or grasses. Some of these aggressive species have additional threats, particularly that of fire or disease.

While the impacts of alien species are multifaceted, complex, and cut across many industries and ecosystem services, the impact on the state’s number one industry, tourism, provides a good example of how the economy depends on the prevention of alien species introduction and/or proliferation. The visitor industry generated $18.9 billion in total sales, 30% of all state and county taxes ($1.1 billion) and 37% of all civilian jobs in 1994. This industry is dependent upon Hawai‘i’s safe and pleasant outdoor environments. Alien species threaten the safe and pleasant outdoor environments. “One of the greatest, unsung advantages we have as a visitor destination is all the things we don't have—snakes, biting flies, tropical diseases. As we work to attract more visitors, it is critical that we also keep these pests out.” Paul Casey, President, Hawai‘i Visitor’s Bureau.

Millions of dollars in direct economic costs might also occur from the arrival of introduced species like the Brown tree snake. Guam’s native bird populations have been devastated by the snake, and power outages due to snakes are a frequent occurrence. Hawai‘i’s trade relations with Guam and the presence of amenable habitat render the Brown tree snake a significant threat to the state economy.

The geometric progression of biological growth functions and the lack of co-evolution with competition among existing species in the state means that prevention of the establishment introduced species will likely have greater cost effectiveness than control expenditures. Once established, control methods cannot be guaranteed to eradicate problems and the delicate nature of Hawaiian ecosystems as well as their limited land area do not leave much room for ignorance, or for trial and error, as the example of Guam’s bird disappearance demonstrates.

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