Land Use Change in Hawaii, 1950-2000: Relationship to Environmental Cofactors affecting the Prevalence of Fibropapillomatosis in the Hawaiian Green Turtle, *Chelonia mydas*

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DEDICATION

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ABSTRACT

Land Use Change in Hawaii, 1970-2000: Relationship to Environmental Cofactors affecting the Prevalence of Fibropapillomatosis in the Hawaiian Green Turtle, *Chelonia mydas*

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Fibropapillomatosis (FP), a debilitating neoplastic condition of marine turtles, is likely a re-emerging epizootic disease. Green turtle FP prevalence has increased or remained high in Hawaii according to systematic surveys initiated in the early 1980s; prevalence across the Hawaiian Islands ranges from 0% to 92%. The maintenance of large differences in FP prevalence through time over relatively small geographic distances suggests that environmental cofactors may be important for complete expression of this disease. Using historical black and white aerial photography, land use and land cover were classified into developed land, cultivated land, total vegetation, bare land and water to investigate the relationship between FP prevalence in the Hawaiian Islands and land use and land cover (LULC) change. Between the early 1950s and 2000, developed land increased between 1% and 14% across the five sites in Hawaii; Kaneohe Bay, Oahu, and Waikiki, Oahu, experienced the largest increase in developed land. Cultivated land increased by 1% to 11% across all site save Punalu'u, Hawaii; bare land remained generally consistent across all sites between 1950 and 2000 except for at Punalu'u. Kaneohe Bay and Waikiki, the sites with the highest percent developed land, exhibit the highest green turtle (GP) FP prevalence. High GT FP prevalence was also observed at Palauu, Molokai; this site is characterized by negligible developed land and 96% vegetation suggesting that though commonly associated with developed land, high FP prevalence also occurs given

minimal development. Shortage of complete historic data suggests the sites for future historical analysis must be chosen carefully; the most informative sites will have similar biophysical properties and exhibit substantial differences in level of development. Given the push towards data integration via fields like conservation medicine - a “new” approach focusing on the health relationships occurring at the interface of humans, animals, and ecosystems - integrating health surveillance with LULC data may provide an informative framework for further GT FP research and management.

I. INTRODUCTION

The green turtle, *Chelonia mydas*, has been an important part of traditional Hawaiian culture for millennia. After decades of exploitation, *C. mydas* gained protection under the Endangered Species Act in 1978 and the population has subsequently shown encouraging signs of recovery (Juvik 1998). However, marine turtle fibropapillomatosis (FP), a disease of unknown etiology, threatens green turtle populations worldwide (Balazs 1990; Herbst 1994; Williams, Bunkley-Williams et al. 1994; Landsberg, Balazs et al. 1999; Quackenbush, Casey et al. 2001). In the last decade, green turtle FP has emerged as a significant threat to the health of Hawaiian green turtle populations. According to a series of systematic pathologic exams on 49 dead or moribund green turtles from various Hawaiian Islands, FP is currently responsible for 73% of morbidity and mortality recorded in *C. mydas* (Work 1998). Over a 17-year time period, annual prevalence of FP among stranded turtles significantly increased and remained consistently high, ranging from 47-69% during the past decade (Murakawa, Balazs et al. 1999). Although FP predominantly affects *C. mydas*, it has appeared with increasing frequency in loggerhead (*Caretta caretta*) and olive ridley (*Lepidochely olivacea*) turtles (Quackenbush, Casey et al. 2001) as well. Given the increasing prevalence, wide geographic range and recent infections in other species of marine turtles, FP is clearly re-emerging as a serious wildlife infectious disease (personal communication Balazs).

Currently, investigators are focusing on two aspects of the etiology of marine turtle FP. First, evidence from controlled transmission experiments suggests that an infectious agent, most likely a herpesvirus or a retrovirus, is responsible for the etiology of marine turtle FP (Casey, Quackenbush et al. 1997; Coberley, Herbst et al. 2001). Secondly, several studies have shown that green turtle FP prevalence varies considerably over short geographic distances. For instance, FP prevalence across the Hawaiian Islands ranges from 0% to 92% (Balazs and Pooley 1991; Balazs, Dudley et al. 1994; Balazs, Miya et al. 1994; Herbst 1994; Balazs, Puleloa et al. 1997; Balazs 1998; Murakawa, Balazs et al. 1999). The maintenance of large differences in FP prevalence through time over relatively small geographic distances suggests that environmental cofactors may be important for the full expression of this disease. A growing body of literature has begun to explore potential environmental cofactors (Landsberg, Balazs et al. 1999).

The goal of this project is to investigate the relationship between FP prevalence in the Hawaiian Islands and land use and land cover change, as an environmental cofactor. The first objective is to quantify the change in extent and rate of agriculture, industrial and urban land use/land cover (LULC) from 1950 to the present across five sites in Hawaii. Exploring and quantifying the trends in landscape pattern may facilitate assessment of the overall condition of natural resources and potential sources of contaminant (O'Neill, Hunsaker et al. 1997); understanding differences in ecological systems based on the explicit composition and spatial form of a landscape mosaic(s) is the underlying premise of landscape ecology (Wiens 1995). A common application of landscape ecology practices is to establish a relationship between landscape pattern and environmental variables of interest (Turner, Gardner et al. 2001). Based on personal observation as well as Herbst and Klein 1995, high green turtle FP prevalence is associated with marine habitats impacted by agriculture, industrial and/or urban development. Quantifying land use change at five sites in Hawaii where long term FP prevalence data has been collected will provide a means to more rigorously test this association. Information garnered describing these associations can then be incorporated into future land use planning exercises and/or management scenarios to minimize undesired impacts. Although coarse scale landscape analysis is not a substitute for finer scale monitoring, analysis of changes in landscape pattern may prove to be a practical, efficient and a less expensive alternative to ground based survey (O'Neill, Hunsaker et al. 1997).

The second objective is to examine the relationship at each site between changes in land use and green turtle FP prevalence in *C. mydas* populations by noting if the rate of increase/ decrease in land use parallels the rate of GTFP prevalence. Daszak *et al.* (2000) surveyed selected emerging infectious diseases (EID) of humans and terrestrial wildlife and concluded that anthropogenic environmental change may be the most significant driver of wildlife and domestic animal as well as human EID (Daszak, Cunningham et al. 2000). Similarly, Harvell *et al.* (1999) provide evidence detailing an increase over the last several decades in both the frequency of marine epidemics and number of new marine diseases reported, particularly in closely monitored groups like corals and marine mammals. Associations among events such as mass mortalities of marine mammals along heavily polluted coastal areas suggest a role of anthropogenic change in marine disease etiology. However, regardless of compelling associations between increasing disease emergence in areas of high anthropogenic change, differentiating between actual increases and simple artifacts related to improved monitoring and detection requires critical analysis.

II. BACKGROUND AND RATIONALE

A. NATURAL HISTORY OF *CHELONIA MYDAS*

1. General Description

The green turtle, *Chelonia mydas*, is a circumglobal species primarily found in warm tropical or sub-tropical waters (Bjorndal, Bolten et al. 2000). In Hawaii, green turtles are found at specific locations throughout the Hawaiian Archipelago extending from 18°54' N, 154°40'W to 28°15' N, 178°20' W (Balazs 1980). They are characterized by slow growth, delayed sexual maturity, high fecundity, iteroparity, herbivory (in most cases) and a relatively long reproductive life under natural conditions (Hirth 1997). However, major gaps remain to be filled in natural history of green turtles including natural sex ratios, ecologies of hatchlings and juveniles during the "lost years", biology of males (because females can easily be studied on the nesting beaches, much less information is know about males), survival rates of different size classes, speciation rates and navigation mechanisms.

In the past, turtle hunting posed the biggest threat to the Hawaiian *C. mydas* population (Balazs 1980). In 1978, Hawaiian *C. mydas* populations were listed as a threatened species and gained protection under the US Endangered Species Act (16 U.S.C. § 1533(c) - 50 C.F.R. § 17.1.1 (2002)). Today, one of the biggest threats to the population is the proliferation of FP throughout the species (Team 1997). Additionally, the loss of foraging habitats to nearshore development in the main Hawaiian Islands, contamination of foraging areas from toxic spills, resort development, entanglement and ingestions of marine debris and incidental take in sport and commercial fisheries adversely affect population viability. The Hawaiian population currently consists of approximately 1400 adult females (Balazs, Miya et al. 1994).

2. Hawaiian Population Distribution

The distribution of adult turtles is determined primarily by the locations of acceptable breeding, foraging and resting habitats (Balazs 1980). Green turtles most commonly reside on the adjacent underwater coastal shelf, often only several kilometers from shore. Adults spend the majority of their time foraging most commonly in the coastal waters off of the main islands and the northwest Hawaiian Islands given that the principle food source is restricted to depths where sunlight, substrate and nutrients are conducive to plant growth. Underwater resting sites are most commonly characterized by lack of strong currents and disturbance from predators and include coral recesses, undersides of ledges and sand bottoms or "nests". In Hawaii, the resting areas closest to the main islands normally occur at depths between 20 to 50 meters (Balazs 1980).

Hawaiian green turtles consistently demonstrate high site fidelity (Balazs, Miya et al. 1994; Balazs, Rice et al. 1998; Landsberg, Balazs et al. 1999). Tagged Hawaiian *C. mydas* have been observed to repeatedly feed at the same locations at all resident foraging locations investigated thus far. This site fidelity has been documented on both a short-term basis (daily and weekly) and for longer periods ranging up to 37 months (Balazs 1980). The majority of evidence accumulated to date indicates that after leaving the pelagic environment, Hawaiian *C. mydas* reside in the same general coastal area, with the exception of reproductive migrations, for extended periods. Correspondingly, turtles of all sizes from 35 cm juveniles to mature adults (> 82 cm) are frequently found along a given coastal area (Balazs, Dudley et al. 1994; Balazs, Miya et al. 1994; Hirth 1997; Balazs, Rice et al. 1998; Balazs 1998).

3. Life Cycle of Hawaiian C. mydas

The large spatial and temporal scales that characterize the life cycle of *C. mydas* make it difficult to study (Balazs 1980; Carr 1980; Carr 1987; Herbst 1994; Hirth 1997). Hatchlings and juveniles move between the pelagic, neritic and benthic zones during development and adults migrate between unique feeding and nesting groups that are hundreds or thousands of kilometers apart. Turtle growth rates are assessed by osteology, histology (Bowen, Meylan et al. 1992) and construction of size-shaped analogues of age-based parametric growth curves (Bjorndal, Bolten et al. 2000). The information available on the biology of Hawaiian *C. mydas* populations comes primarily from ongoing systematic tagging and monitoring programs initiated by Balazs on the French Frigate Shoals in June 1973 (Balazs 1980).

A. Hatchlings

Hatchlings emerge after an incubation period of eight weeks; they enter the pelagic habitat where they remain for several years (Balazs 1980). During the hatchling's tenure in the pelagic zone, they are probably carnivorous and feed on invertebrates such as jellyfish. The time following the hatchings departure from their nesting beach is commonly known as the "lost year(s)" (Witham 1980), a lifestage of unknown duration which is believed to be passed in pelagic habitats, but neither the location nor any aspect of the biology of this stage in green turtles has been elucidated (Bolten and Balazs 1995).

B. Juveniles

When green turtles attain a size greater than 35cm carapace length, the juveniles eventually enter the neritic foraging habitats and switch to the primarily herbivorous adult diet (Balazs 1980). Because foraging areas are restricted to depths where sunlight, substrate and nutrients are conducive to plant growth, foraging grounds are usually less then 10 m deep and are often not more than 3 m deep.

C. Adults

Adults commonly reach 100 cm in carapace length and 150 kg in mass (Balazs 1980; Hirth 1997). Published age of sexual maturity ranges from 9 to 58 years in Hawaii (Balazs 1982). At intervals of two to ten or more years, approximately 90% of all mature females migrate from near-shore habitat to their natal nesting locale in the French Frigate Shoals (Balazs 1980). Tagging data indicate that nesting adults typically return to the same feeding grounds. Males appear to migrate annually and typically arrive ahead of the females. During a single nesting season, a female typically lays one to five clutches of approximately 100 eggs before returning to the feeding grounds. Though the lifespan of *C. mydas* – similar to other marine turtles – remains unknown, the lifespan is likely to be substantial given that turtles may require 58 years to reach sexual maturity.

D. Sex Ratio

Given the life history of *C. mydas* and the inability to morphologically distinguish sex in juvenile turtles, sex ratio data is limited at best. According to Balazs's (1980) synthesis of biological data on the Hawaiian *C. mydas* population, the Hawaiian population consists of more females than males. This observation is consistent with limited sex ratio data on other green turtle populations synthesized by Hirth (1971). Today, researchers still have a limited understanding of natural sex ratios (Hirth 1997). However, a number of case studies exist; most recently in Hawaii, the sex ratio of a pooled sample (N=66) of immature Hawaiian turtles caught in their feeding habitats did not differ significantly from 1:1 (Wibbels, Balazs et al. 1993).

4. Diet

Green turtles' primary food sources are benthic algae and sea grasses (Balazs 1980; Russell and Balazs 2000). *C. mydas* has been documented foraging on 56 algal species, 1 marine angiosperm and 9 invertebrate species. Marine angiosperms, such as turtle grass *Thalassia testudinum*, constitute the primary food source for a number of global *C. mydas* populations. However, in Hawaii, the only seagrass species present is *Halophila hawaiana*; it occurs in small, low density meadows around the main islands and at Midway. The primary food sources here consist of nine species of algae. *Codium* and *Ulva* are the primary food source of juveniles, subadults and adults on both the main Hawaiian islands. *Pterocladia* and *Amansia* are important dietary sources on the main islands while *Caulerpa*, *Turbinaria* and *Spyridia* are predominantly utilized on the northwest Hawaiian Islands. Hawaiian green turtles also forage on *Sargassum*. A detailed description of algal species found in crop/stomach samples of Hawaiian *C. mydas* can be found in Russell and Balazs (2000).

B. CHARACTERISTICS OF GREEN TURTLE FP

1. General Description

Fibropapillomatosis, a debilitating neoplastic disease of marine turtles, is a likely a re-emerging disease representing a new viral epizootic (Quackenbush, Casey et al. 2001). Originally described in 1938 in green turtles from the Florida Keys (Smith and Coates

1938), the disease was first documented in Hawaii in 1958 (Balazs 1991); green turtle FP prevalence has increased or remained high in Hawaii according to systematic surveys initiated in the early 1980s (Balazs 1991). In addition to marine turtle FP persistence in Hawaii, FP has been documented in populations residing in the Atlantic Ocean (Florida, Brazil), the Indo-Pacific region (Australia, Sri Lanka, Sarawak, Malaya, Bononin Islands, Japan) and the Caribbean Sea (Cayman Islands, Puerto Rico, Dominican Republic, Virgin Islands, Barbados, Antigua and Barbuda, Central America) (Landsberg, Balazs et al. 1999) with sporadic but generally increasing frequency in green, loggerhead and olive ridley turtles (Balazs and Pooley 1991).

Figure 1. ***Chelonia mydas*** **"Spot" with no tumors, 1992 (Photo courtesy of Turtle Tracks, http://www.turtles.org/ [December 2002]).**

Figure 2. ***Chelonia mydas*** **"Spot" (the same turtle) with fibropapilloma tumors, 1995 (Photo courtesy of Turtle Tracks, http://www.turtles.org/ [December 2002]).**

2. *Characterization of Fibropapillomatosis*

FP is characterized by single to multiple histologically benign fibroepithelial tumors that are primarily found on the soft skin, but can also be found anywhere on the turtle's body or in the viscera (Herbst 1994). The tumors range in size from 0.1 cm to over 30 cm in diameter. Commonly, tumors are located on the flippers, neck, chin, inguinal and axillary regions, tail base and the conjunctiva and ocular region. Effected turtles may be emaciated, weak, anemic and suffer from flotation problems resulting, for example, from fibrous tumors in the lungs. FP tumors, like many proliferative diseases of poikilotherms, have been observed to regress in a few cases, although the mechanism of regression remains unknown (Ehrhart 1991). The tumors are life-threatening both because they compromise the host physiologically and affect its ability to compete in the natural environment (Balazs 1991; Herbst 1994; Balazs, Aguirre et al. 1997). The disease primarily affects age groups of high reproductive value, large juveniles, and to a lesser extent, adult green turtles (Herbst 1994). Consequently, FP poses a significant threat to the long-term survival of this threatened species (Balazs and Pooley 1991; Herbst 1994; Team 1997; Landsberg, Balazs et al. 1999).

3. *Current Research*

Currently, investigators are focusing on two aspects of FP. One avenue of investigation is the molecular etiology of the disease. Herbst et al. (1995) demonstrated that green turtle FP tumors contain an infectious agent that can be transmitted to other turtles through skin injection or scratch inoculation. The infectious agent is small (under 0.45 micrometers), found in the cell free (filterable) fraction of tumor tissue homogenate and is inactivated by organic solvents, strongly suggesting that the causative agent is an enveloped virus (Herbst, Moretti et al. 1996). Herbst et al. (1995) also reported two cases of spontaneous horizontal transmission from tumor-bearing turtles to naïve turtles following co-housing involving extensive physical contact. A strong association between antibody reactivity to herpesvirus antigens and green turtle FP status in both captive-reared and free-ranging turtles is consistent with the hypothesis that the transmissible agent that causes green turtle FP is a herpesvirus (Herbst, Greiner et al. 1998). Independent investigators have confirmed the presence of herpesvirus in association with green turtle FP tumors; turtles in Hawaii, Florida, Costa Rica, Australia, Barbados and Pacific Mexico have been positively identified as harboring fibropapilloma-associated turtle herpesvirus (Quackenbush, Work et al. 1998; Quackenbush, Casey et al. 2001). Koch's postulates are traditionally used in epidemiology to establish disease causation (Evans 1976). In terms of the viral etiology, transmission of FP with the purified virus remains the only outstanding postulate to prove that this virus is the etiologic agent of this disease (Coberley, Herbst et al. 2001).

The second avenue of investigation addresses the hypothesis that environmental cofactors may be important for the full expression of this disease. FP prevalence varies considerably among geographic locations, ranging from 0% to 92% across the Hawaiian Islands (Ehrhart 1991; Balazs, Miya et al. 1994; Herbst 1994; Balazs, Rice et al. 1998; Balazs 1998). The maintenance of large differences in FP prevalence through time over relatively small geographic distances suggests that environmental cofactors may be important for the full expression of this disease. Generally, most cases of FP are found in nearshore areas or lagoons near urban or agricultural activities associated with eutrophication (Herbst and Klein 1995b; Landsberg, Balazs et al. 1999).

4. Possible Environmental Associations

The etiologic agent of FP is most likely a herpesvirus; however, environmental cofactor(s) may be important in differential disease expression in naturally occurring populations (Herbst and Klein 1995b; Landsberg, Balazs et al. 1999). A single cause-effect relationship cannot necessarily be inferred from the observation that tumors have been experimentally induced in animals using oncogenic viruses or cell-free filtrates in laboratory studies in what may be a multifactored or multistep neoplastic process occurring in wild populations (Landsberg, Balazs et al. 1999). There are many examples where potentially oncogenic viruses require interacting cofactors to express carcinogens (Landsberg, Balazs et al. 1999). A classic example is the interaction of bracken fern forage and epithelial carcinomas in cattle; if cows ingest bracken fern, its mutagenic and immunosuppressive cofactors cause papillomas to transform into squamous cell carcinomas (Campo and Jarrett 1986).

A variety of environmental associations have been proposed and (Balazs and Pooley 1991; Herbst 1994; Landsberg, Balazs et al. 1999) including dietary biotoxins (Landsberg, Balazs et al. 1999; Anderson 2002), parasites (Aguirre, Balazs et al. 1994; Aguirre, Spraker et al. 1998; Herbst, Greiner et al. 1998), chemical pollution (Aguirre, Balazs et al. 1994; Miao, Balazs et al. 2001), interaction with other species (Zamzow 1998), genetic predisposition (Herbst 1994), ultraviolet radiation (Smith and Coates 1938), immunospression (Herbst 1994) and other undefined environmental cofactors, with varying degrees of experimental and observational support (Herbst and Klein 1995b).

A. Dietary biotoxins

Landsberg (1999) and her student Anderson (2002) have made a compelling case for the link between *Prorocetrum* dinoflagellate blooms and green turtle FP prevalence. Toxic benthic dinoflagellates (*Prorocentrum* species) are not typically considered to be tumorigenic agents, but several species produce a substance called okadaic acid found in a laboratory setting to be a tumor promoter (Aikman, Tindall et al. 1993; Landsberg, Balazs et al. 1999). *Prorocentrum* species have a worldwide distribution and are epiphytic on macroalgae and seagrasses that are normal components of *C. mydas* diets. Landsberg *et al* (1999) have hypothesized a link between increased concentration of okadaic acid and increased presence of FP in turtles. It is often suggested that the increase of toxic algal blooms are related to changes in nutrient inputs from human activities (Aikman, Tindall et al. 1993).

B. Parasitic Infections

In addition to the viral agent associated with most of the FP tumors, spirorchid trematode eggs are frequently associated with the FP tumors (Smith and Coates 1938; Herbst 1994; Aguirre, Spraker et al. 1998). Given the ubiquitous presence of spirorchid trematode ova within the fibrotic portion of the FP lesions, a trematode etiology was posited as a plausible cause of green turtle FP (Aguirre, Spraker et al. 1998). Based on serodiagnostic experimental evidence, Herbst et al. (1998) suggest that spirorchids do not play a major role in green turtle FP pathogenesis; their results are consistent with the hypothesis that a herpesvirus is the transmissible agent responsible for green turtle FP. Similarly, Aguirre et al (1998) concluded that spirorchid trematodes and their eggs are not directly responsible as a primary cause of FP. Although experimental transmission studies have ruled out spirochid eggs as a direct cause of green turtle FP, an indirect role for spirorchidiasis in the epizootiology of green turtle FP remains plausible (Herbst, Jacobson et al. 1995a).

C. Chemical Carcinogens

Chemical carcinogens have been monitored by papillomas and other tumors in fish (Aguirre, Balazs et al. 1994). However, relatively few studies correlate the exposure of sea turtles and their eggs to organic pollutants. In a discrete green turtle population at Kaneohe Bay, Oahu, Hawaii, none of the tissues and shells (N = 12) analyzed for chemical carcinogens (organochlorine, polychlorinated biphenyl, organophophate, or carbamate insecticides) were found in concentrations above stated detection limits. Most concentrations of selenium and heavy metals were also considered to be below levels reported normal in other animal species. Similarly, Miao et al. (2001) found no significant result in a toxicity assessment of green turtles from the Hawaiian Islands; however, a larger set of specimens needs to be analyzed to evaluate the potential interaction between green turtle FP and pollutant exposure.

D. Cleaner Fish

Cleaning relationships between green turtles and several species of reef fish have been reported in the literature (Balazs 1996). The fish feed on organisms growing on the turtles' skin, scales and carapace. In Hawaii, the Hawaiian saddleback wrasse *Thalassoma duperrey* picks the turtle-specific skin barnacle *Platylepis hexastylos* from the skin of the green turtle (Losey, Balazs et al. 1994). These fish may act as vectors of

FP as 1) they move between turtles or 2) by causing wounds and consequently increasing the probability of infection (Zamzow 1998). Alternatively, the cleaning behavior may provide health benefits by controlling ectoparasites and/or ameliorating tumor tissue.

T. duperrey observed in Kaneohe Bay do not target green turtle tumors; conversely, the whitespotted toby *Canthigaster jactor* in both Kaneohe Bay and Hanauma Bay (Oahu) attacked the tumored turtles; this action may deleteriously affect green turtles (Zamzow 1998). Preliminary DNA evidence suggest an association of a herpesvirus with saddleback wrasse, suggesting that cleaner fish may serve as vectors or carriers of the agent causing FP in green turtles (Lu, Yu et al. 2000). Further investigation concerning the role of reef fish in the etiology of green turtle FP is warranted.

E. Immune System Suppression

A variety of factors have been discussed that may modulate immune system suppression and thus affect FP prevalence. In addition to DNA damage caused by ultraviolet-B radiation, UV-B also causes immunosuppression (Herbst 1994). However, green turtle FP prevalence varies too greatly over short geographic distances to be a major factor in disease expression (Herbst 1994). Low temperatures, stress and pollution are also known to modulate and/or disrupt normal immune system function (Zapata, Varas et al. 1992).

Currently, the strongest association of green turtle FP prevalence is with habitat type (Herbst and Klein 1995b). Available data suggests that green turtle FP is more prevalent in near-shore ecosystems such as lagoons and bays (Herbst 1994; Herbst and Klein 1995b). Exogenous factors, such as water temperature, may facilitate tumor development. Temperature effects on the development and growth rates of tumors have been shown in turtles and other poikilotherms (Haines and William 1977; Asashima, Oinuma et al. 1985). Temperature, as well as salinity and nutrient concentrations, may also affect dinoflagellate blooms in turtle foraging areas (Aikman, Tindall et al. 1993). Other marine environmental conditions, including flushing rates, bathymetry, available food, population density, etc., may provide physical conditions favorable for either infectious or noninfectious disease agents.

III. GOALS OF THIS STUDY

The objectives of my project are two-fold: 1) quantify the change in extent and rate of agriculture, industrial and urban land use/land cover (LULC) through time across five sites in Hawaii based on a series of aerial photographs from the 1950s, 1970s, partial coverage from the 1990s and 2000; and 2) to examine the relationship at each site between changes in land use and GTFP prevalence in *C. mydas* populations by noting if the rate of increase/ decrease in land use parallels the rate of GTFP prevalence. Information on land use patterns may facilitate the development of future finer scale FP related research questions that should explore improved methods to quantify LULC, the ramifications of the most significant LULC changes, and strategies to mitigate LULC change. Ultimately, the goal of my project is to contribute to on-going research and conservation efforts directed toward the green sea turtle.

A. HYPOTHESIS

Site-specific LULC characteristics of my five Hawaiian study sites strongly correlate to FP tumor prevalence in green turtle populations.

Predictions

I expect to observe a larger proportion and faster rates of change to or within agriculture, industrial and urban LULC in watersheds draining into study sites where FP prevalence is high. Conversely, I expect to find a smaller proportion and slower change to or within agriculture, industrial and urban LULC at sites with little to no FP prevalence. However, LULC, such as agriculture, industrial and/or urban, is only part of the equation as the actual practices employed within a land-cover type can have very strong effects (Turner, Gardner et al. 2001).

B. ASSUMPTIONS

1. LULC patterns affect coastal marine water quality; quantification of the extent and rate of these patterns will facilitate understanding of environmental differences between the five study sites.

A number of studies have shown strong relationships between water quality, water quantity and run-off to landscape characteristics, including demonstrating that land uses within a watershed can account for a relatively high percentage of the variability in stream and estuary water (Jones, Neale et al. 2001; Turner, Gardner et al. 2001). Anthropogenic impact on the sediment and nutrient budgets of watersheds are well documented (Carpenter, Caraco et al. 1998). LULC within a watershed can account for much of the variability in stream water quality (Omernick 1977; Lenat and Crawford 1994; Allan, Erickson et al. 1997). Across a region, increases in agriculture and urban land cover or decreases in natural vegetation indicate a potential for water quality problems. The correlations between landscape properties and nitrogen, phosphorous, turbidity and temperature characteristics of water suggest indicators that relate spatial patterns to water quality (O'Neill, Hunsaker et al. 1997). The export of metals and organics, in addition to sediment inputs, from land to water is also a function of land-use change (Turner, Gardner et al. 2001).

In a study of coastal water quality of southern Oahu, Hawaii, Laws et al. (1999) reported that buffer zones and dilution are critical to maintaining high coastal water quality. Buffer zones, such as estuaries and harbors, trap a portion of the sediments and nutrients that would otherwise enter the coastal ocean. The trapping efficiency of buffers is a function of various factors, including loading rate, buffer site morphology and water residence time. Correspondingly, loading rate is a function of LULC. Coastal water quality is also greatly influenced by the degree of mixing with the offshore ocean; mixing rates are positively correlated with dilution effects. In Law's study, freshwater runoff had a significant impact on coastal water quality at one site (N=10) due to the absence of the moderating effect of a buffer zone. At other sites within the same region on Oahu, impacts of freshwater discharge on water quality appeared to be relatively subtle.

2. Aquatic environmental characteristics are important in the etiology of fibropapillomatosis.

Many studies have demonstrated the link between environment and health outcomes (Aron and Patz 2001; McMichael 2001). Given that the life cycle of *C. mydas* takes place in the marine in environment – with the exception of nesting and basking – it is plausible that aquatic environmental characteristics are associated with FP prevalence.

3. Hawaiian green turtles exhibit high site fidelity.

The majority of evidence accumulated to date indicates that after leaving the pelagic environment, Hawaiian *C. mydas* reside in the same general coastal area for extended periods, possibly throughout their entire lifetime except for reproductive migrations (Balazs 1980; Balazs, Miya et al. 1994; Balazs, Rice et al. 1998). High site fidelity implies limited interaction between members of different *C. mydas* population groups suggesting that the difference in FP prevalence is more likely to be a result of environmental variation than co-mingling with FP-infected individuals.

4. Hawaiian green turtles have the same life history characteristics among the five study sites investigated.

Turtles of all sizes from 35 cm juveniles to mature adults are frequently found along a given coastal area (Hirth 1997; Balazs, Rice et al. 1998). This assumption eliminates the possibility that FP preferentially affects a certain life stage and suggests that the difference in FP prevalence is more likely to be a result of environmental variation.

IV. METHODS

There are six tasks associated with investigating the relationship between land use change, as an environmental cofactor, and FP prevalence in the Hawaiian Islands: 1) site delineation, 2) tumor prevalence data collection, 3) land use/ land cover classification, 4) change detection, 5) trend analysis, and 6) accuracy assessment.

A. SITE DELINEATION

Long-term tagging studies of green turtles in near shore waters of the Hawaiian Islands have been established to gather comprehensive data on growth rates, movements, food sources, health status and habitat requirements (Balazs 1980; Balazs 1982; Balazs 1991). Discrete foraging areas for systematic investigation were selected on the basis of sufficient numbers of turtles residing in an area as well as site accessibility (Balazs, Dudley et al. 1994).

The tumor data was collected in approximate nearshore locations at each study site over time; no explicit spatial data was collected at the time of turtle capture nor are the upland terrestrial study sites explicitly defined. Within the constraints of available historical photography, study sites were defined based on watershed delineation (using the ArcView Hydrologic Extension and 10 meter digital elevation models) and elevation.

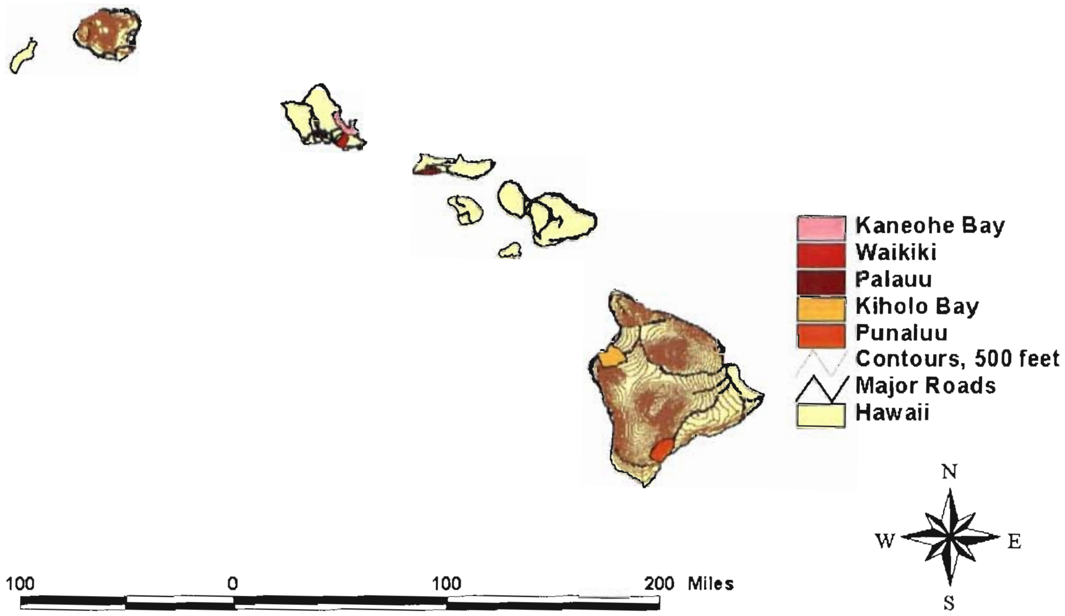

Figure 3. Location of study sites.

1. Study Site 1: Kaneohe Bay, Island of Oahu

Kaneohe Bay, (21°30'N, 157°50'W) on the northeast coast of Oahu, is the largest bay in the Hawaiian Islands and comprises substantial foraging and resting habitat for green turtles (Aguirre, Balazs et al. 1994). It is one of several important long-term research sites established in the Hawaiian Islands to monitor FP prevalence and obtain baseline data on the biology, ecology and life history of green turtles (Brill, Balazs et al. 1995; Balazs 1998).

The shape of Kaneohe Bay approximates a rectangle 13 km long and 4 km wide (Smith, Kimmerer et al. 1981); situated on the windward coast, its long axis (17 km) is open to large swells (Cheroske 2000). This axis consists of a shallow (2.5 m average depth) reef flat of unstable coral rubble (dead coral fragments) with occasional coral heads providing limited relief (Cheroske 2000). The water temperature in the bay averages 24-27° C and is generally less than 10 meters in depth (Balazs 1998; Cheroske 2000).

The nearly vertical Koolau mountain range sharply delineates the landward boundary of the Kaneohe watershed (Smith, Kimmerer et al. 1981). Approximately a dozen streams drain from the watersheds into Kaneohe Bay; most of the stream flow enters the northwest sector. Groundwater seepage, the other major avenue for water entry from the watershed, averages about $22 \times 10^3 m^3 * day^{-1}$ (Sunn 1976). Thus, Kaneohe Bay is a weakly developed estuary with moderate land influence in the form of freshwater, sediments and nutrients (Smith, Kimmerer et al. 1981).

Mean annual precipitation has a steep orographic gradient and varies widely; on the northeastern side of Oahu (windward), precipitation varies from approximately 60 inches/year to approximately 275 inch/year near the crest of the Koolau Range (Hunt, 1996). Precipitation on Oahu is markedly seasonal; 70% of the total precipitation occurs during the winter months (October through April) in the lowland and coastal areas.

Land Use: A variety of activities - including dredging, sewage discharge, siltation, increased vessel traffic and elevated nutrients in freshwater associated with human use and habitation of the surrounding landscape - have impacted Kaneohe Bay over the last fifty years (Balazs 1998). Along the longitudinal axis, there is a general increase in urban influence from north to south, especially in terms of sewage input. Along the transverse axis, the continuum moves from a heavy land influence, across coral reefs and out to the open ocean (Smith, Kimmerer et al. 1981).

FP Prevalence: The earliest confirmed cased of GTFP was reported in Kaneohe Bay in 1958 (Balazs 1990). FP prevalence became high in Hawaii, as well as in Florida, during the mid-1980s (Balazs 1998). Turtles have been monitored in Kaneohe Bay since 1989 (Balazs 1990); FP prevalence at this site is high.

2. Study Site 2: Waikiki, Island of Oahu

Waikiki Beach, (21°N, 157°W) is located on the south shore of Oahu a short distance from downtown Honolulu and extends for 3 km from Diamond Head to the Ala Wai Yacht Harbor where the Ala Wai Canal enters the ocean (Balazs, Miya et al. 1994). The shallow Waikiki reef, sizable numbers of turtles and proximity to tourists and corresponding ecotourism and conservation education programs make Waikiki an appealing study site.

The Ala Wai Canal is approximately 3100 m long and water depth ranges between 1 and 3 meters; after the canal is dredged, water depth ranges from 2 to 3m (Fox 1995). The canal is classified as a type B estuary (defined by Pritchard 1967) where only a small proportion of the suspended sediment introduced from upland sources escapes the estuary to the sea. Sedimentation removes approximately 40% of the allochthonous inputs of organic carbon to the Ala Wai Canal (Laws, Ziemann et al. 1999). The Ala Wai Canal has long been known to have poor water quality (Fox 1995). Investigations into options to alleviate the problem started over 20 years ago (Fox 1995).

The boundaries of the watershed where Waikiki Beach resides generally include the land between Diamond Head and Punchbowl craters and extent to the crest of the Koolau Mountains. The upper reaches of the watershed form part of the Honolulu Watershed Forest Reserve. The altitude within the watershed ranges from sea level to over 800 meters. Median annual rainfall varies from 640 mm in Waikiki to over 4000 mm at the crest of the mountains (Fox 1995).

Land Use: Honolulu is heavily urbanized and densely populated [Program, 2002 #16]. Almost 60% of the drainage basin is urban or built-up land. Industrial, commercial and residential areas supply high levels of nutrients, suspended sediments, automobile contaminants, lawn and garden chemicals and termiticides, among other pollutants. In 1989, traffic count across the watershed was about 250,000 vehicles per day (Fox 1995).

FP Prevalence: Turtles have been monitored in Waikiki Beach since 1990 (Balazs, Miya et al. 1994); FP prevalence at this site is high.

3. Study Site 3: Palauu, Island of Molokai

Palauu, (21°10' N, 157°45'W), is located on the southwestern side of the island of Molokai (Wibbels, Balazs et al. 1993; Balazs, Puleloa et al. 1997; Work and Balazs 1999). This site is a major foraging aggregation site for the green turtle (Balazs, Puleloa et al. 1997).

Along the coastal areas of southwestern Molokai, mean annual rainfall is less than 16 inches; further inland, the maximum mean annual rainfall is approximately 25 inches (Oki 1997).

Land Use: Molokai can be characterized by traditional agricultural practices as well as some commercial agriculture and development (CCAP 2002). Based on the Hawaiian State Land Use Classification, conservation areas cover 77.8 square miles; urban and rural areas cover 6.8 square miles; and agriculture land, used primarily for field crops, nurseries and livestock grazing, covers approximately 176.4 square miles (Oki 1997). In central and west Molokai, pineapple was the island's economic mainstay for decades but gradually declined and was abandoned by the early 1980s. In addition to tourism, cattle ranching, irrigated fruit and vegetable farming and coffee are the most significant components of the rural economy (Juvik and Juvik 1998).

FP prevalence: Turtles have been monitored in Palauu since 1982 (Balazs, Puleloa et al. 1997); FP prevalence at this site is high.

Island of Hawai'i

Hawai'i, the youngest and largest island, is characterized by more bare land than any other island. Grasses have colonized large portions of these bare areas; correspondingly, a large proportion of the island is suitable for pasture (CCAP 2002).

4. Study Site 4: Kiholo Bay, Island of Hawai'i

Kiholo Bay (19° N, 155° W, (Wibbels, Balazs et al. 1993)) and Wainanali'i Pond, the adjoining 2 hectare mixohaline lagoon, are located on the western coast of the island of Hawaii (Balazs, Rice et al. 1998). This site constitutes one of sixteen resident areas for green turtles under investigation throughout the Hawaiian Islands.

Land Use: Kiholo Bay consists primarily of agriculture and land use conservation districts[1].

FP prevalence: Turtles have been monitored periodically in Kiholo Bay since 1973 (Balazs, Rice et al. 1998); FP prevalence at this site is rare.

5. Study Site 5: Punalu'u Bay, Island of Hawai'i

Punalu'u Bay (20° N, 155° W, (Wibbels, Balazs et al. 1993)) is a small sheltered bay and black sand beach on the southwest coast of the Ka'u district on the island of Hawaii (Balazs, Dudley et al. 1994). It is one of several important long-term research sites established in the Hawaiian Islands; this site has been periodically visited since 1976 to

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[1] Office of Planning, Honolulu, Hawaii. Accessed at: http://www.hawaii.gov/dbedt/gis/slud00.htm (December 2002).

monitor green turtle populations. Of behavioral interest at this site, sub-adult and juvenile turtles regularly crawl onto the black sand to bask (Balazs 1998). The primary food source for green turtles at Punalu'u is an intertidal red alga, *Pterocladia capillacea.*

Land Use: The area is a county park and a popular tourist stop (Balazs, Dudley et al. 1994). In addition, surrounding land use is primarily vegetated slopes with a resort community developing to the southeast of the bay.

FP Prevalence: Turtles have been monitored in Punalu'u since 1976; FP prevalence at this site is rare (Balazs 1991).

B. TUMOR PREVALENCE DATA COLLECTION

Techniques for capturing turtles for examination include hand-capture of turtles by diving from a slow moving boat in shallows where foraging occurs; snorkeling or scuba diving to hand-capture turtles resting in bottom habitats (Balazs 1998); and/or use of large-mesh nets to capture turtles foraging close to shore (Balazs, Miya et al. 1994). The tumor data was collected in approximate nearshore locations at each study site over time; no explicit spatial data was collected at the time of turtle capture nor are the upland terrestrial study sites explicitly defined.

FP is diagnosed through a process of systematic investigation. Each captured turtle is weighed and measured. External rating of tumors is accomplished by a standard rating procedure (Work and Balazs 1999). In some circumstances, the oral cavity is opened and assessed with a flashlight for the presence of small oral tumors. All prevalence data was kindly supplied courtesy of George Balazs, Leader Marine Turtle Program, NMFS, Hawaii.

C. CLASSIFICATION

Aerial photographs are commonly employed for historical analyses of land use and land cover change (Turner and Ruscher 1988; Kienast 1993; Medley, Okey et al. 1995; Skinner 1995; Lambin 1996; Turner, Wear et al. 1996; Olsson, Austrheim et al. 2000; Zaizhi 2000; Turner, Gardner et al. 2001). Development of an appropriate classification system for clearly defined natural communities, spectral uniqueness of these natural communities in remotely sensed images, and accurate classification algorithms in the image processing software are critical criteria for accurate landscape classification.

Historical aerial photographs of Hawaii were obtained from a variety of sources, including the USGS EROS Data Center; Dennis Kim of the USGS in Honolulu, HI; NOAA; and Craig Tasaka at the Office of Planning, Honolulu, HI (Appendix I). In addition to aerial photographs, I also utilized Coastal Change Analysis Program (CCAP) land use/land cover data. CCAP's classifications are based on mosaics of Landsat 7 Enhanced Thematic Mapper (ETM) imagery. Because Hawaii is characterized by almost constant cloud cover, multiple image dates and scenes were used to map each island. In some cases, no clear imagery was available for portions of the land surface.

To prepare the hard copy photographs for classification, I scanned them at 600 dpi and georeferenced the photographs in ArcMap using digital raster graphs (purchased from Land Info) as my source of ground control points (GCPs). To achieve complete coverage of each site at each timepoint based on a watershed-based site delineation, I mosaiced the photographs to create a continuous (thematic) coverage using ArcView's Image Analyst[2]. After importing the mosaic into ERDAS Imagine version 8.5 (ERDAS 1999), I conducted a texture analysis on each mosaic. Texture analysis is a spatial image enhancement technique that defines texture as a quantitative characteristic of an image; this is particularly useful in single band imagery i.e. black and white photographs. As opposed to color and brightness – radiometric measures associated with one pixel that describe the average tonal variation in the various bands of an image - texture is calculated from a set of connected pixels and contains information about the spatial distribution of tonal variations within a band (ERDAS 1999). Image texture measurements segment an image and classify its segments. The texture analysis algorithm used was variance (2nd order) with a 3 x 3 (pixel) window. After texture analysis, the texture layer and the raw image were stacked to create a composite image; this file was used for subsequent supervised classification.

Classification Scheme

Under usual circumstances, a classification is performed with a set of target classes in mind. Based on the primary LULC classifications of interest – agriculture and urban (Herbst and Klein 1995b) – and common landscape characteristics, the final classification

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[2] I deleted Band 255 in each of the images to create each mosaic; the vast majority of 255 pixels were a "junk" border that ArcMap automatically put around each image after georeferencing.

scheme consisted of water, developed land, cultivated land, total vegetation, and bare land categories. Developed land was characterized by buildings designated "buildings" (used only on multispectral imagery), roads characterized by concrete with < 5% trees designated "roads" (used only on multispectral imagery), and residential areas characterized by >10% trees, homes and characteristic 'S'-shaped developments. Cultivated land was delineated based on fields. Total vegetation consists of complete tree cover designated "trees" (used only on multispectral imagery), grass in urban parks designated "grass" (used only on multispectral imagery), and other scrub/shrubs. Bare land was characterized predominantly by lava formations.

The scheme developed here is a coarse classification; it was selected to maximize accuracy given historical sources of varying quality and to evaluate the information obtained from a simple sampling scheme. The classification is coarse because, for example, developed land includes urban, industrial and military uses – all of which have very different outputs. Given its coarse nature, this scheme provides a means to focus subsequent classifications.

Classification Procedure

Imagery classification proceeds by either supervised or unsupervised classification or a hybrid of the two. Supervised classification proceeds where the user selects the training signatures. Supervised classifications are appropriate in cases with sampling schemes with relatively few classes or when distinct, homogeneous regions representative of each class are readily identifiable. Both because unsupervised methods did not generate

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accurate classifications and because the selected sampling scheme contained few classes, a supervised classification procedure was employed.

Supervised classification is an iterative process. Parametric and nonparametric signatures can be collected ERDAS Imagine. Parametric signatures were derived from the thirty to forty training signatures collected per image. By visual inspection, training signatures were evenly distributed across each image and sampled to represent each LULC classification. Each signature was generated by growing an area of interest where the maximum area of interest was not greater than 350 pixels and the spectral Euclidean distance was not greater than 15; these parameters were chosen to maximize training signature homogeneity. The parametric signatures were then merged and deleted to optimize exclusive and exhaustive signatures. Nonparametric signatures, derived from feature space plots in ERDAS Imagine, capture information contained in both the texture and raw image layers. Nonparametric signatures were particularly useful in classifying areas with distinct texture and heterogeneous pixel values, e.g. urban areas.

The Mahalanobis distance algorithm was used as the classification decision rule. Unlike the minimum distance and parallelepiped decision rules featured in ERDAS Imagine, the Mahalanobis decision rule takes into account the intra-variability of the LULC classes. For example, a class like urban land cover is made up with pixels with a high variance where the pixels may tend to be farther from the mean of the signature. The Mahalanobis decision rule facilitates the inclusion of outlying urban (or other class of interest) pixels.

Though the maximum likelihood rule also accounts for class variability, its computation time is more extensive than the Mahalanobis decision rule.

Table 1. Methodology for Land Use and Land Cover Quantification.

STEP	PROGRAM	PARAMETERS
1. Delineate Study Sites	ArcView – Hydro.avx	DEM
2. Scan Ariel Photographs	LeafScan-45 transmission (film) scanner	600 dpi
3. Georeference Ariel Photographs	ArcMap – Georeference utility	Source of ground control points (GCPs): Digitial Raster Graphs (DRGs) from Land Info (250 dpi; UTM; meters; NAD27; 1:24000; tiff format)
4. Mosaic Photographs	ArcView – Image Analyst	Image Analyst data source
5. Texture Analysis	IMAGINE	Interpreter | Spatial Enhancement | Texture Output: unsigned 8 bit Operator: variance, 3x3
6. Image Stacking	IMAGINE	Interpreter | Utilities | Layer Stack Output: unsigned 8 bit Output option: union
7. Unsupervised Classification	IMAGINE	Classes: 10 Maximum Interations: 24 Convergence: 0.95
8. Accuracy Assessment	IMAGINE	Classification | Accuracy Assessment
9. LULC Quantification	Excel	

D. CHANGE DETECTION

Land use and land cover change was quantified by subtracting the percentage of developed land, cultivated land, total vegetation, bare land and water between the 1950 and 1970 black and white aerial photography; the 1970 photographs and 2000 Coastal Change Analysis Program (CCAP) data; and the 1950 photographs and 2000 CCAP data.

E. TREND ANALYSIS

The strength of traditional methods of assessing the significance of correlations are inappropriate for data that are spatially autocorrelated as spatially constrained samples lack independence (Thomson, Weiblen et al. 1996). Despite the temporal scope and large number of fibropapilloma observations, these data represent only 5 independent samples. Given the varying nature (with respect to sample size, seasonality, regularity, etc.) of the FP prevalence collection, the FP data have been categorized as ordinal data. Simple trend analysis was used to assess the potential relationship between FP tumor prevalence and the extent of developed land, cultivated land, total vegetation and bare land across the five study sites.

V. RESULTS

A. CLASSIFICATION ACCURACY

Accuracy assessment is a method for comparing the analyst's classification to geographical data assumed to be true; in this case, the reference data used were digital raster graphs, field knowledge of site characteristics and aerial photography. Because it is not practical to ground truth every pixel in a given classification, a set of reference pixels were randomly selected and used to assess the accuracy of the classification parameters (parameters in this assessment: stratified random, 40 points). Though 40 points were evaluated per image in this analysis, the classification accuracy is most likely overestimated. Congalton et al. suggest that greater than 250 reference pixels are necessary to estimate mean accuracy within +/- five percent (Congalton 1991). Given additional resources, the accuracy assessment could be expanded.

The Kappa coefficient represents the proportionate reduction in error generated by a classification process compared with the error of a completely random classification (Table 3). The Kappa coefficient ranges between 0 and 1, where the latter indicates complete agreement; it is often multiplied by 100 to give a percentage measure of classification accuracy. For example, the Kappa value of 0.81 for Kiholo 1970 implies that the classification process employed avoided 81% of the errors that a completely random classification would have generated (ERDAS 1999). Kappa values can be characterized into 3 groupings: a value greater than 0.80 (80%) represents strong agreement, a value between 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement (Congalton 1996).

Constraints associated with this classification process included availability of historical imagery, tonal variation in photographs and narrow spectral difference between the LULC(s) of interest as recorded by historic photographs. Archival imagery was explored at the Bishop Museum, Honolulu, HI; the Hawaii State archives, Honolulu, HI; the National Archives, Washington, DC; as well as the data sources described above. Tonal variation was partially compensated for by using image enhancement techniques (texture analysis) to deduce additional information from the single band black and white imagery and by performing color balancing between photographs before mosaic construction. Overall, the Kappa values for the classification scheme presented here represent moderate agreement. Given the variation in brightness values across the 1950 and 1970 black and white images, achieving higher Kappa values presents a significant challenge and is beyond the scope of this project. Differentiating between the bare land and vegetation on the big island via the acquired imagery was especially difficult; here the classification scheme is biased towards bare land. More accurate information regarding land uses and land cover would not only be obtained through intensified image processing and field visits, but via survey research designed to quantify more detailed LULC information at each site.

Table 2. Accuracy Assessment. CCAP data has a very detailed outline[3] describing its accuracy assessment. Reference data for CCAP accuracy assessment must have a resolution and reliability which meet or exceed those of the C-CAP remotely sensed data. Sources of collateral data include soil maps, NOAA coastlines (T-sheets), timber surveys, USGS digital line graphs, and digital elevation models (for elevation, slope, and aspect). These can be incorporated by masking, filtering, probability weighting, or inclusion in the signature file. See Appendix IV for overall classification accuracy.

Site	Year	Kappa (range 0-1)
Kaneohe	1960	0.72
	1970	0.75
	2000	0.94
Waikiki	1950	0.60
	1970	0.60
	2000	0.94
Molokai	1950	0.76
	1970	0.50
	2000	0.88
Kiholo	1950	0.78
	1970	0.81
	2000	0.90
Punaluu	1950	0.62
	1970	0.54
	2000	0.90

B. LAND USE & LAND COVER CHANGE

Based on this classification, the developed land increased between 1% and 14% across the five sites in Hawaii (Table 4, Table 8); Kaneohe Bay and Waikiki experienced the largest increase in developed land. This trend is consistent with Hawaii's growth patterns; between 1970 to 1980, Hawaii experienced a 25% increase in its resident population and from 1980 to 1990, the population growth was 15% (Planning 1997). Historically, urban development has been concentrated in Honolulu and a few other urban areas. Oahu is currently experiencing significant urban growth in its central plain and Kapolei areas, with more planned in the near and long term. This analysis suggests

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[3] http://www.csc.noaa.gov40.7/crs/lca/pd0f/protocol.pdf (December 2002)

that growth in Kaneohe, Oahu, was most rapid between 1970 and 2000; developed land decreased between 1950 and 1970 (Table 6). This decrease most likely reflects 1) a build-up rather than built-out of the urban area and 2) a potential limitation of the change detection protocol.

Though thousands of acres of sugarcane and pineapple have been taken out of production, intensely farmed sites were not represented in this analysis (Planning 1997). The biggest changes in cultivated land – Kiholo (11% increase) and Punalu'u (15% decrease) – were detected on the big island. While interpreting these results it is imperative to bear in mind that the big island is characterized by more bare land than any other island. Distinguishing between bare land, vegetation and cultivated land proved to be challenging given the available black and white imagery.

Similarly, bare land remained generally consistent across all sites between 1950 and 2000 save at Punalu'u, where this analysis suggests bare land decreased by 40%. The forty percent change most likely reflects the difference between the coarser aerial photograph classification designed to use historical information and the finer scale coastal change analysis program classification predicated on a very intensive accuracy assessment protocol. CCAP's data validation included teams of personnel from the NOAA Coastal Services Center, Hawaii Dept. of Forestry and Wildlife, US Fish and Wildlife Service, US Geological Survey, and The Nature Conservancy equipped with a portable color laptop computer linked to a Global Positioning System (GPS). Seven thousand random points were generated within this area for the accuracy assessment. Though the CCAP data is more accurate, CCAP did not attempt a historical classification of LULC change given the incomplete nature of historical data. The current analysis attempts to make use of all data to address a critical conservation issue.

Total vegetation decreased most dramatically at the sites (Kaneohe Bay and Waikiki) that experienced the highest increase in developed land. At Palauu, Molokai, vegetation decreased by 4% between 1950 and 2000; most likely, this is explained by slight increases of 2% and 3% in developed and cultivated land, respectively. Total vegetation dramatically increased at both sites on the big island; however, this may be an artifact of classification as discussed above.

From 1950 to 1970, water varies between 0% and 2% across sites reflecting the moderate agreement between the classifications (Appendix I).

Table 3. Percent Land Use/Land Cover in 1950 and 2000.

Site & Year	Developed Land	Cultivated Land	Total Vegetation	Bare Land	Water	Total
Kaneohe 1950	14	0	86	0	0	100
Kanehoe 2000	22	1	71	5	1	100
Waikiki 1950	52	0	48	0	0	100
Waikiki 2000	66	0	30	2	2	100
Palauu 1950	0	0	100	0	0	100
Palauu 2000	2	3	96	0	0	100
Kiholo Bay 1950	0	0	0	100	0	100
Kiholo Bay 2000	1	11	86	2	0	100
Punaluu 1950	0	15	85	0	0	100
Punaluu 2000	1	0	52	45	2	100

Table 4. Land Use Transition Table; the values presented represent the detectable LUCL in 1970 compared to the 1950 LUCL.

Site	Developed Land	Cultivated Land	Total Vegetation	Bare Land	Water
Kaneohe Bay	-12%	0%	12%	0%	0%
Waikiki	8%	0%	-8%	0%	0%
Palauu	0%	0%	0%	0%	0%
Kiholo Bay	0%	0%	0%	0%	0%
Punaluu	24%	9%	0%	-33%	0%

Table 5. Land Use Transition Table; the values presented represent the detectable LUCL in 1970 compared to the 2000 LUCL.

Site	Developed Land	Cultivated Land	Total Vegetation	Bare Land	Water*
Kaneohe Bay	20%	1%	-27%	5%	5%
Waikiki	22%	0%	-27%	2%	2%
Palauu	2%	3%	-4%	0%	0%
Kiholo Bay	1%	11%	86%*	-98%*	0%
Punaluu	-23%*	24%	52%	-7%	2%

**Due to difference in CCAP classification scheme and the classification scheme developed for the aerial photographs.*

Table 6. Land Use Transition Table; the values presented represent the detectable LUCL in 2000 compared to the 1950 LUCL.

Site	Developed Land	Cultivated Land	Total Vegetation	Bare Land	Water*
Kaneohe Bay	8%	1%	-16%	5%	1%
Waikiki	14%	0%	-18%	2%	2%
Palauu	2%	3%	-4%	0%	0%
Kiholo Bay	1%	11%	86%*	0%	0%
Punaluu	1%	-15%	52%	-40%*	2%

*Due to difference in CCAP classification scheme and the classification scheme developed for the aerial photographs.

C. TREND ANALYSIS

The primary reason for undertaking this project was to assess the relationship between developed and cultivated land uses and prevalence of fibropapillomatosis in Hawaiian *C. mydas*. From the first detected case of GT FP at Kaneohe in 1958, the prevalence has steadily increased at some long term monitoring data sites while remaining constant at others (Figure 4). Currently, there is no causal explanation for this trend.

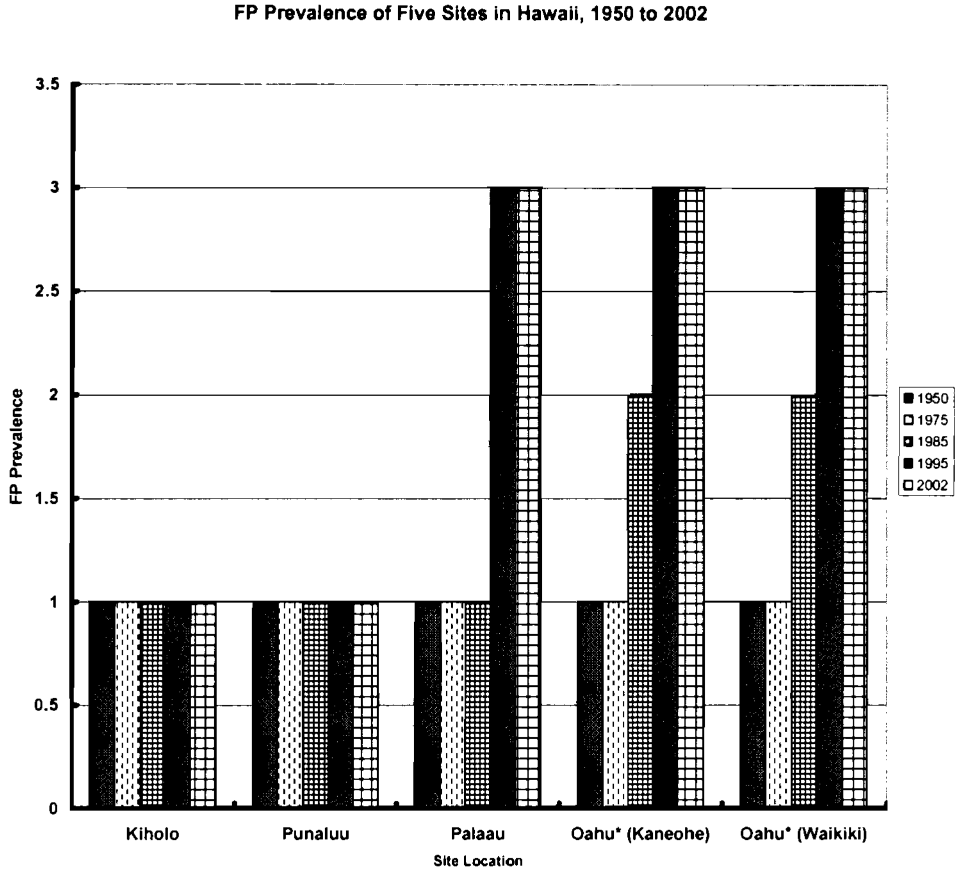
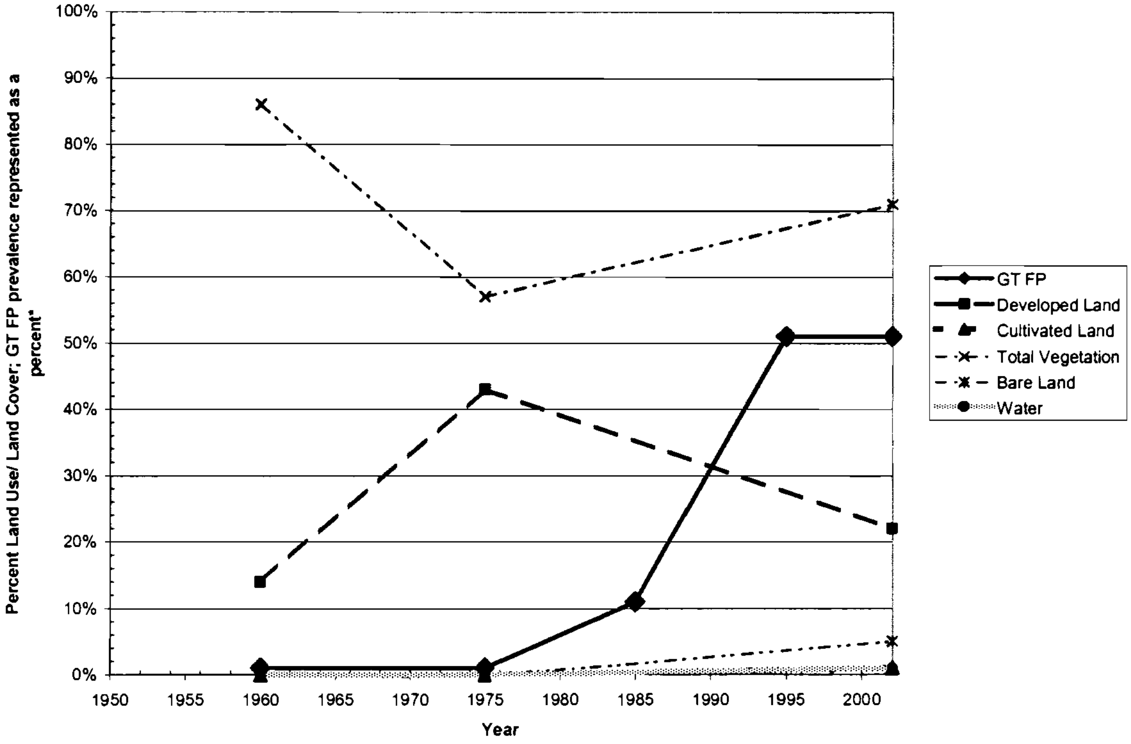
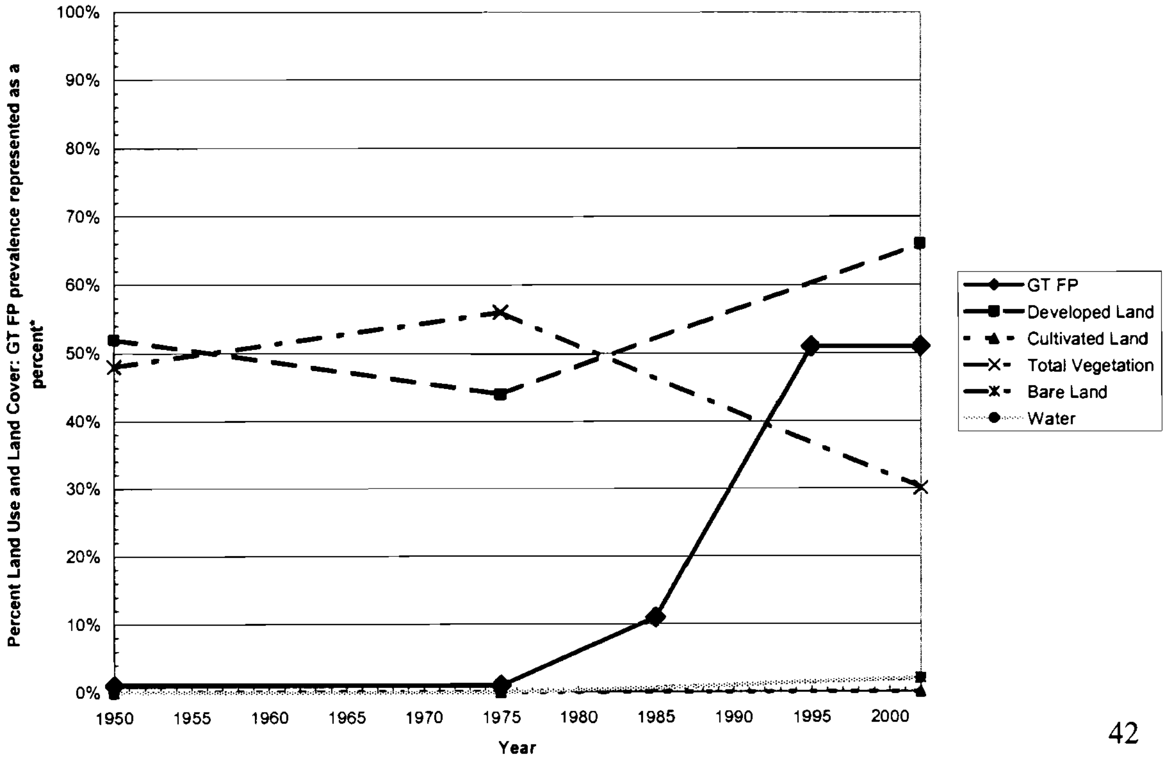


Figure 4. Prevalence of FP in Hawaiian *Chelonia mydas*, 1950 to 2002 (personal communication George Balazs). The Y axis represents tumor score where a score of 1 corresponds to prevalence < 1% (rare); a score of 2 corresponds to prevalence 11-50% (medium); and a score of 3 corresponds to prevalence 51-100% (high). *Oahu: FP prevalence cannot be differentiated across Oahu.

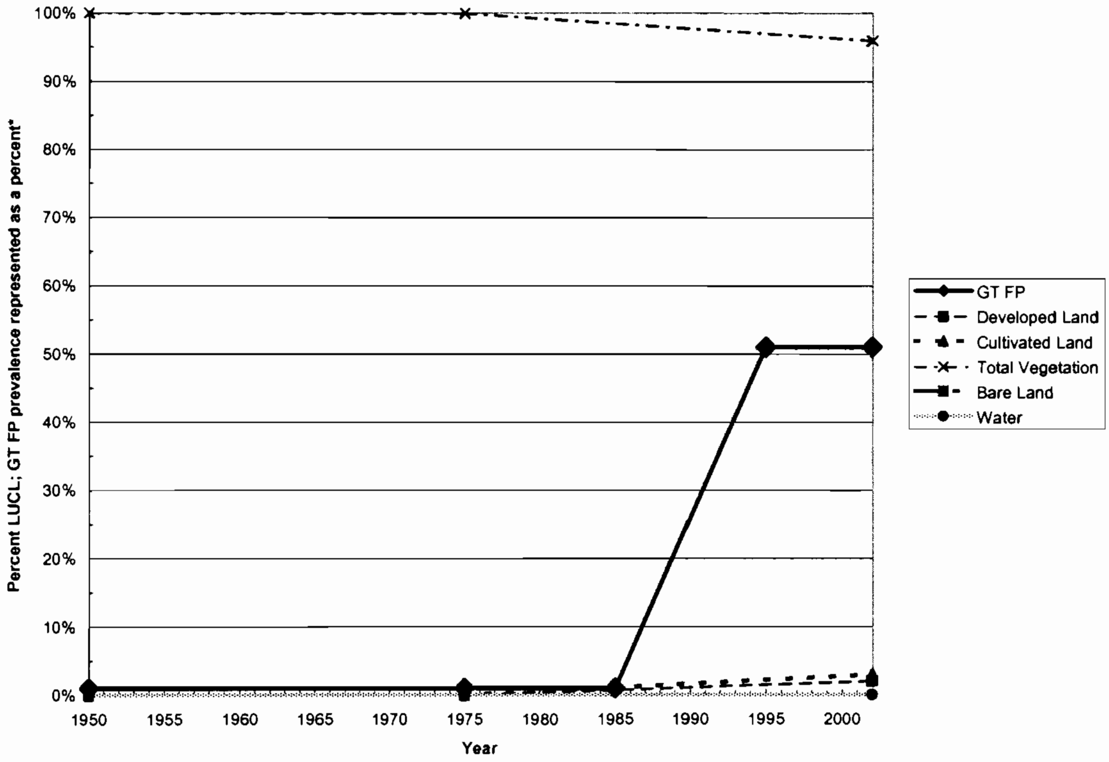
A. Kaneohe Bay, Oahu: GT FP Prevalence and LULC, 1960 to 2002



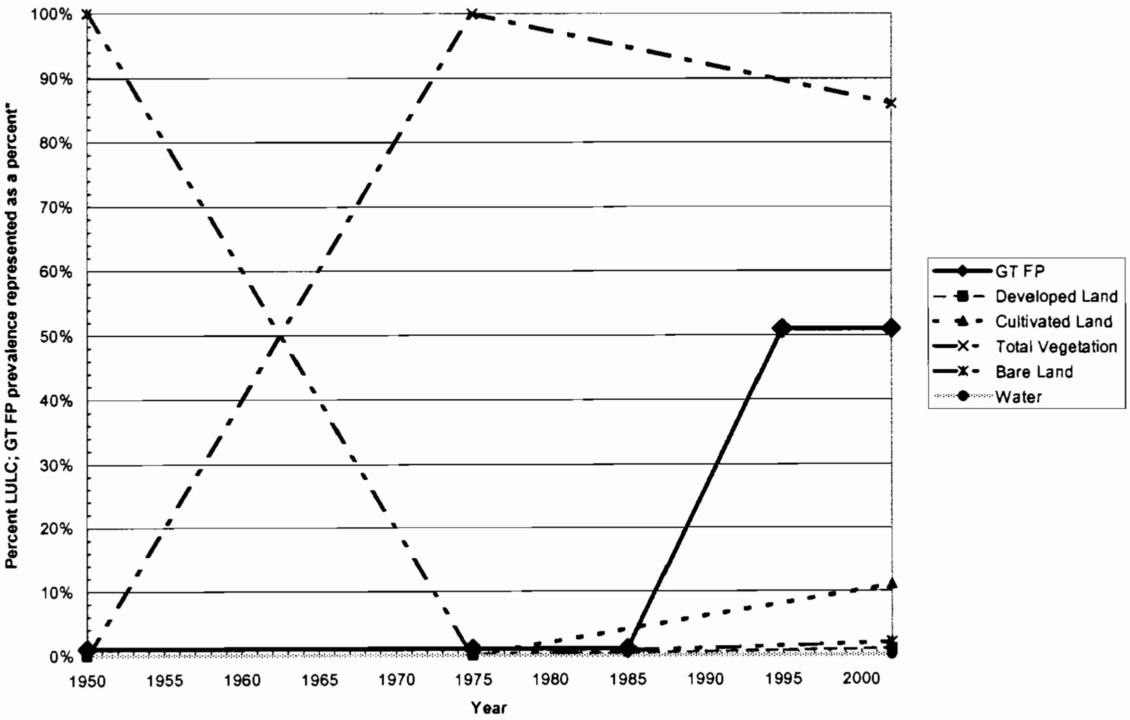
B. Waikiki, Oahu: GT FP Prevalence and LULC, 1950 to 2002



C. Palauu, Molokai: GT FP Prevalence and LULC, 1950 to 2002



D. Kiholo Bay, Hawaii: GT FP prevalence and LULC, 1950 to 2002



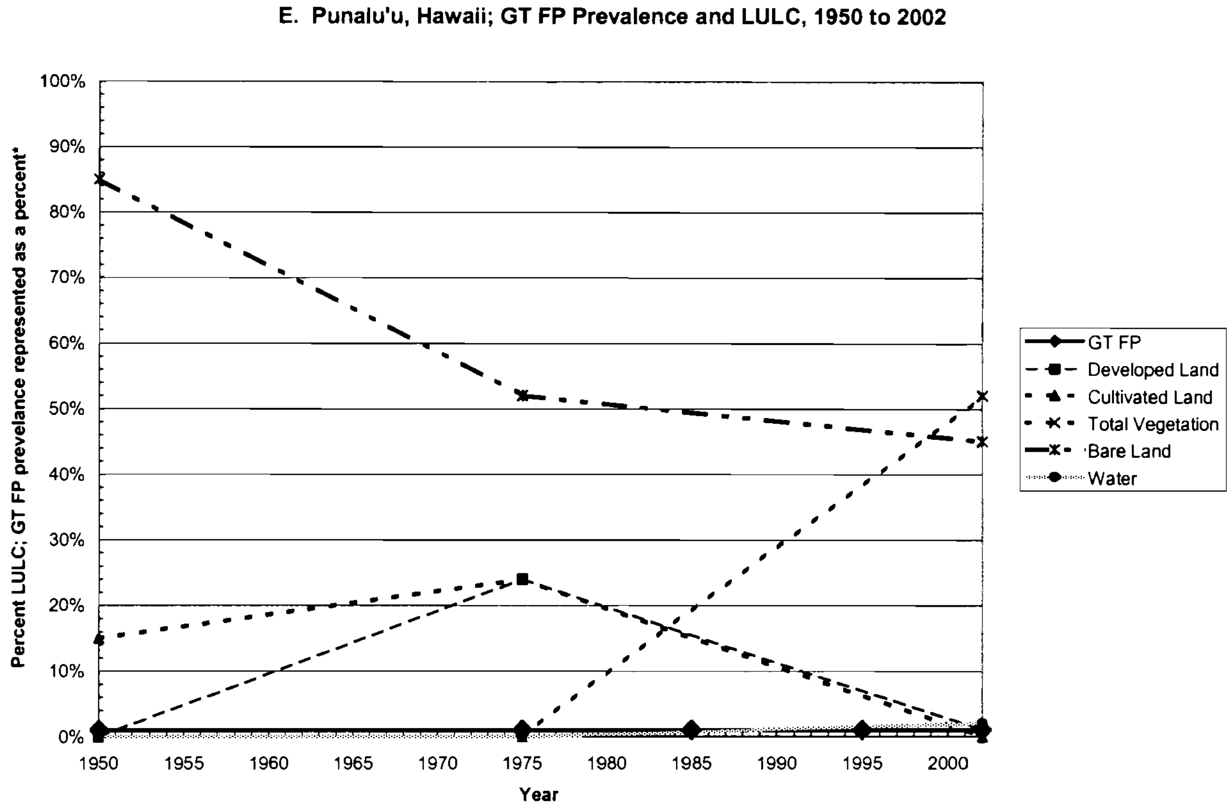


Figure 5. Relationship between developed land, cultivated land and total vegetation in 1970 and 2000 to prevalence of FP in Hawaiian C. mydas during the same time period. *FP prevalence data (scored from 1 to 3) was converted to a percentage value based on a conservative estimate of tumor score were 1 = 1%, 2 = 11% and 3 = 51%. A) Kaneohe Bay, Oahu; B) Waikiki, Oahu; C) Palauu, Molokai; D) Kiholo Bay, Hawaii; E) Punalu'u, Hawaii.

Patterns of LULC are juxtaposed against GT FP at each site in Figure 5, A-B. Kaneohe Bay and Waikiki, the sites with the highest percent developed land, exhibit the highest GT FP prevalence. It is interesting that high GT FP prevalence is also observed at Palauu, Molokai; this site is characterized by negligible developed land and 96% vegetation (CCAP, 2000). Due to the multicollinearity between land-use categories and the small number of sites evaluated, multiple regression techniques were not considered feasible for analyzing this data set (McFarland and Hauck 1999). At this scale, the current analysis does not suggest a transparent relationship between a specific land use and FP prevalence. However, the analysis suggests that though commonly associated with developed land, high FP prevalence can occur with minimal development as well.

VI. DISCUSSION

Fibropapillomatosis in green turtles is hypothesized to be influenced by dietary biotoxins, parasitic infections, chemical carcinogens, cleaner fish and immune system suppression; these factors, in turn, are affected by environmental variables such as eutrophication, sea surface temperature and salinity, and flushing rates (Figure 6). Disease mapping and pattern analysis is commonly used for exploratory analysis of disease patterns. A cause of a disease is an event, condition or characteristic that precedes the disease event and without which the disease event would not have occurred or would not have occurred until some later time; it is possible that no specific event, condition or characteristic is sufficient by itself to produce the disease (Rothman and Greenland 1998). For biological effects, most - sometimes all - of the components of a sufficient cause are unknown (Rothman 1976).

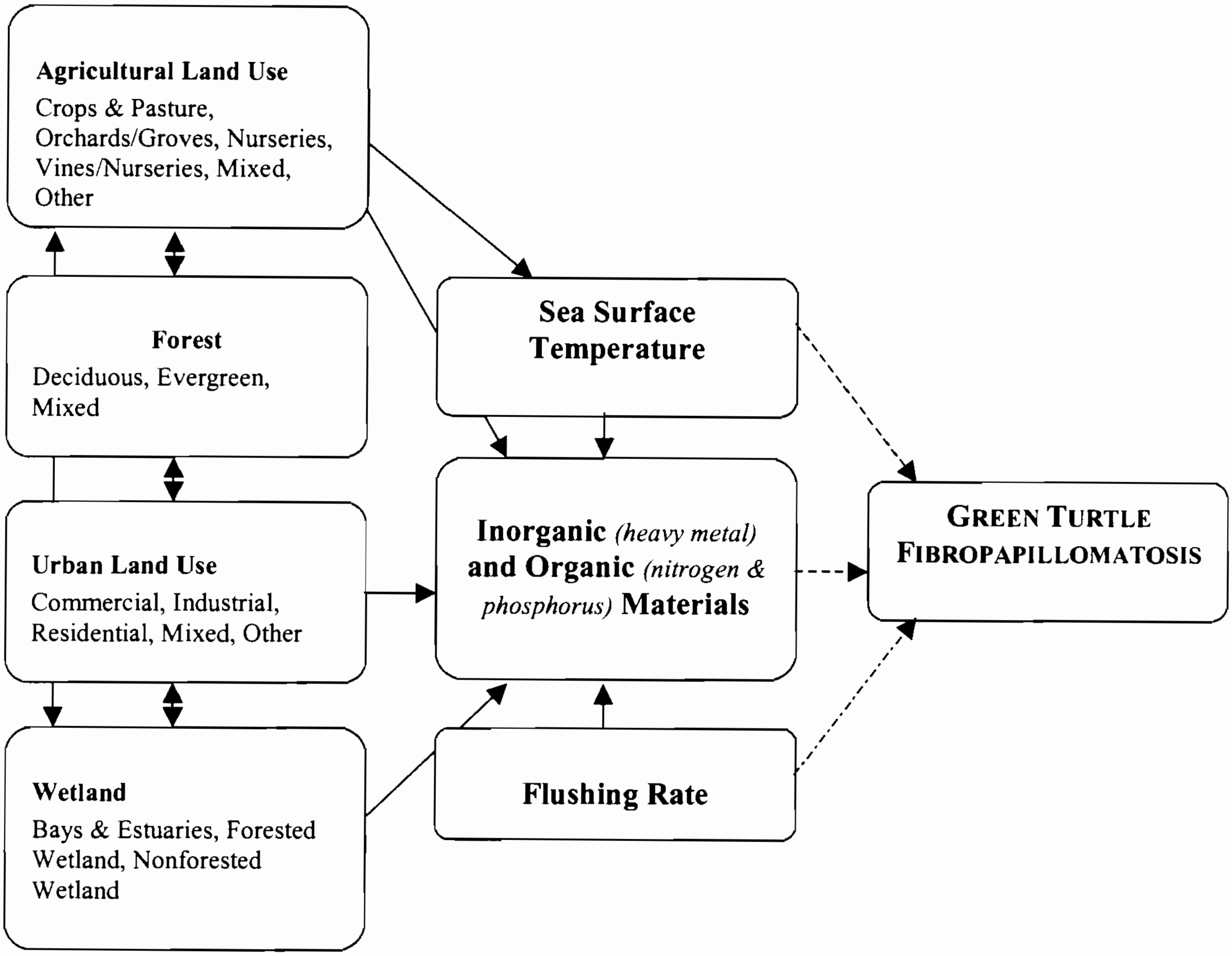


Figure 6. The strongest association of GTFP prevalence is with habitat type. Data from several field studies indicate that GTFP is more prevalent in near-shore ecosystems such as lagoons and bays. Marine environmental conditions, including flushing rates, bathymetry and water temperature/quality, may provide favorable physical conditions for either infectious or noninfectious disease agents. Solid lines represent strong associations; dotted lines indicate possible linkages.

Development of hypotheses for specific cofactors in FP pathogenesis must be met with appropriate criteria for accepting or rejecting them (Herbst and Klein 1995b). Hill's criteria provide a set of nine considerations useful for environmental epidemiological analysis. The criteria are based on nine factors including: the strength, consistency, and specificity of the association, temporal patterns, biological gradient, plausibility of association, coherence with accepted associations, experimental evidence, and analogy to similar situations (Hill 1965). The evidence is presented is consistent with the proposed role of dietary biotoxins in the etiology of viral-induced fibropapillomatosis in Hawaiian *C. mydas*. Many examples persist where potentially oncogenic viruses require interacting cofactors to express carcinogenicity; for instance, when cattle consume bracken fern containing mutagenic and immunosuppressive cofactors, benign tumors can be transformed into squamous cell carcinomas (Landsberg, Balazs et al. 1999). However, no such approach solves the central epistemologic problem of inferring causation from observational data (Greenland, Pearl et al. 1999).

Though the results presented here suggest that at this scale, changes in specific land use between 1950 and 2000 cannot be explicitly linked to changes in fibropapillomatosis prevalence, three key points can be derived from this analysis. First, the level of development tended to be incremental rather than dramatic across the sites from 1950 to 2000; if there is a explicit link between a specific land use/land cover and GT FP prevalence, it appears too subtle to detect at this level of analysis. At Waikiki, Oahu, for example, the developed land footprint grew by 14% from 1950 to 2000 but the surrounding mountain valleys serve to limit development. The same pattern is observed at Kaneohe, Oahu, where the Koolau mountain range to the west challenges urban and industrial growth. At Palauu, Molokai, the detectable difference between 1950 and 1970 was a single agriculture section at the north point of the site; today the main land uses/ land covers are open land (vegetation) and agriculture. The two sites on the big island – Kiholo Bay and Punalu'u – exhibit a similar pattern. Kiholo remained basically unchanged between 1950 and 1970; in recent years more urban development has occurred along the coast. At Punalu'u, agriculture land use gained prominence between 1950 and 1970; developed land increased by only 1% between 1950 and 2000.

Based on the level of development, Hawaiian sites alone may not yield causal information between land use and land cover changes at this scale. An alternative approach is to refine the Hawaiian analysis by including – for example – information on historical inorganic and organic chemical input information and/or historical sea surface temperature data.

Given that GT FP is a global pandemic, an ideal approach would be to select geomorphically similar sites with GT FP data, historical land use/land cover information, and high land use conversions. Though difficult to find a site that meets all these criteria, further examination of the land use question is important. Research, conservation and land management communities are concerned about the broad scale changes in land use and landscape pattern and their cumulative impact on hydrological and ecological processes that affect stream, wetland and estuary conditions (Jones, Neale et al. 2001). High levels of nutrients have adverse effects on both humans and aquatic ecosystems (Jones, Neale et al. 2001). There has been an increasing interest in evaluating the relative condition or health of water resources at regional and national scales (Jones, Neale et al. 2001); of particular interest is the ability to identify the areas where surface and ground waters have the greatest potential for high levels of nutrients. In aquatic ecosystems, these nutrients cause diverse problems such as toxic algal blooms, loss of oxygen, fish kills, loss of biodiversity, loss of aquatic plant beds and coral reefs and other problems (Carpenter, Caraco et al. 1998). Agricultural activities have been identified as major sources of non point source pollution (sediments, animal wastes, plant nutrients, crop residues, inorganic salts and minerals, pesticides) and are know to have major impacts on water quality (Basnyat, Teeter et al. 1999). Urban areas have the potential to generate large amounts of non point source pollution from storm water discharge. The imperviousness of many urban areas increases their hydrological activity and even small rains are capable of washing accumulated pollutants into surface waters. Spreading urban areas and uncontrolled developments can result in deterioration of water quality (Basnyat, Teeter et al. 1999).

Juxtaposing changing land use/land cover patterns and their respective outputs against the rising green turtle fibropapillomatosis prevalence, Hill's plausibility, consistency and analogy criteria warrant further investigation regarding link between land use/land cover output and GT FP prevalence. Shortage of complete historic data suggests the sites for future historical analysis must be chosen carefully; the most informative sites will have similar biophysical properties and exhibit substantial differences in level of development. Additionally, ancillary information on LULC organic and nonorganic outputs should be included to more fully interpret the meaning of any observed changes.

Future Directions

Despite research on the effects of individual landuse/land cover types, very little has been done to analyze the joint contribution of multiple land-use activities (Basnyat, Teeter et al. 1999). Given the difficulties associated with inferring accurate patterns of historical land use and land change patterns, assessing historical joint contributions in the absence of consistent and complete field data is challenging. Multiple land use interaction questions might be more easily addressed within a current timeframe via employment of rigorous monitoring and assessment protocols; combined with statistical tools and spatial analysis – such as GIS mapping – multiple LULC interactions may be elucidated. Due to the fact that some correlation exists between pollution loading and land use, there is always potential for improving the health of the aquatic environment with proper land-use management practices if the role of different land-use combinations within a contributing area are known (Basnyat, Teeter et al. 1999).

What can be done in Hawaii to address management of fibropapillomatosis? Aguirre et al. suggests that the development of an integrated regional monitoring program, including integrated health surveillance, to address the health of sea turtles as well as other marine mammals (Aguirre, Ostfeld et al. 2002). Other regions have adapted similar monitoring programs to address relevant environmental issues. For example, in 1996, a regional-scale land cover database was developed for the five-state area of the United States mid-Atlantic region; this database, along with other regional landscape coverages, was used to assess landscape conditions across the entire region. The assessment used a set of landscape metrics to evaluate the spatial patterns of human-induced stressed and the spatial arrangement of forest, forest-edge and riparian habitats as they influence forest habitat suitability and stream conditions. Given the push towards data integration via fields like conservation medicine – a "new" approach focusing on the health relationships occurring at the interface of humans, animals, and ecosystems – integrating health surveillance with LULC data may provide an informative framework for further GT FP research and management.

Similarly, unplanned urban growth and suburban sprawl in metropolitan Chicago were among the major contributors to Chicago's accelerated degradation of natural communities as well as to the deterioration of human living conditions. In 1996, organizations in Chicago's metropolitan region began linking efforts to reverse these trends (Wang and Moskovits 2001). Under the umbrella of a parent organization (Chicago Regional Biodiversity Council), an alliance of diverse institutions – including local, state and federal government agencies, landowners, research institutions and conservation organizations – formed to implement a strategy to manage the long term viability of natural remnants of high integrity. Remotely sensed imagery and GIS allow analysis of threats and conservation success across these geographic regions and scales. Similar efforts in Hawaii could provide an organizing point around which a region sea turtle conservation constituency might grow.

Appendix I: Change Detection Images

A. Kaneohe Bay, Oahu

   i. Kaneohe, 1968 (earlier imagery is not available)
   ii. Kaneohe, 1970
   iii. Kaneohe, 2000

B. Waikiki, Oahu

   i. Waikiki, 1952
   ii. Waikiki, 1970
   iii. Waikiki, 2000

C. Palauu, Molokai

   i. Palauu, 1950
   ii. Palauu, 1970
   iii. Palauu, 2000

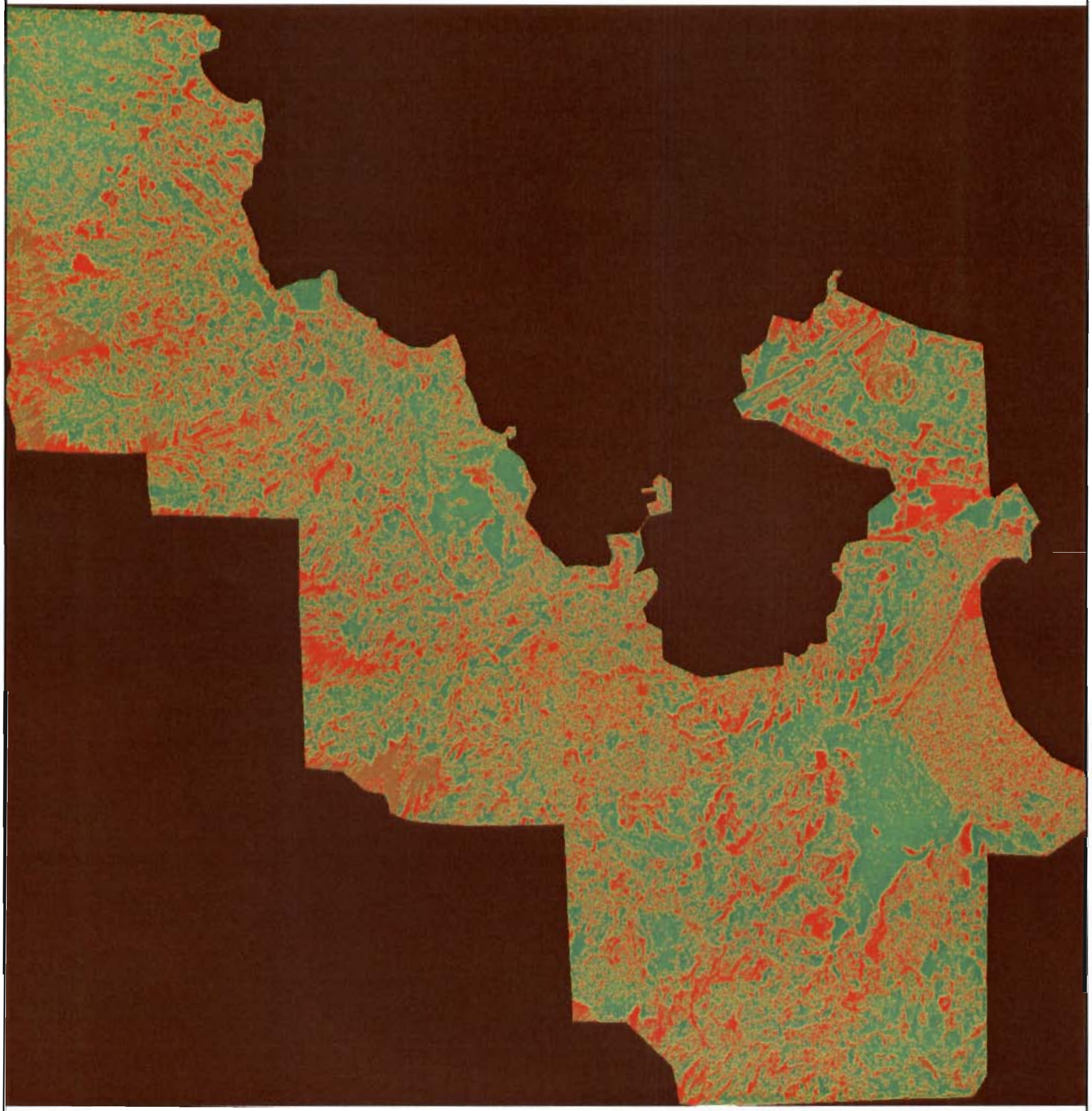
D. Kiholo Bay, Hawaii

   Complete coverage for this site is not available for 1950; subsequent years were matched to the available 1950 data.

   i. Kiholo Bay, 1954
   ii. Kiholo Bay, 1970
   iii. Kiholo Bay, 2000: File is corrupted and unable to print.

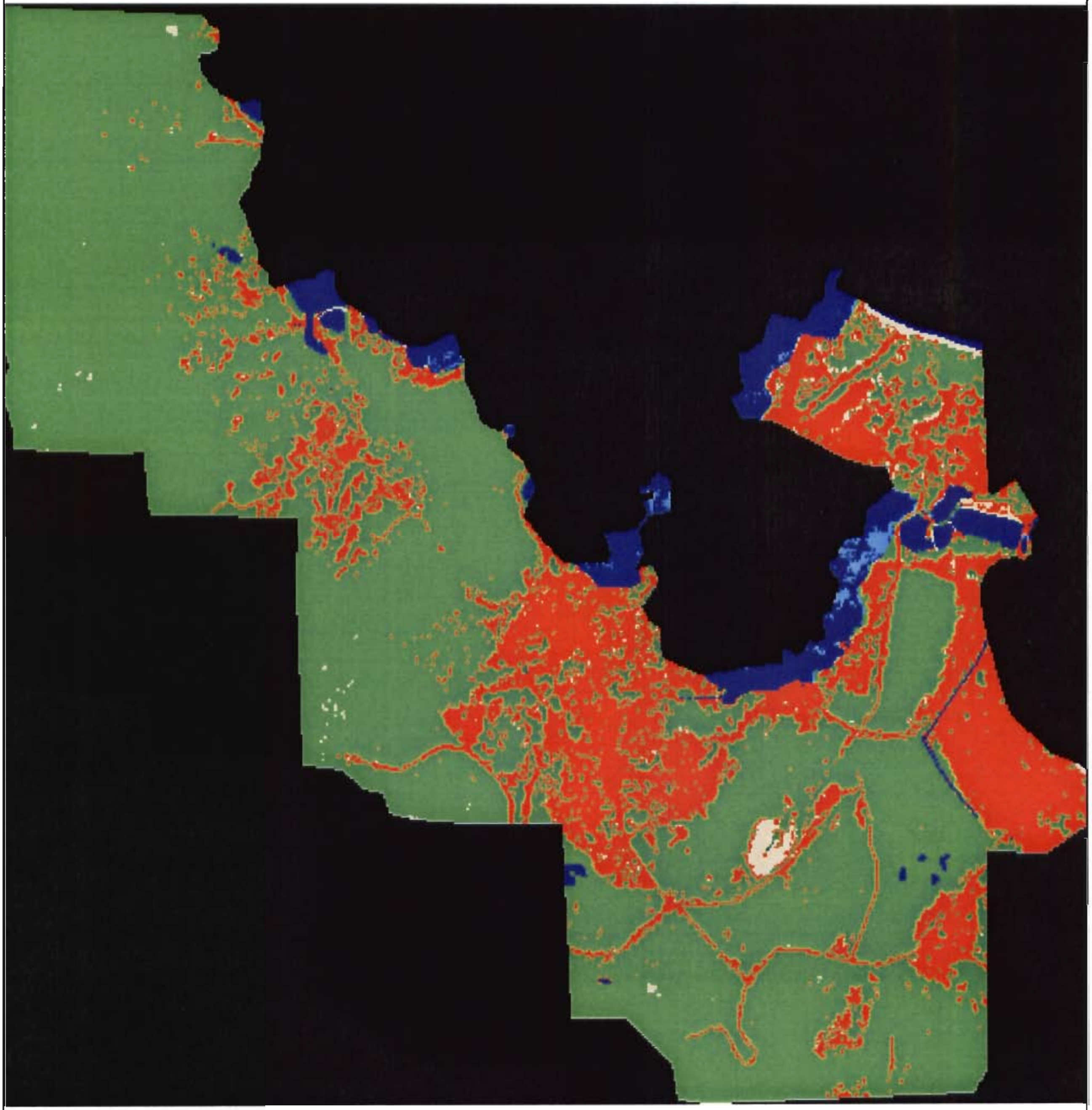
E. Punalu'u, Hawaii

   i. Punalu'u, 1954
   ii. Punalu'u, 1970
   iii. Punalu'u, 2000: File is corrupted and unable to print.

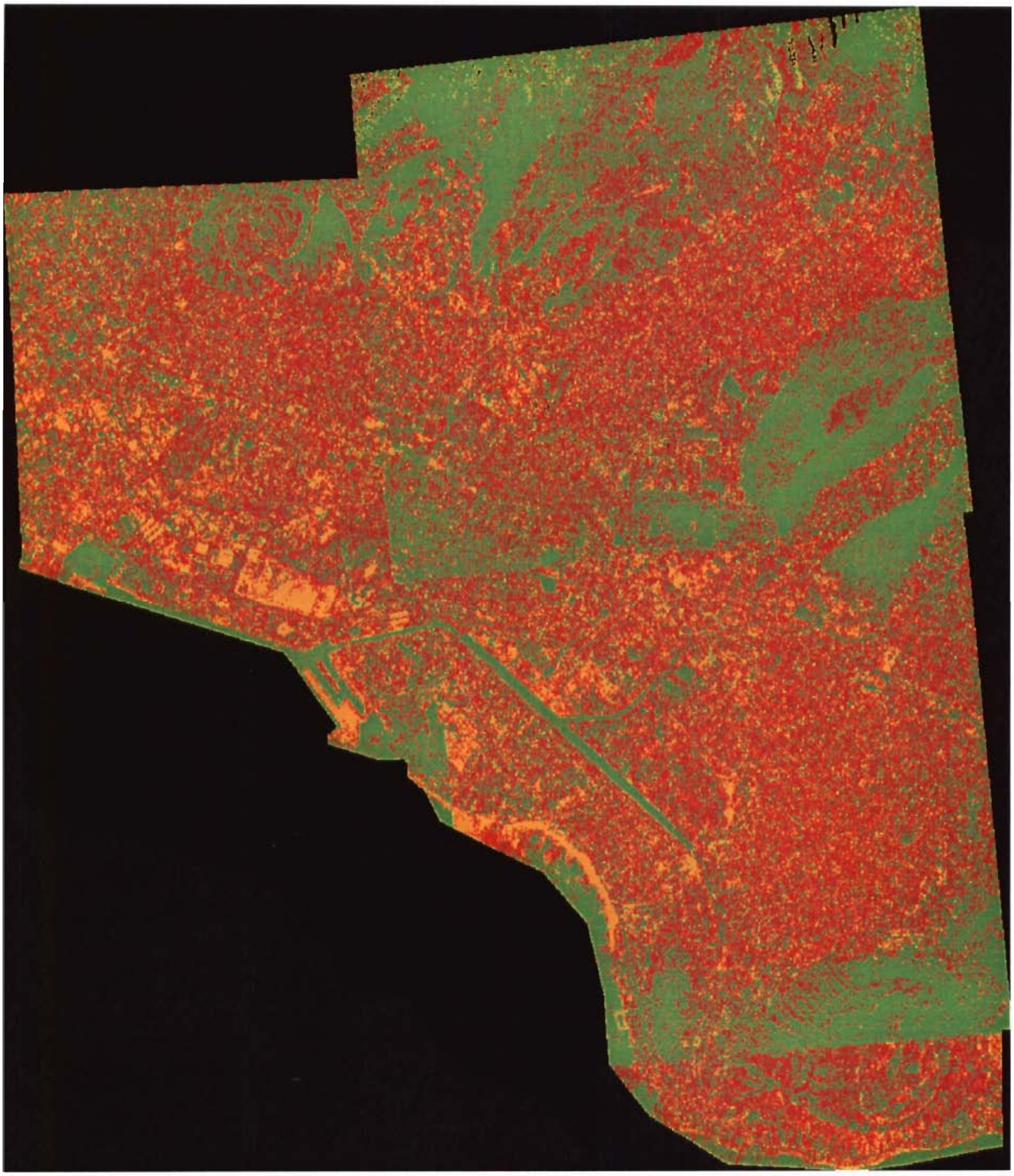


Kaneohe Bay, 1968

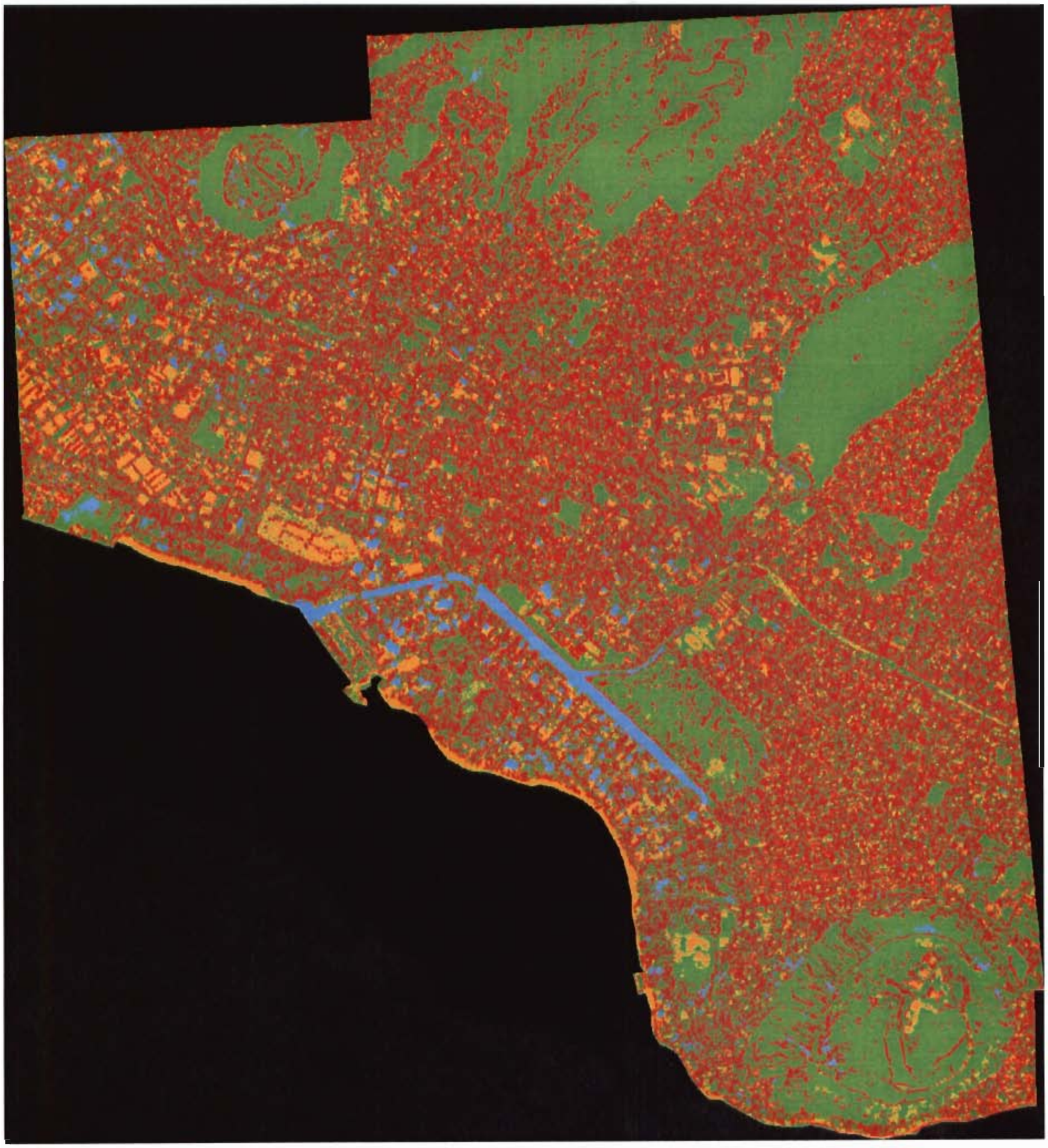
Kaneohe Bay, 1970



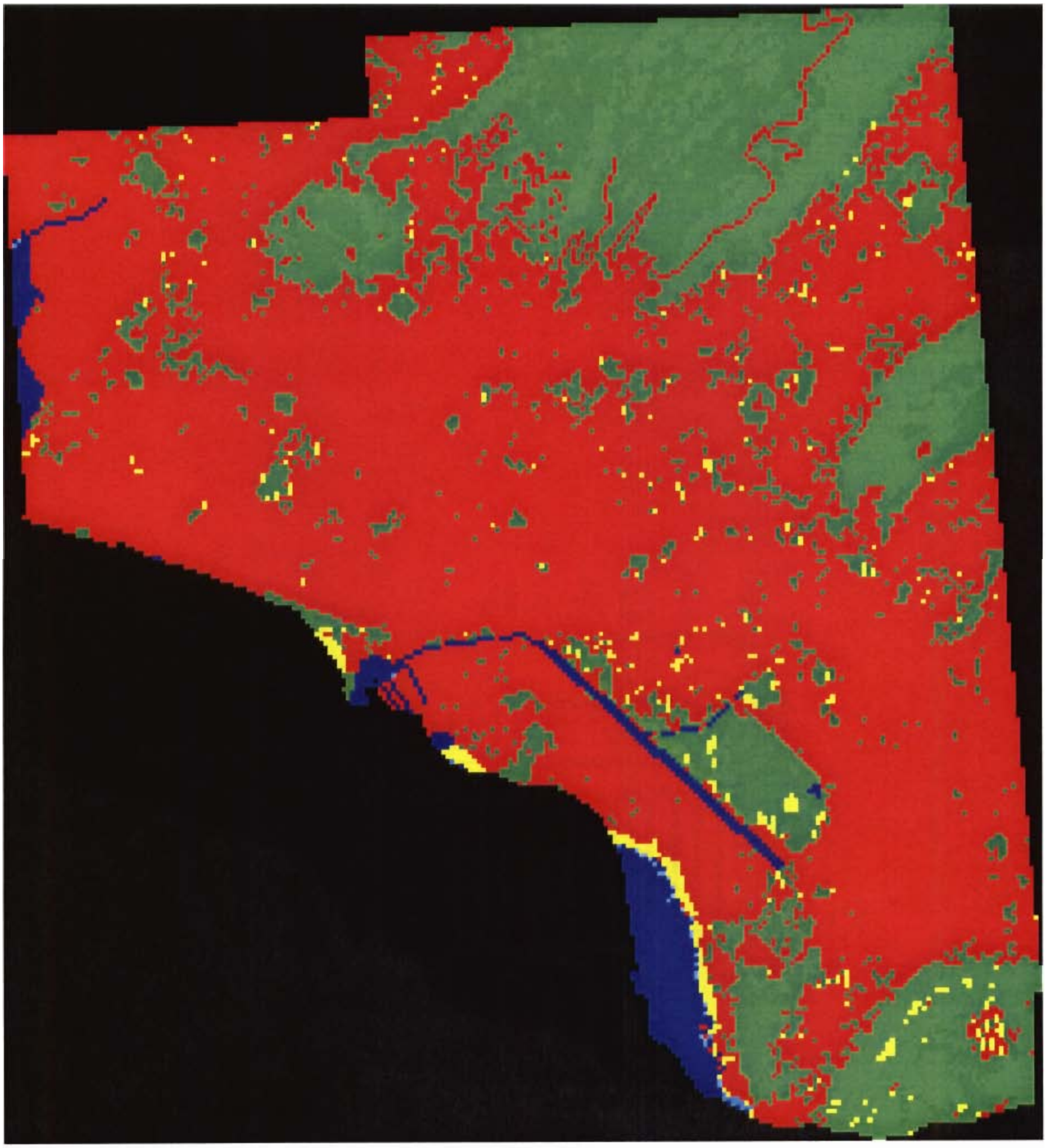
Kaneohe Bay, 2000



Waikiki, 1952



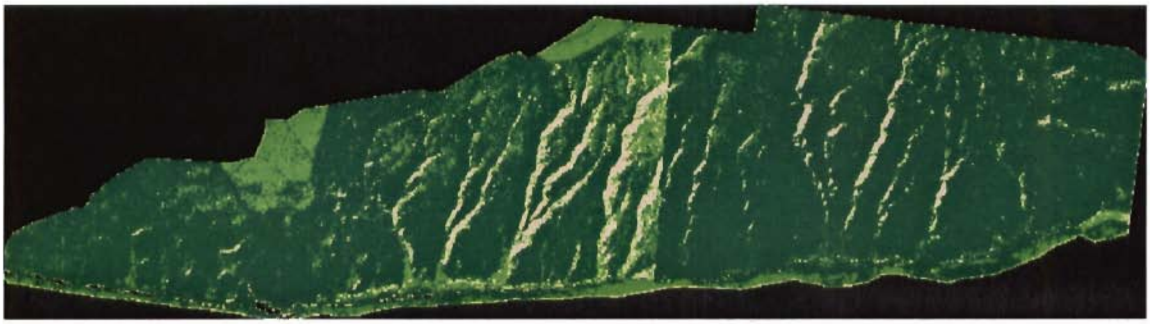
Waikiki, 1970



Waikiki, 2000

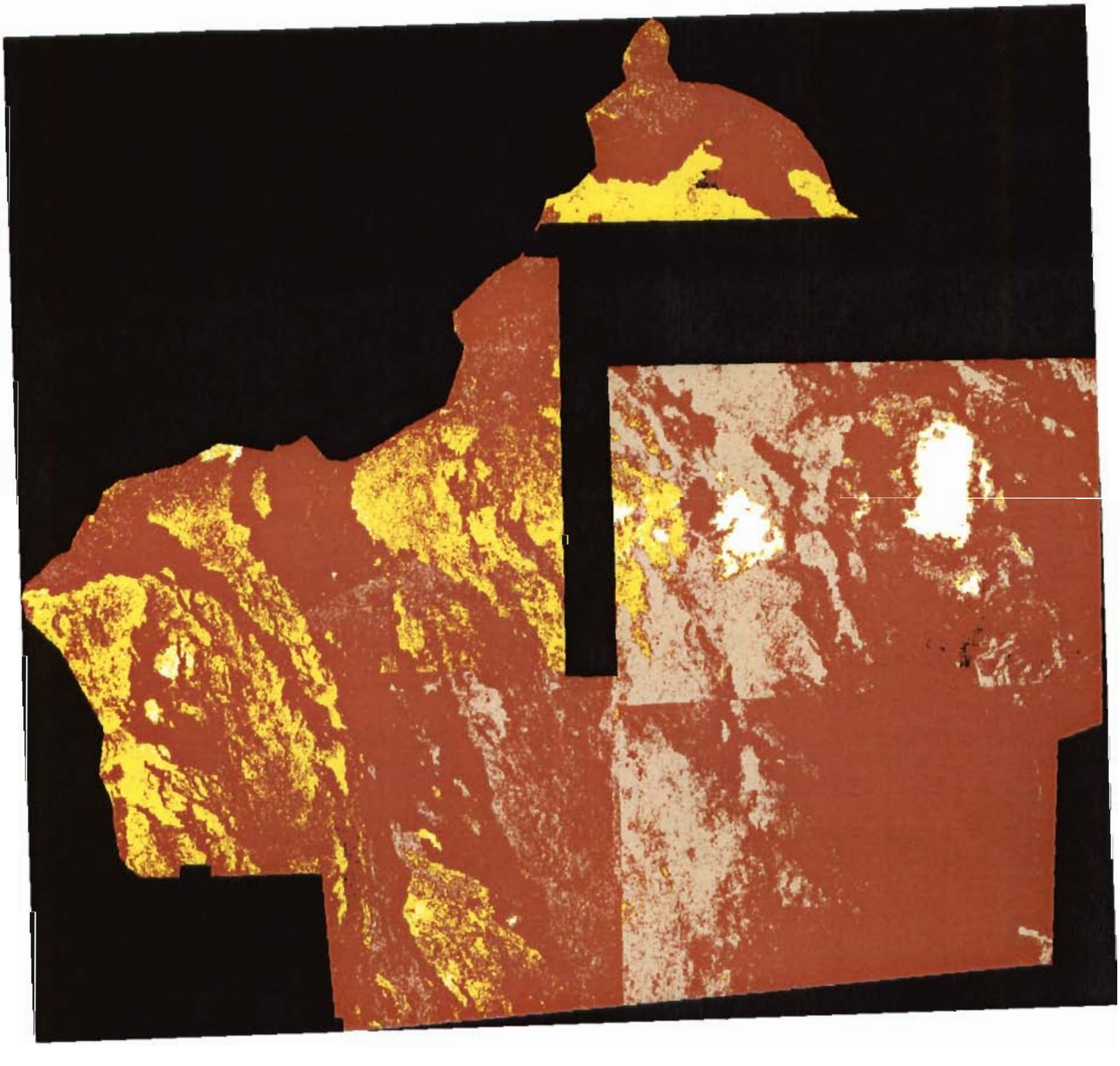
Palauu, 1950

53g

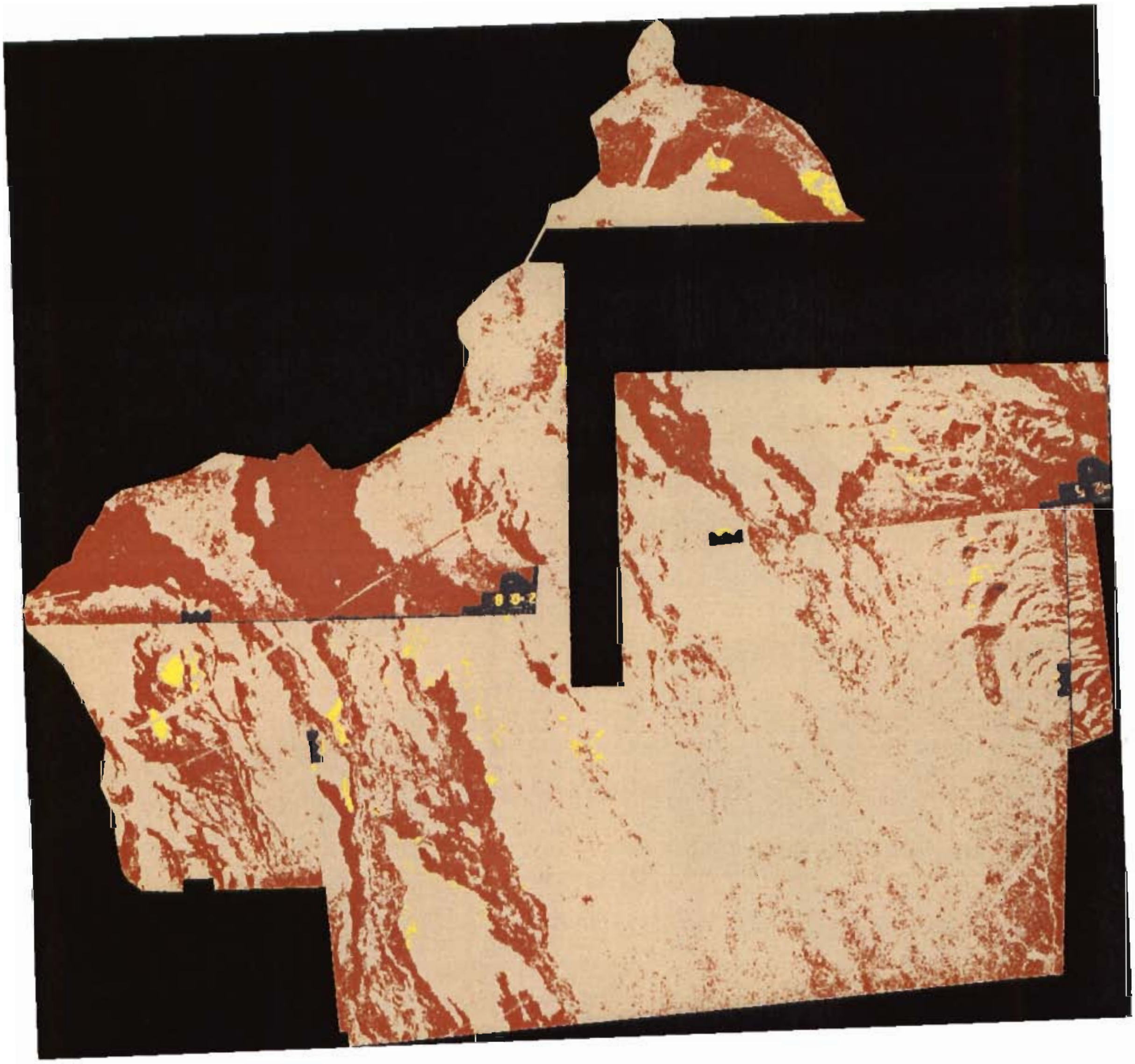


Palauu, 1970

Palauu, 2000



Kiholo Bay, 1954



Kiholo Bay, 1970

Punalu'u, 1954

Punalu'u, 1970

Appendix II: Data and Sources

1) Aerial Photographs obtained from:

Site	Year	Source	Scale	Type
Kaneohe Bay	1968	EROS	12000	B/W
	1970	Craig Tasaka	24000	B/W
	1990	Craig Tasaka	8000	CIR
	2000	Web (NOS), CCAP	24000	C
Waikiki	1952	EROS	12000	B/W
	1970	Craig Tasaka	24000	B/W
	1990	Craig Tasaka		
	2000	Web (NOS), CCAP	24000	C
Palauu	1950	EROS	28000	B/W
	1970	Craig Tasaka	24000	B/W
	2000	Web (NOS), CCAP	24000	C,TM
Kiholo Bay	1954	EROS	1200	B/W
	1970	Craig Tasaka	24000	B/W
	2000	Web (NOS), CCAP	24000	C
Punalu'u	1954	EROS	12000	B/W
	1970	Craig Tasaka	24000	B/W
	2000	CCAP		TM

2) NOAA Coast Change Analysis Program (CCAP) Data
http://www.csc.noaa.gov/crs/lca/hi_index.html

The CCAP data is based on mosaics of Landsat 7 Enhanced Thematic Mapper (ETM) imagery. Hawaii is characterized by almost constant cloud cover. To minimize cloud cover, multiple image dates and scenes were used to map each island. In some cases, no clear imagery was available for portions of the land surface.

3) Tumor Data (courtesy of George Balazs, Leader, Marine Turtle Research Program)

Table 1. FP Prevalence and Case Severity

Site	Time 1950	Time 1975	Time 1985	Time 1995	Time 2002	# Annual Samples**	N	Range	Prevalence
Kiholo	R	R	R	R	R	23	2803	1973-1995	RARE
Punalu'u	R	R	R	R	R	18	?	1976-1993	RARE
Palaau	R	R	R	H	H	14	1498	1982-1996	RARE-HIGH
Oahu*	R	R	M	H	H	9	777	1989-1997	RARE-HIGH
Oahu*	R	R	M	H	H	3	46	1990-1993	RARE-HIGH

*Includes Kaneohe Bay and Waikiki.
**Estimates based on published literature.

Appendix III: Image Processing Protocol

1. Scan Hard Copy Black and White Photograph.

2. Georeference each image using ground control points (GCP) collected from digital raster graphs.

3. Mosaic images using ERDAS Imagine's DataPrep / Mosaic Images.
    a. Before creating the mosaic, perform color balancing to facilitate contrast matching between images.
    b. Construct a mosaic for the 1950 timepoint and the 1970 timepoint.

4. Clip mosaic to site size; ensure the 1950 and 1970 sites are the same size.

5. Perform a texture analysis on the each clip. Texture analysis is a spatial image enhancement technique that defines texture as a quantitative characteristic of an image; this is particularly useful in single band imagery i.e. black and white photographs. As opposed to color and brightness – radiometric measures associated with one pixel that describe the average tonal variation in the various bands of an image - texture is calculated from a set of connected pixels and contains information about the spatial distribution of tonal variations within a band

6. Stack the raw image (original mosaic) and the texture layer using ERDAS's Image Interpreter / Utilities / Layer Stack functionality.

7. Perform a supervised classification on each image.

    a. Supervised classification is an iterative process. There are two ways to collect training signatures in ERDAS Imagine. First, I collected between thirty to forty training signatures per image. These signatures were generated by growing an area of interest where the maximum size = 350 pixels and the spectral Euclidean distance was not greater than 15. This method of collecting signatures proved to be more efficient and accurate than user defined polygons as the range of seeded signatures is inherently bounded. These parametric signatures were later merged and deleted to create as mutually exclusive and exhaustive classes as possible.

    b. Nonparametric signatures are collected from a plot of the texture information plotted against the raw data; this plot is called a feature space image. After a feature space image is generated, the user links a cursor between the raw image and the feature space image. By moving the cursor on land uses of interest (i.e. urban and water), the user gains a sense of where a particular feature falls within the feature space image. Signatures are collected from sections of the feature space image where a particular characteristic consistently falls.

Nonparametric signatures were particularly helpful in parameterizing the urban signature. However, the feature space image is somewhat difficult to interpret with respect to defining the feature space region that corresponds to a unique class.

c. The Mahalanobis distance algorithm was used as the classification decision rule. Unlike the minimum distance and parallelepiped decision rules featured in ERDAS Imagine, the Mahalanobis decision rule takes into account the variability of the classes. For example, a class like urban land cover is made up with pixels with a high variance where the pixels may tend to be farther from the mean of the signature. The Mahalanobis decision rule facilitates the inclusion of outlying urban (or other class of interest) pixels. Though the maximum likelihood rule also accounts for class variability, its computation time is more extensive than the Mahalanobis decision rule.

8. Following the classification method in the ERDAS field guide (5th edition), a fuzzy classification was performed on each image; fuzzy classification recognizes that there are pixels of mixed make-up, i.e. some pixels cannot definitively be assigned to on category. Fuzzy convolution creates a context-based classification to reduce the speckle or "salt and pepper" in the classification. The fuzzy convolution operation creates a single classification layer by calculating the total weighted inverse distance of all the classes in a window of pixels and assigning the center pixel the class with the largest total inverse distance summed over the entire set of fuzzy classification layers. Classes with a very small distance value will remain unchanged while classes with higher distance values may change to a neighboring value if there are a sufficient number of neighboring pixels with class values and small corresponding distance values. A 3x3 window was used in the convolution process.

9. Perform an accuracy assessment of each classification. The number of reference pixels is an important factor in determining the accuracy of the classification. In this classification, I generated forty random points in a stratified random fashion, where the number of points was stratified to the distribution of thematic layer classes (excluding the "Background" class in each case as well as in any case where the number of pixels classified in a particular class was equal to zero). The accuracy assessment generates an error matrix, an accuracy report and a kappa coefficient.

10. Perform land use/land cover change detection by subtracting each land use in 1950, 1970 and 2000 and calculating the LULC change in Microsoft Excel.

Appendix IV: Overall Accuracy Assessment

	Kaneohe Bay, Oahu		**Waikiki, Oahu**		**Palauu, Molokai**		**Kiholo Bay, Hawaii**		**Punalu'u, Hawaii**	
	1968	1970	1952	1970	1950	1970	1954	1970	1954	1970
Developed Land										
Users	83%	91%	63%	79%					0%	40%
Producers	63%	77%	71%	61%					0%	100%
Cultivated Land										
Users						60%				100%
Producers						100%				100%
Total Vegetation										
Users	91%	75%	80%	83%	90%				80%	
Producers	71%	90%	80%	91%	90%				89%	
Bare Land										
Users							100%	94%		
Producers							78%	100%		
Water										
Users										
Producers										
Overall Accuracy	78%	90%	68%	73%	88%	65%	85%	95%	70%	60%

Overall accuracy is computed by dividing the total number of correctly classified pixels by the total number of reference pixels. Producer's accuracy indicates how well a training signature characterizes a specific land use/land cover type; it is calculated by dividing the number of correctly classified pixels in each category by the number of training set pixels used for that category. User's accuracy is a measure of commission error and indicates the probability that a pixel classified into a given category actually represents that category on the ground (Lillesand and Kiefer 2000).

Though 40 points were evaluated per image in this analysis, the classification accuracy is most likely overly optimistic. Congalton et al. suggest that greater than 250 reference pixels are necessary to estimate mean accuracy within +/- five percent (Congalton 1991). Given additional resources, the accuracy assessment could be expanded.

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Dear George, 2/04

Sorry for the delay. Hope this is of interest.

Take good care!

Sincerely,
Kyra