Using GIS in human impact analysis of mangroves

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ABSTRACT

In this study a GIS approach was developed to provide ground-level classification of mangrove communities and their impact by human. Mangroves around Suva are declining due to peripheral pressures from expanding land use and interior pressures of increased resource utilization. Increasing urbanisation, particularly growth of industrialisation and squatter settlements, has resulted in greater utilisation of mangrove communities (Rhizophora - Bruguiera). Better information is needed if sustainable environmental management practices are to succeed. Remote sensing is unable to provide the detail and scale of data that is required, but in situ field work, combined with GIS approaches, offers an enhanced methodology. This project examines the mangroves of the Suva peninsula using a geographical information system (GIS) approach in order to derive better techniques for monitoring, analysing and managing these deteriorating environments.

Keywords*: Mangroves, GIS, human impact, Bruguiera.*

1 INTRODUCTION

GIS (Geographical Information Systems) is an invaluable information technology for a wide range of environmental applications, particularly for monitoring and studying the effects of humans in ecosystems that are difficult to access and analyse, such as mangrove habitats. As an integrative digital methodology, GIS combines diverse data and techniques into a convenient spatial analysis and mapping framework. It has been used with remote sensing and field data, for example, to map and monitor regional and global environments, including the extent and dynamics of mangrove communities (e.g., Chaudhury, 1991; Hussain *et al.* 1999). However, data collection within mangroves is difficult, especially from remote sensing imagery, and GIS can be applied to ground scale, *in-situ* field work. Reported here is a small demonstration project that successfully used traditional and new GIS techniques to analyse the activities within mangrove communities in Fiji at the field level in order to help characterise the human-environment interactions that are important knowledge components for practical environmental management.

GIS has been an evolving information technology since the late 1970s and today it is an integrative "umbrella" that incorporates other information support systems, such as remote sensing, GPS, database and graphics techniques, traditional field data collection, and almost any other method useful in acquiring spatial and associated non-spatial information. GIS can be defined as a computer-based technology and methodology for collecting, managing, analysing, modeling, and presenting geographic data for a wide range of applications (Davis, 2001). Remote sensing, with its overhead view, has limited utility for gathering detailed interior mangrove information, primarily because of the dense canopy and entangled vegetative structure within. However, when coupled with traditional field techniques, GIS offers possibilities for effective and efficient analysis of detailed mangrove communities.

Accurate spatial analysis and presentation of ecological data of biological communities can be critical for the development of successful coastal zone management strategies. This project was designed to test the feasibility and utility of GIS as a tool for mangrove habitat analysis and assistance in sustainability management. GIS methodologies can help to organize, analyse, and present data in ways that were previously difficult or even impossible, thereby offering relatively new approaches to studying and monitoring mangrove communities.

1.1 MANGROVES AND HUMAN INTERACTION

Maximum ecological development for mangroves requires warm tropical temperatures (>20^{o}C), a high level of freshwater discharge periodically, shelter from strong waves, and a gentle sloping shore. They are among the most useful and productive ecological environments, with very high rates of Net Primary Productivity (NPP), yet they are also fragile and susceptible to human degradation. Found throughout the tropics and subtropics, approximately 32^{o}N to 32^{o}S, and occupying a combined area of approximately 160,000 km^2 (Saenger *et al.* 1983), mangroves function to prevent coastal erosion, trap silt and detritus, and provide a sheltered habitat for many juvenile fish and crustaceans, as well as providing resources for humans (Odum and Heald, 1972). Mangrove trees are the primary producers of organic materials in tropical estuarine ecosystems. For example, annual leaf fall rates for mangrove forests in Puerto Rico (Golley *et al.* 1962) and Florida (Lugo and Snedaker, 1974) are 2 g/m^2/day or 730 g/m^2/year. It has been estimated that as much as 30% of the fisheries in Fiji between the shoreline and the fringing reef is intimately tied to mangroves (Lewis, 1983).

For centuries, indigenous people have used mangrove communities as food sources, dyes, medicine, timber, fuel (firewood and charcoal), and building materials (Swarup, 1983; Wong, 1991). Such exploitation was not associated with major environmental impacts because human populations were small and many societies had traditional conservation practices that reduced the human impact (Saenger *et al.* 1993; Rao, 1987; Watson, 1928).

The modern view, beginning with early European colonials, perceives mangroves as malodorous, muddy, insect infested wastelands that need to be "reclaimed" and converted to more "useful" land. Interestingly, deforestation of mangroves is often considered "reclamation." (Lal, 1983). The change from subsistence to a developed cash economy was accompanied by over-exploitation and destruction of mangrove communities. For example, when the Colonial Sugar Refinery established sugar cane production in Fiji, the first areas farmed were the flat lands close to shore or on the banks of the lower reaches of the larger rivers. Many of the early embankments for tramlines were constructed through mangroves and created large scale land filling in Fiji (Pepper, 1983). Although historically there has been little reluctance to clearing mangroves in favor of urbanisation, aquaculture, and agriculture, contemporary views are increasingly conservative, exhibiting new concerns for guarding fragile ecosystems.

This project investigates the impact of humans on a mangrove area surrounded by urban land uses. There is clear evidence of deforestation by encroaching urban land uses on the fringes of the study area (such as residential development), which can be interpreted and measured by remote sensing. However, in this project special attention was given to individual activities inside the mangroves that cannot be detected by imagery. The working hypothesis was that individuals or small groups of users were "invading" the interior for small scale, typically traditional use, such as charcoal, firewood, construction material, dyes, and food and that the impact can be significant.

1.2 SITE DESCRIPTION

The Suva Peninsula is on the southeastern side of Viti Levu, Fiji. It covers 15 km^2 and includes the capital of Fiji, Suva (Figure 1). The protected shores around the peninsula consists of soft, silty to fine sand flats stabilised by the sea grasses *Syringodium isoetifolium* (Ascherson) Dandy, 1939, *Halodule uninervis* (Forskål) Ascherson, 1882, and *H. minor* (Zöllinger) den Hartog, 1957, (Penn, 1981; Morton, 1990; Penn and Ryland, 1995). Suva Harbor has semi-diurnal tides with a range of 0.9 metres at neap tides and 1.3 metres at spring tides. Typically the flats are exposed during daylight for three to five hours and support an important subsistence fishery (Quinn and Davis, 1997). The mangrove communities that once lined much of the shore have been reduced to a few isolated patches (Naidu *et al.* 1991) (See Figure 1).

In Fijian, mangroves are collectively referred to as *dogo* or *tiri*. The common species include *Bruguiera gymnorhiza* (*dogo*), *Rhizophora samoensis* (*tiriwai*), *R. stylosa* (*tiri*), and *R. x. selala* (*selala*), an endemic sterile hybrid of the other two *Rhizophora* species that is only found in Fiji, New Caledonia, and Tonga. *Rhizophora* spp. is a pioneer genus starting growth on mudflats, supporting itself against wave action by a complex set of prop roots and columnar roots from its branches. This dendritic structure makes the estimation of tree size difficult using standard forestry techniques. Other higher plants restricted to the mangroves and hence included in gross measurements of mangrove areas are: *Lumnitzera littorea* (*sagali*), *Xylocarpus granatum* (*dabi*), *Excoecaria agallocha* (*sinu gaga*), and *Heritiera littoralis* (*iolonimasima*) (Pillai, 1990).

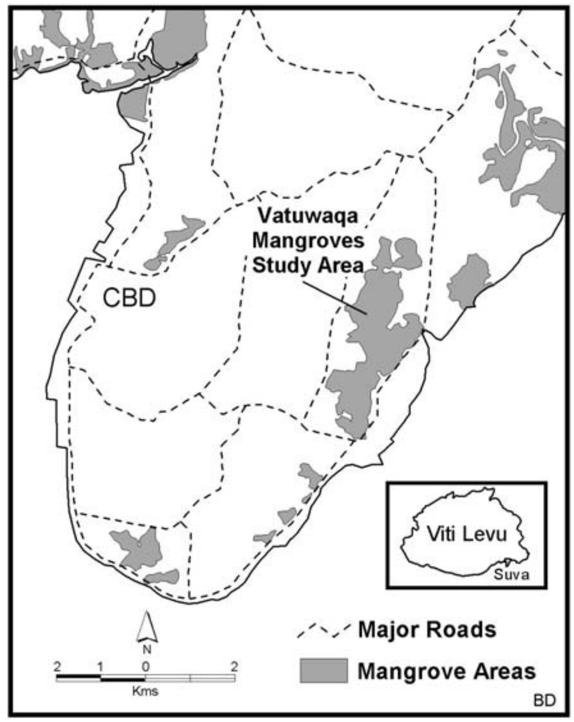

Figure 1. Suva Peninsula and Vatuwaqa mangroves study area.

Suva is Fiji's premier city and the cosmopolitan center of the South Pacific. The metropolitan population has increased by about 32% since 1980, to more than 175,000 people today. It is a multi-racial, multi-cultural city populated mainly by Fijians and Indo-Fijians, with a mix of other Pacific islanders, Asians, and Europeans. As such, there is a wide variety of environmental perspectives, with different values on the use and preservation of natural resources. To some, mangroves are exploitable in a sustainable manner, while others view the environments as having little intrinsic worth.

Mangrove destruction has been especially pronounced in rapidly growing urban areas in the developing world and Suva is no exception. It has experienced many of the advantages and disadvantages of city development, including severe environmental modification and degradation. Mangroves around Suva are declining due to peripheral pressures from expanding land uses and from interior pressures due to increased resource use by locals. Urbanisation, industrial development, drainage alterations, squatter settlements, urban discharges (e.g., primary and secondary treated sewage effluence), landfills, and other non point source pollution have damaged vital coastal wetlands in recent years.

Prior to 1980, 3,350 hectares of mangrove were "reclaimed" (destroyed for cultural use) around the Suva peninsula (Lal, 1983). From 1980 to 1996, over 343 hectares of mangrove community and an additional 1,185 hectares in the rest of Viti Levu were lost. For example, based on a comparison of a 1951 topographic map and a 1991 airphoto, mangrove loss around part of the Vatuwaqa study site was about 15 hectares, almost a 26% decrease, most of which has been the conversion to industrial and residential use (with a small amount for recreation).

Clearly, such ecological loss cannot continue. With even more urban growth and change in the near future, Suva (and its counterparts throughout the Pacific) must confront the potential for environmental damage and destruction. What is needed is a sensible balance between renewable and non-renewable use with emphasis on multiple use of the resource. New approaches to the analysis and management of mangrove ecosystems are necessary.

2 METHODS AND MATERIALS

2.1 FIELD WORK

Figure 1 shows numerous mangrove communities around the Suva peninsula, ranging from 2.4 ha and to almost 70 ha. The Vatuwaqa mangrove site, the largest on the Suva peninsula, was selected as the primary study area. Nineteen sampling sites, accessible by foot or boat, were chosen at random and convenience (a pattern of sample sites is very difficult to develop in mangrove environments) (Figure 2). Sampling commonly was performed within about ten metres of the water due to inaccessible interiors. The sites were clustered in the central section of Vatuwaqa with a secondary group in the southern part.

Standard published maps and 1994 1:8,800 aerial photos were used in the field for orientation and locating plots. The available GPS units gave positions of only 100-metre accuracy, not much better than what careful crew observations could provide. Improved technology will enhance future siting accuracy. Field data collection was limited to observations attainable by portable equipment, concentrating primarily on botanic measures and observations of human activity.

The Point-Centered or Point-Quarter Method (POCQ) was used at each site (Cox, 1972; UNESCO, 1984). POCQ was chosen because the technique is commonly used with vegetation studies and considered suitable for sampling difficult environments, such as mangroves. At selected points in the mangroves, either along the creek or on land, a tree typical of the site was chosen and designated the "central tree." Four quadrants were then formed around the tree. Within each quadrant a tree nearest the quadrant's center was identified according to genus, size (diameter at breast height, tree height), and its distance from the central tree. Trees were identified only to genus level because of the difficulty in identifying species hybrids. Tree heights were determined using hand-held clinometers.

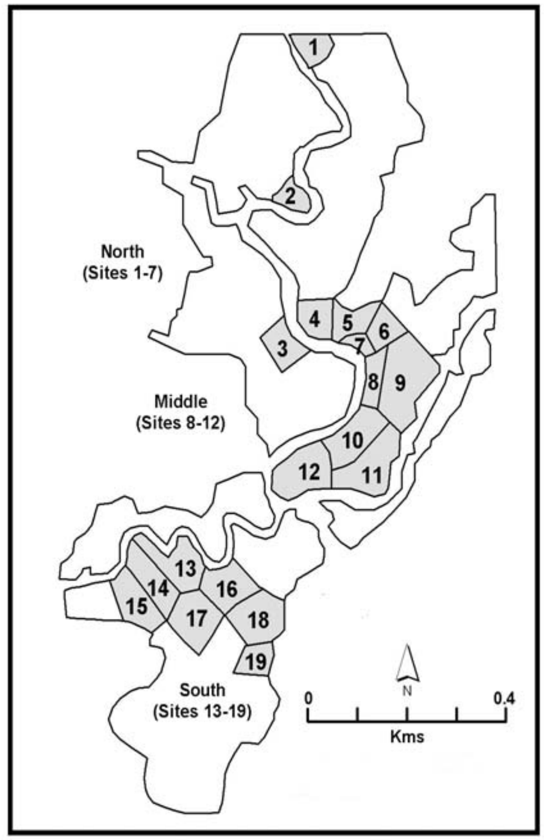

Figure 2. Vatuwaqa mangrove area study sites map. Data site points converted to polygons.

Additional ordinal observations were made regarding human impact, such as human littering, cuttings of branches and trunks, and bark stripping. Diameters at breast height for all of the trunks were measured and summed to represent the diameter of the trees. An index of the tree size was calculated by multiplying the pooled tree diameters at breast height by the estimated height of the tree.

Field data were entered into a Lotus 1-2-3 spreadsheet to calculate the parameters listed in Table 1. The spreadsheet was transferred to Excel for additional analysis and then into a GIS database for basic mapping. Additional GIS operations provided spatial analysis and secondary, derived data. A standard format of rows (study sites) and columns (attributes of observations and measurements) was employed for all of the databases.

Overall, a relatively simple and standard process for data collection, analysis, and mapping was used to keep the project manageable, easy to employ using untrained students, and for easy replication.

Table 1. Field Observation Measurements

S	Total number of sampling points
Q	Total number of quarters ($Q = 4S$
Dbh	Diameter at breast height for each tree
L_i	Distance from point to tree main trunk in m for individual $_i$
θ	Angle to top of tree from point ld
h_I	$L_i \tan \theta$
D	Sum of all the distances measured (m)
D'	Average distance ($d' = d / Q$) (m)
D	Community density ($D = 1 / d'^2$) (m^2)
N_i	Number of individuals of genus i
Φ	Index of tree size (dbh_i) x (h_i)
$\Phi_{c.v.}$	Coefficient of variation of mean tree index for each site
P_i	Percentage cover of genus i ($P_i = 100 \times A_i$ / total area for all genera) (%)

2.2 GEOGRAPHICAL INFORMATION SYSTEM APPROACH

Remote sensing, particularly from satellites, has been a major provider of ecological data for several decades and has been used for macro-scale mapping, monitoring, and resource management of mangrove ecosystems (e.g., Hussain, *et al.* 1999; Chaudhury, 1991; ESCAP/UNEP, 1989; Green *et al.* 1997; Green *et al.* 1998(1); Green *et al.* 1998(2); Ratanasermpong, *et al.* 2000, Sremongkontip *et al.* 1997; Zhang *et al.* 2002). Various sensors can help to map macro-ecological features, such as distribution of species, land use, and to show temporal changes (e.g., deforestation). However, even with the new higher resolutions (sometimes one meter), the perspective from overhead and the heavy canopy prevent detection and interpretation of ground level (micro-environmental) factors that are used in this study, such as detailed human activity and tree damage. This project used standard panchromatic aerial photography (1:50,000 and 1:8,800) for regional mangrove mapping and detailed land use mapping around the study area, but GIS was needed to integrate field data.

As noted, GIS offers convenience and efficiency in data collection, management, and presentation. It permits easy mapping and a wide range of analytical options. Spatial analysis, its distinctive strength, can reveal patterns or associations not evident in the field. As an integrated database and graphics technology, GIS can examine single observations or groups of observations with multiple attributes. Selected mangrove environment components are investigated in this pilot project and many others could be incorporated in a larger study. Almost any GIS software is suitable for this type of investigation and four were tested because of various options—MapInfo 4.1, PC ArcInfo, Idrisi, and ArcView 3.2.

To support mapping and spatial analysis, the 19 data site locations (points on a map) were converted to polygons using a Theissen operation in GIS, which determines the representative "territory" of each point according to placement of surrounding points and environmental features. These are the study site mapping units shown on Figure 2. The polygons are relatively small and are credible representations of the sample points.

GIS can help to analyse data spatially in several ways and two primary GIS strategies were followed. The first is termed "inventory" operations (Davis, 2001), those tasks that provide basic mapping and distribution analysis of single factors, e.g., locations of *Brugueria* species. This may reveal whether the species is clustered in certain areas, is evenly distributed throughout the study site, or has no spatial pattern. Subsequently, spatial analysis operations were used to test location relationships between factors, such as the association between cuttings and bark stripping or between land use factors and mangrove destruction. Basic mapping shows initial patterns, while overlays (spatial combination) of two or more data layers will help to show associations and their patterns. These approaches were used in the initial analysis of the study area, but many others are available in GIS. Several basic locational and thematic maps are presented here in simplified format (although GIS is capable of producing sophisticated large format maps and diagrams).

3 RESULTS

Data visualisation in map form is a strength of GIS and selected results are presented in map format for convenience. The initial interpretations discussed here are preliminary. The first set of examples includes the single factor observations (inventory operations—basic mapping and interpretation), followed by selected overlay combinations to evaluate spatial and functional relationships. The maps included here are demonstrations of how simple cartography can be useful as fundamental environmental management information, but all field observations were mapped for a more thorough investigation. Each map alone may not explain the causal reasons for the observed factors (their magnitudes or distributions), but acting in concert with other data, a better understanding usually can be achieved. Also, questions often arise that ultimately contribute to further insight.

Land use (Figure 3): Using airphotos, maps, and field checking, the land use around the Vatuwaqa study area was interpreted to determine the types and magnitude of pressures on the natural environment. The map shows a variety of land uses on all sides of the mangrove, mainly residential and industrial. Residential developments, including squatter settlements, create opportunities for intensive use and destruction of mangroves. Such settlements are sources of continued, and typically uncontrolled, resource consumption of mangrove habitats and hence represent continuing harm to those habitats. Industrialisation tends to destroy large portions of the communities, usually in an initial land-clearing operation, but expansion and pollution can cause longer-term consequences. Ironically, in some ways the industrial areas can form protective barriers against residential access of mangroves, thereby sparing some of the harmful impact to the environment.

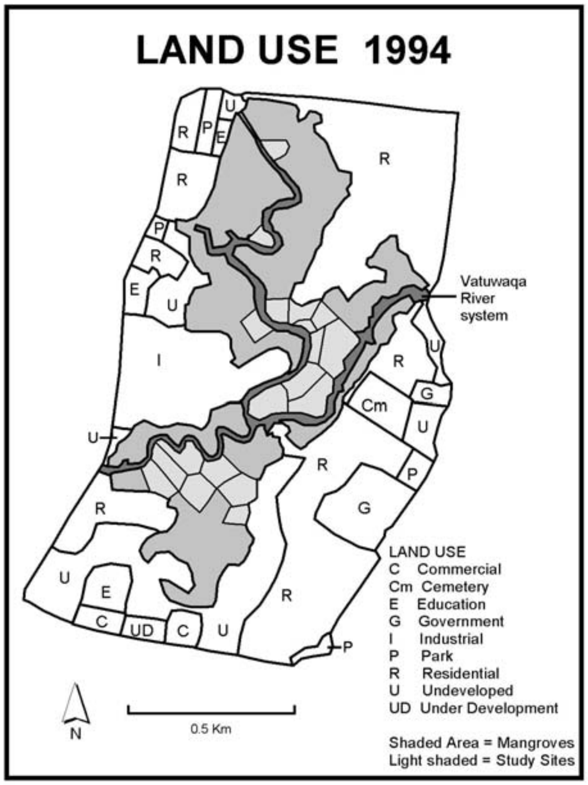

Figure 3. Vatuwaqa area land use map, interpreted from 1:8,800 and 1:50,000 airphotos (with ground checking).

There is a substantial amount of "undeveloped" land use (largely unused and in various states of vegetative growth), which in a rapidly growing urban area typically is subject to development within a short time. In effect, Vatuwaqa's mangroves are severely pressured and invaded by expanding land use on its margins, and the pressures will continue.

Bruguiera cover (Figure 4): Almost three-fourths of the sites (14, 74%) are predominantly *Bruguiera gymnorhiza*), with eleven sites composed of 90-100% of the species. This is consistent with riverine mangroves in that *Bruguiera* is more freshwater tolerant than *Rhizophora samoensis*. These sites are mostly in the central part of the study area, and the two upstream are the result of a less saline environment. Three of the five sites having less than 50% *Bruguiera* are in the southern part of the study site.

Other botanic data can provide maps and analysis of the study area, such as various measures of size and density that can indicate patterns of age (even or uneven growth), or possibly the intensity of use and destruction by humans. The next three maps consider the impact of human activity on the sites using qualitative field observations.

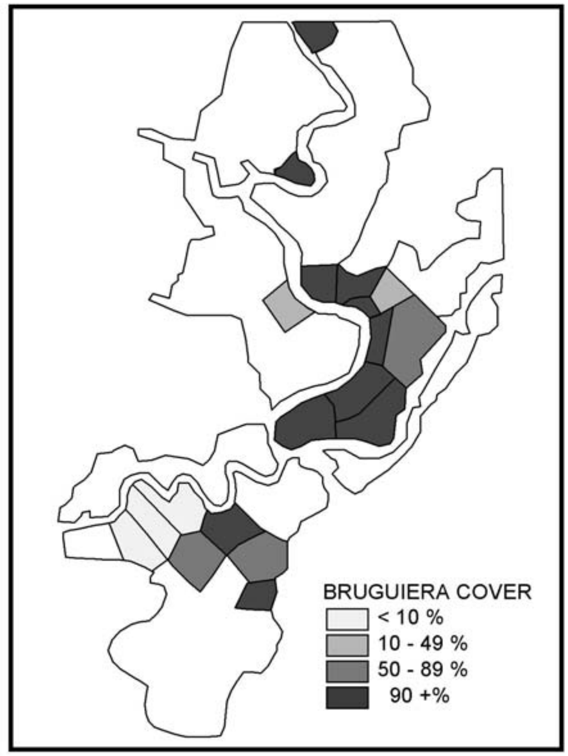

Figure 4. *Bruguiera* cover map. Percent coverage of *Bruguiera* in each site.

Mangrove cuttings (Figure 5): Harvesting of mangroves is evidenced by the removal of trees (leaving only trunks) or the presence of numerous branches as ground litter. Only two sites (4, 7) showed severe destruction (leaving trunks only), both along the main channel. Bordered by sites with many branches removed, this area evidently has been used intensively by people. The large residential development is nearby, suggesting a close relationship that bodes ill for the mangrove community. Eight sites have negligible evidence of cuttings, which would indicate little or no use, but other observations discussed next suggest some human activity in most sites. Interestingly, there are no sites with just "some" cuttings, suggesting that sites are used either heavily or not at all, although there is conflicting data in other field observations.

Bark stripping (Figure 6): Another activity of potentially damaging human use is stripping bark from mangroves. This measure shows the intensity of the damage, ranging from no harm to dead or dying trees that were killed by bark removal. Two of the three most impacted sites are adjacent to the residential area in the central part (4 and 5), while the third site (19) is in the southern section. Only two other sites (6, 18, adjacent to 5 and 19) show significant damage. The remaining sites are not seriously harmed. Bark stripping does not seem to be an extensive problem in the study area.

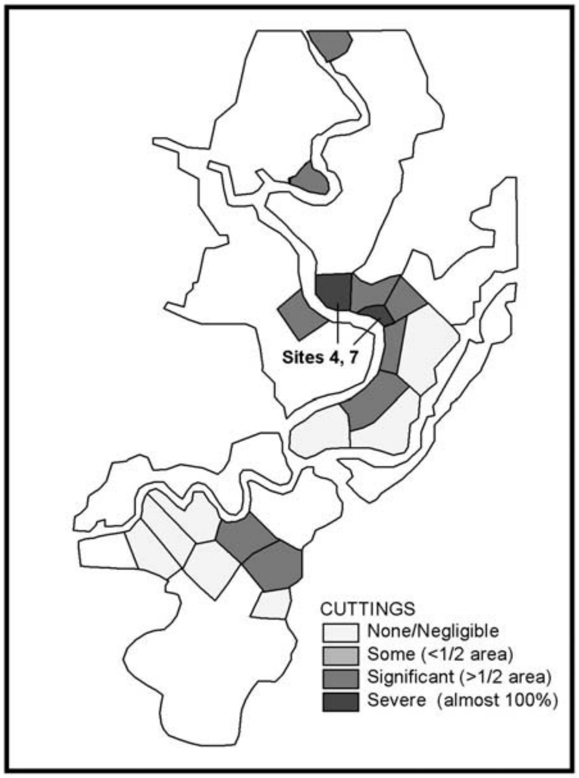

Figure 5. Mangrove cuttings map. Evidence of mangrove harvest.

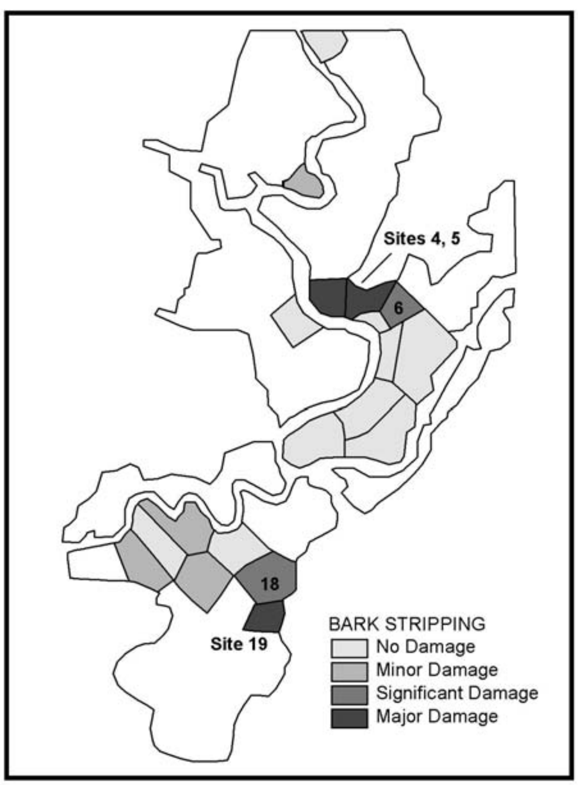

Figure 6. Bark Stripping map. Stripping from mangrove trees.

Human littering (Figure 7): Cultural littering (e.g., cans, trash) or other evidence of human visitation indicates the presence and impact of humans. The heavily impacted sites are in the central and northern part of the study area, closer to the residential areas, as would be expected. Six sites show moderate human impact (~50% area affected), indicating significant but not highly destructive use of the sites. Four of the seven southern sites are moderate and three are largely unaffected.

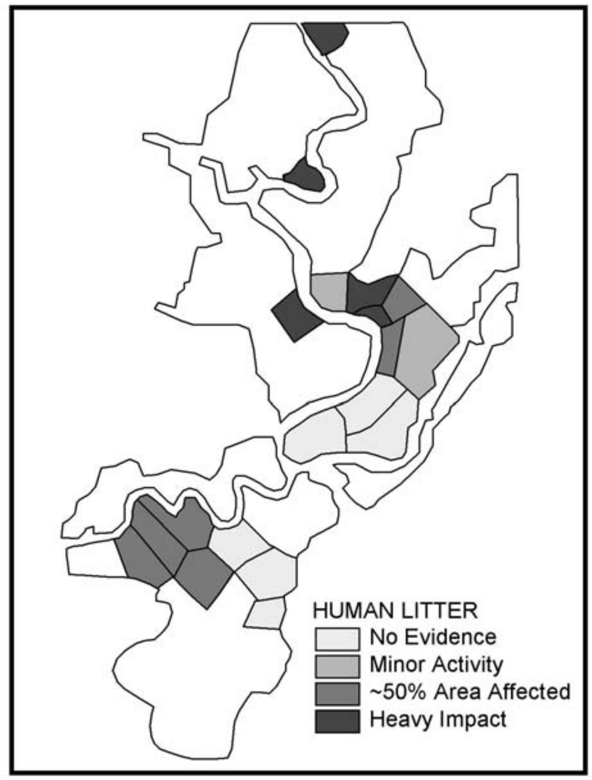

Figure 7. Human littering map. Evidence of human visits.

The preceding three maps present inconsistent evidence of the effect by humans in the study area, e.g., the high intensity sites of one theme do not correlate perfectly with those of another theme. The use of single theme maps to show spatial and causal links between human activity, land use, and botanic effects may be inconclusive. This type of analysis can be useful, but GIS offers the capability of combining data layers (themes) for more comprehensive views and an "integrative analysis" that may lead to better understanding of the study area.

The term "overlay" is used here in a generic sense (traditionally referring to superimposing maps), but GIS merges data in both the graphics (map analysis) and in the database. Demonstrated here are two basic methods—a matrix technique that generalises two sets of data and a database analysis that can merge two or more themes (layers of data). The matrix process is discussed first.

Table 2 presents a generic coding matrix for two fictional themes, i.e., how each intersection (combination) of a row and column is classified into a Low to High category (or any ordinal alphanumeric scheme). This effectively is: Data Set A (input rows) + Data Set B (input columns) = Data Set C (output, or derived data). For example, any study site having a low Data A observation and a 95% Data B measurement (medium) will be classified Low-Medium in the new Data C theme. This rule is used to assign a code for the new Data C theme.

Table 2. Coding Matrix Model

Data Set A: Ranking	Data Set B: Percentages		
	<50% (Low)	50-90% (Medium)	>90% (High)
Low	Low	Low	Low-medium
Medium	Low	Low-medium	High-medium
High	Low-medium	High-medium	High

This technique can be objective (using statistical classes) or subjective (based on logical inference or project need). There are many combinations of data pairing even in this relatively small project data set and one example testing the relationship between *Bruguiera* cover and bark stripping is presented.

Bruguiera cover and bark stripping (Figure 8): Preference for *Bruguiera* or *Bruguiera*-rich locations for bark stripping is investigated in this overlay. Table 3 shows the four measures of *Bruguiera* coverage in columns and the four classes of bark stripping damage in rows. The intersecting combinations are classed from 1 to 4 and separate the high and low of *Bruguiera* coverage and bark stripping damage, as designated in the text below the table. Also, the number of sites for each class and the percentage of sites are given. Figure 8 shows the spatial distribution.

Table 3. *Bruguiera*-Stripping Matrix

Stripping Damage	***Bruguiera*** **Cover**			
	<10% (Low)	10-49% (Low)	50-90% (High)	>90% (High)
None	1	1	2	2
Minor	1	1	2	2
Medium	3	3	4	4
Major	3	3	4	4

1 = Low *Bruguiera*, Low Damage; 4 sites = 21%
2 = High *Bruguiera*, Low Damage; 11 sites = 58%
3 = Low *Bruguiera*, High Damage; 1 site = 5%
4 = High *Bruguiera*, High Damage; 3 sites = 16%

An initial interpretation indicates a fairly low preference for stripping high *Bruguiera* sites. Only four sites (21%) show high damage to high *Bruguiera* coverage, but ten sites (53%) have high *Bruguiera* coverage with low stripping damage. Two of the high sites are located adjacent to the northern residential area, as is the single low *Bruguiera* area with high damage. On the other hand, an alternate interpretation could be that of the five high bark stripping damage sites, four have high *Bruguiera* coverage, and that users actually do prefer the species when there is intensive activity.

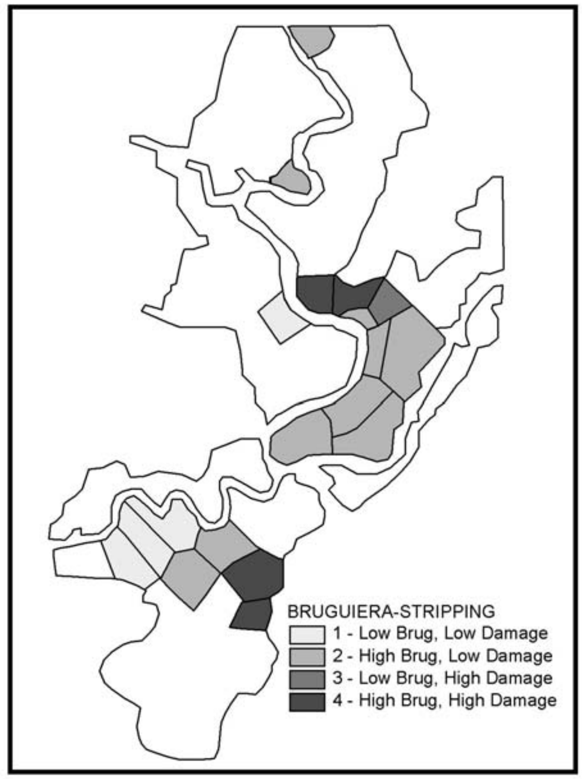

Figure 8. *Bruguiera* cover and bark stripping overlay map.

It is not unusual for GIS analysis to present additional questions rather than conclusive answers, leading the investigation to broader and deeper examination. Although the matrix approach is effective, it is also rather cumbersome because of manual encoding and because it uses only two data layers in the overlay process. The *Bruguiera*-Stripping overlay does not address all human activity and, although other pairs of field observations could be analysed, a more comprehensive approach can be used for better insight. In GIS, much of the analytical work occurs in the database, where observations can be easily reclassified, recoded, and represented as new (derived) data. For example, by coding field observations of one attribute (e.g., none, low, medium, high) into a simple 0-3 scheme, multiple attributes can be merged through simple arithmetic operations to portray a deeper view of activity.

Human impact (Figures 9 and 10): Three human activity field observations were collected at each site (mangrove cuttings, human littering, and bark stripping) and each entered as codes 0 – 3, noting interpretations from no evidence of human activity to significant damage. The numbers for each site were summed in the database, in effect an overlay of the three themes using an add operation. The sum of all three may be a better, more comprehensive indicator of how humans use and impact each site.

The sums ranged from 0 to 8 (no site showed a high-high-high value of 9), which were then generalised into three equal interval categories of Low, Medium, and High. Figure 9 shows the distribution, with five of the northern sites receiving the most damaging effects from humans.

Four of the sites are the closest to the residential area and site 5, the most exposed to the settlement, has the highest human impact value (8). This demonstrates the clear endangerment of sensitive environmental sites that are in close proximity to settlements. Site 2 seems to be the most isolated and spatially protected, yet it is also highly damaged and an explanation for its condition may require additional ground investigation, e.g., search for a direct and easy access path from the western settlement areas. Again, GIS discovered additional questions.

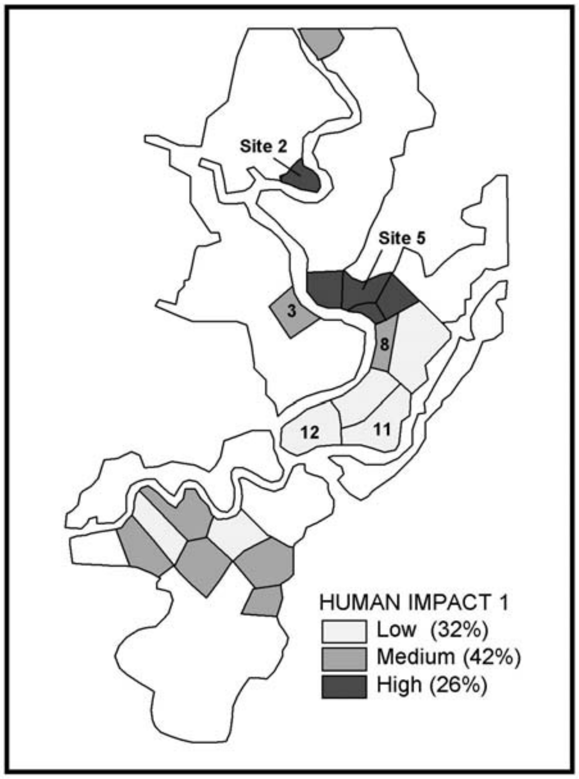

Figure 9. Human Impact 1 map. Overlay adding Mangrove Cuttings, Human Littering, and Bark Stripping values, generalised into three classes.

Two medium human impact sites border these high damage sites (3 and 8), probably an "activity spillover" feature. The middle sites are mostly low values, e.g., sites 11 and 12 present human impact scores of 0, indicating no observed human activity of any kind. These middle sites seem to be easily accessible by boat, but their low impact suggests that most human activity is by people on foot. If so, that may explain the medium damage for site 3, across the creek from the high damage sites that are accessible by foot from the nearby residences.

A patchwork of low and medium sites exists in the southern area, indicating some activity, probably from the lower intensity residential areas in the vicinity. Overall, the mix of low (32%), medium (42%), and high (26%) values denotes a fairly even range of human impacts over the study area (but more intense in the northern sites).

GIS offers numerous analytical and data visualisation options. Various combinations of schemes could be used to construct different classifications. An interesting alternate coding and interpretation of human activity is to assign to each site the maximum observed value of any of its human activities (mangrove cuttings, human litter, or bark stripping). Figure 10 shows a different pattern than Figure 9.

In the Figure 10 alternative classification, all high damage sites from Figure 9 remain except 6, which has no single high observation (interesting given its proximity to the residential area and maximum impact site 5). Three sites have been "upgraded" to high (1, 3, 19) and sites 10, 14, and 16 increased from low to medium. The southern sites are all medium or higher, indicating a stronger presence of humans than previously inferred (which is logical considering the proximity of settlement areas). This classification indicates a substantial level of human activity throughout the study area. Further explorations undoubtedly will reveal additional insights.

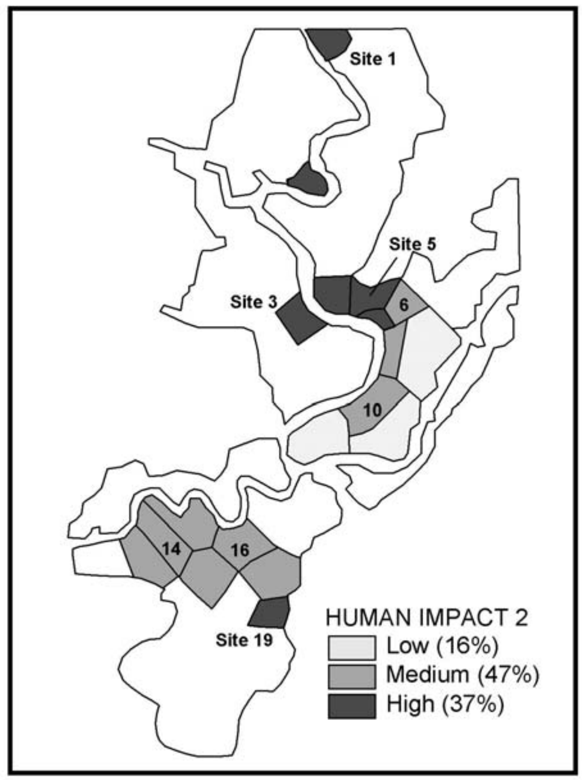

Figure 10. Human impact 2 map. Classes based on maximum value of Mangrove Cuttings, Human Littering, or Bark Stripping.

4 DISCUSSION

Not surprising, the study sites near the most populated residential area are the most endangered. They are impacted by human activities such as bark stripping, cutting, and environmental damage. There is no apparent relationship between the magnitude of impact and botanical factors, e.g., percentage of *Bruguiera* species, tree size, or community density. Therefore, location and access seem to be the central dynamics in assessing the basis for environmental harm. However, at least one site registers high human impact but does not seem to be readily accessible (site 2), suggesting that either direct access is not interpreted by the available data or that other aspects of the area, either cultural or physical, may be important. Further investigation will be interesting and useful.

Location also may be a primary component for most of the sites with lesser but significant damage, although there are exceptions. As noted, no obvious relationships exist between these sites and vegetation characteristics. The low impact sites seem to those with the least apparent easy access by humans.

Because GIS offers a variety of analytical options, two versions of deriving human impact classifications were tested, with some differentiation in results and interpretation. While the basic observations are largely consistent between the two classification versions, eight sites (47%) changed categories between the two maps. The changes, however, are only one level difference in the classification, suggesting that the distinction is due to subtle statistical variations and not necessarily results of compelling environmental contrasts. GIS is able to provide varying perspectives to data and discrepancies are the consequences of diverse analytical techniques.

In this project, two basic objectives were planned: development of a GIS methodology for investigation of the human impact on mangrove communities and preliminary insight to mangrove dynamics of the Suva peninsula. These topics are summarized here.

Remote sensing is an excellent data acquisition tool for macro scale communities and conditions that are visible from above, but for practical resource management analysis applications, it cannot provide the necessary detailed ground data of dense mangrove forests. This project applied a GIS approach to gathering and analysing data throughout a Suva, Fiji test area, first by adopting a standard *in-situ* sampling technique (point-centered quarter method) that collected both natural and cultural component, followed by various GIS techniques to analyse and present the data.

The GIS approach worked satisfactorily. Field data were collected, entered into a spreadsheet, and then transferred to a GIS database, where analysis and mapping of features were performed. GIS provided the important spatial function to the data, showing distributions and patterns (or lack of patterns) over the study site. Integrative analysis, such as overlays of different types of observations, considered spatial relationships between mapped features, e.g., mangrove destruction and surrounding land use. Results revealed some causality of human activity damage and proximity to residential areas, but also pointed to study sites where that relationship is not apparently strong. GIS provided additional questions to investigate.

Because of spatial inconsistencies and the availability of data that were not included in this report, further GIS work may help to explain the human-environment relationships better. GIS offers many options for analysis and presentation in addition to the basic procedures demonstrated in this project, e.g., advanced analytical techniques that combine diverse data. Incorporation of remote sensing analysis (airphotos or satellite imagery), for example, may identify environmental and cultural factors that are not part of the field observations. In fact, a strong asset of GIS is the integration of various formats of data that have varying spatial coverage, i.e., not limited to specific study sites but cover the surrounding or entire study area, such as population densities and socio-economic income levels, species mapping, tidal and salinity measurements, and other useful information.

In many parts of the world mangroves are under stress from human pressures, particularly near expanding urban areas. Although they are essential ecological communities, mangroves contain useful resources for human use and consequently, they are undergoing destruction and reduction. The mangroves of the Suva peninsula may be disappearing at a relatively rapid rate. Developing land uses around the area and human activities within the mangroves are responsible agents for the loss.

5 CONCLUSION

Overall, GIS proved useful in this project, demonstrating value in compiling, analysing, interpreting, and presenting natural and social data, both as single units and as integrated information. As a pilot project, the approaches tested showed the need for more comprehensive data collection and more GIS analysis. Thorough and effective mangrove community management requires depth and breadth of understanding, which can be provided only by detailed *in-situ* data collection, supported by remote sensing, and using a broad range of GIS analytical options. The next steps should include experimentation of a wider array of ground and GIS approaches, such as time series data for the study area, sophisticated remote sensing techniques, and additional presentation options. GIS technology offers powerful opportunities for management techniques in many environmental applications.

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