

ATOLL RESEARCH BULLETIN

NO. 464

**SOIL-PLANT RELATIONSHIPS AND A REVISED VEGETATION
CLASSIFICATION OF TURNEFFE ATOLL, BELIZE**

BY

**MALCOLM R. MURRAY, SIMON A. ZISMAN AND
CHRISTOPHER D. MINTY**

**ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
AUGUST 1999**

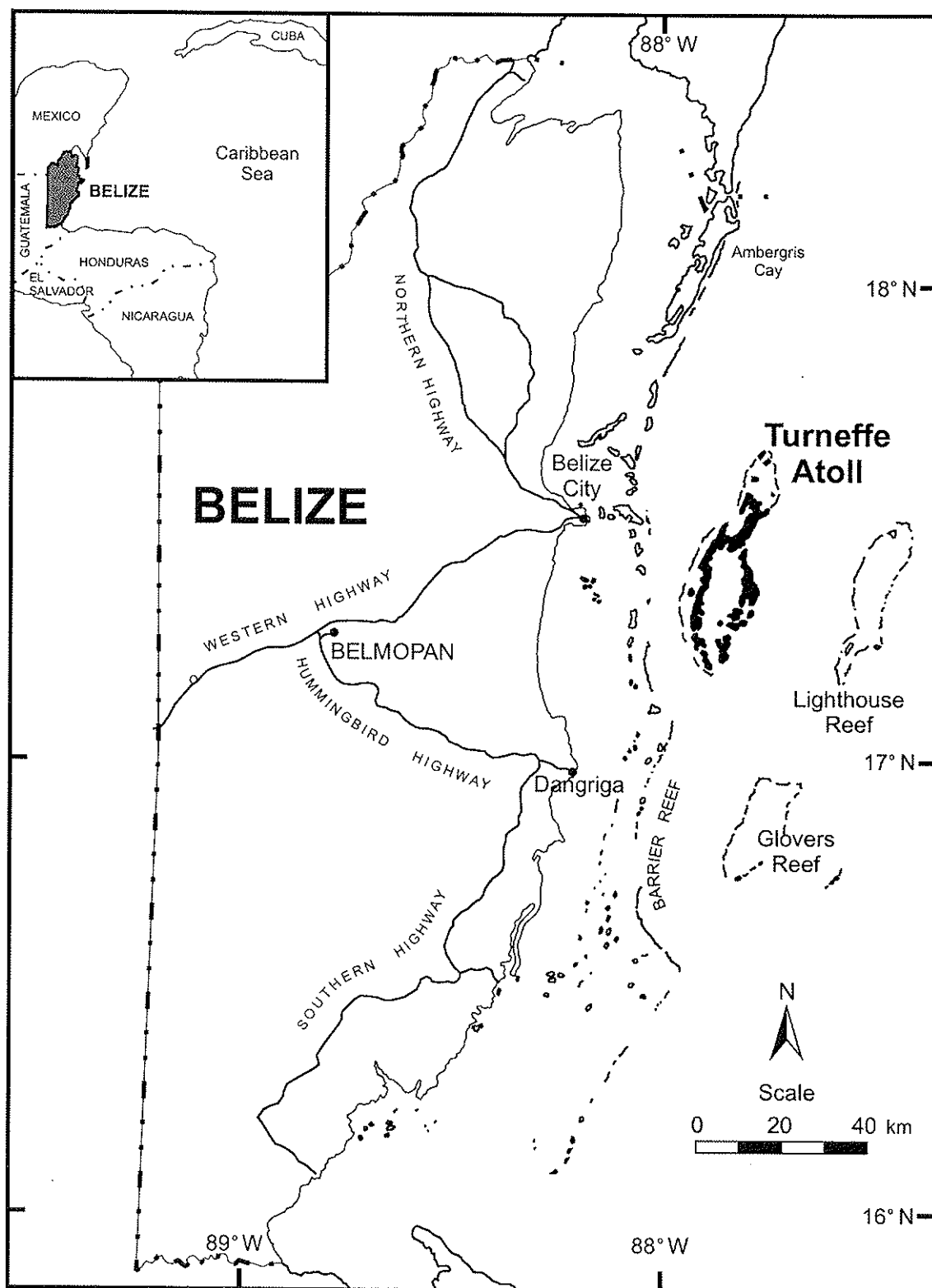


Figure 1 Location map: Turneffe Atoll, Belize

Based on maps in Murray (1995)

Showing the location of the study site - Turneffe Atoll, a series of small islands approximately 30 kilometres east of mainland Belize, Central America.

SOIL-PLANT RELATIONSHIPS AND A REVISED VEGETATION CLASSIFICATION OF TURNEFFE ATOLL, BELIZE

BY

Malcolm R. Murray¹,

Simon A. Zisman¹

and

Christopher D. Minty¹

ABSTRACT

This paper presents the findings of an investigation into the land cover and soils of Turneffe Atoll, Belize. Ten vegetation associations and four soil types are identified along with the evolving impact of human activities on the atoll. This information is timely given the increasing threat to this area from new tourist development. An enhanced understanding of Turneffe's environment enables coastal zone managers to better identify conservation priorities and to actively guide the development taking place.

INTRODUCTION

Turneffe Atoll lies 18 kilometres beyond the edge of the main Belizean Barrier Reef, which is itself 13 kilometres from the Atlantic coast of mainland Belize, Central America. The least well known of Belize's three atolls, neither its soils nor its vegetation have been studied in depth. Consequently it remains the most extensive but least studied atoll in the Caribbean.

The Turneffe complex is 50 kilometres long and reaches a maximum width of 16 kilometres (Figure 1). It comprises roughly 450 islands, locally known as cays. They range from large complex land masses (the largest island covers 4,493 ha) to small coral rubble cays under 0.02 ha. The islands encircle two large inner lagoons, both of which are generally limited to depths of less than 4 m. Channels (creeks and boggles) link the lagoons to the sea. These are broad on the windward eastern side of the atoll and narrow on the west. In total, the land area of Turneffe amounts to 10,831 ha. Added to this, some 400 ponds and lagoons within the islands occupy a further 252 ha.

¹ Department of Geography, The University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, Scotland, UK

Geologically, Turneffe lies on the second of five tilted fault-blocks that form sub-parallel, SSW trending submarine ridges. The faults are down-thrown towards the basin – dropping to the east (James and Ginsberg, 1979). The innermost ridge runs from Ambergris Cay in the north, down to the complex of cays off Belize City (St George's Cay, Drowned Cays, etc.). The second ridge includes Chinchorro Bank (NE of Belize), Turneffe Atoll and the barrier reef islands off Dangriga (e.g. Tobacco Reef). The third ridge includes Glover's Atoll and Lighthouse Reef. Thus, although on a map Turneffe appears very exposed to the east, it is actually shielded by three submarine ridges. The closest of these is the ridge forming Glover's Atoll and Lighthouse Reef. The main surface circulation pattern shows water from the Atlantic flowing towards the west. Average surface flow velocities are thought to be in the range of 50-100 cm s⁻¹ (James and Ginsburg, 1979). The mean wave direction can be summarised as a series of crests perpendicular to 074.5°N (Rutzler and Macintyre, 1982). This means that Lighthouse Reef will act to shelter the southern half of Turneffe, locally reducing wave velocities and favouring deposition.

Many of the cays which form the Belizean Barrier Reef have been studied in detail (e.g. Woodroffe, 1995; Stoddart *et al.* 1982). Such works tend to focus on the more accessible cays of the inner reef, rather than the islands of the outer zone - Lighthouse Reef, Glover's Atoll and Turneffe. The only previous examination of Turneffe as a whole was undertaken during the national resource assessment by Wright *et al.* (1959). Soils, vegetation and land use were recorded but the results were relatively cursory, given the agricultural emphasis of their work (Wright pers. comm. 1996). Furthermore, the resulting plant communities derived and shown on their 1:250,000 *National Vegetation Map* are somewhat misleading (Zisman, 1992).

More detailed assessment of Turneffe's terrestrial characteristics has been restricted to studies of the smaller cays of its eastern shore (Stoddart 1962, 1963). As a result, the soils and vegetation found on the larger islands have not been comprehensively surveyed.

Over the period 1988-1993, Belize experienced rapid economic growth, a significant part of which was due to the increase in coastal tourism (World Bank 1996). As a result, Turneffe Atoll has come under close scrutiny from tourism and real estate developers seeking to establish resorts (Zisman 1998). In response, Belize's embryonic coastal zone management institution has sought new information on the atoll's natural resources. This need is reflected by the establishment of University College Belize's Marine Research Centre at Calabash Cay in 1996/7 and the extensive underwater survey activities of Coral Cay Conservation Ltd. To assist in terrestrial resource evaluation, the authors were invited to carry out a rapid reconnaissance survey of the Turneffe Atoll.

METHODOLOGY

A combination of methods were used to investigate Turneffe's evolving land use, recent land cover and soil characteristics. Government archives yielded a range of secondary data that were used to reconstruct Turneffe's land use history. Satellite imagery, air photos and over-flights were deployed for land cover mapping and to locate a comprehensive range of survey sites. Field work was completed in April 1995, during the dry season, allowing examination of soils and vegetation.

For a basemap, a preliminary outline of the cays was derived by tracing the islands from black and white 1:40,000 scale (1993) stereo aerial photographs and digitising this on to a GIS (Arc/INFO). The resulting map was geo-referenced using a network of 12 ground co-ordinates obtained using differential GPS. Fieldwork and scrutiny of 1990 air photos (also 1:40,000) allowed this outline to be refined. Land cover boundaries were mapped from these air photos onto acetate and then digitised for integration with the basemap. A false colour composite image of Landsat TM bands 3, 4, and 5 (scene 19/48, captured 4/1/1987) was produced to assist with air photo interpretation. This revealed differences in land cover poorly differentiated on the black and white air photos. The composite was also used to stratify the placement of sample points. This ensured that examples of all the vegetation communities were visited, and a broad geographical spread of points was obtained, reflecting the different geomorphological environments across the atoll.

In total, 55 sets of observations were made at the 40 sample points selected (shown in Figure 2). At each point, field measurements were taken of interstitial soil-water pH, conductivity, sulphide and sulphate levels. The sample sites were also coded according to observed drainage and the energy level of the geomorphic setting. As well as providing information essential to the understanding of soil-plant relations, this information allowed soils to be classified according to the national framework for Belize, produced by Baillie *et al.* (1993). Structural characteristics of the different vegetation types were also recorded. The dominant plant species at each site were identified using the inventories of Fosberg *et al.* (1982) and comparison with specimens from the Forest Department and the Royal Botanic Garden, Edinburgh.

Upon return to the UK, the provisional soil and vegetation community classifications were tested using dendrograms and clustering methods. Soil samples were grouped together using the Gower Similarity Index, Vegetation communities using Jaccard's Index. Maps showing the resulting land cover classes were produced using Arc/INFO.

LAND USE HISTORY

Turneffe has a long history of settlement, dating back at least 1100 years. In order to understand present land cover, it is therefore necessary to identify the legacy of previous inhabitants on the atoll's vegetation and physical features. This is the purpose of the following summary, drawn from secondary sources and field observations.

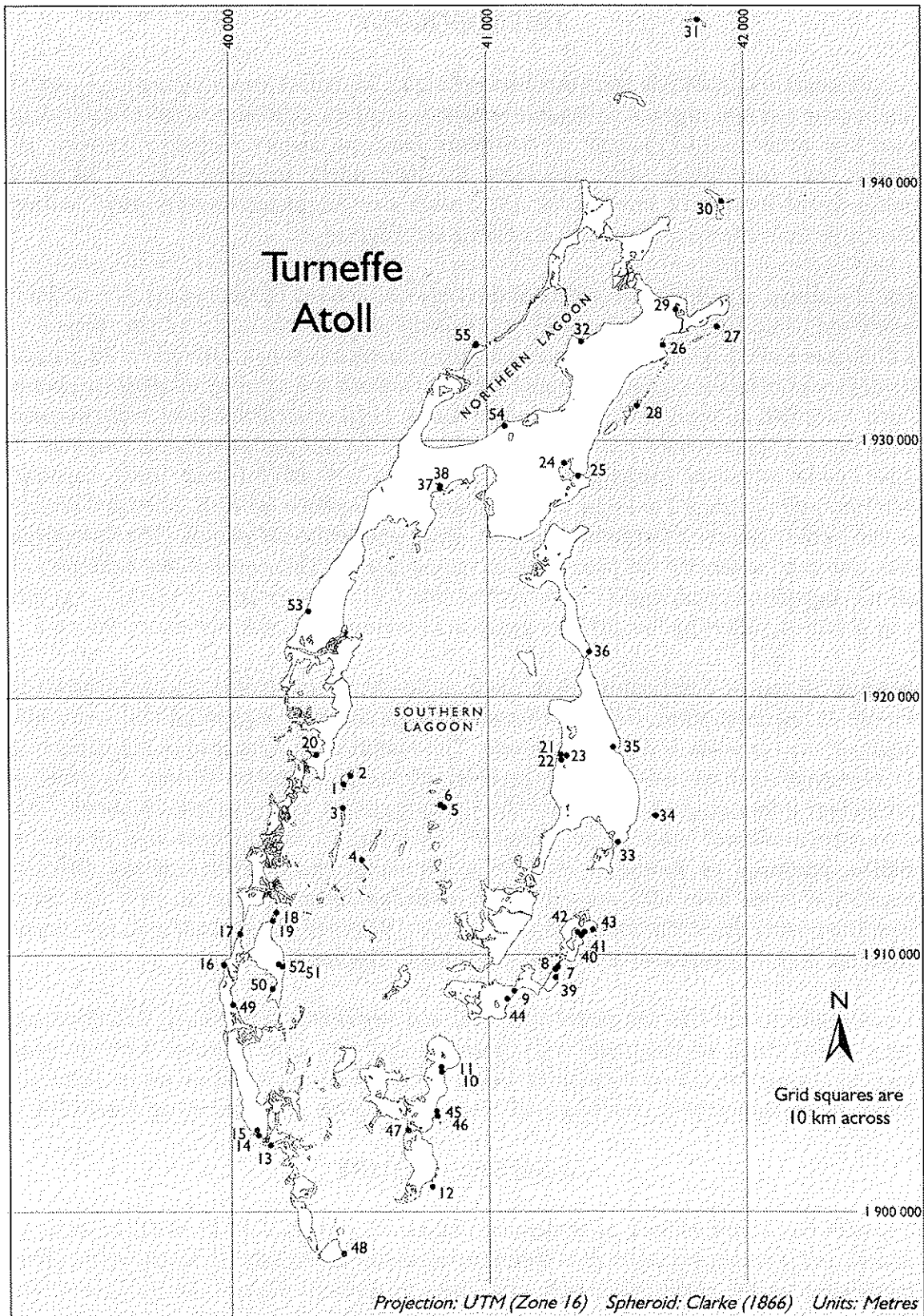


Figure 2 Location of the sampling sites

As mentioned by Wright *et al.* (1959) and MacKie (1963), pottery fragments on several of Turneffe's cays indicate the presence of Maya Indians in the past (dating from the Late Classic to early Post-Classic). From their abundance, Wright *et al.* speculate that, as well as fishing camps, the Maya may well have established "more or less permanent trading posts with a permanent population engaged in a certain amount of subsistence farming" (p. 256). The likelihood of the prolonged existence of these trading and fishing settlements is made more probable by recent findings of such settlements on other cays in Belize (McKillop and Healey 1989). Lasting impacts on Turneffe's vegetation, soils and land cover are difficult to assess, but clearly, well-defined shell-heaps raised the level of many small areas and enabled colonisation by non-mangrove species. There is no evidence from remote sensing imagery or field work that the shoreline of any areas were artificially altered to create salt evaporation ponds, which have been found elsewhere in Belize.

Colonial contact from the 1600s onwards led to the decimation and complete withdrawal of the coastal Maya from Turneffe. No evidence has been identified that precisely dates this event but the atoll was already charted, and therefore presumably visited, by the Spanish in 1625. The Mayan demise enabled regeneration of the atoll's vegetation as Colonial settlers were far less numerous and their encampments were generally transitory, particularly up to the late 18th century when fighting and attrition between British and Spanish forces ceased.

As evidenced by the considerable detail of the West India Pilot of 1771, by this time, the British knew the area well and were frequent visitors (Stoddart 1962). Physical evidence from the era is lacking, but it is likely that camps were established on higher land for ship repairs and harvesting tortoise shell (Wright *et al.* 1959). Areas of fertile higher land were partially cleared for small farm plots, and from this time, fruit trees, goats and pigs were introduced to the islands (*Ibid.*). It is most likely that prime sites on the atoll were used, and that the initial alterations to these made by the Maya were compounded by early colonialists. The extent of settlements was still, however, relatively limited by the small number of people present. It is likely, therefore, that Turneffe's vegetation remained relatively intact.

Towards the end of the nineteenth century, two new activities became established on Turneffe, reflecting the general growth of the Colony's economy. Between the late 1880s and early 1920s, the sponge industry flourished on the atoll, based on the "farming" of sponges in the southern inner lagoon (particularly *Hippospongia gossypina*, the "velvet sponge" - see Stevely and Sweat, 1994). Disease sealed the fate of this livelihood, however, wiping out the industry in 1919. Despite attempts to restock the lagoon in the 1920s and 1930s (Stoddart 1962; Smith 1941), sponge farming failed and left no significant impacts on the land cover².

² A 1938 map of the licensed sponge growing areas at Turneffe is held in the Public Record Office, Kew, London, UK.

In contrast to the sponge industry, the second activity established on Turneffe during the 19th century resulted in far more extensive impacts on the land cover than any other activity to date. This was the establishment of commercial coconut (*Cocos nucifera*) plantations. As noted by Stoddart (1962, 1963), coconuts were already present in 1720 on Lighthouse Reef, a second atoll 30 km further east. It is almost certain, given its proximity and the direction of currents, that they were present on Turneffe from this time as well. It was not until the latter part of the century, however, that commercial plantations (cocals) were widely established, producing whole nuts for export to the US. At its peak in 1914, national production averaged 6 millions nuts a year (Goodban 1952), almost entirely from coastal plantations. Large areas of beach thicket and coastal forest were therefore cleared, mainly on land leased from the government specifically for this purpose.

From the export data available, the industry first became important around 1870, and thereafter plantations were progressively extended until 1920, by which time nearly all the suitable coastal and cay areas had been planted (Anon. 1920). During this time, Turneffe became one of the main producing areas, with extensive plantations on both its eastern and western sides.

From the late 1930s onwards, despite increasing prices, national production went into decline, from an average for the decade of 4.4 million nuts to 2.7 million over the 1940s. Nonetheless, Goodban (1952) estimated that up to that year, "Turneffe, still had 1,000 acres (405 ha) under coconuts".

The tall varieties grown and the location of the plantations meant that they were extremely vulnerable to wind damage. Following the devastation caused by Hurricane Hattie in 1961 (Stoddart 1962), little interest was shown in rehabilitating the industry (Jenkin *et al.* 1976). Fieldwork carried out for this work shows that since then, although the plantations have generally fallen into a state of neglect, the groves of self-seeding coconuts persist, albeit now mixed with other plants. Land cover mapping does, however, reveal that cocals now occupy only a tenth of the area that they did in 1952, a reduction almost entirely attributable to the impact of Hurricane Hattie.

The last of the longer-established land uses on Turneffe are fishing camps built by the crayfish (locally known as lobster) fishermen. These small sites are strategically placed for access to water, higher land and clear views over fishing grounds (to prevent theft of lobster pots) (Zisman 1998). Fishing of this nature began to attract significant numbers of seasonal settlers from the 1930s, when commercial exports to the US began. As Wright *et al.* (1959) describe, this attracted a few more families to seasonal residence on the cays. They also found that "many of these families have small cassava, yam and sweet potato plantations and the soils of the old Maya fishing sites are made use of almost without exception" (p. 256). This also led to the introduction of a small range of decorative plants. Notably however, the spread of the most problematic of these, *Casuarina equisetifolia* (known locally as 'Christmas tree') has not been extensive. To

date, it is limited to less than a dozen trees, mainly on the leeward side of the atoll. This is in contrast to other cays and other parts of the Caribbean coast, including Florida, where this pine has become a major ecological pest because of its low value for native wildlife and its tendency to out-compete certain native vegetation (Meadows, 1986).

Turneffe's fishermen are the only group responsible for on-going exploitation of native flora, albeit restricted to just four species. The palmetto *Thrinax radiata* and *Acoelorrhaphe wrightii* are harvested to make lobster traps³. Exploitation is extremely widespread and extraction was evident at almost all of the 40 sites visited. It results in thinning of the more accessible stands but as both species regrow rapidly, the vegetation composition is not being radically altered. The two other plant species being harvested are both mangroves. *Rhizophora mangle* and *Laguncularia racemosa* are cut for poles used to mark the location of lobster pots and for various minor construction purposes around fishing camps. Dead red mangrove is also used for cooking when butane gas is not available. This type of exploitation is less widespread, again restricted to the most accessible stands near to fishing camps.

The most recent development on Turneffe is the rapid expansion of tourism. Up to the early 1990s, two small sports fishing establishments were the only resorts on the atoll. In operation since the 1970s, these facilities had relatively minor impact, occupying limited areas of mangrove (1.6 ha) and beach thicket (2.9 ha) most of which had been converted to coral already.

However, the rapid expansion of tourism towards the late 1980s put a premium on picturesque coast with white sandy beaches and access to good dive sites. As well as meeting these criteria, Turneffe also had the benefit of comprising mostly national land, cheap for developers to lease and disposable by Ministers as a form of political patronage. Following the change of government in 1989, tourism on Turneffe escalated, with the leasing of large areas to politically favoured developers (Zisman 1998). Specifically, 455 ha were awarded on Blackbird Cay in 1990, covering the largest area of high land on the windward side of the atoll. A further 56 ha was leased to a second developer on Calabash Cay. This rapid escalation not only caused concern amongst conservationists but also to the atoll's fishermen, who saw tourism as a threat to their livelihoods from its potential damage habitats and water quality (*Ibid.*).

Given these increasing pressures, it has become important to (1) identify the habitats on the atoll, and (2) understand the processes that govern their composition and sensitivity to environmental change. The findings of this research are now presented in response to these requirements. The first sections detail the vegetation associations identified in the field. By combining these with Stoddart's (1962) classes, a comprehensive classification of all the atoll's plant communities has been assembled for the first time.

³ *Acoelorrhaphe wrightii* is now the accepted name for this species. *Paurotis wrightii* is an earlier synonym used by Stoddart (1962, 1963), and Wright *et al.* (1959).

In the next section, the composition of Turneffe's land cover is quantified (as of 1990), including the remaining extent of its natural plant communities. The third component of the research results is the soil analysis. Finally, consideration is given to the inter-relationships between vegetation, soil and land use, in particular, to the characteristics with immediate implications for proposed tourism development.

IDENTIFYING THE VEGETATION TYPES FOUND ON TURNEFFE ATOLL

As already stated, Stoddart (1962, 1963) produced an early vegetation classification for Turneffe. However, it was based on fieldwork almost entirely restricted to the atoll's small eastern cays. Examination of the vegetation of the atoll's larger islands was limited. The author therefore stresses the preliminary nature of the vegetation classes derived. For the present work, it was considered most appropriate therefore, to concentrate on surveying the larger islands, then to re-examine Stoddart's classification and hence to produce a combined vegetation classification encompassing all of Turneffe's vegetation types. A secondary consideration was that the classification should also be applicable to Belize's other atolls, Lighthouse and Glover's Reef.

Field classification of the vegetation communities

Six vegetation types have been identified during the reconnaissance survey: (i) mangrove, (ii) beach thicket, (iii) broken palmetto thicket, (iv) broken palmetto-buttonwood thicket, (v) palmetto buttonwood scrub and (vi) cay forest. The term 'broken' refers to the local description of vegetation with an uneven, discontinuous canopy. It has been widely employed in previous descriptions of Belizean vegetation (e.g. Wright *et al.* 1959; Jenkin *et al.* 1976; King *et al.* 1992).

Of the six vegetation types, mangroves are by far the most intensively studied. A national survey of Belize's mangroves was carried out in 1991 (Furley and Ratter, 1992). Building on this work, a classification of Belizean mangrove sub-communities has been developed (Zisman 1998) based on differences in physiographic setting, species and vegetation structure. As the objective here is to establish only *broad* vegetation groupings, such a detailed breakdown is considered unnecessary. Thus, in this work the different mangrove communities are combined into a single category (although they are mapped in three separate height classes - tall, medium and dwarf).

Mangroves

The mangrove association varies widely, in composition and structure. At the level of highest structural development, it forms tall monospecific stands of black, white or red mangrove (up to approximately 18 m tall). Intermediate forms comprise mixed or pure red thickets, whilst the least structurally developed communities are the stunted black mangrove scrub and dwarf red mangrove. Overall differences in salinity, seasonal

salinity fluctuations, inundation regime (depth, duration and frequency) and nutrient inputs (particularly phosphorus and nitrogen availability) are responsible for this variation (Murray, 1995; McKee, 1993). The mangrove association is most common leeward of Turneffe's main sand ridge, but mangroves also grow on the windward side, particularly where extensive reef flats reduce the wave energy nearshore. Fringing mangrove occur on the lee of the windward coral rubble cays, such as the Deadman Range. Mangroves also dominate the cays within the central lagoons. Mangroves are recorded growing on peat soils, sands and coral rubble.

Beach thicket

The beach thicket association is located on windward sand and coral rubble ridges. Such locations are relatively well drained, due to the underlying sandy or coral rubble soils. The structure of the beach thicket community is heavily influenced by exposure to the prevailing winds, in many cases this leads to a marked stunting.

Broken palmetto thicket

Broken palmetto thicket is found at a wide range of locations around Turneffe, both coastal and inland, both leeward and windward. It is a broad association, covering thickets of varying densities. The palm *Acoelorrhaphe wrightii* (known locally as "palmetto") forms a significant component of the vegetation. *Myrica cerifera*, ("teabox") is the other main species. The relative abundance of palmetto in this association is variable but insufficient to justify further division given the reconnaissance nature of this study. Suffice it to note that at four sites (numbers 25, 32, 51 and 52) a mangrove/broken palmetto thicket transition is found. This transition is a mix of mangrove species (*R. mangle*, *A. germinans* and the fern *Acrostichum aureum*) with terrestrial trees and shrubs from the broken palmetto thicket association. A second variant also exists which includes abundant *Metopium brownei* ('black poisonwood'). It is thought that this indicates a transition to cay forest. Broken palmetto thicket occurs on drained peat and organic sand.

Broken palmetto-buttonwood thicket

The broken palmetto-buttonwood thicket association was isolated from the other thicket because of the predominance of *Conocarpus erectus* ('buttonwood'), a mangrove associate (Tomlinson, 1986). In some areas buttonwood is found almost to the exclusion of palmetto. The association ranges in form from a dense thicket to a scrubby savanna, where "cutting grass" (*Scleria spp.*) occurs between clumps of *C. erectus* and shrubs such as *Myrica cerifera*. Broken palmetto-buttonwood thicket grows on drained peat, and evidence of burning suggests it may be a fire affected plagio-climax. Although likely to exist in smaller patches amidst the broken palmetto thicket, only one extensive area of this community has been identified and mapped, on the western side of the atoll.

Palmetto-buttonwood scrub

This community is also recorded from one major area only, also on the west of the atoll. Again, finer scale mapping and further investigation is likely to reveal areas of this

scrub associated with broken palmetto-buttonwood and broken palmetto thicket. Several sites presently supporting scrub show signs of recent burning (e.g. numbers 37, 38 and 53). It is thought that regular burning may be important in maintaining the characteristic open canopy of this class. It is this open canopy which differentiates it from broken palmetto-buttonwood thicket. Palmetto-buttonwood scrub favours sites with drained peat soil.

Cay forest

Cay forest is the climax association of the higher cays, where saline influence upon the groundwater is minimal or absent. It is restricted to sand ridge areas and organic sands. Structurally, it is the most developed vegetation association, forming fully developed closed canopy forests. Wright *et al.* (1959) record this type of vegetation on the higher more stable cays, suggesting that "at one time, mahogany and sapodilla forest were established on parts of Soldier, Calabash and Ropewalk Cays of the Turneffe archipelago" (p. 254). The present survey identifies only small isolated patches of this community, all of which have been altered to some degree, due to earlier farming. Of the four cay forest areas remaining in 1990, the largest is 13.7 ha on Blackbird Cay, part of the 455 ha parcel slated for tourist development.

A comprehensive classification for Turneffe's vegetation communities

By combining the vegetation associations described above with those of Stoddart (1962), it is possible to provide a preliminary categorisation of all the vegetation types found on Turneffe. Some changes to his original nomenclature are necessary, however, to maintain consistency and for the sake of clarity. Stoddart's *sand-area thicket* is renamed beach thicket and the *broadleaf forest*, cay forest. His other non-mangrove classes are retained. As already explained, his mangrove categories have been superseded and a single mangrove class is used here.

Table 1 and Table 2 summarise the characteristics of the resulting vegetation associations, giving information on structure and dominant species.

Turneffe's vegetation has therefore to be sub-divided into ten basic associations. Some overlap is likely between beach thicket and marginal and interior thicket, but at the reconnaissance level the divisions are relatively satisfactory. The only other vegetation community identified were single species 'meadows' of *Batis maritima* but these were too few in number and too small (generally less than 0.01 ha) to warrant separate delineation.

Testing this vegetation classification

In order to test the vegetation classes developed in the field, nearest neighbour cluster analysis was applied to the sample site data upon return to the UK. This numerical

technique arranges the sample sites in a dendrogram so that sites with a similar suite of plant species plot close together. Following the algorithm protocol given by Dunn and Everitt (1982), similarity is assessed using Jaccard's Index (Jaccard, 1912). This simple similarity coefficient is designed for use with binary (presence/absence) data. The resulting dendrogram is shown below in Figure 3.

The grouping in the dendrogram accords well with the classes developed in the field. Five groups can be identified in the dendrogram, using the first branches at the left hand side of the figure, corresponding to a similarity index of zero (i.e. maximum difference). Examining the species present at each site in an individual branch reveals the "indicator species" used in the classification. From top to bottom, these groups are defined by the presence of: (i) *Rhizophora mangle* or *Avicennia germinans*, (ii) *Metopium brownei* and *Thrinax radiata*, (iii) *Laguncularia racemosa*, (iv) *Cocos nucifera*, and finally (v) *Acoelorrhaphe wrightii* and *Scleria sp.*

The first group, defined by the presence of *R. mangle* and/or *A. germinans*, corresponds well with the mangrove vegetation class developed in the field. The second group, based around *M. brownei* and *T. radiata* comprises sites from cay forest and the poisonwood variant of broken palmetto thicket. The fact that these two field classes are combined in the Jaccard classification supports the idea that this poisonwood variant of the broken palmetto thicket is indeed a precursor to the development of cay forest vegetation. The third group, defined by the presence of *L. racemosa* contains all the sites classified in the field as beach thicket. In addition, it contains the mangrove site 36 (included in this group because, unusually, it contains a cover composed completely of white mangrove) and three other sites classified in the field as a possible transition. This transition class contains species representative of both the mangrove and beach thicket classes and it is suggested that this group marks the inland limit of sites at which mangroves can compete effectively with other species. The fourth group is defined by the presence of coccol (*C. nucifera*) and therefore consists of sites which have undergone the greatest human alteration. These range from small cultivated patches of fruit trees and palms to areas where the natural vegetation cover has been completely replaced by coconut plantations. The final group of sites on the dendrogram are linked by the presence of *A. wrightii* and *S. bracteata*. This category encompasses both the broken palmetto thicket and palmetto-buttonwood scrub classes devised in the field. This pairing supports the interpretation that palmetto-buttonwood scrub is a degraded form of the broken palmetto thicket. Both show a similar range of species, but the scrub has a lower density of trees and shrubs.

The fact that the first branching separates mangroves from the other vegetation associations is likely to be due to the low range of species present at the sites covered by mangroves. The Jaccard index is known to be sensitive to species richness (van Tongeren, 1995). In general, however, the field and numerical classifications show a high degree of commonality. This suggests that they correspond with actual vegetation associations found at Turneffe. Furthermore, the placing of the less common field

Table 1 Plant associations identified by the reconnaissance survey.

Vegetation association	Vegetation structure	Main species	Stoddart's equivalent classes
Mangrove	Height: wide ranging. Includes single species and mixed mangrove stands, from 0.6m high scrub to 18m high forest with variants between. Canopy: complete to sparse. Understorey: generally absent. Shrub layer: generally absent. Herb layer: present where canopy is open or moderately open, with scarce to abundant mangrove seedlings. Ground cover: leaf litter, algal mats and/or standing water.	Canopy: <i>Rhizophora mangle</i> , <i>Avicennia germinans</i> , <i>Laguncularia racemosa</i> . Occasional <i>Conocarpus erectus</i> at transition to higher ground. Understory, Shrub & Herb layers: Occasional young of above, plus <i>Batis maritima</i> .	Predominantly <i>Rhizophora</i> on mangrove cays. Mangrove transition zone on mangrove-sand cays. <i>Rhizophora</i> on mangrove-sand cays.
Beach thicket	Height: approx. 2-7m depending on degree of exposure and stunting. Canopy: continuous to slightly broken. Understorey: generally absent. Shrub layer: generally absent. Herb layer: occasional woody herbs, plus grasses and xeromorphic species Ground cover: leaf litter or bare sand/coral rubble.	Canopy: <i>Coccoloba uvifera</i> , <i>Cordia sebestena</i> , <i>Bursera simaruba</i> , <i>Cocos nucifera</i> , <i>Conocarpus erectus</i> , <i>Suriana maritima</i> , <i>Thrinax radiata</i> and occasional mangroves. Understory & Shrub layer: <i>Erithalis fruticosa</i> , <i>Pithecellobium keyense</i> , <i>Chrysobalanus icaco</i> , <i>Tournefortia gnaphalodes</i> . Herb layer: <i>Hymenocallis littoralis</i> , <i>Sesuvium portulacastrum</i> , <i>Wedelia</i> , <i>Stachytaphra</i> , <i>Andropogon</i> , <i>Cyperus</i> and <i>Eragrostis</i> spp.	Sand-area thicket on mangrove-sand cays.
Cay forest	Height: approx. 7-15m. Canopy: continuous. Understorey: present. Shrub layer: generally present. Herb layer: sparse or absent. Ground cover: leaf litter.	Canopy: <i>Bursera simaruba</i> , <i>Metopium brownei</i> , <i>Cordia sebestena</i> , <i>Thrinax radiata</i> , <i>Ponteria campechiana</i> , <i>Bumelia retusa</i> , occasional <i>Coccoloba uvifera</i> . Understorey: <i>Ficus</i> spp. plus young individuals of above. Shrub layer: <i>Pithecellobium keyense</i> . Herb layer: No data.	Broadleaf forest on sand cays.
Broken palmetto thicket	Height: approx. 3-8m. Canopy: rarely continuous, generally slightly to moderately discontinuous. Understorey: generally absent. Shrub layer: present. Herb layer: sparse. Ground cover: leaf litter.	Canopy: <i>Acoelorrhaphe wrightii</i> , <i>Metopium brownei</i> , <i>Conocarpus erectus</i> . Understory & Shrub layer: <i>Myrica cerifera</i> . Herb layer: <i>Scleria bracteata</i> .	No equivalent as not covered by Stoddart.
Broken palmetto-buttonwood thicket	Height: approx. 3-7m. Canopy: rarely continuous, generally slightly to very discontinuous. Understorey: generally absent. Shrub layer: present. Herb layer: continuous to sparse. Ground cover: bare ground, algal mats or leaf litter.	Canopy: <i>Acoelorrhaphe wrightii</i> , <i>Conocarpus erectus</i> , with occasional <i>Metopium brownei</i> . Understory & Shrub layer: <i>Myrica cerifera</i> . Herb layer: <i>Scleria bracteata</i> .	No equivalent as not covered by Stoddart.
Palmetto-buttonwood scrub	Height: approx. 0.3-2m. Canopy: moderately to extremely discontinuous Understorey: absent Shrub layer: present Herb layer: continuous to sparse. Ground cover: leaf litter.	Canopy: <i>Acoelorrhaphe wrightii</i> , <i>Conocarpus erectus</i> , Understory & Shrub layer: <i>Myrica cerifera</i> . Herb layer: <i>Scleria bracteata</i> .	No equivalent as not covered by Stoddart.

Common names of these species are given in King *et al.* (1992) and Wright *et al.* (1959).

Table 2 Additional plant associations described by Stoddart, 1962.

Vegetation association	Typical setting	Vegetation structure	Main species
Strand	Sand and mangrove-sand cays.	Height: up to approx. 0.3m. Canopy, Understorey & Shrub layer: not applicable. Herb layer: sparse to continuous. Ground cover: bare sand.	Herb layer: Outer zone – <i>Sesuvium portulacastrum</i> , <i>Ipomea pes-caprae</i> . Inner zone – <i>Sporobolus virginicus</i> , <i>Euphorbia</i> spp., <i>Canavalia rosea</i> .
Other interior areas - chiefly grass	Sand cays.	Height: no data. Canopy, Understorey & Shrub layer: not applicable. Herb layer: continuous to sparse. Ground cover: bare ground, algal mat or sand.	Herb layer: grasses
Interior marsh and swamp ‡.	Sand cays.	Height: no data. Canopy, Understorey & Shrub layer: generally removed. Herb layer: present. Ground cover: algal mat and/or standing water.	Canopy: originally likely to be <i>Avicennia germinans</i> , <i>Laguncularia racemosa</i> , <i>Rhizophora mangle</i> , <i>Conocarpus erectus</i> . Herb layer: <i>Wedelia trilobata</i> .
Cocal ‡	Cocal on sand cays.	Height: approx. 7-15m. Canopy: continuous to moderately discontinuous. Understorey: generally absent. Shrub layer: generally absent. Herb layer: present especially under moderately discontinuous canopies. Ground cover: bare ground and/or litter of palm fronds.	Canopy: <i>Cocos nucifera</i> . Herb layer: <i>Stachytarpheta jamaicensis</i> , <i>Ambrosia hispida</i> , <i>Cakile lanceolata</i> , <i>Wedelia trilobata</i> .

Source: Stoddart (1962) except for the vegetation structure data (this work). Common names of these species are given in King *et al.* (1992) and Wright *et al.* (1959).

‡ Indicates that these vegetation associations are anthropomorphic. The interior marsh and swamp is created by clearance of basin mangrove *sensu* Lugo and Snedaker, (1974), the cocal by clearance of cay forest, beach thicket and occasionally small areas of mangrove.

derived classes (e.g. the poisonwood variant of the broken palmetto thicket) with other related groups (e.g. cay forest) corroborates the hypothesised pattern of vegetation succession. Thus, this analysis supports the validity of the field vegetation classification.

Quantifying land cover on Turneffe Atoll

The distribution of land cover across the atoll is shown in Figure 4 and quantified in Table 3. The map, produced using Arc/INFO GIS, is derived from interpretation of 1:40,000 black and white air photos (dating from February 1990 and March 1993). Reference was also made to 1987 Landsat TM imagery and ground survey at the points shown above.

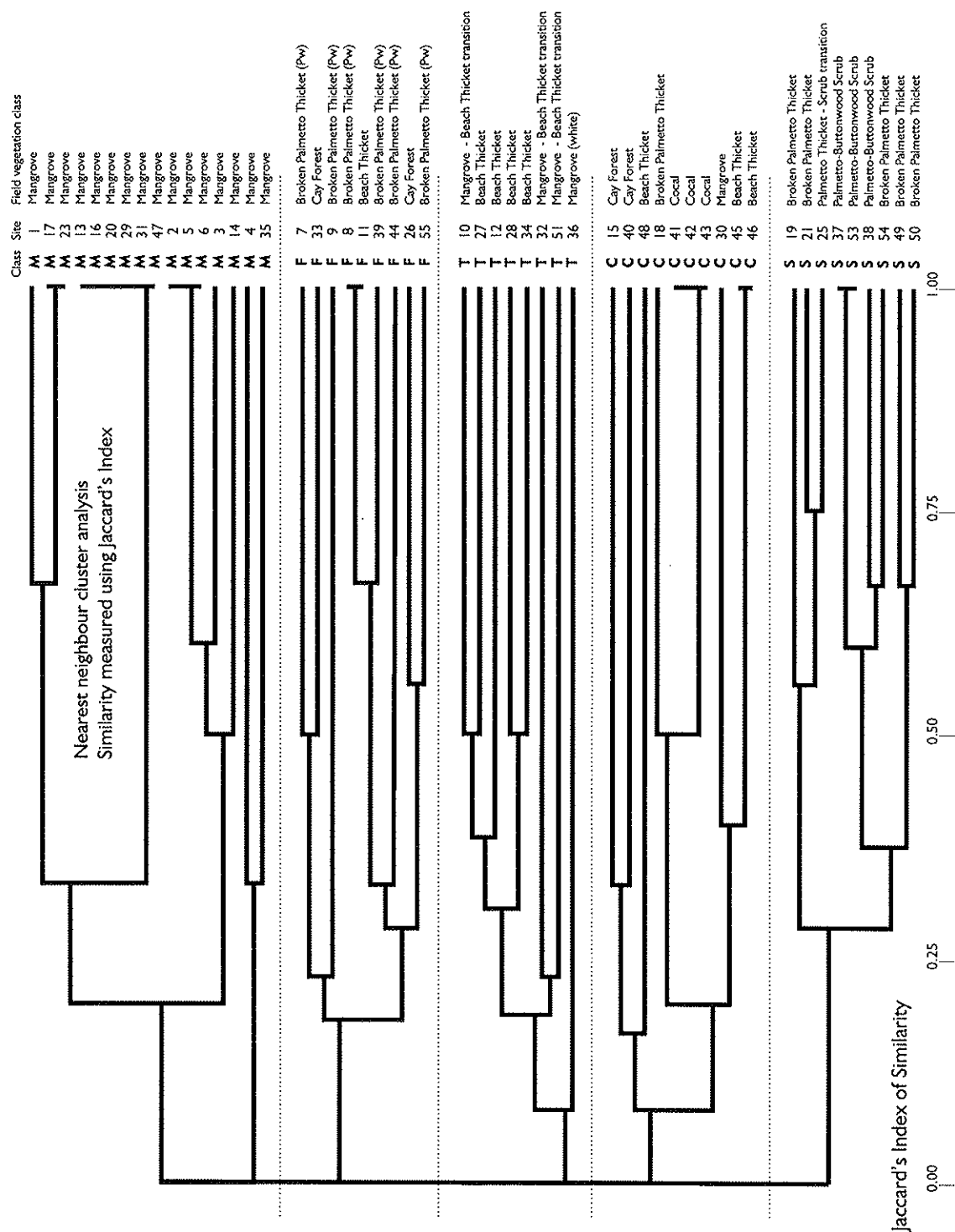


Figure 3 Classification of sampling sites by vegetation cover

This figure shows the sample sites (numbers) arranged along the right hand side of a dendrogram. They have been arranged numerically to produce classes with similar vegetation characteristics. A five group classification (labelled M, F, T, C and S) is emphasised using dotted lines. This corresponds closely with the groupings developed in the field.

The results show that 98.4 % of Turneffe is under natural (or near-natural) vegetation, with human activities responsible for the alteration of the remainder (176.5 ha). This is a considerably smaller area than earlier this century following the demise of coconut plantations, from the 405 ha in 1952 to 105 ha in 1990. The most significant finding in relation to contemporary changes in land use however, is the recent increase in tourism development.

Mapping reveals relatively large areas of broken palmetto thicket and beach thicket degraded for tourist resorts. Over 48.1 ha was affected in this way, all between mid-1989 and March 1990. Evidently, tourism is already having substantially increased impacts on Turneffe's land cover.

Mapping also reveals the limited extent of cay forest. Confined to 24.5 ha in 1990, it has been reduced by 46% from its original extent. This is of concern because it contains the highest biodiversity amongst any of the vegetation communities identified on the atoll.

The information presented to date comprise Turneffe's land use history, vegetation composition and land cover. The final component studied during fieldwork was its soils. Examination of this facet helps to understand land cover patterns, it also is useful for determining certain environmental implications of recent land use. The next section of this paper therefore reports on the investigations of soil properties at the 40 study sites.

ANALYSIS OF SOIL CHARACTERISTICS











Field examination of soil samples taken around Turneffe Atoll allows the development of a preliminary classification. This divides the soils into four groups based largely on differences in their organic content and drainage. This field classification accords well with the results of later testing using numerical agglomerative classification methods. These four field soil groups are then labelled according to the existing soil nomenclature employed in Belize, that of Baillie *et al.* (1993).

Table 3 Nature and Extent of Land Cover on Turneffe Atoll, March 1990

Type of Natural Land Cover Remaining	Extent ha	Anthropomorphic (modified) Land Cover	Extent ha
Mangrove	7419.3	Cleared mangrove	1.0
		Degraded mangrove	0.4
		Fishing camp in mangrove	10.1
		Cocal in mangrove	3.6
		Tourist area in mangrove	1.6
		Marina/boat access in mangrove	0.6
		Total Mangrove Altered	17.3
Beach Thicket	138.3	Cleared beach thicket	0.7
		Degraded beach thicket	16.3
		Cocal in beach thicket	77.3
		Tourist area in beach thicket	4.5
		Fishing camp in beach thicket	1.3
		Total Beach Thicket Altered	100.6
Broken Palmetto Thicket	2303.1	Fishing camp in broken palmetto Thicket	1.7
		Total broken palmetto thicket Altered	1.7
Broken Palmetto Thicket poison wood variant)	28.8	Degraded broken palmetto thicket poison wood variant)	31.8
		Cocal in broken palmetto thicket	4.1
		Total broken palmetto thicket poison wood variant) altered	35.9
Broken Palmetto- Buttonwood Thicket	602.3	None altered	0.0
Palmetto-Buttonwood Scrub	314.4	None altered	0.0
Cay Forest	24.5	Degraded cay forest	0.7
		Cocal in cay forest	20.3
		Total cay forest altered	21.0

Figure 4 1990 Land Cover for Turneffe Atoll

Key:

-  Mangrove
-  Cay Forest
-  Beach Thicket
-  Broken Palmetto Thicket
-  Broken Palmetto-Buttonwood Thicket
-  Broken Palmetto Thicket (Poisonwood variant)
-  Palmetto Buttonwood Scrub
-  Coconut Plantations
-  Other modified land cover
-  Degraded and cleared vegetation

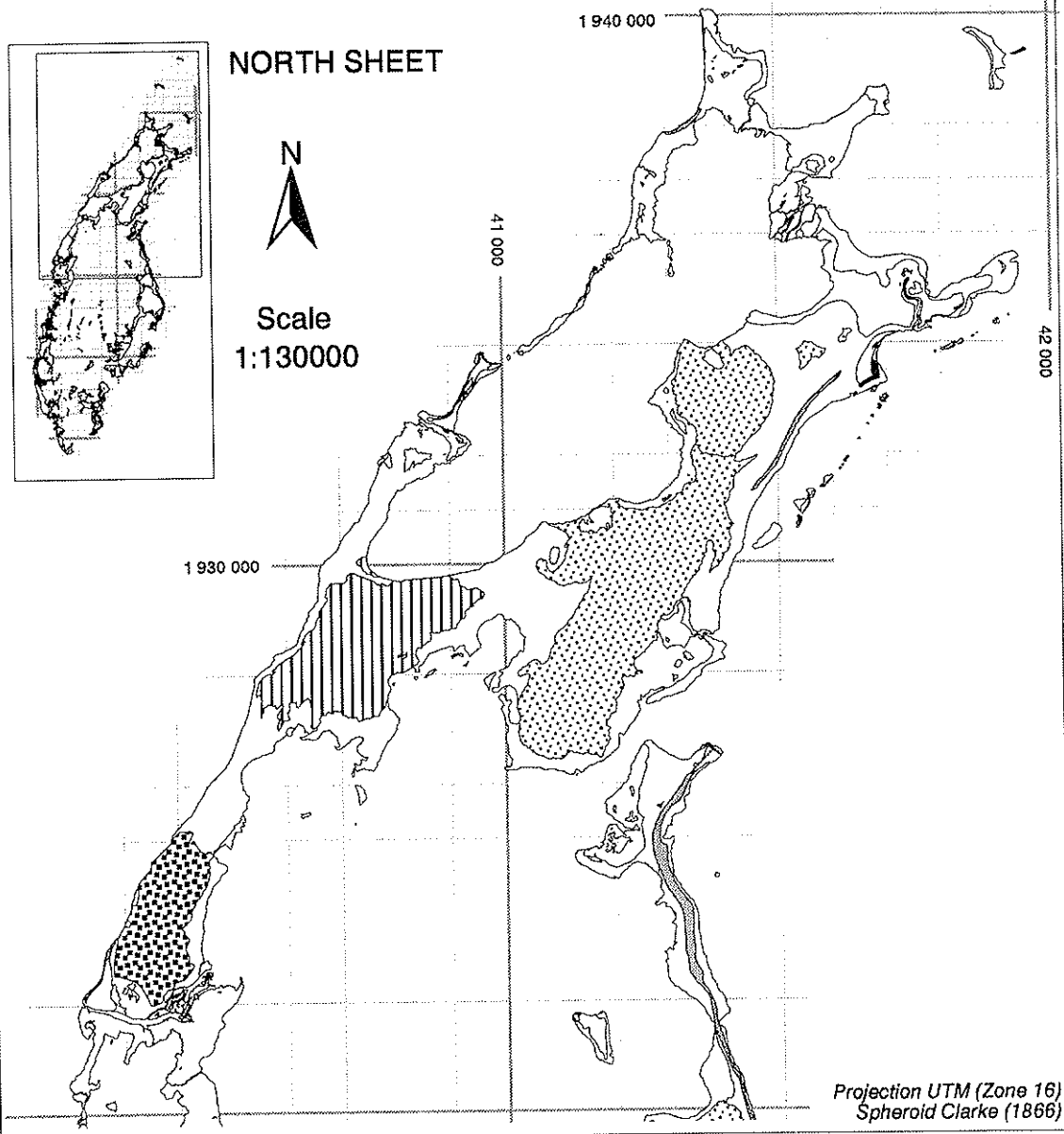
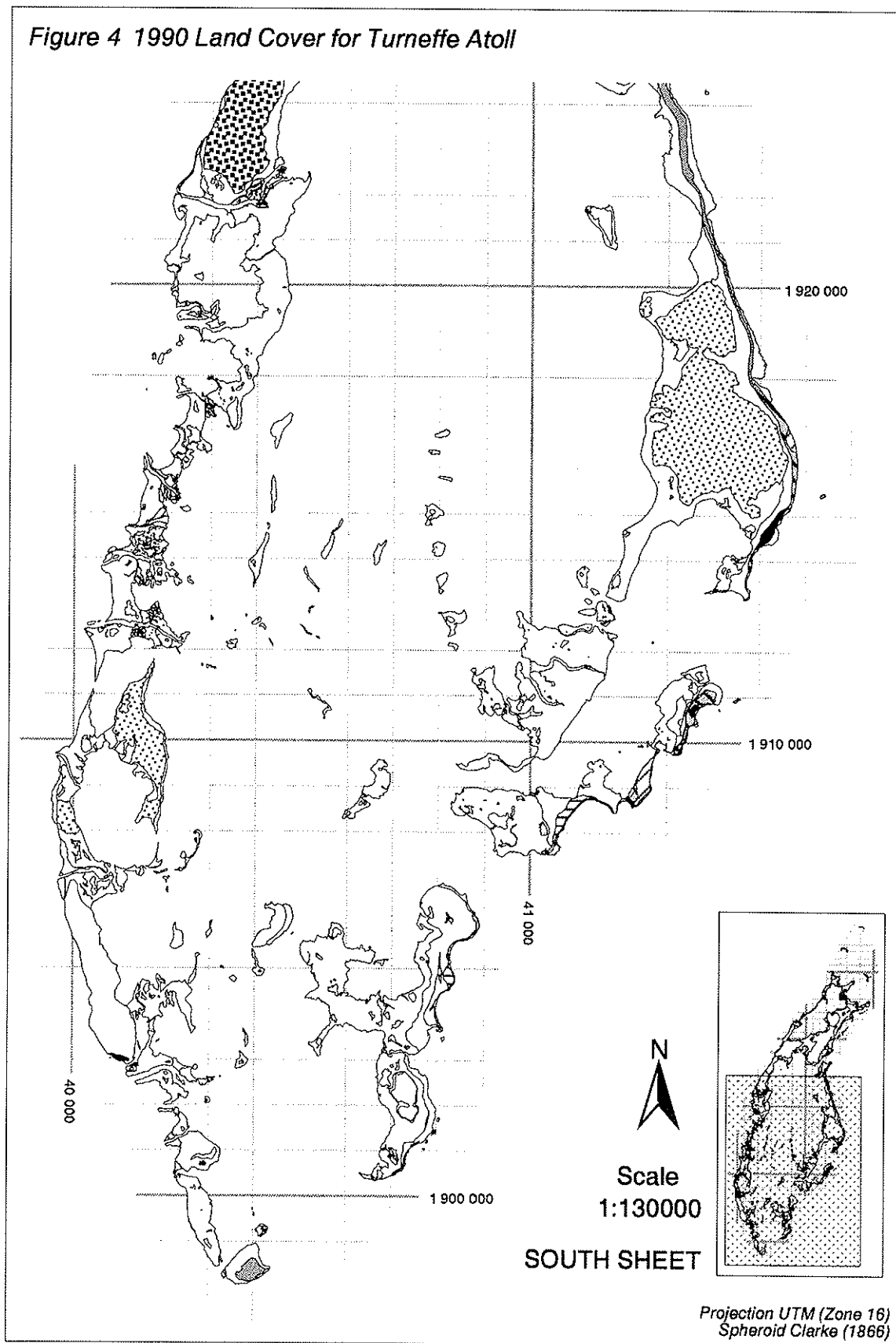


Figure 4 1990 Land Cover for Turneffe Atoll



Classification of soils in the field

A four-group soil classification was developed in the field, namely: (i) waterlogged saline peat, (ii) drained peat, (iii) organic sand, and (iv) coral sand. Waterlogged saline peats are deep, permanently wet organic soils. They are found across the full range of low to high energy environments around Turneffe, on both the leeward and windward sides of the islands.

Drained peats are seasonally dry, highly organic soils. They are found in low to medium energy environments on both the leeward and windward sides of the islands and along the shores of lagoons.

Organic sands are well drained, moderately organic soils. They are found in all geomorphic settings around the atoll, but are most common on moderate and high energy, windward coastal settings.

Coral sands are well drained carbonate-derived mineral soils, with clasts which vary in size from sand to cobble fractions. They are found almost exclusively in high energy, windward environments.

The soils of Turneffe can effectively be split into two groups – the mineral sands and the organics. The mineral sands are derived from *in situ* weathering of terrestrial material such as “beach rock” together with wave and wind deposition of sand and coral rubble from offshore sources. The organic rich waterlogged saline peat has accumulated in areas supporting mangrove forest. In common with other coastal areas in Belize, it is composed largely of decomposing vegetative material from *Rhizophora mangle* plants.

The origin of the drained peat is more problematic. To the naked eye it appears very similar to the mangrove peat, albeit slightly finer. Because of its present elevated position, decomposition of the drained peat is dominated by aerobic rather than anaerobic pathways and it too supports soil macrofauna. These will both act to reduce the average particle size. It is thought that the drained peat is indeed derived from mangrove areas. This requires a mechanism of uplift to explain its present elevation. The most likely candidate is storm wave and/or hurricane transportation. The banks of the creeks and boggles around Turneffe are composed of peat. Many of these are aligned east-west, i.e. along the track of previous hurricanes. The peat is highly fibrous and it is thought likely that blocks torn off would retain their shape rather than fall apart. Light and able to float, these peat “rafts” could be transported considerable distances. Further palaeo-ecologic investigation (such as pollen and diatom identification) are, however, needed to fully resolve the origin of this soil.

Selected soil-water properties characteristic of the four identified soil groups are given in Appendix 1, and summarised in Table 4.

Table 4 Summary of the field soil class properties.

<i>Field Soil classification</i>	<i>Vegetation association</i>	<i>Geomorphic setting</i>	<i>Drainage</i>	<i>Salinity</i>	<i>pH</i>
<i>Waterlogged saline peat</i>	Mangrove	All	very poor	high	neutral to acidic
<i>Drained peat</i>	Broken palmetto thicket, broken palmetto-buttonwood thicket	low to moderate	slightly impeded	moderate	neutral
<i>Organic sand</i>	Cay forest, coccol, beach thicket, broken palmetto thicket	All	good	low	slightly alkaline
	Mangrove	All	moderate to poor	high	slightly alkaline
<i>Coral sand</i>	Beach thicket	high energy	good	moderate	slightly alkaline
	Coccol	high energy	good	very low	slightly alkaline

Testing the soil classification

The use of numerical methods to test classifications developed in the field is becoming increasingly common in soil science, mirroring their use in the wider field of ecology. These use algorithms to mathematically "cluster" sample sites according to a numerical measure of similarity. This creates discrete groups of samples. One such measure considered applicable to studies of soils (Webster and Oliver, 1990) is the Gower Similarity Index (Gower, 1971). This measure was applied to the sample data using the program MVSP Plus (Kovach, 1993) and the resulting classification expressed pictorially as a dendrogram (Figure 5).

Gower's Index values were calculated for each sample site using both the measured soil parameters and scorings representing the drainage and the energy level of the site's geomorphic setting. The sites were arranged into groups using an unweighted pair clustering algorithm.

The dendrogram shows that the sites can be split into a number of groups, depending on the threshold value of the index used. At the extreme left of the figure, (index = 0.51) the sites can be allocated to one of two distinct soil groups; at the far right, (index = 1.00) 22 groups can be identified. The four-group classification developed in the field lies somewhere between these two extremes. Looking at the sample sites, it seems that the major factor separating the two largest (left-hand) groups is soil drainage. The upper 39 sites (later assigned to classes WP, Mix and OS) represent sites where for a large part of the year the water table is regularly very close to the soil surface. The lowest 10 samples are all typically well drained. As the number of classes increases, other differences are brought into play.

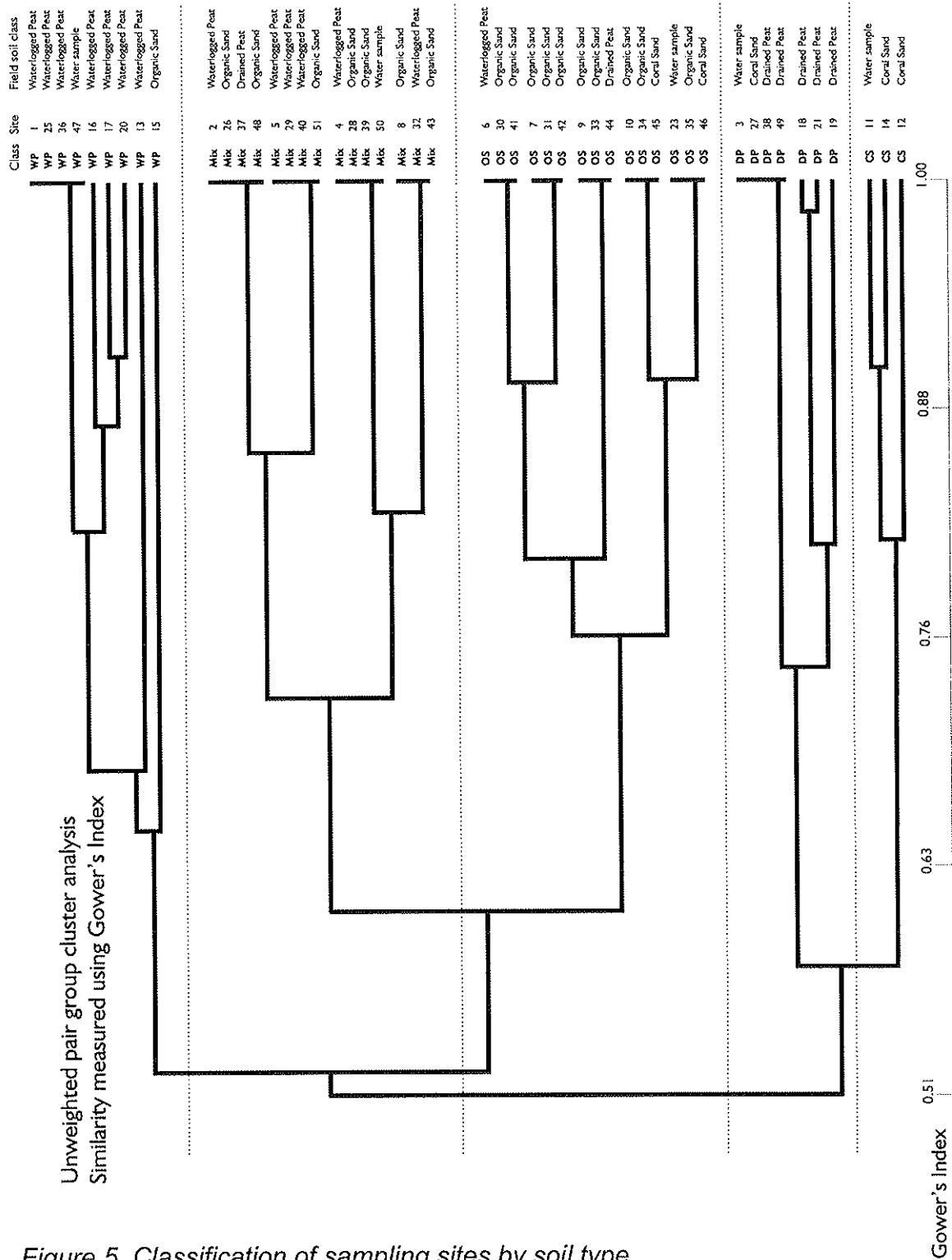


Figure 5 Classification of sampling sites by soil type

This figure shows the sample sites (numbered on the right) and their associated field soil descriptions (the nearby text) arranged in a dendrogram. The clustering of sites into groups has been achieved using a numerical classification routine. Five classes (labelled as WP, Mix, OS, DP and CS) can be distinguished. These classes are shown separated by dotted lines.

Moving to the right of the dendrogram, the number of possible classes increases. Figure 5 shows the dendrogram split into five classes (labelled WP, Mix, OS, DP and CS) at an index value of approximately 0.60. Four of these groups (WP, OS, DP and CS) appear well differentiated (for example, seven out of the nine sites in the WP class have waterlogged peat soils) and correspond closely to the classes identified in the field. The fifth group (shown as Mix on Figure 5) contains sites with soils of either waterlogged saline peat or organic sand.

This fifth numerical class appears to be an amalgam of the others, rather than a further, equally unique group. It is probably an outcome of the limited suite of soil measurements taken. If this was broadened (e.g. to include measurements of the macro-nutrient elements) this artificial grouping would be expected to disappear. Soil properties from sites in this fifth class are not thought to differ significantly either chemically, or in the processes forming and maintaining them. Therefore, the addition of a fifth class to the field groupings was rejected.

In any classificatory scheme there is likely to be some degree of overlap between the classes. The strong overall correlation between the field and numerical grouping of the sites supports the validity of the field classification. The four-group classification is therefore retained.

Existing classificatory schemes for the soils of Belize

Many schemes exist for classifying soils. The two international systems are 'Soil Taxonomy' (USDA, 1975; SMSS, 1990) and the FAO/UNESCO 'Legend of the Soil Map of the World' (FAO/UNESCO, 1974, 1988). The authors agree with Baillie *et al.* (1993) who have shown both these systems to have considerable drawbacks to applications in the humid tropics and Belize in particular. They criticise the low weighting given to parent material and the morphology of the entire profile in the 'Soil Taxonomy' system. Furthermore and significant to local use, Belizean farmers, forest workers and planners already use a system of nomenclature based on a 1959 survey by Wright *et al.* Many later local soil maps also employ this scheme. Any attempt to introduce the FAO or USDA schemes is therefore likely to increase confusion rather than clarity. The local terms are largely retained in the *Land Resource Assessment of Belize* produced by King *et al.* (1986, 1989, 1992) which provides a comprehensive mainland soil survey, mapping units at a scale of 1: 100,000. It is an example of the emergent Belizean three tier system of soil classification. This draws on the earlier system of Wright *et al.* (1959) and has since been consolidated and revised by Baillie *et al.* (1993). This, the local system, was chosen for use in this work.

In the Belizean system, the soils are divided into suites, sub-suites and series. Soil suites are defined predominantly by their parent material, although some developed on similar lithology may be further differentiated by climatic differences. Sub-suites are defined

using major morphological and chemical features, with an emphasis upon agronomic utility. Because of the reconnaissance nature of the work of King *et al.*, the soil classification was not extended to the series level. The study had an understandable mainland focus, meaning that few of the defined suites occur in the Turneffe area. However, one of the soil suites is relevant to the present work - the Turneffe Suite, first defined by Wright *et al.* (1959). A brief description of this soil suite, taken from King *et al.* (1992, p 72) is given below:

Turneffe Suite

The Turneffe Suite consists of well- and moderately drained soils formed on Pleistocene to recent coastal deposits, sometimes underlain by shallow coral, and which can be predominantly siliceous or calcareous.

Five sub-suites are distinguishable: Shipstern, Ambergris, Hopkins, Matamore and Barranco⁴. Full soil sub-suite descriptions are given in Baillie *et al.* (1993), but their key characteristics are summarised in Table 5 below.

Table 5 Characteristics of soils from the Turneffe Suite.

	Parent materials	Pedogenic environment	Soil characteristics	Agricultural potential
Shipstern	Raw shallow sandy and muddy sediments usually calcareous over recently emergent coral.	Coastal flats, near sea level, often covered by mangrove savanna.	Pale-coloured, some soils are saline	Limited. Shallow and droughty
Ambergris	Raw pale coarse soils in deep calcareous sands of modern or recent beaches.	Close to beaches.	Raw, coarse, pale sand, derived from coral and/or shells.	Moderate: cashew, pineapple and coconuts. Tourist potential
Hopkins	Raw pale coarse soils in deep quartzose sands of modern or recent beaches.	Close to beaches.	Raw, coarse, pale siliceous sands.	Limited: possibly cashew. Droughty and infertile. Tourist potential.
Matamore	Young and slightly developed pink or yellow sands on relict subrecent coastal deposits.	Inland, stranded fossil beach deposits.	Weathering leads to yellow and yellowish-red colouring, weakly developed fine texture, but still predominantly coarse.	Moderate, for chemically undemanding, deep, free-draining root-zone crops, e.g. cashew, coconuts and cassava.
Barranco	Moderately leached red and yellow loams and clays on old coastal deposits.	No data*	No data	No data

Parent material description are from Baillie *et al.* (1993, p43). Other descriptions are adapted from King *et al.* (1992 pp187-213).

* The Barranco sub-suite is not listed in King's 1992 report.

These sub-suites can be distinguished by differences in parent material and pedogenic

⁴ The Barranco sub-suite was added to the soil schema by Baillie *et al.* in 1993.

environment. Parent material differences divide the sub-suites in two. Soils with a high carbonate content (the Shipstern and Ambergris suites) have a marine source of minerals. Soils rich in silica such as the Hopkins, Matamore and Barranco sub-suites, are derived from terrestrial sediments. Therefore, the sub-suites found at Turneffe will be the carbonate dominated ones: Shipstern or Ambergris. Choosing between these sub-suites depends upon the pedogenic environment, primarily the depth of soil and the local depositional regime.

Placing the soil groups identified in the field into the Belizean classification

Relating the field identifications to the Belizean system, two of the field soil groups correspond closely with soils of the Turneffe Suite. The coral sand matches the Ambergris sub-suite and the organic sand is very similar to the Shipstern sub-suite, although the profiles found at Turneffe are generally deeper than those described by Baillie *et al.* (1993) and King *et al.* (1992). The high organic content of the waterlogged saline peat soil does not however, accord well with reported organic values across the Turneffe Suite. Instead, it is more typical of the Tintal suite (described by King *et al.* (1992, p 208).

Tintal Suite

Tintal Suite soils are poorly drained for all or a considerable part of the year. Soil formation is dominated by the gleying processes associated with wet and reducing conditions....

They occur in low-lying positions.

This classification is commonly applied to terrestrial environments in Belize: wet alluvium and hillslope-material derived soils. Yet the presence of peat, the high salinity and the continual waterlogged state of the waterlogged saline peat soils accords with a sub-suite of the Tintal suite - the Ycacos (described in Table 6).

Table 6 Characteristics of soils from the Ycacos sub-suite Tintal Suite)

	<i>Parent materials</i>	<i>Pedogenic environment</i>	<i>Soil characteristics</i>	<i>Agricultural potential</i>
<i>Ycacos</i>	Permanently waterlogged portion of mineral and organic material. Very young – parent material is still often accumulating.	Coastal and pericoastal swamps and small patches inland fed by saline or brackish springs.	Pedogenesis has hardly begun. Dominant chemical characteristic is its salinity; moderate to extremely high; Calcium and magnesium are the dominant exchangeable cations.	Negligible. Poor drainage, flood hazard and salinity.

The only soil which does not seem to fit well in any of the established classes is the drained peat. It is suggested that this could be considered as a new series of the Ycacos sub-suite, as a result of its subsequent drainage and salinity. These findings are summarised in Table 7 below.

Table 7 Summary of soil classes found at Turneffe Atoll

<i>Field Classification</i>	<i>Equivalent in the Belizean classification system</i>	
<i>Coral sand</i>	Turneffe suite	Ambergris sub-suite
<i>Organic sand</i>	Turneffe suite	Shipstern sub-suite
<i>Waterlogged saline peat</i>	Tintal suite	Ycacos sub-suite
<i>Drained peat</i>	Tintal suite	Possibly a new series in the Ycacos sub-suite

The identification of key environmental gradients

Ordination analysis (to be reported elsewhere) reveals two environmental gradients acting upon the vegetation. The first axis aligns sites along a well-drained-waterlogged soils gradient. The second differentiates between sheltered, low-energy, acid soils and exposed, high energy alkaline soil conditions. These gradients can be used to interpret the position of the clusters of sample sites which indicate vegetation communities.

DISCUSSION OF PLANT-SOIL RELATIONSHIPS

The controlling factor for mangroves is evidently the capacity to endure saline or brackish waterlogging, made possible by their characteristic morphological adaptations (pneumatophores and aerial roots). Sample sites covered by mangroves plot at positions near the centre of the second, acidity-alkalinity gradient. This is not to say that mangroves cannot tolerate either of the extreme conditions of acidity/alkalinity or high/low energy environments, for indeed mangroves are the plants with the widest physiological tolerance range of any found at Turneffe. Rather, it is precisely this wide tolerance to such conditions which means that this gradient does not act to constrain their colonisation activity.

Broken palmetto thicket and broken palmetto-buttonwood thicket are found in sheltered, low-energy areas with well-drained soils. Lack of morphological adaptations means that they cannot tolerate soils likely to experience extended periods of flooding or survive saline or brackish influence.

Well-drained conditions are also favoured by the beach thicket and cay forest communities, but their preference for soils derived from limestone places them at the alkaline end of the acid-alkali gradient. Beach thicket species are also adapted to extreme drought and low soil nutrient levels. This is not the case with cay forest species. The presence of sites covered by coral is not the result of physiological restraints, for they have a wide range of tolerances (Langdon, 1991). Rather it is the

result of human activity, clearing beach thicket and cay forest areas to create coconut plantations.

CONCLUSIONS

Vegetation distribution

The vegetation of Turneffe Atoll has been shown to be far more varied than the original "mostly mangrove" inferred from earlier maps such as that of Stoddart (1962) and Wright *et al.* (1959). Mangroves dominate low-lying areas, forming overwash islands or fringes along creeks, around lagoons and the coastline. In freely-drained windward areas cays are covered in beach thicket. In well-drained soils with a greater organic component, broken palmetto thicket, broken-palmetto buttonwood thicket or even cay forest occurs. In disturbed areas there are patches of cocal and palmetto buttonwood scrub.

With the exception of the cay forest (which dominates the higher sand ridges), the vegetation of Turneffe is characterised by a low structural complexity and the absence of "climax" species. This is typical of coastal forests across the Caribbean (Roth, 1992). This low complexity can be attributed to the lack of nutrients and impact of hurricanes. Signs of these (both sites which have suffered considerable erosion and others which have experienced subsequent re-deposition) can be found across Turneffe. Hurricanes tend to encourage plants with a cyclical pattern of development. Mangrove species are characteristic of these conditions. Features such as the large number of propagules produced, sharp zonation and even-aged stands reflect their adaptation to a rapid cycle of growth and mortality (Jiménez *et al.*, 1985). Yet as noted above, mangroves are not the only species present. The considerable vegetation diversity which exists across Turneffe Atoll today (only a few decades after the last major hurricane) demonstrates that through seed transportation mechanisms (air, water and bird vectors) the other plant species are also able to re-establish themselves.

Hydrology

With the absence of terrestrial freshwater drainage features, rainfall is the only freshwater input on the cays. Their surface is typically composed of loose, open sediments which favour high infiltration rates. Surface runoff is likely to be very rare, if it occurs at all it will be limited to extremely large precipitation events. Plants will therefore be dependent upon a mixture of direct interception of rainfall during the wet season and groundwater sources in the dry season to obtain the water necessary for their survival. Urish (1991) has shown that cay size has a considerable effect upon both the volume and seasonal availability of fresh water lenses. He found that on small cays (such as Carrie Bow Cay – 0.4 ha) the fresh water lens effectively disappeared during

the dry season, to be replaced with a shallow brackish water zone. He notes that the small tidal range typical of Belize reduces the tidal effects. Thus, at Turneffe, freshwater lenses are likely to exist even on the smaller cays, which in areas with a greater tidal amplitude, would quickly be dispersed. This freshwater availability will act to favour species diversity, supporting non-halophytic species. In particular, given their deeper roots and sensitivity to brackish conditions, freshwater lenses are extremely important for the development and survival of Turneffe's cay forest.

Soils

The soil chemistry and plant-soil relationships at Turneffe are broadly similar to those seen on other cays and calcareous-dominated mainland sites in Belize (e.g. Furley *et al.*, 1993; Murray, 1995). The key differences relate to variations in soil salinity, redox potential and organic content. All soils are likely to show limited amounts of available nitrogen and phosphorus.

Development

In the four hundred years after the Maya were dislocated from Turneffe, human impact on its land cover was minimal. The establishment of commercial coconut plantations in the 1890s changed this, producing the most extensive habitat alteration ever to take place. At least 450 ha were cleared, mostly beach thicket but also significant areas of cay forest. However, with the declining viability of coconut exports and the devastation caused by Hurricane Hattie in 1961, many coconut groves began returning to semi-natural vegetation. Nonetheless, 105 ha still remain, by far the most extensive artificial land cover on Turneffe. Between the 1960s and late 1980s, land use on Turneffe remained relatively stable, and as a consequence, further human impact was minimal. However, evidence of land clearing and land speculation signals the spread of tourism since then. This development is opening a new chapter in the evolving exploitation of the atoll and already land clearance has rapidly escalated.

This has caused considerable concern amongst the resident fishing community, who see risks to their livelihoods resulting from marine pollution and mangrove clearance. Conservationists are also concerned, since the atoll is a stronghold for the endangered Salt Water Crocodile (*Crocodylus acutus*), and may provide suitable sea turtle nesting habitat if disturbance is prevented. Furthermore, the recent discovery of the endemic gecko (*Phyllodactylus insularis*) on Belize's other atolls, makes it likely that it is also present on Turneffe. To date, these are the only localities from which it is recorded anywhere in the world.

The particular concern with tourism development is that it is concentrated along the coast and highest land (especially where freshwater wells can be sunk). Clearance for

the resorts themselves, for ancillary facilities (including a proposed airstrip) and for holiday homes makes it inevitable that mangroves and cay forest will be affected. Whilst the impact on the first is to some extent, mitigated by the prevalence of this habitat, it is not the case with cay forest. Now identified as the most floristically diverse habitat (and the environment likely to prove richest in archaeological interest), the remainder of this habitat needs protection and sensitive management. In addition, areas of beach thicket are being cleared. Far less damage to this habitat would result if existing beach front coconut plantations were used for tourism.

In relation to the soil characteristics identified, the risk of accelerated erosion following the clearance of fringing mangroves is already well known. It is also evidently the case however, that the atoll's dried organic soils are at risk from deflation and erosion if cleared of all vegetation.

Belize's embryonic coastal management bodies are trying to balance different stakeholder interests by promoting land use zoning for Turneffe (see McGill 1996). To date, they lack the legal framework or political backing to enforce the resulting plan, a fact explained by the links between resort developers and the ruling party (Zisman 1998). With a new government in place (September 1998), the sustainability of development on Turneffe is in the balance.

ACKNOWLEDGEMENTS

The first phase of this research was funded by the Darwin Initiative of the UK's Department of Environment and was carried out on contract to Coral Cay Conservation Ltd. (CCC). Their staff in London and Belize City offices provided logistical support and materials. Later work was supported by the Carnegie Trust for the Universities of Scotland. Whilst on Calabash, CCC volunteers helped in many small, but much appreciated ways. Thanks are especially due to Kevin Coye for guiding us around the islands and contributing to the data collection, Expedition Leader Jim Thomas and Science Officer Paul Scott. University College Belize provided office space and computing facilities at their campus in Belize City and offshore accommodation at the Marine Research Centre. The Belize Center for Environmental Studies and the Belize Audubon Society provided valuable access to their library resources. The Forest Department allowed us to use their herbarium. The Lands and Surveys Department granted access to their aerial photograph collection. David Stoddart and Ian Macintyre made helpful comments on an earlier draft of this manuscript. Sincere thanks are extended to the individuals and institutions concerned.

REFERENCES

- Anon. (1920) Colonial annual report. Colonial Office, London, UK.
- Baillie, I.C., Wright, A.C.S., Holder, M.A. and Fitzpatrick, E.A. (1993) Revised classification of the soils of Belize. NRI Bulletin 59. Natural Resources Institute Chatham, UK.
- Dunn, G. and Everitt, B.S. (1982) An introduction to mathematical taxonomy. Cambridge University Press, Cambridge, UK.
- Food and Agricultural Organisation of the United States/United Nations Educational, Scientific and Cultural Organisation - FAO/UNESCO (1974) Soil Map of the World. Vol. 1. Legend. Paris. UNESCO.
- Food and Agricultural Organisation of the United States/United Nations Educational, Scientific and Cultural Organisation - FAO/UNESCO (1988) Soil Map of the World. Revised Legend. Rome. FAO.
- Fosberg, F.D., Stoddart, D., Sachet, M.-H. and Spellman, D. (1982) Plants of the Belize cays. Atoll Res. Bull., No. 258.
- Furley, P.A., Minty, C.D., Murray, M.R. and Ross, S.M. (1993) Soil and sediment characteristics within coastal and inland mangrove communities. p. 34-78 *In* Furley, P.A. and Munro, D.J. eds. The wetlands of Belize: ecology, environment and utilisation. Department of Geography, The University of Edinburgh, Edinburgh, UK. ISBN 0 900475 22 6.
- Furley, P.A. and Ratter, J.A. eds. (1992) Mangrove distribution, vulnerability and management in Central America. ODA/OFI Forestry Research Programme Contract No R4736. Department of Geography, The University of Edinburgh, Edinburgh, UK.
- Goodban, J. W. D. (1952) A report on the coconut industry of British Honduras. Director of Agriculture, Belize.
- Gower, J.C. (1971) A general coefficient of similarity and some of its properties. *Biometrics*, v. 30, p. 643-654.
- Jaccard, P. (1912) The distribution of the flora of the alpine zone. *New Phytologist* v11 pp 37-50.
- James, N.P. and Ginsberg, R.N. (1979) The seaward margin of Belize barrier and atoll reefs. The International Association of Sedimentologists, Special Publication No. 3. 191p.

Jenkin, R.N., Rose Innes, R., Dunsmore, J.R., Walker, S.H., Birchall, C.J. and Briggs, J.S. (1976) The agricultural development potential of the Belize Valley Land Resources Division, Tolworth, UK.

Jiménez, J.A., Lugo, A.E. and Cintron, G. (1985) Tree mortality in mangrove forests. *Biotropica*, v. 17 p.177-185.

King, R.B., Baillie, I.C., Abell, T.M.B., Dunsmore, J.R., Gray, D.A., Pratt, J.H., Versey, H.R., Wright, A.C.S. and Zisman, S.A. (1992) Land resource assessment of northern Belize. Natural Resources Institute Bulletin 43, 2 volumes.

Kovach, W.I. (1993) MVSP Plus - A multivariate statistical package for IBM-PCs, ver 2.1. Kovach Computing Services, Pentraeth, Wales, UK.

Langdon, J.R. (1991) The Booker Tropical Soil Manual. Longman Scientific and Technical. New York.

Land Information Centre/Coral Cay Conservation - LIC/CCC (1995) Geometrically corrected map of Turneffe Atoll. Land Information Centre, Lands and Surveys Department, Ministry of Natural Resources, Belmopan, Belize.

MacKie, E. (1963) Some Maya pottery from Grand Bogue Point, Turneffe Islands, British Honduras. Cited In D. Stoddart Effects of Hurricane Hattie on the British Honduras Reefs and Cays, October 30-31, 1961. Atoll Res. Bull., No. 95, p. 131-135.

McGill, J. (1996) Draft Comprehensive development plan for Turneffe Atoll. UNDP/GEF Coastal Zone Management Project and the Fisheries Department. Belize City, Belize.

McKee, K.L. (1993) Soil physiochemical patterns and mangrove species distribution - reciprocal effects? *Journal of Ecology*, v. 81, p. 477-487.

McKillop H. and P. Healey (1989) Coastal Maya trade, Trent University Occasional Papers in Anthropology 8, Peterborough, Canada.

Meadows, M. (1986) *Casuarinas* 'pine trees' in Belize. Belize Audubon Society Newsletter, v. 182., p. 3. Belize City, Belize.

Murray, M.R. (1995) The environmental effects of mangrove clearance in Belize, Central America Unpublished Ph.D. thesis. Department of Geography, The University of Edinburgh.

Roth, L.C. (1992) Hurricanes and mangrove regeneration: effects of Hurricane Joan, October 1988, on the vegetation of Isla del Venado, Bluefields, Nicaragua. *Biotropica*,

v. 243, p. 375-384.

Rutzler, K. and Macintyre, I.G. (1982) eds. The Atlantic barrier reef ecosystem at Carrie Bow Cay, Belize: I Structure and communities. Smithsonian Contributions to the Marine Sciences v. 12, 539p. Washington D.C., USA.

Soil Management Support Services - SMSS (1990) Keys to soil taxonomy. Blacksburg, Virginia. Virginia Polytechnic Institute and State University.

Stevely, J.M. and Sweat, D.E. (1994) A preliminary examination of the commercial sponge resources of Belize with reference to the location of the Turneffe Islands sponge farm. Atoll Res. Bull. No. 424, 21pp.

Stoddart, D.R. (1962) Three Caribbean atolls: Turneffe Islands, Lighthouse reef, and Glover's reef, British Honduras. Atoll Res. Bull., No. 87, 151p.

Stoddart, D.R. (1963) Effects of Hurricane Hattie on the British Honduras Reefs and Cays, October 30-31, 1961. Atoll Res. Bull., No. 95, 142pp.

Stoddart, D.R., Fosberg, F.R. and Spellman, D.L. (1982) Cays of the Belize Barrier Reef and Lagoon. Atoll Res. Bull., No. 256, 76pp.

Tomlinson, P.B. (1986) The Botany of Mangroves. Cambridge University Press, New York, USA.

United States Department of Agriculture - USDA (1975) Soil Taxonomy. Soil Conservation Service, Washington D.C. USA.

Urish, D.W. (1991) Hydrogeology of Caribbean coral reef islands. pp136-148 in Cambers, G. (editor) Coastlines of the Caribbean. American Society of Civil Engineers, New York, USA. 187 pp.

van Tongeren, O.F.R. (1995) Cluster analysis. p. 174-212 In Jongman, R.H.G., ter Braak, C.J.F. and van Tongeren, O.F.R. Data analysis in community and landscape ecology. Second edition. Cambridge University Press, New York, USA.

Webster, R. and Oliver, M. (1990) Statistical method in soil and land resource survey. Oxford University Press, Oxford, UK.

Woodroffe, C.D. (1995) Mangrove vegetation of Tobacco Range and nearby mangrove ranges, Central Belize Barrier Reef. Atoll Res. Bull. No. 427, 35pp.

World Bank (1996) Belize Environmental Report. Report No. 15543-BEL. Caribbean Division, Country Department III, Latin America and Caribbean Region. Washington

D.C.

Wright, A.C.S., Romney, D.H., Arbuckle, R.H. and Vial, V.E. (1959) Land in British Honduras. Report of the British Honduras Land Use Survey Team. Colonial Research Publications No. 24, Colonial Office, HMSO, London, UK.

Zisman, S.A. (1992) Mangroves in Belize: their characteristics, use and conservation. Forest Planning and Management Project. Forest Department. Belmopan, Belize.

Zisman, S.A. (1998) Sustainability or *status quo*: An assessment of elite influence in the political ecology of Belizean mangroves. Unpublished Ph.D. thesis. Department of Geography, The University of Edinburgh.

APPENDIX I: SOIL DATA

Table 8 Selected characteristics of the soils of Turneffe Atoll

pH	Mean	Mode	Range	of	values
Waterlogged saline peat	7.24	6.87	5.56	to	8.58
Drained peat	7.20	-	6.18	to	7.96
Organic sand	7.56	-	6.80	to	8.06
Coral sand	7.68	-	7.56	to	7.85
Conductivity (mS cm⁻¹ at 25°C)	Mean	Mode	Range	of	values
Waterlogged saline peat	95.37	-	54.60	to	113.98
Drained peat	20.17	-	11.36	to	36.38
Organic sand	56.19	-	1.22	to	154.27
Coral sand	25.43	-	2.68	to	70.74
Sulphate (mg l⁻¹)	Mean	Mode	Range	of	values
Waterlogged saline peat	1480	1600	400	to	1600
Drained peat	1275	1600	300	to	1600
Organic sand	931	1600	200	to	1600
Coral sand	733	300	300	to	1600
Sulphide (mg l⁻¹)	Mean	Mode	Range	of	values
Waterlogged saline peat	3.5	0	0	to	10
Drained peat	1.2	0	0	to	5
Organic sand	1.2	0	0	to	10
Coral sand	0	0	0	to	0
Water table height (cm)	Mean	Mode	Range	of	values
Waterlogged saline peat	-4.0	0.0	-24.0	to	20.0
Drained peat	-43.8	-30.0	-98.0	to	-30.0
Organic sand	-58.9	-	-150.0	to	-17.0
Coral sand	-81.6	-	-150.0	to	-28.0

Heights are expressed relative to the local ground surface. Negative values indicate that the water table was below the ground surface, positive values that standing water was present at the time of sampling.

Absence of mode values indicates that the frequency histogram was not unimodal.