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# Holocene Sea-Level Rise and the Fate of Mangrove Forests Within the Wider Caribbean Region

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## ABSTRACT

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This paper (1) reviews mangrove forest peat accretion data obtained from carbonate settings of the Wider Caribbean Region and (2) evaluates the fate of these forests based upon current global eustatic sea-level rise projections. Historical peat accretion rates calculated using $^{137}$Cs or $^{210}$Pb average 3.7 mm $\text{yr}^{-1}$. Peat accretion rates calculated using $^{14}$C average 1.0 mm $\text{yr}^{-1}$. The discrepancy between historical and geological accretion rates, also recognized in salt marsh settings, is attributed to organic decomposition and sediment compaction.

Our conceptual model, which is based upon comparisons between projected rates of global eustatic sea-level rise and peat accretion, predicts stable forest conditions only if historical accretion rates persist during a conservative (low) sea-level rise of ~1.3 mm $\text{yr}^{-1}$. Best guess (middle) and high estimates of a sea-level rise of as much as 8 mm $\text{yr}^{-1}$ will likely submerge mangrove forests located within carbonate settings of the Wider Caribbean Region.

ADDITIONAL INDEX WORDS: *coastal wetland, global climate change, peat accretion.*

## INTRODUCTION

In 1984, HOFFMAN suggested that by 2100 sea level may rise by as much as 3.5 m in response to global climate change. Estimates of maximum sea-level rise have steadily decreased over the years, although a rise of as much as ~0.86 m (~8 mm $\text{yr}^{-1}$) is still considered possible (Figure 1; WIGLEY and RAPER, *personal communication*, 1993). WIGLEY and RAPER's best guess (middle) estimate is ~0.45 m (~4 mm $\text{yr}^{-1}$; Figure 1), considerably lower than the earlier estimates of HOFFMAN (1984). However, a sea-level rise of ~4 mm $\text{yr}^{-1}$ may still exert a dramatic influence on coastal wetlands. For example, geologic studies suggest that when Holocene sea level was rising at a similar rate (prior to ~3,500 yrs B.P.), coastal wetlands were submerged and replaced by shallow marine environments (*cf.*, BLOOM, 1964; REDFIELD, 1972; STEVENSON *et al.*, 1986; PARKINSON, 1989). This submergence occurred because the rate of sea-level rise was greater than wetland sediment accretion.

Wigley and Raper's conservative (low) estimate of sea-level rise is ~0.14 m (~1.3 mm $\text{yr}^{-1}$; Figure 1). This forecasted rate of sea-level rise is essentially no different from the historical global eustatic sea-level rise (1–2 mm $\text{yr}^{-1}$; WARRICK and OERLEMANS, 1990). Thus, it is logical to assume that salt marsh and mangrove forests would continue to respond as they have over the past century.

In all cases, coastal wetland adjustments anticipated to accompany global climate change will reflect an interaction between the rate of sea-level rise and substrate accretion. While numerous studies have focused on sediment accretion processes in salt marsh systems (*cf.*, the summary in HATTON *et al.*, 1983), comparable studies in mangrove forests are rare (LYNCH *et al.*, 1989; WOODROFFE, 1990; ELLISON, 1993).

This paper reviews south Florida mangrove peat accretion data determined on both historical and geological time scales. Comparisons with mangrove peat accretion data obtained from studies conducted in other carbonate settings (THOM, 1984) within the Wider Caribbean Region (Figure 2) are also made. The fate of these mangrove for-

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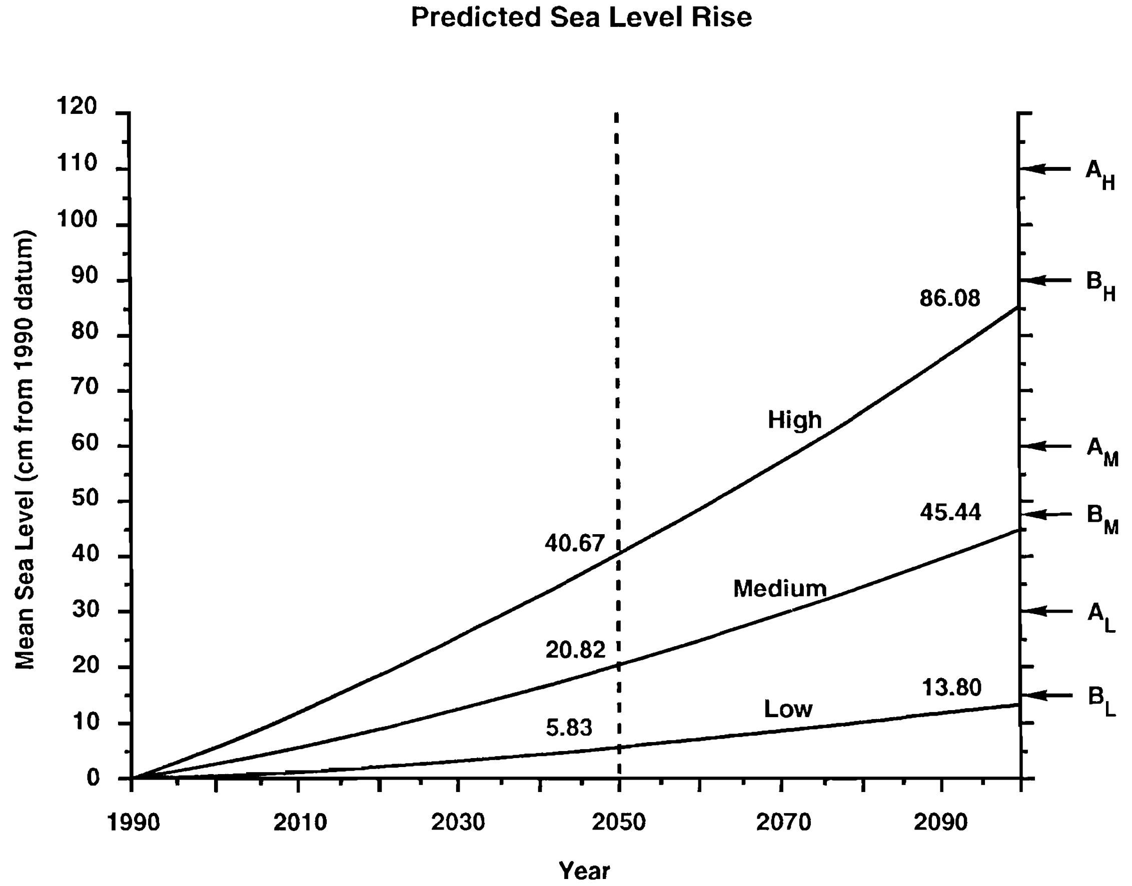


Figure 1. Predicted change in global eustatic sea level as calculated by WIGLEY and RAPER (*personal communication*, 1993). Model parameters are analogous to WARRICK and OERLEMANS' (1990) Business as Usual scenario. Elevations at year 2050 and 2100 noted. Symbols A and B located along right y-axis refer to sea-level elevations forecasted by WARRICK and OERLEMANS (1990) and WIGLEY and RAPER (1992), respectively. Subscript H, M and L refer to the high, medium, and low estimates.

ests is then evaluated in light of existing mangrove peat accretion data and current global eustatic sea-level rise projections.

## HISTORICAL STUDIES

Historical wetland sediment accretion rates have generally been determined using $^{137}$Cs (DELAUNE *et al.*, 1978) and $^{210}$Pb (ARMENTANO and WOODWELL, 1975) radionuclides or marker horizons (*e.g.*, brick dust, kaolinite; RICHARD, 1978). Cesium and lead isotopic profiles yield information on the scale of 10's to 100's of years, whereas marker horizon studies are generally utilized to determine seasonal or annual accumulation rates.

We are not aware of any mangrove sediment accretion studies that have utilized the marker horizon method. This method is designed to measure above ground sediment accumulation and may be practical in areas where tidal and fluvial processes are delivering allochthonous sediment to a mangrove study site. In carbonate settings, where mangrove sediment accretion is controlled primarily by below ground peat production, the marker horizon may remain exposed at the sediment-air interface despite the fact that vertical peat accretion is taking place.

### Florida

One published report contained data on Florida's historical mangrove peat accretion rates

(Lynch *et al.*, 1989). This study was conducted in Rookery Bay National Estuarine Research Reserve (Figure 2 and 3), located along the southwest coast. The area is characterized as a micro-tidal, basin forest (Lugo and Snedaker, 1974) consisting primarily of red mangrove (*Rhizophora mangle*). Lynch *et al.* (1989) determined peat accretion rates from four short cores taken along a shore-normal transect using both $^{137}$Cs and $^{210}$Pb radionuclides. This site is located along the margin of the south Florida peninsula, an emergent carbonate platform, and therefore sediment accretion is controlled primarily by autochthonous processes. Their results are shown in Table 1.

We have documented peat accretion rates in three backbarrier mangrove forests located along the micro-tidal east central Florida coast (Hutchinson Island, Figure 2 and 3) using five $^{137}$Cs activity profiles. The forests are contained within mosquito control impoundments constructed in the early 1960's. Prior to impoundment, these areas supported high-marsh vegetation (*e.g., Avicennia germinas, Salicornia spp.*). The construction of perimeter dikes and surface water impoundment triggered the mass mortality of high-marsh vegetation and the establishment of a red mangrove basin forest. Peat accretion within this hydrologically isolated forest is controlled by autochthonous processes and the values are shown in Table 1.

### Other Areas

Lynch *et al.* (1989) obtained four cores from two areas located along the western margin of Terminos Lagoon, Mexico (Figure 2 and 3). At one location, two cores were collected from within a micro-tidal backbarrier (Carmen Island) fringing to basin forest (Lugo and Snedaker, 1974). The forest consists of red and black mangroves. The second location supports a riverine forest (Lugo and Snedaker, 1974) located along the Yucatan Peninsula mainland shoreline (Boca Chica). One core was collected in a mixed forest of red and white (*Laguncularia racemosa*) mangroves and the other from a black mangrove forest. In contrast to the Rookery Bay and Hutchinson Island study sites, the western margin of Terminos Lagoon receives a large volume ($\sim 6 \times 10^9$ m$^3$y$^{-1}$) of sediment-laden water from three major river systems (Phleger and Ayala-Castanares, 1971; Lynch *et al.*, 1989). Peat accretion rates determined from these study sites are shown in Table 1.

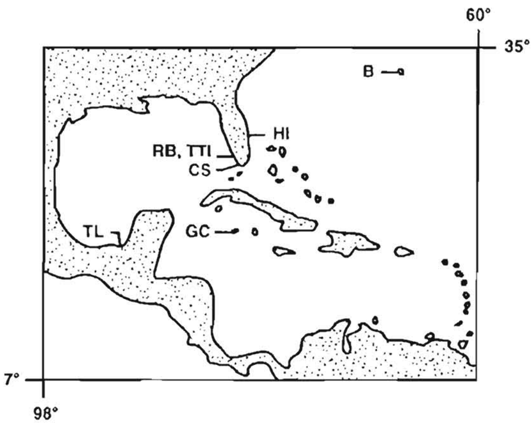
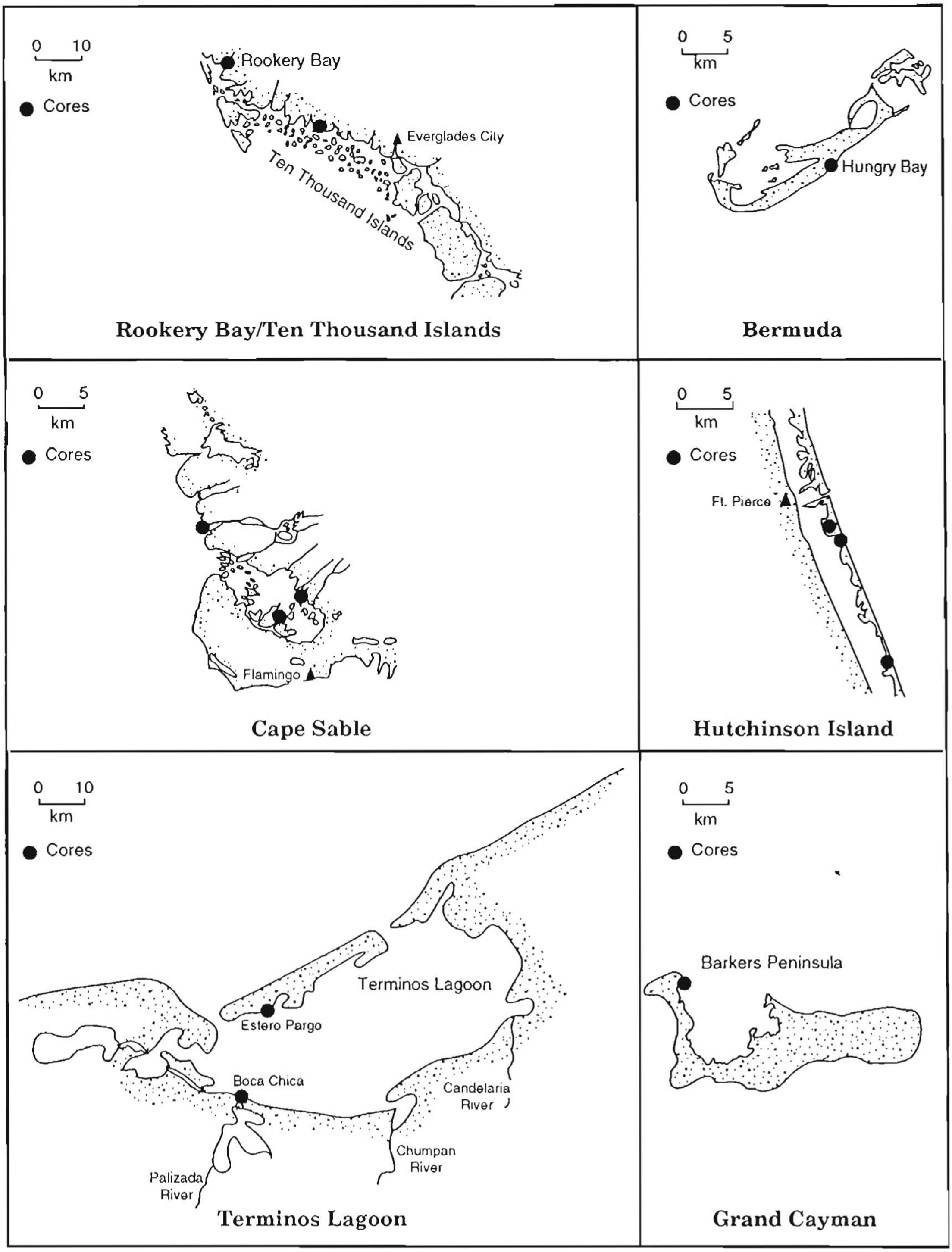


Figure 2. Map of Wider Caribbean Region showing location of six mangrove peat accretion sites used in this study. Enlargement of each area shown in Figure 3. B = Bermuda (Ellison, 1993), HI = Hutchinson Island (this study, unpublished), CS = Cape Sable (Spackman *et al.*, 1964, 1966), RB = Rookery Bay (Lynch *et al.*, 1989), TTI = Ten Thousand Islands (Parkinson, 1987), GC = Grand Cayman (Woodroffe, 1981), TL = Terminos Lagoon (Lynch *et al.*, 1989).

## GEOLOGICAL STUDIES

Estimates of the average rate of sediment accretion on time scales of 100's to 1000's of years are based upon $^{14}$C analysis of peat samples collected from the base of a continuous layer. Because a peat deposit several meters thick may have accumulated under changing environmental conditions (*cf*, Spackman *et al.*, 1966), the recent depositional setting is not necessarily representative of the conditions under which the entire deposit had accumulated. The average rate of sediment accretion calculated using radiocarbon methods may be the product of numerous brief intervals of relatively rapid accumulation interspersed within a background of slow accumulation. If this were the case, how reasonable is it to use this average to predict the fate of mangrove forests over the next 100 years?

The potential effects of changing environmental conditions on short term sediment accretion is most significant in areas where allochthonous sediment is and has been available (*e.g.*, fluvial dominated settings). In carbonate settings, where allochthonous sediment availability is minimal, problems associated with broadly fluctuating short term sediment accretion are minimized. Hence, of all possible mangrove settings (Thom, 1982; 1984), the carbonate setting is the most suitable



Rookery Bay/Ten Thousand Islands

Bermuda

Cape Sable

Hutchinson Island

Terminos Lagoon

Grand Cayman

Table 1. *Historical mangrove accretion rates (mm yr$^{-1}$) calculated using $^{137}$Cs and $^{210}$Pb isotopes. Results of a paired t-test ($\alpha = 0.05$), run with and without Hutchinson Island data, suggest no significant difference between $^{137}$Cs and $^{210}$Pb accretion rates. Grand mean calculated using all data. Ninety-five percent confidence interval calculated using PSI™ statistical software. See Figures 2 and 3 for site locations.*

| | Historical Rate | | |
|---|---|---|---|
| Location | $^{137}$Cs | $^{210}$Pb | Source |
| Florida | | | |
| Rookery Bay | 1.8 | 1.3 | Lynch *et al.*, 1989 |
| | 1.8 | 1.4 | |
| | 2.0 | 1.6 | |
| | 1.8 | 1.7 | |
| Average | 1.8 | 1.6 | |
| Hutchinson Island | 11.9 | | This study |
| | 6.1 | | |
| | 5.8 | | |
| | 13.3 | | |
| | 7.2 | | |
| Average | 9.5 | | |
| Mexico | | | |
| Terminos Lagoon | | | Lynch *et al.*, 1989 |
| Boca Chica | 5.4 | 4.4 | |
| | 1.0 | 1.3 | |
| Carmen Island | 2.9 | 3.3 | |
| | 1.0 | 0.7 | |
| Average | 2.6 | 2.4 | |
| Grand mean | 3.7 | | |
| 95% Confidence interval | [2.1, 5.3] | | |

for use in extrapolating sediment accretion rates based upon geological methods into the next century to predict the effects of global eustatic sea-level rise on mangrove systems.

### Florida

Geological peat accretion rates determined from mangrove forests located along the southwest (Ten Thousand Islands, Cape Sable) and east central (Hutchinson Island) Florida coast (Figure 2 and 3) are shown in Table 2. Both sites receive minimal allochthonous sediment input from the limestone hinterland; therefore, accretion rates are controlled primarily by autochthonous processes.

Table 2. *Geological mangrove accretion rates (mm yr$^{-1}$) calculated using $^{14}$C isotopes. Grand mean calculated using all data. Ninety-five percent confidence interval calculated using PSI™ statistical software. See Figures 2 and 3 for site locations.*

| Location | Geological Rate $^{14}$C | Source |
|---|---|---|
| Florida | | |
| Ten Thousand Islands | 1.5 | Parkinson, 1987 |
| | 0.7 | |
| Average | 1.1 | |
| Cape Sable | 0.5 | Spackman *et al.*, 1964, 1966 |
| | 0.4 | |
| | 1.0 | |
| Average | 0.6 | |
| Hutchinson Island | 1.3 | This study |
| | 1.0 | |
| | 0.8 | |
| | 0.9 | |
| | 1.2 | |
| | 1.3 | |
| Average | 1.0 | |
| Caribbean | | |
| Grand Cayman Island | 1.0 | Woodroffe, 1981 |
| | 0.7 | |
| | 0.8 | |
| | 1.0 | |
| | 1.4 | |
| | 1.0 | |
| | 0.8 | |
| Average | 1.0 | |
| Bermuda | 0.8 | Ellison, 1993 |
| | 1.1 | |
| | 1.1 | |
| Average | 1.0 | |
| Grand mean | 1.0 | |
| 95% Confidence interval | [0.8, 1.1] | |

### Other Areas

Woodroffe (1981) conducted radiocarbon dating of basal peats collected from Barkers Peninsula, Grand Cayman (Figure 2 and 3). His stratigraphic cross-sections indicate the peat deposits are contiguous to the Pleistocene limestone bedrock surface. Because Grand Cayman is an emergent limestone platform, sediment accretion is controlled entirely by autochthonous peat accu-

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Figure 3. Enlargement of six study areas from which accretion data reviewed in this paper were obtained. Bermuda, south Florida peninsula, and Grand Cayman are emergent carbonate platforms lacking significant allochthonous sediment sources. Terminos Lagoon receives sediment-laden water from three major rivers and the bulk density data of Lynch *et al.* (1989) suggests this allochthonous sediment has contributed to the relatively rapid accretion rates of the mangrove forests (Table 1).

mulation (Woodroffe, 1981). We have calculated peat accretion rates using Woodroffe's data and include them in Table 2.

Ellison (1993) recently published geological peat accretion rates obtained from the mangrove forests of Bermuda. These islands are composed of a thin surficial limestone layer which overlies volcanic rock. At 32°N, these forests are the most northerly occurrence of mangroves in the world (Ellison, 1993). The accretion rates, controlled entirely by *in situ* peat production, are included in Table 2.

## DISCUSSION OF PEAT ACCRETION DATA

Sediment accretion in salt marsh systems has been shown to vary as a function of species composition, hydroperiod, allochthonous sediment contribution, organic decay, erosion, and compaction (*cf.*, Bloom, 1964; DeLaune *et al.*, 1978; Hatton *et al.*, 1983; Stevenson *et al.*, 1985, 1986; Kearney and Ward, 1986). While it would be advantageous to consider such variability in an analysis of mangrove peat accretion rates, detailed studies investigating these effects have only recently been undertaken (*cf.*, Woodroffe, 1990). Therefore, our assessment of mangrove forest response to sea-level rise is based solely upon the average rate of accretion calculated using historical and geological methods. We recognize that this is an oversimplification and that these effects, once quantified, should be factored into conceptual models designed to forecast the fate of mangrove forests under rising sea level.

### Historical

The historical mangrove peat accretion data shown in Table 1 appears to contain considerable geographic variability (s = ± 3.5 mm $yr^{-1}$). The lowest rates were obtained from the natural forests of the southwest Florida coast, where allochthonous sediment input is minimal. The Terminos Lagoon sites exhibit accretion rates at least twice as high as the southwest Florida sites and this is logically related to the availability of allochthonous sediment delivered to the lagoon by the three major river systems (Figure 3). Surprisingly, the highest rates of historical mangrove forest peat accretion were obtained from the Hutchinson Island sites (Figure 2 and 3). These sites do not receive any allochthonous sediment because they are hydrologically isolated from the adjacent estuary by mosquito control impoundment perimeter dikes. As noted above, mangrove colonization occurred after dike construction and therefore this relatively rapid rate of historical accretion is a consequence of current water management techniques and not natural environmental conditions (see also White *et al.*, 1992).

The historical data were subjected to a One-Way Analysis of Variance (ANOVA) to determine if this geographic variability is statistically significant. The results of the ANOVA suggest the geographic variability is highly significant ($p<0.001$). The practical implication of this observation is that our conceptual model must utilize site specific historical peat accretion rates if the rate of sea-level rise approximates (*e.g.*, lies within the 95% confidence interval) the grand mean accretion rate (Table 1). Armentano *et al.* (1988) used site specific accretion data in their attempts to forecast the effects of sea-level rise on salt marshes. On the other hand, the grand mean accretion rate can be used in forecasting the fate of mangrove forests if it is significantly greater or less (*e.g.*, lies outside of the 95% confidence interval) than the predicted rate of sea-level rise.

### Geological

The geological mangrove peat accretion data shown in Table 2 displays much less geographic variability (s = ±0.3 mm $yr^{-1}$) than the historical data (s = ±3.5 mm $yr^{-1}$; Table 1). The geological data were subjected to a One-Way ANOVA to determine if this geographic variability is statistically significant. The results of the ANOVA suggest the geographic variability in geological mangrove peat accretion rates is significant ($p<0.01$). Again, the practical implication of this observation is that any forecasting model constructed to predict the fate of mangrove forests under rising sea level must utilize site specific geologic accretion rate data if the two variables are similar, as described above.

A comparison between geological and historical mangrove peat accretion rates (Tables 1 and 2) indicates that the geological rates are much lower than the historical rates, even within the same geographic location (*e.g.*, southwest Florida; see also Lynch *et al.*, 1989). A paired t-test ($\alpha$=0.05), run with and without Hutchinson Island historical data, suggests this difference is significant. The discrepancy between geological and historical peat accretion rates has been previously noted in both salt marsh (*cf.*, DeLaune *et al.*, 1983; Stevenson *et al.*, 1985, 1986; Kearney and Ward, 1986) and mangrove data (Woodroffe, 1990) and has been attributed to organic decomposition and sediment compaction.

Clearly, the outcome of any conceptual model forecasting the fate of mangrove forests under conditions of rising sea level will be dependent on whether geological or historical peat accretion rates are utilized. Both methods of measurement are applicable to the 100-year planning horizon discussed herein, albeit this range lies at the upper limit of $^{137}$Cs extrapolation and at the lower limit of $^{14}$C resolution.

## FORECASTING THE FATE OF MANGROVE FORESTS

WARRICK and OERLEMANS (1990) published estimates of eustatic sea-level rise (Figure 1), anticipated to accompany global climate change, are based upon an international (Intergovernmental Panel on Climate Change [IPCC]) assessment of the greenhouse problem. The IPCC produced an update (HOUGHTON *et al.*, 1992) which included significant changes in emission estimates and methodologies. These changes were utilized by WIGLEY and RAPER (1992) to produce a new set of sea-level rise estimates (Figure 1). Wigley and Raper have continued to update the models and we have obtained their most recent estimates of sea-level rise (Figure 1; WIGLEY and RAPER, *personal communication*, 1993), which we have used to forecast the fate of mangrove forests. These new curves are analogous to the "Business as Usual" conditions of the 1990 IPCC report.

WARRICK and OERLEMANS (1990) and WIGLEY and RAPER (1992) both noted that the rates of sea-level rise projected towards the year 2100 were not linear. WARRICK and OERLEMANS (1990) subdivided their curves into three segments (1990–2030, 2030–2070, 2070-2100), while WIGLEY and RAPER (1992) noted a significant acceleration at 2050. Because the sea-level curves are nonlinear, we have used an average rate of rise calculated from Wigley and Raper's data (*personal communication*, 1993; Figure 1) for the time interval 1990-2050 and 2050-2100 in estimating the fate of mangrove forests.

Our forecasts of mangrove forest response to global eustatic sea-level rise are shown in Table 3. These forecasts are based upon a comparison between the 95% confidence interval of the grand mean accretion rate (Tables 1 and 2) and estimates of the average rate of global eustatic sea-level rise (Figure 1). The forecasts we present in Table 3 are limited to mangrove forests located within the tectonically stable carbonate settings of the Wider Caribbean Region. Carbonate settings, where sedimentation is predominantly autochthonous, are less likely to keep pace with sea-level rise than allochthonous settings where a large volume of terrigenous sediment is available (WOODROFFE, 1990).

Table 3. *Predicted mangrove forest response to sea-level rise to accompany global climate change. Forecasts arranged according to time interval, accretion rate time scale and rate of sea-level rise. Historical rate of sea-level rise from* WARRICK *and* OERLEMANS *(1990). Projected sea-level rise from* WIGLEY *and* RAPER (personal communication, *1993). S = stable, ? = uncertain response, US = unstable.*

| Time Interval | Accretion Rate Time Scale | Sea-Level Rise Estimate (mm $yr^{-1}$) | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| 1890–1990 | | 1 | | 2 |
| | Historical | S | | S |
| | Geological | ? | | US |
| 1990–2050 | | 1.0 | 3.5 | 6.8 |
| | Historical | S | ? | US |
| | Geological | ? | US | US |
| 2050–2100 | | 1.6 | 4.9 | 9.1 |
| | Historical | S | ? | US |
| | Geological | US | US | US |
| 1990–2100 | | 1.3 | 4.1 | 7.8 |
| | Historical | S | ? | US |
| | Geological | US | US | US |

If the upper limit of the 95% peat accretion confidence interval is exceeded by the projected rate of sea-level rise, it is forecasted that mangrove forests will become unstable, perhaps submerging or retreating landward. If the rate of rise is less than the lower 95% confidence limit, it is forecasted that mangroves will remain stable. In both examples the fate of mangrove forests is not dependent on site specific peat accretion rate estimates. If the rate of rise lies within the 95% confidence interval, their fate is uncertain. It is under these conditions that site specific peat accretion rate estimates must be used.

We begin by comparing the historical rates of global eustatic sea-level rise (1-2 mm $yr^{-1}$; WARRICK and OERLEMANS, 1990) to our historical and geological peat accretion rate data (Table 3). This was done in an attempt to validate our projections. For example, our conceptual model would be erroneous if it predicted the destabilization (submergence, landward retreat) of a mangrove forest that was documented to have been stable over the past century. Unfortunately, we could find only one study (ELLISON, 1993) that included both accretion rate estimates (geological) and historical (100's of years) forest response. ELLISON (1993) reported the mangrove forests of Bermuda were submerging over the past few centuries because peat accretion (determined using $^{14}C$ data) was less than the historical rate of sea-level rise (estimated to be ~2.3 mm $yr^{-1}$). This observation is consistent with the *geological* hindcast of our conceptual model (Table 3). If the *historical* grand mean accretion rate is utilized (Table 1), our conceptual model incorrectly hindcasts that mangrove forests were stable during this historical period of sea-level rise (Table 3; ELLISON, 1993). These observations suggest that predictive models of mangrove forest response to rising sea level may be more accurate when geologic peat accretion rates are used.

Under maximum (high) rates of sea-level rise, our conceptual model predicts unstable (submerging) mangrove forest conditions within the Wider Caribbean Region regardless of whether the historical or geological peat accretion rate estimate is used (Table 3). Under conditions of the best-guess (medium) estimate of sea-level rise, mangrove forests are predicted to submerge if forest peat accretion approaches geological rates. An uncertain response is predicted under conditions of medium sea-level rise and historical peat accretion. Inspection of the site specific historical peat accretion rate data (Table 1) indicates the Hutchinson Island sites, contained within a mosquito control impoundment, accreted at much greater rates than the peats collected from natural systems. Therefore, we would predict submergence of natural mangrove forests within the Wider Caribbean Region under medium conditions of sea-level rise regardless of whether the forests continue to vertically accrete at historical or geological rates. This includes the Terminos Lagoon sites which receive abundant allochthonous sediment from three major river systems (PHLEGER and AYALA-CASTANARES, 1971; LYNCH *et al.*, 1989).

Finally, if the low estimate of sea-level rise is realized, mangrove forests will remain stable if historical peat accretion rates continue, but may become unstable if geological rates of peat accretion are maintained. Subdividing the rate of rise into the two time intervals did not improve the sensitivity of the forecast regardless of whether the historical or geological peat accretion rate data was used (Table 3).

## CONCLUDING REMARKS

Our conceptual model of mangrove forest response to global eustatic sea-level rise predicts stable conditions within carbonate settings of the Wider Caribbean Region if the lowest rate of rise is realized and then only if the historical rate of peat accretion continues. These projections of mangrove forest response to rising sea level are not in agreement with HENDRY (1993), who suggested most coastal wetland areas in the Wider Caribbean Region will keep pace with accelerated sea-level rise. However, HENDRY'S (1993) predictions were based upon the relatively rapid sediment accretion measurements (as much as 9 mm $yr^{-1}$) of ELLISON and STODDART (1991). These sediment accretion rate estimates are not directly applicable to the carbonate settings of the Wider Caribbean Region because a number of the mangrove sites used by ELLISON and STODDART (1991) are located in areas where allochthonous sediment is a significant part of the sediment budget.

Although our model predicts the submergence of mangrove forests within the Wider Caribbean Region, we do not suggest a total collapse of the world's 22 million hectares (SNEDAKER, 1993) of mangrove forest. Mangrove forests located within carbonate settings bear little resemblance to the more extensive tide- and river-dominated forests (THOM, 1982) underlain by mud and receiving large volumes of allochthonous sediment (WOODROFFE, 1990; *personal communication*, 1993).

Paleobotanical studies indicate mangroves have existed since the early Cretaceous (RETALLACK and DILCHER, 1981), and therefore, they have successfully endured geologic periods when the rate of sea-level rise was at least as high as that predicted to accompany global climate change (WOODROFFE and GRINDROD, 1991). Loss of mangrove forests can be expected to occur in carbonate settings, such as the Wider Caribbean Region discussed herein. Loss can also be expected to occur in areas where landward migration of the mangrove forest is inhibited by urbanization or local topographic relief (see also HENDRY, 1993). Therefore, forest loss in peninsular Florida, a highly urbanized carbonate platform rimmed by Pleistocene coastal ridges, could be very significant. A total collapse of Florida's existing forests would represent an 8.5% loss to the Wider Caribbean Region and a 1.3% loss to the world's mangrove forests (data from SNEDAKER, 1993). However, anticipated global sea-level rise is not likely to lead to catastrophic disruption of the largest river-dominated deltaic mangrove systems or of the major tidally-dominated systems (WOODROFFE, 1990). Hence forests along continental margins with abundant allochthonous sediment supply will continue to act as refuges, as they have during previous Quaternary sea-level fluctuations (WOODROFFE and GRINDROD, 1991).

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