A Re-Evaluation of Bruun’s Rule and Supporting Evidence

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ABSTRACT


Bruun’s rule postulates that in order to maintain an equilibrium shore profile in the face of rising sea level, sediments must be eroded from the beach and shoreface and deposited on the ramp so as to increase the ramp elevation in direct proportion to the rise in sea level. After evaluating results presented in support of the rule, it is argued here that at this time there is no hard evidence which links rising sea levels with the transference of sediments from the shoreface to the ramp. Data do show, however, that the rule is applicable to the beach and nearshore zone. Further, the limited depth of sediment transport that has an effect on shore erosion may be located near the base of the shoreface, not on the ramp as suggested by the rule. If this is the case, then there is no need to elevate the ramp in proportion to a rise in sea level. Consequently, in the face of rising sea level, the shoreface should transgress while the ramp may be simply abandoned by wave action.

ADDITIONAL INDEX WORDS: Barrier island, barrier transgression, beach erosion, gradation, mass movement, nearshore, ramp, sea-level rise, sediment budget, shoreface, transgression.

INTRODUCTION

During the past quarter of a century, many coastal scientists have come to accept the theory that a relative rise in sea level, in conjunction with wave and current action, causes beach erosion (SCHWARTZ, 1987). This theory was first proposed by BRUUN (1962) who not only linked beach erosion with rising sea level, but also implied that present-day beach erosion rates are a function of rising sea level. BRUUN (1962, 1988) explained that if sea level rises above an equilibrium shore profile, sediments should be eroded from the shoreface and deposited on the ramp so as to increase the bottom elevation in proportion to the rise in sea level, thereby maintaining a profile of equilibrium. Based on results of laboratory and field experiments, SCHWARTZ (1967) concluded that Bruun’s model had been validated and suggested that this model be known as “Bruun’s rule.” Bruun’s rule has since been cited in numerous articles (BRUUN, 1988 gives a list of references) and text books (KING, 1972; KOMAR, 1976; BIRD, 1984; PETHICK, 1984; CARTER, 1988). While some researchers have accepted the rule, others, as will be noted later in this paper, have raised some concerns about its validity. The theory, which links beach erosion with rising sea level, may be correct (DUBOIS, 1990), but the explanation, which requires continuous offshore transport of shoreface sediments, is questionable (DEAN, 1987a,b; INMAN and DOLAN, 1989; SCOR WORKING GROUP 89, 1991). The purpose of this paper is to (1) re-evaluate Bruun’s rule and supporting evidence, to (2) suggest that Bruun’s rule may apply only to the beach-nearshore zone and not to the shoreface-ramp zone, and (3) to suggest that in the face of rising sea level the shoreface of a barrier should transgress, whereas the ramp may be abandoned by wave action.

Coastal terms used in this report, which could cause confusion among some readers, are defined as follows. The nearshore is the zone between the foreshore and the position of breaking waves (KOMAR, 1976). In some literature (SCHWARTZ, 1965, 1967, 1987), the term nearshore includes the shoreface and ramp. The shoreface, which has an overall concave-skyward profile, extends seaward from the foreshore and terminates at the ramp, where the shore bottom profile generally becomes planar with a gentle seaward-dipping slope (Figure 1). The limited depth of sediment transport is the maximum seaward depth where the oscillatory motion of water molecules, caused by the passage of surface waves, initiates sediment motion. Seaward from this depth, no bottom sediments are set in motion by wave action. Knowing the limited depth of sediment transport is crucial to those who construct models to predict rates of
Figure 1. Shore terms used in this paper. The location of the limited depth of sediment transport (D) is in question; it may be at the base of the shoreface or on the ramp as shown by the shaded region.

beach erosion and volumetric loss in response to rising sea levels (BRUUN, 1962; DEAN and MAURMEYER, 1983; EVERTS, 1987; DUBOIS, 1990). Determining the limited depth of sediment transport is problematic. Theoretically, the limited depth can be predicted if the physical properties of bottom sediments and a statistical summary of annual wave dimensions are known (HALLEMEIER, 1981). On the other hand, some investigators have suggested that the limited depth is located on the ramp (BRUUN, 1962; SCHWARTZ, 1965) while others believe it is located at the base of the shoreface (EVERTS, 1987; DUBOIS, 1990). In all probability, however, for a time frame of a year or more when wave dimensions vary considerably, the limited depth will not be found at a specific depth but will vary over a range of depths (BRUUN, 1983) (Figure 1).

BRUUN’S RULE

Model

Prior to a rise in sea level, the rule assumes a shore is at equilibrium in the cross-shore and longshore directions. In such a system, the coastal processes remain fairly constant over time, excluding seasonal fluctuations, and the shore zone is closed to the influx of terrestrial materials imported by gradational agents such as fluvial processes and mass movement (BRUUN, 1962, 1988). The resultant shape of a cross-shore profile at equilibrium reflects the mutual adjustment between sediments and processes so as to yield a bottom gradient that minimizes the expenditure of wave energy.

Assuming a cross-shore profile does not extend across immovable materials, a rise in sea level should cause coastal processes to re-establish an equilibrium profile by eroding sediments from the beach and shoreface and depositing them on the ramp (BRUUN, 1962, 1988). The coastal processes erode no more sediments than what is required to readjust the shore profile to its former equilibrium shape (Figure 2). The width of beach erosion (W) is given as

\[ W = XS/Y, \]  

(1)

where \( X \) is the horizontal length from shore to the limited depth of sediment transport, \( S \) is the sea level rise, and \( Y \) is the vertical length of the profile, which is the sum of the limited depth of sediment transport (D) and the foredune elevation (E) (Figure 2); \( D \) is assumed to be located over the ramp (BRUUN, 1962, 1988). Approximately 90 percent of profile displacement should be accounted for if \( D \) is set at \( 2H_{\text{max}} \), where \( H_{\text{e}} \) is the maximum breaker height within a time frame of 50 to 100 years; setting \( D \) at \( 3.5H_{\text{max}} \) should account for the remainder (BRUUN, 1988). If muds are part of the shoreface material, then these fines may be swept seaward beyond the closure depth during times of profile adjustments, forcing additional shoreface erosion before equilibrium is re-established. Therefore, in order to compensate for the loss of fines (\( r \)), a percent of sediment sizes less than 0.06 mm relative to the total amount of shoreface erodible material, equation (1) was modified (BRUUN, 1983) so as to yield

\[ W = XS(1 + r/100)/Y \]  

(2)

Bottom currents are believed to be responsible for shoreface erosion and ramp accretion (BRUUN, 1962). Storms are known to generate strong rip and/or downwelling currents capable of transferring sediments from the shoreface to the ramp.
Evidence

Bruun (1962) provided neither supporting laboratory nor field evidence for his model. In his Florida study, he assumed the model was correct and proceeded to adjust the variables in equation (1) so as to yield a $W$ value of 57 cm/yr, which he believed was a realistic shore erosion rate for the beach segment between Palm Beach and Miami. All sediments eroded from the upper shore profile were believed to be deposited on the ramp.

In wave tank experiments, Schwartz (1965, 1967) observed that as water levels rose above an equilibrium profile, the profile migrated upward and landward, the elevation of the shore bottom increased in proportion to the increase in water level, and the volume of sediment eroded from the beach was equal to that deposited on the shore bottom. In addition along the shore of Cape Cod, Massachusetts, Schwartz (1967) surveyed two beaches between neap and spring tides; as tide levels rose, some beach erosion and nearshore accretion was recorded and interpreted as evidence supporting Bruun's rule.

Dubois (1975, 1976, 1977) investigated the changes of beach and nearshore profiles as water levels of Lake Michigan rose by 0.3 m from spring through summer of 1971. The results were similar in principle to those reported from wave tank studies (Schwartz, 1965, 1967); with a rise in lake level, the beach migrated upward and landward, the nearshore bottom was elevated in direct proportion to rising lake level, and the volume eroded from the beach was about equal to that deposited in the nearshore. The cause of beach erosion and nearshore deposition during times of rising water levels may have been linked with normal cycles of beach erosion and recovery. Following beach erosion and nearshore deposition caused by storm waves, swells rebuild a beach using sediments from the nearshore. However, during times of rising water levels, not all nearshore sediments may be redeposited on a beach; a sediment layer equal to the change in water level may be left on the nearshore bottom (Dubois, 1982).

Handis (1976, 1979, 1983) studied changes in coastal profiles along a segment of the eastern shore of Lake Michigan (Figure 3). From 1969 through 1976 when lake levels rose an average of 0.2 m, the observed and predicted (Eq. 1) rates of shoreline retreated were 13.6 m. The volume of sediment eroded landward of the inner trough was equal to the volume deposited offshore. The results of this field investigation were interpreted as evidence confirming Bruun's rule.

For the Virginia shoreline of the Chesapeake Bay, Rosen (1978) compared long-term shoreline erosion rates with those predicted by equation (1) and found that the predicted erosion rate varied by $3\%$ from the measured rate. The study was an application of Bruun's rule and did not actually investigate shore profile changes with rising water levels.

Pickhill (1985) conducted a study along shore segments of Lakes Manapouri and Te Anau, New Zealand. Based on shore profiles, he noted that with rising lake levels, sediments were eroded from the center of the foreshore and deposited on the upper foreshore and on the immediate nearshore bottom. Volumetric analyses were not presented.
CONCERNS

Evidence

After re-evaluating the evidence, one is faced with a fundamental question: Does the evidence support the model? With rising water levels and with no infusion of sediments by gradational agents into the shore system, the model requires sediment transfer from the upper shoreface and beach, as far as waves can reach, to the ramp. It is this writer’s opinion that the results are not in full agreement with the model.

No evidence presented by Schwartz (1965, 1967) supports the concept of shoreface erosion and ramp accretion as water levels rise. The results of his wave tank studies do not differentiate as to whether erosion and deposition were confined to the foreshore-nearshore zone or to the shoreface-ramp zone; whereas the results of his Cape Cod study are based on evidence collected from the foreshore and upper shoreface zone, not from the shoreface-ramp area. The Lake Michigan (Dubois, 1976) and New Zealand (Pierick, 1985) investigations showed that sediments eroded from the beach were deposited in the nearshore. In the Lake Michigan study, lakeward of the surf zone a longshore bar migrated landward as lake level rose, but its elevation did not increase (Dubois, 1976).

Although the results reported by Hands (1976, 1979) and Rosen (1978) show an agreement between measured and predicted rates of shoreline erosion, and offshore deposition was noted by Hands, these investigations were conducted at locations where terrestrial materials were transported by mass movement to the shore zone, and therefore, these results do not provide definitive evidence confirming Bruun’s rule. Lake Michigan is generally ringed by bluffs derived from glacial drift on the western shore (Martin, 1965) and from Quaternary dune sands on the eastern side (Hough, 1958). Bluff relief above lake level can be greater than 50 m. During the past 122 to 147 years, the bluffs have receded by an average of 0.4 m/yr (Buckler and Wintern, 1983). When lake levels are high, as they generally were from 1969 to 1976, and storm waves attack the toe of the bluff (Hands, 1979, Figure A-4), slope materials are transported and deposited directly onto the upper shore by mass movement (Figure 4), and are then dispersed along the shore bottom by coastal processes (Figure 3) and at times by ice-rafting (Reimnitz et al., 1991). Similarly, the Chesapeake Bay is flanked in many areas by bluffs composed of weakly cemented Quaternary materials resting unconformably on consolidated Tertiary and Cretaceous deposits (Palmer, 1973). Bluff relief at some locations is over 40 m. Presently, with high bay-water levels and narrow beaches, and storm waves eroding the bluff base, mass movement is directing bluff materials onto the beach and into the bay (Miller, 1987) (Figure 5). Some parts of the bay are sheltered from wind, waves, and currents, and yet bluff erosion continues. Here, mass movement is the sole agent responsible for coastline retreat (Palmer, 1973). Thus, the total sediment volume eventually deposited on the lower shore profile not only comes from the erosion of the beach by coastal processes in order to readjust the shore profile to its former equilibrium shape, but also from bluff erosion. The volume of sediment eroded for a unit length of coastline is dependent on the rate of coastline retreat and on the bluff relief. The rate of coastline retreat will not only depend on rising water levels and wave action, but also on soil and climatic conditions favorable for mass movement; and for a rate of coastline retreat, greater volumes of sediments will be deposited in the shore system with increasing bluff heights. Therefore, during times of rising water levels, the sediment volume contributed to the shore zone by mass movement along relatively high bluffs is more than what is required by the shore system to readjust its crossshore profile. The addition of colluvium to the shore zone may change the shape and/or the dimensions of the shore profile; note in Figure 3 that swales in the lower shore profile have filled-in and the shape of that profile segment has changed. In such cases equation (1) should be used with caution for the assumption of profile equilibrium may not be reasonably met.

Hands (1976) reported an interesting sequence of events. With a rise in lake level, longshore bars numbering up to five advanced landward thereby contracting the shore profile. This type of bar response was similar to the response of the second longshore bar reported by Dubois (1976). Then the shore profiles expanded as sediments eroded from the bluffs were deposited on the shore bottom (Hands, 1976). This second phase was not recorded by Dubois (1976) because there was no infusion of bluff sediments into the shore system during the study period. In all probability had there been no influx of terrestrial material by mass movement into Lake Michigan, the response of
the shore profile to rising water levels would have been much different than what has been reported (Figure 3). During times of rising water levels in Lake Michigan, the question of whether shoreface erosion and ramp accretion take place remains unanswered.

In the opinion of this writer, the results of Hands’ study may be a simple example of gradation, of materials being eroded from topographic highs and deposited in lows by geomorphic processes so as to bring a land surface to a common level (Chamberlin and Salisbury, 1909). Here, lake level serves as the general boundary between the subaerial zone of degradation and the subaqueous zone of aggradation, although on a worldwide scale, sea level is the ultimate boundary. To test Bruun’s rule, a study should be conducted at a shore that is closed to the input of terrestrial materials by gradational agents, such as a barrier island shore.

Thus, the sum of these lake studies suggest that if there is no input of bluff sediment by mass movement, then as water level rises the processes causing erosion and accretion are confined to the beach and nearshore, and that the lower shore profile simply migrates landward until it achieves equilibrium. There is, therefore, at this time no hard evidence that links rising sea level with shoreface erosion and ramp accretion. Bruun’s rule seems applicable only in the beach-nearshore zone. On the other hand, bluff material introduced into the nearshore by mass movement appears to be transported offshore where it accretes the lower shore zone, creating what may be an illusory confirmation of Bruun’s rule (Figure 3).

**Barrier Island Systems**

The applicability of the rule has been challenged by some who have investigated the response of barrier island systems to rising sea levels. The rule excludes sediment transfer from the shoreface to the barrier; but in the face of rising

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Figure 4. A 20 m bluff of Quaternary dune sands overlooking Lake Michigan at Van Buren State Park, Michigan. Note the accumulation of dead trees on the slope and beach in response to mass movement. (Photo taken by author during August 1975).
sea level, transgressive barrier islands must be supplemented with shoreface sediments in order to maintain their subaerial integrity (HOYT, 1967; DILLON, 1970; KRAFT et al., 1973; FIELD and DUANE, 1976; FISHER and STAUBLE, 1977; LEATHERMAN, 1979; KOCHEL and DOLAN, 1986). These bottom sediments are driven onshore and deposited on barriers or in adjacent lagoons by overwash, or are driven through inlets forming flood tidal deltas (VAN ANDEL and POOLE, 1960; PIERCE,
Figure 6. A two-dimensional model of a shore profile responding to a rise in sea level. Arrows show potential directions of sediment transport. This model does not apply to shorelines in the vicinity of tidal inlets.

1969; GILES and PILKEY, 1965; BARTBERGER, 1976; MEZA and PAOLA, 1977; WILLIAMS and MEISHUGER, 1987). Thus, for a barrier island system, the rule has been modified to conceptually (McLEAN, 1973; SWIFT, 1975; FISHER, 1980; BELKNAP and KRAFT, 1981) and quantitatively (DEAN and MAURMEYER, 1983; EVERTS, 1987) include sediment derived from the shoreface.

Others have rejected the rule. DILLON (1970) concluded that the rule did not apply to barrier island shores because sediment eroded from the shoreface must be deposited on a barrier in order to maintain its existence during rising sea levels. DEAN (1987a,b) and INMAN and DOLAN (1989) argued that the concave shape of a shoreface profile is primarily a function of waves generating a net onshore bottom stress, and therefore, a rise in sea level should force waves to readjust a profile by displacing the bulk of shoreface sediments landward. The dominant process responsible for re-adjusting the shoreface profile should be wave action, not seaward-flowing bottom currents as suggested by the rule. From the shoreface base to the lagoonal edge of a barrier, wave action should move the total shore profile upward and landward (INMAN and DOLAN, 1989).

**TRANSGRESSIVE BARRIER MODEL**

Although this paper has questioned the applicability of Bruun's rule to describe the response of the shoreface and ramp to rising sea level, field evidence clearly shows that the rule is a suitable model for the beach and nearshore zone (DUBOIS, 1976; PICKHILL, 1985). Thus, the combination of a transgressive shoreface and Bruun's rule, when applied to the beach-nearshore zone, may help explain the response of a simple transgressing barrier shore to rising sea level (Figure 6). Note in this two dimensional model (Figure 6) that as the barrier transgresses, (1) the shoreface erodes and sediments are deposited on the barrier by overwash. The predicted rates of beach erosion, as a consequence of transgressing shorefaces, have been shown to be reasonably close to observed rates reported for shoreline segments bordering the U.S. Atlantic coast and Gulf of Mexico (DUBOIS, 1990). Although some shoreface sediments may be swept out onto the ramp by downwelling currents, there may be no need to uniformly elevate the ramp in direct proportion to the increase in sea level, if the limited depth of sediment transport which has an effect on shore erosional rates is located at the base of the shoreface (EVERTS, 1987; DUBOIS, 1990); as sea level rises, the ramp for all practical purposes can be simply abandoned by wave action. For those sediments that are swept seaward and deposited on the ramp by currents, it is difficult to say whether these materials will remain there or be redirected landward because ramp processes are not fully understood (WRIGHT, 1987). Clearly, if these sediments are not returned to the barrier system, then the barrier would lose some of its mass (PENLAND et al., 1985), (2) Beach sediments are not only lost to the lagoonal side of a barrier during times of severe storms, but are also lost to the nearshore during moderate storm events. However, with rising sea level, not all sediments are returned to the beach by swells during fair-
weather conditions. A sediment layer equal in thickness to the rise in sea level remains on the nearshore bottom (Dubois, 1982). Although the back-barrier may take several years to adjust to rising sea level, the beach and nearshore, where Bruun’s rule is applicable, should adjust in a relatively short time, within a year or so. As seen in Figure 6, Bruun’s rule is embedded in a transgressing shore profile; however, the rule contributes only a small amount to the total shore erosion caused by transgression. For example, the transgressing Delaware-Maryland shoreface, with a sea level rise of 3.1 mm/yr, causes a shoreline retreat of 1.1 m/yr and a volumetric loss of 10.5 m³/m/yr (Dubois, 1990). Whereas, for the same general location and a sea level rise of 2–4 mm/yr, Bruun’s rule accounts for beach erosion rates of 6.5–13 cm/yr and sediment volumetric exchange rates, between beach and nearshore, of 0.5–1.0 m³/m/yr (Dubois, 1988).

In the third dimension (Figure 7), (3) shoreface sediments, driven landward by waves generating a shorward net bottom stress, should be eventually introduced into the longshore current system; during storms, these sediments will be flushed through tidal inlets and deposited in the form of tidal flood deltas; some of these lagoon deposits may be flushed-out later by ebb tidal currents and return to the shoreface or even deposited on the ramp (Liu and Zarillo, 1990). Where the shoreline terminates at a spit, other sediments should be transported downdrift to be ultimately deposited at the tip and on a bay side of a spit, causing spit length to increase at the expense of a transgressing shoreface. Likewise if a longshore current terminates at a cape, then the littoral drift will add to and maintain the shoals that form the submarine topography off of most capes.

The proposed transgressive barrier model is similar to, yet different from other models that have appeared in the literature (McLean, 1973; Swift, 1975; Fisher, 1980; Dean and Maurmeyer, 1983; Penland et al., 1985; Everts, 1987). Similarities involve shoreface transgression and washover deposition. The difference entails the spatial application of Bruun’s rule. Following the conventional interpretation of Bruun’s rule, other models have depicted shoreface erosion and ramp.
accretion in proportion to sea level increases; on the other hand, the present model applies Bruun's rule to the beach and nearshore.

SUMMARY AND CONCLUSION

Although there has been a strong feeling among many coastal scientists that a rise in sea level is responsible for some degree of beach erosion, concerns have been raised about the validity of Bruun's rule when applied to the shoreface and ramp. Proponents of the rule have pointed to the results of some lake and bay studies that claim the shoreface erodes and the ramp accretes with rising water levels. On the other hand, some opponents have noted that continuing sediment loss from the shoreface to the ramp along barrier shores would be detrimental to the maintenance of barriers and would be in conflict with the "rollover" evolutionary trend of barriers; further, others have argued that wave processes should drive shoreface sediments onshore, not offshore, as sea level rises. When the evidence in support of Bruun's rule is re-evaluated, the results imply that the rule is applicable to the beach and nearshore. At this time there does not appear to be strong evidence justifying the application of the rule to the shoreface and ramp. Indeed, the limited depth of sediment transport that has an effect on shore erosion may be located near the base of the shoreface, not on the ramp; if this is the case, then there is no need to elevate the ramp in proportion to a rise in sea level. As sea level rises, the shoreface should transgress while the ramp may be simply abandoned by wave action. Rip and/or downwelling currents may be able to transport sediments beyond the limited depth and deposit them on the ramp, thereby causing some ramp locations to aggrade; however, wave action, not currents as suggested by Bruun (1962), may be the dominant process responsible for a shoreface transgression as sea level rises.

Although the proposed transgressive barrier model seems plausible, clearly more research is needed. Efforts should be directed towards improving our understanding of the shore hydrodynamics in a three-dimensional perspective relative to a stable water level and then to rising water levels. However, because of the relatively slow rise in sea level and the difficulty in gathering temporal and spatial field data, wave-basin research may be the only way to verify changes in shore hydrodynamics and shore profiles in response to rising water levels.

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LITERATURE CITED


RESUMEN
La regla de Bruun postula que a fin de mantener el equilibrio de un perfil de playa frente a una elevación del nivel del mar, los sedimentos deben ser erosionados de la playa y del frente de playa y depositados sobre el declive tal que aumenta la elevación de este último en una proporción directa de la elevación del nivel del mar. Después de evaluar los resultados presentados de acuerdo a esta regla, se concluye que no existen evidencias que relacionen las elevaciones del nivel del mar con la transferencia de sedimentos del frente de playa hacia el declive. Sin embargo, los datos muestran que la regla es aplicable a la playa y a la zona cercana a la costa. Además, la profundidad límite del transporte de sedimentos que posee un efecto sobre la erosión costera puede ser localizada cerca de la base del frente de costa y no sobre el declive como es sugerido por la regla. Si este es el caso, no habrá necesidad de elevar el declive proporcionalmente a la elevación del nivel del mar. En consecuencia, ante una elevación del nivel del mar, el frente de costa sufrirá una transgresión mientras que el declive será abandonado por la acción de la ola.—Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.

RESUME
La règle de BRUUN postule que le maintien du profil d'équilibre d'une plage, face à une montée du niveau de la mer, implique que les sédiments doivent être érodés de la plage et de la plage sous marine et déposés sur l'avant plage, de façon à en accroître la hauteur. Cet accroissement est directement proportionnel à la hausse du niveau de la mer. Après avoir évalué les résultats présentés pour étayer cette règle, on montre l'absence de règle stricte liant la hausse du niveau de la mer et le transfert de sédiments depuis la plage vers l'avant plage. Les données montrent pourtant que la règle de Bruun s'applique à la plage et à la proche plage sous marine. De plus, la profondeur limite du transport sédimentaire qui a un effet sur l'érosion de la plage peut être localisée à la base de la plage sous marine, et non sur l'avant plage, comme le suggère la règle. Dans ce cas, on n'a pas besoin d'éléver l'avant plage proportionnellement à l'élévation du niveau de la mer. Donc si le niveau de la mer monte, la plage sous marine devrait transgresser, tandis que l'avant plage ne serait plus soumise à l'action de la houle. —Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montreouge, France.

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