The Bruun Rule: its validity and its limitation

As you have already learned, sea level rise is one of the main problems affecting coastal zones on a global scale. It is not as simple as that the coast will just drown as if the coast is in a bath tub with increasing water level, since the coast will respond in a dynamic sense. Actually, a natural coast will adapt to sea level rise, the coast will want to keep pace with sea level rise, raising its profile relative to the sea level. A perfect response to rising sea levels! In order to do this a sediment budget deficit is created however. How does this actually work?

Bruun (a Danish born coastal engineer that spent most of his career as a University Professor in Gainesville, FL, USA) was the first to describe this effect in 1962. The main idea behind the Bruun-Rule (c.f. Bosboom and Stive, 2010) is the assumption that the upper shore face (the morphologically active -on a time scale of years- part of the continental shelf, vertically extending from the first dune or berm ridge to a depth of 5 m to 20 m depending on the strength of the stormy waves) has a profile that is in equilibrium with the hydrodynamic forcing (i.e. wave driven processes mainly, but also density driven currents near river or estuarine entrances) and that for any perturbation in the forcing, the response of the profile will be relatively fast (see the video The origin and evolution of beaches, with the sand castle being absorbed in the coastal profile within a few wave motions). Now think of a beach where, under site-characteristic hydrodynamic conditions, an equilibrium upper shore face bottom profile has developed. Now imagine what will happen if an instantaneous sea level rise occurs. The new (increased) water depth on the subaqueous profile will be too large to be in equilibrium with the hydrodynamic forces, so the profile strives to adjust. In geological terms we say that the lower part of the profile has now additional space, so-called *accommodation space,* for sediment deposition. This sediment can only be delivered by the upper, mostly sub areal, part of the profile. This will result in a retreat of the coastline position, while the profile remains vertically invariant in space and time relative to sea level.

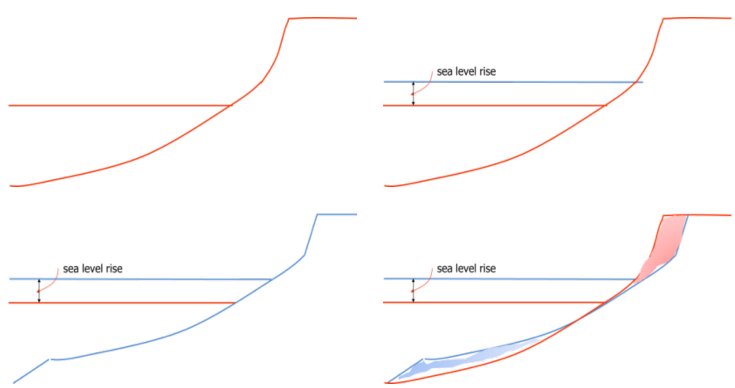

Figure 1 The shore profile and hydrodynamic forcing are in equilibrium for a constant sea level (top-left). When an instantaneous sea level rise occurs accommodation space is created on the lower profile (top-right). The Bruun Rule states that the blue profile is the new equilibrium profile (bottom-left) requiring a shift upward and landward (bottom-right) , the coastline will retreat until

the volume of sediment that has been eroded on top of the profile is equal to the volume deposited in the bottom(bottom-right). You may notice how the profile shape remains unchanged.

In summary, when sea level rise occurs the shoreline retreats and a new equilibrium profile will form at the new shoreline position by moving sediments to deeper water, or in other words, the profile is shifted to an upward and landward position.

The Bruun Rule can be applied in practice when one wishes to assess possible future effects of sea level rise. As long as there are no other sources or sinks, the shoreline retreats to supply sediment to the lower part of the active profile (i.e. the part that on the time scale of years exchanges sand along the cross-shore profile) the equilibrium profile is then maintained, as mentioned above. The shoreline retreat distance *R* can be derived as follows:

Consider a beach profile like the one in figure 2. Horizontally, the migration of the shoreline landwards leads to a sediment yield of $R\, d$ where *R* is the shoreline retreat and d is the height in the profile over which erosion and sedimentation occur (i.e. the closure depth plus the dune or berm crest height). Vertically, sea-level rise will result in a demand of sand of $L\, \Delta MSL$, where L is the length over which erosion and sedimentation take place and ΔMSL is the rise in sea level above mean sea level (figure 2). When there is no net loss or gain of sediment, these two expressions can be balanced resulting in:

$$R\, d = L\, \Delta MSL$$

$$R = \frac{L}{d}\, \Delta MSL$$

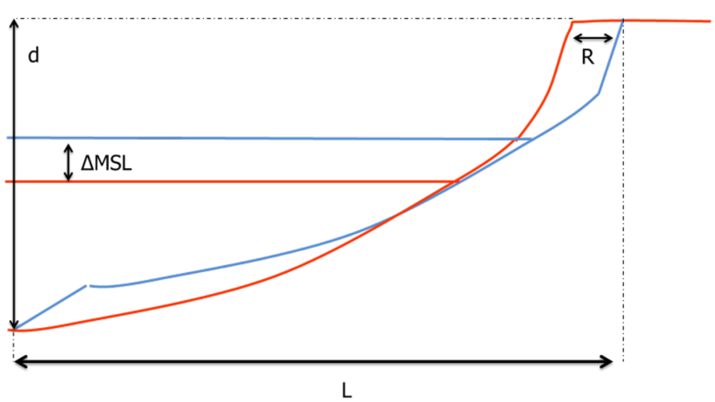

Figure 2 Shore profile subject to sea level rise

In practice the ratio L/d is of the order 50 to 100. This means that for a eustatic rise in sea level of 2 to 4 mm the coastline will retreat only a distance of 0.1 to 0.4 m which is often small compared to the impacts of human interventions. Realize that when we consider local subsidence (due to human interventions) to give local sea level rise levels of 5 to 10 cm's per year, the coast will retreat an order of magnitude more.

Even though the Bruun Rule is very often used it has a number of limitations and care must be taken when using this tool to predict the coastline response to sea level rise. Some of these limitations and oversimplifications include:

-It can only be applied to soft-sediment coasts not to rocky or hard-engineered coasts;
-It assumes a response to an elevated sea level such that an equilibrium profile is always attained;
-It assumes that all the eroded sediment is redistributed along the profile in the cross-shore direction; this implies a cross-shore sediment balance (no other sources or sinks);
-It considers shoreline erosion due to sea level rise alone, gradients in alongshore sediment transport are ignored.

If we focus on the three last bullet points we may notice that these assumptions may not be valid under a number of circumstances. An additional input or output of sediment within a coastal environment might result in an increase or decrease of the alongshore transport rates, respectively. For the case when a particular stretch of coast undergoes an increase in the alongshore transport rates, additional erosion will take place and vice versa a decrease in the alongshore transport rates will lead to sedimentation.

Especially, the applicability of the Bruun Rule in coastal stretches adjacent to inlets is rather limited. The interruption of the coastline by an inlet represents another sink of sediment: The inlet basin will give additional accommodation space for sediments to be deposited. A bigger space to accommodate sediments will give a stronger response to sea level rise. This additional recession due to basin infilling will even exceed recession due to the Bruun effect when the tidal area of the basin is larger than approximately 10 km^2 (Stive and Wang, 2003).

References

Bosboom, J.; Stive, M.J.F. (2010). Coastal Dynamics I. VSSD, Delft.

Stive, M.J.F.; Wang, Z.B. (2003). Morphodynamic Modeling of Tidal Basins and Coastal Inlets. Advances in Coastal Modeling. Elsevier Oceanography series: Volume 6 pages 367-392.