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Shoreline morphological changes and the human factor. Case study of Accra Ghana

Kwasi Appeaning Addo

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Abstract The interface between the sea and land is a very dynamic system that is always migrating landward or seaward. The landward migration results in the shoreline threatening coastal infrastructure and destroying the coastal environment. Coastal erosion has resulted in both social and economic problems. Coastal cities have also experienced increasing infrastructure development and population growth. This has resulted in a land "squeeze situation" in which both the shoreline and the "humanline" are competing for space along the coast. This struggle for space could result in serious environmental disaster as a result of the dynamics of the oceanic system, which could impact the immediate environs severely. The aim of this study was to determine if the rate of human encroachment of coastal lands for development exceed the rate at which the shoreline is moving inland as part of its natural cyclic behaviour. This study used 1985 aerial photographs and 2005 orthophoto map of the Accra western coast. Major land cover was identified, classified and overlayed in GIS environment. This enabled changes to be estimated. The shorelines were also digitised and the rate of change computed using the DSAS software. The results indicate that the estimated total area of land lost by human encroachment on the coastal land within the period under study is about 242,139.7 m2. However, the rate of land lost to human development is about 8,349.64 m2/year, which is relatively high. The historic rate of erosion computed for the period under study is about 1.92 m/year. Comparing the two rates indicates that human activities are moving closer to the shoreline as compared to the rate at which the shoreline is moving inland. This study recommends that setback lines should be put in place to protect lands for the shoreline's cyclic activities.

Keywords Shoreline · Land squeeze · Erosion · Shoreline change · Sea level rise

K. Appeaning Addo (✉)
Department of Marine and Fisheries Sciences,
University of Ghana,
P. O. Box Lg 99, Legon,
Accra, Ghana
e-mail: kappeaning-addo@ug.edu.gh

K. Appeaning Addo
e-mail: appeaning@yahoo.com

Introduction

The shoreline is highly dynamic and undergoing morphological changes all over the world. These changes, which are natural and largely driven by processes within the oceanic system and exacerbated by human activities, have resulted in the shoreline moving more inland in most areas. The shoreline, which represents the interface between the land and the sea within the coastal zone, characterises a challenging environment between human development and environmental conservation that has resulted in conflict between the natural phenomenon and the human influence. The sea appears to be taking what rightfully belongs to it and encroached on by the activities of mankind. Humans are also devising strategies to reclaim coastal lands taken over by the sea to protect their investments in the coastal zone. Thus the seasonal landward movement of the shoreline competes with the increasing coastal development for the limited space that has resulted in a "coastal land squeeze" situation.

The conflict, as a result of continuous human settlement along the coast and the natural cyclical evolution processes by the sea, has opened a new thinking which tends not to wholly blame the sea for erosion associated problems. Human influence in the coastal zone has been identified as a major cause of shoreline morphological change, which ultimately drives coastal erosion (Appeaning Addo 2009).

Coastal erosion is not a problem if it is not displacing coastal communities, threatening assets and destroying infrastructure. This natural phenomenon is cyclical in the short and long term. Short term events usually take a shorter period for the system to be restored to its initial state. However, long term morphological change tends to mimic the short term phenomenon and thus may take a longer period for the system to be restored. According to Cambers (1976), the cyclic time for shoreline change is about 10^4 for the long term and approximately between 10^2 (Graded time) and less than 10^{-1} year (steady time) for the short term.

Over cyclic time, the coastal system which may be showing some progressive change in the short term and the long term operates unimpeded if the operation does not conflict with human activities. This process is usually in conflict with human development in the coastal zone. As developments move closer to the shoreline position, future land space for the cyclic lateral movement in the shoreline position is compromised. This result in the 'land squeeze' situation as the shoreline fights to reclaim the space for its activities.

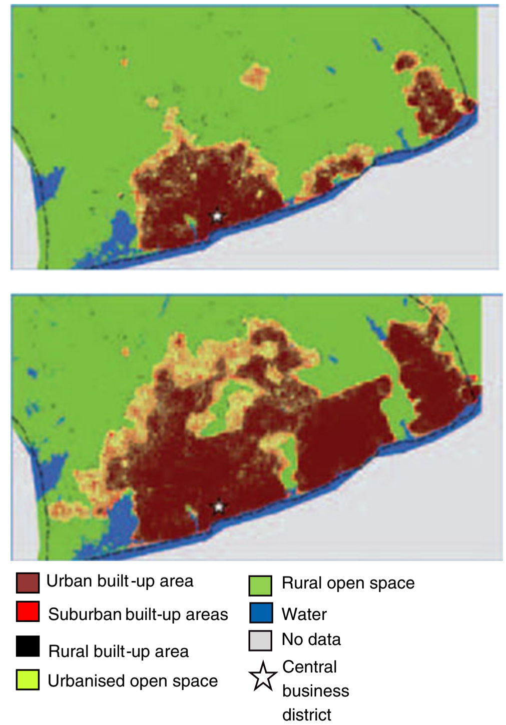

Fig. 1 Built up area of Accra, 1995–2000 (Source: Angel et al. 2011)

Background

Various studies have quantified the rate of landward migration in the shoreline position (Appeaning Addo, et al. 2008; Morton et al. 2005; Boateng et al. 2012). However, not much study has been conducted to estimate the rate at which human settlement is moving closer to the shoreline. Studies into changes in coastal land cover and land use have quantified changes in the vegetation cover within a coastal section (Appeaning Addo et al. 2011b), the extent of previous bare land now occupied by infrastructure, and the spatial change in settlement pattern. A study by Angel et al. (2011) identified that there has been a significant change in land cover in Accra. Land cover change as a result of infrastructural development in Accra is concentrated along the coast as indicated in Fig. 1, which reveals the built up area over a 5 year period.

Although coastal land use and land cover studies have been undertaking to analyse the spatial changes in coastal vegetation (Abbott et al. 2000; Appeaning Addo et al. 2011b), most of these studies did not focus on the impact of the changes on the dynamic shoreline position. Human habitation is a major cause of coastal erosion (Appeaning Addo et al. 2011a). In most cases human influences along the coast have exacerbated erosion problems (Appeaning Addo et al. 2008). In many coastal countries, population in the coastal areas are growing much faster than those in the non-coastal areas (Culliton et al. 1990; Duedall and Maul 2005). This situation is a cause for concern since population growth and the activities associated with it can influence significantly the evolution pattern of the shoreline through changing the land cover in the coastal zones. Generally, the coastal zone has been attractive for human settlement because of transport, food and ecological benefits. These factors are some of the major causes of natural migration towards the coastal areas. In recent years, other factors such as tourism development are adding to the increasing pressure on the coastal environment. It has frequently been the case that developers have built hotels in choice spots with little consideration for the geomorphologic sensitivity of the site (Woodroffe 2003). The rapid increase in coastal population imposes more pressure on the coastal lands through altering the natural habitats to accommodate them that leads to increased erosion.

Many of the world's coasts are becoming increasingly urban with its attended upsurge in population. The coastal zone has become highly attractive for human habitation since it provides some of the most productive and richest habitats on earth (Shan and Hussain 2010; Al-Tahir and Ali 2004). It is reported that about 14 of the world's 17 largest cities are located along coasts, while two-fifth of cities with populations of 1 million to 10 million people are located near coastlines (Tibbetts 2002). The zone is habited by approximately 50% of the global total population (Woodroffe 2003). According to Duedall and Maul (2005), this phenomenon is predicted to increase by 32% in 2025 as more people migrate to the coastal sections. The near coastal population has average densities that are nearly 3 times higher than the global average density (Small and Nicholls 2003). According to Appeaning Addo et al. (2011a), rural urban migration is a major driver in coastal population increase in developing nations. Increased human activities associated with settlement directly affect the coastal zone both positively and negatively, while the results of these activities indirectly impact the coastal section. Such activities have resulted in an alteration of the littoral system leading to accelerated coastal erosion.

The coastal zone is also among the highly invested areas globally. Coastal tourism activities in several coastal nations are a major source of income generation (Duedall and Maul 2005). They represent the fastest growing sector of the global economy and dominate the economy of some sections, where they are the only source of hard currency (Brown et al. 2003). Thus coastal tourism globally is increasingly growing in importance with regard to its scale of operation and contribution to national economies as well as improving the livelihood of local communities. It is estimated that world tourism grew from 160 million to 341 million people in 1985 on an annual growth rate of about 5% (Goldberg 1994). Duedall and Maul (2005) projected tourism growth rate exponentially from 1985 through 2025 and estimated that the total world tourism will grow to 2.5 billion, which is about four times the increase in world resident coastal population. The study concluded that this will significantly affect the coastal environment. Apart from polluting the coastal environment, the increase in tourism development will further reduce the space available for the natural cyclical migration of the shoreline position over time.

Numerous activities within the coastal zone have increased stress on the natural migration pattern of the shoreline. As coastal population and infrastructure development increases, available space more closer to the shoreline are encroached upon and occupied. The encroachment on the coastal land has thus resulted in a 'land squeeze' situation, whereby less space is now available for the coastal zone to accommodate eroding forces or adjust to changes such as sea-level rise.

Study area

Accra is the political and economic capital of Ghana and it lies along the Gulf of Guinea. The location of Accra is at latitude 5.6260 N and longitude 0.10140 W, which influences the climatic conditions that prevail along the coast. The coastal zone is divided into three geomorphic sections (Appeaning Addo et al. 2008). The western section stretches from Bortianor to Jamestown and covers a distance of approximately 14.3 km. This section has fine sand with gentle beaches backed by coastal lagoons and it forms a low-lying terrain with gently rolling hills further inland. The drainage system in this area shows a dendritic pattern and the main rivers are perennial. A sandbar separates the Densu wetlands from the sea. The wetland is important industrially for salt extraction and is also a Ramsar site of international ecological importance as a habitat for approximately 35,000 waterfowl (BirdLife International 2005).

Elevation of the foreshore in the western section rises gradually towards the central section. The western section is considered highly sensitive to erosion (Anokwa et al. 2005). The coastal geology consists of unconsolidated and poorly consolidated rocks mainly from sediments and superficial deposits that belong to the Quaternary age (Muff and Efa 2006). Potential sediment transport rates increases significantly from the western section towards the east (Appeaning Addo et al. 2008). The shoreline is eroding at a rate of about 1.3 m/year in the long term while in the short term erosion rate is about 0.35 m/year (Appeaning Addo et al. 2008). According to Campbell (2006), in the western section of the Accra coast, 17 coastal inhabitants have lost their buildings to coastal erosion over 26 years. This indicates on average of approximately 0.7 houses eroded annually in the western section that is significantly high and thus results in displacement of families. Figure 2 is the map of Ghana showing the location of Accra and an enlarged portion of the shoreline indicating the three geomorphic sections according to Appeaning Addo et al. (2008), while Fig. 3 shows the devastating effect of erosion along portion of the Accra western coast at Glefe.

The opportunity for employment continues to attract an average of about 25,000 migrants per year to the Accra

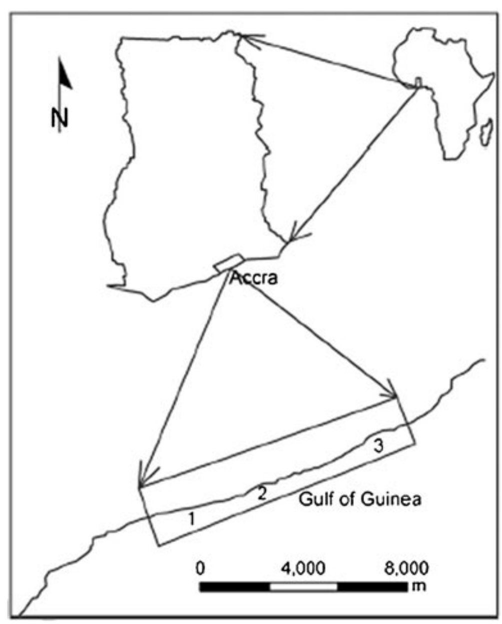

Fig. 2 Ghana map showing Accra and the three zoned sections

Fig. 3 Abandoned buildings due to erosion at Glefe

coastal region and according to Duedall and Maul (2005), this is expected to increase by 82% in 2025. The expanding coastal population has increased pressure on the coastal environment and resulted in increased coastal erosion through unsustainable use of the coastal resources. Increased coastal population has also made planning and decision making about infrastructure location difficult. This has resulted in developments close to the shore with minimum land left for coastal processes. The situation has also created squatter settlement and the World Bank (1995) identified inappropriate mitigating measures to this problem as a cause of high rate of erosion.

Waves approach the open coast from the south-southwest direction. The significant wave height at 50% of the time is about 1.2 m and the period is from 10 to 15 s (AESC 1980; AESC 1988). Three types of current operate along the coast in the west-east direction. They include the longshore current that varies between 0.5 and 1.5 m/s, the Guinea current which can measure up to 0.5 m/s during raining season but is weak most of the year and the tidal current which plays no significant role in the coastal morphology (Wellens-Mensah et al. 2002). The neap and spring tidal ranges are 1.3 m and 0.6 m respectively. The local sea level is rising in conformity with the global trend at a historic rate of approximately 2 mm/year, but this is expected to increase, potentially up to as much as 6 mm/year (Armah et al. 2005; IPCC 2007). Sources of sediment for the coastal zone include cliff erosion, river discharge and seabed erosion, transport through tidal inlets, wind transport gradient, cross-shore transport, bio-geneous deposition and biological activity (Appeaning Addo 2009; Boateng 2012).

Methodology

The method adopted involved identifying and computing changes in the land cover within the coastal area. This gave indication of the spatial development that has taken place within the period under study. The concept was to access if the rate of development and encroachment towards the shoreline is higher relative to the rate of the shoreline moving inland. Two data sets, aerial photographs for the period 1985 and orthophoto representing the year 2005 covering the study area, were used for this study. The data span a period of 20 years, which was long enough for the change analysis. Both data were obtained from the Survey and Mapping Division of Ghana Lands Commission. The data were georeferenced using the 1974 digital topographic map also obtained from the Survey and Mapping Division of Ghana Land Commission.

The accuracy of the reference map, assessed by Appeaning Addo et al. (2008), was adopted for this study. Further positional accuracy test was conducted on the 1974 map by comparing the shoreline positions in rocky areas with shoreline positions on the 1985 and 2005 aerial photographs and orthophotos respectively. This was based on the assumption that shoreline in rocky areas will experience minimum changes and any significant change will indicate error in the data. This increased confidence in using these data for the study. The aerial photos and the orthophoto map were exported and compiled in ArcGIS on the Ghana Metre Grid coordinate system, which made the two data sets compatible for detecting and analyzing change.

A total of four land cover classes were manually identified from the photographs and the orthophoto map. They include built up area, bare/grassland, water/saltpond and bare beach. They were digitized and saved separately as shape files. A site visit was undertaken to verify the land cover classes identified using a hand held GPS. The coordinates observed from the field were reconciled with those from the shape files. The two shoreline positions were carefully identified, digitized and saved separately as shape files. The high water line (HWL) was adopted as the shoreline proxy for this study. This is because it is the geomorphic feature used to represent shoreline position on Ghana maps (Ly 1980; Appeaning Addo et al. 2008). It models the appearance of a shoreline that is detectable on the ground, aerial photographs and satellite imageries. On remotely sensed imageries, e.g. aerial photographs, the HWL appears as a still shore-parallel band that is visible after the tide has receded and the shore has been exposed to drying from the sun. It is usually depicted either by change in colour (greytone) or by a line of seaweed and debris (wave run-up line).

Overlay of the digitized target land cover classes on the aerial photographs and the orthophoto map enabled changes to be identified and computed. The area of the polygons created was estimated using the 'Calculate Geometry' function in Arc Map. The unit of calculation was set to Square kilometers and the results were then exported to Microsoft Excel for the rate of change computation. The shoreline rate of erosion was computed between 1985 and 2005 using the end point rates (EPR) method in the Digital Shoreline Analysis System (DSAS) software. The software, which was developed by the USGS (Himmelstoss 2009), is an extension for ArcGIS and computes rate of change at user specified interval along the shoreline using different methods. A geodatabase was created for the extracted shoreline positions. Each shoreline has attributes which include date, length, ID, shape and uncertainty. The date of acquisition for each image was entered for the date column while the length, ID and shape were automatically generated. The two shoreline positions were then appended to one shapefile for rate calculation.

The DSAS uses measurement baseline method to calculate rate of change statistics for a time series of shorelines. The baseline is constructed to serve as the starting point for all transects cast by the DSAS application. For this analysis the baseline was constructed onshore, taking into consideration the general orientation of the shoreline. Once all the inputs were ready in the database, transects were constructed at 50 m intervals. The transects were cast at simple right angles from the baseline. Historic rates of shoreline change were then calculated at each transect using the end point rate (EPR) method. The EPR is usually employed where only two shoreline positions are available (Crowell et al. 2005; Genz et al. 2007) as was the case for the period between 1985 and 2005. The distance between the two points where the shoreline intercept a transect is calculated and this distance is divided by the number of years that have elapsed in this case 20 years, to give the end point rate.

Results and discussions

The various land cover classes adopted for this study revealed considerable change from 1985 to 2005. The breakdown of the change in the various land cover classes between 1985 and 2005 is tabulated in Table 1. Figure 4 is a graph of the changes that has occurred in the land cover classes identified between 1985 and 2005. The built up area increased by about 33% which was relatively high. Bare/Grassland reduced by about 60%, while the dry beach size reduced by about 35% within the period under study. However, the size of the water bodies (salt pond) increased by 28%. The estimated total area of land lost by human encroachment on the coastal land within the period under study is about 242,139.7 m^2. The historic rate of land lost to human development is about 8,349.64 m^2/year, which is relatively high. However, the historic rate of erosion for the period under study is about 1.92 m/year. Comparing the two rates indicates that human activities are moving closer to the shoreline as compared to the rate at which the shoreline is moving inland.

Table 1 Changes in the various classes in the study area

Class	1986 (m^2)	2005 (m^2)
Built up area	2992765	3971197
Bare/grassland	2895193	1195149
Water/saltpond	1333733	1710142
Bare beach	469896	307071
Shoreline	2882397	3551274
Total area	10573984	10734833

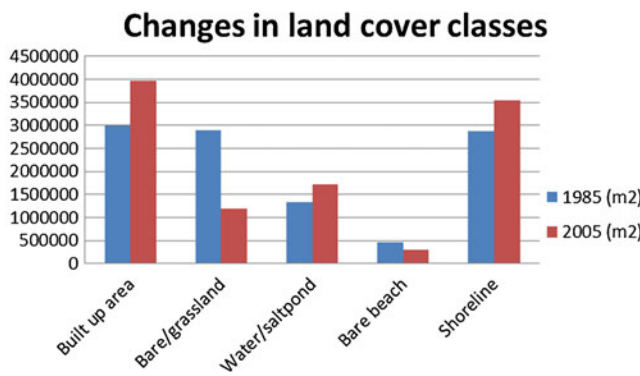

Fig. 4 Changes in the classes

The change in the various land cover classes is shown in Fig. 5. The built up area is extending more in both the eastern and the western sides, thus reducing the bare land cover area. The built up area has thus seen significant increase in development within the period under study and the result corroborates Angel et al. (2011). Field observation during the field work also confirms this as population increase has resulted in unplanned development along part of the eastern side. More surface area covered by water has increased from 1985 to 2005. Parts of the areas classified as grasslands in 1985 are now occupied by water bodies and part of the lagoon system. The sea has significantly moved inland. While pockets of beaches have emerged along portions of the western side, the few ones along the eastern side is fast reducing in size. The size of the riverine system in the eastern side that drains into the sea has reduced significantly.

The observed phenomenon can be explained by several factors. Accra is generally considered as densely populated according to the 2010 national population census (Ghana Statistical Service 2011). Every available land along the coast is a potential space for infrastructural development to accommodate the increasing population. This is evident by the reduction in bare/grassland cover that have been cleared for infrastructure development. The built up area also increased significantly during the period under study to facilitate accommodating the increased population. The rapid infrastructure development along the eastern and western sides of the study area relative to the central part is as a result of the presence of the Densu Wetlands in the central part. Population increase along the Accra coast has resulted in an urbanisation rate of 52% per year (Churcher 2006).

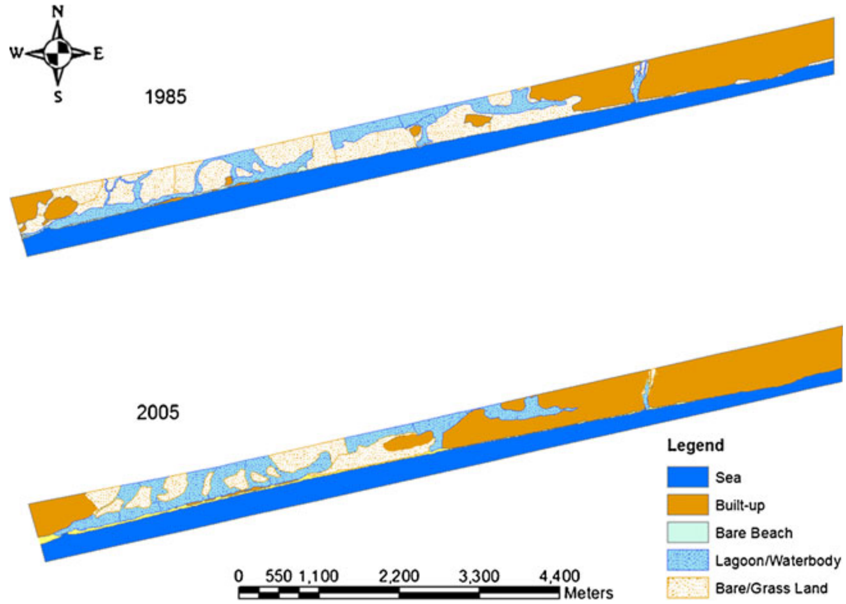

Fig. 5 Land Cover classes for the study area

The situation has created squatter settlement (Appeaning Addo 2009) and the World Bank (1995) identified inappropriate mitigating measures to this problem as a cause of high rate of erosion. The study area is eroding at a relatively high rate, which explains the decrease in the size of the beaches. However, portions along the shoreline in the western side experienced accretion during the period under study as a result of the presence of exposed rock outcrops. The rocks trap sediment to build the up drift beach and starve the down drift of sediment.

The presence of natural fish landing sites (Appeaning Addo 2009) attracts fishermen from other parts of Ghana to reside in the study area. Most of the local inhabitants use the beach sand to build their houses, which ends up affecting the sediment budget in the area. Lack of jobs for the local population has made some of the local inhabitants to engage in mining and selling beach sand (Mensah 1997). Although this activity is banned, the presence of a readily available market for the commodity and lack of enforcement of the ban is making the business to thrive. Trenches created as a result of the sand mining activities in the grasslands areas have been filled up with water. This in part explains why sections of the areas classified as grasslands in 1985 are now occupied by water bodies and part of the lagoon system.

The coastal areas are also responding to the government policy to develop coastal tourism. This has resulted in the springing up of holiday resorts along the beach, increased tourist activities and their associated problems, such as pollution and solid waste generation, in the study area. Greater percentage of the increased solid waste generated by the inhabitants is deposited into the riverine system. This explains the silting of the river in the eastern side and the reduction in the size of the river between 1985 and 2005. Despite the relatively huge cost in constructing within the wetlands, the emerging coastal tourism development along the coast has resulted in considerable increase in hotel infrastructure development within portions of the wetland through reclamation of the lands (Alvarado 2003). Again to accommodate the increasing population, coastal lands are reclaimed and used for construction (Alvarado 2003). Over harvesting of mangroves for construction and as firewood by the settlers has exposed the previously vegetated areas and increased the surface area covered by water. The increase in small scale salt mining activities as a source of livelihood has resulted in constructing more saltpans that has also increased the surface area covered by water.

Although the shoreline is moving inland in the study area at a relatively high erosion rate, the rate of human activities and development moving towards the shoreline position is higher. Thus available land for the shoreline cyclic activities gets occupied resulting in a "land squeeze" situation.

Conclusion

Although coastal erosion is a natural phenomenon, the study has revealed that activities of man have impacted several areas of the shore significantly. It has initiated fresh erosion problems along portions of the coast, while in other areas it has exacerbated the erosion problem. Space available for the cyclic activity of the shoreline has been taken over by human development. This conflict has resulted in 'land squeeze' situation. The study has demonstrated that, although the shoreline's natural migration inland is encroaching on settlement, problems in the coastal zone has increased because settlement is rather encroaching on the available land for shoreline dynamic change in Accra at a relatively faster rate. It is recommended that setback lines should be put in place in the study area to prevent human development taking over available lands for the shoreline's cyclic activities as well as the shoreline threatening development.

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