



Impacts of lagoon opening and implications for coastal management: case study from Muni-Pomadze lagoon, Ghana

K Sian Davies-Vollum¹ · Zihao Zhang² · Andrews Agyekumhene³

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Abstract

Lagoon-barrier systems are a dynamic coastal environment. When an ephemeral connection between a lagoon and the ocean develops, it has significant impact on hydrology, sedimentology and ecology. Increasingly, human actions and sea level rise also influence lagoons with the potential to increase their connectivity with the ocean. The Muni-Pomadze lagoon in central Ghana is a small lagoon-barrier system that is intermittently open to the ocean. Following opening in 2014 the lagoon was open to the ocean for more than two years. Causes for the unusually long period of lagoon opening are unclear although human intervention has played a role. Field observation, digital mapping and GIS analysis of the shoreline during the two year period of lagoon opening has enabled an understanding of how the lagoon-ocean connection has impacted coastal morphology, erosion and sedimentation. Opening has resulted in rapid changes to the location of the barrier breaching (tidal inlet), erosion on the barrier and sedimentation in the lagoon. Such modifications have implications for local resources and ecosystem services that underpin the livelihood and wellbeing of local communities. Elucidating how a connection to the ocean impacts lagoons and the coastal communities they support are important to managing lagoons not only in Ghana but across West Africa.

Keywords Lagoon · Shoreline change · Ghana · Coastal management

Introduction

Lagoon-barrier environments are estimated to occupy 13% of coastal areas worldwide (Duck and De Silva 2012) where they are found along tectonically-stable, low-lying coastlines. They are highly productive ecosystems that provide a wide range of natural functions (Flower and Thompson 2008). The lagoons and the barriers fronting them formed as sea levels rose at the start of the Holocene. Rising sea levels transported sand onshore

depositing it at the mouth of estuaries to create beach barriers that impound lagoons behind them (Dias et al. 2000). Beach barriers are by nature transient, responding to variations in sea level and coastal sediment budget as well as changes in local weather, oceanic and hydrological conditions (Kjerfve 1994). Increasingly, human influences play a key role in their evolution and development (Escudero et al. 2014). The complex interplay of physical and human variables influences the geomorphology of barriers and the incidence of tidal inlets (lagoon openings). The spatial and temporal extent of inlets along a barrier then controls the connectivity between the lagoon and ocean. A shift to a more open connection to the ocean can impact the whole lagoon system (Duck and de Silva 2012) strongly influencing sedimentation, erosion, water quality and ecology. Understanding the nature of the ocean-lagoon connectivity and the impacts of lagoon opening are thus important for managing these coastal systems (Spaulding 1994). With projected sea level rise linked to an increasing likelihood of more open lagoons, understanding the impacts of lagoon opening is particularly critical for long term coastal zone management.

As coastal populations have grown globally there is increasing potential for human intervention to modify lagoon systems and their ocean connectivity (Evans 2008). Human influence on lagoon opening may be direct or indirect. Direct

✉ K Sian Davies-Vollum
s.davies-vollum@derby.ac.uk

Zihao Zhang
zz3ub@virginia.edu

Andrews Agyekumhene
andyaohene@yahoo.com

¹ Environmental Sustainability Research Centre, University of Derby, Kedleston Rd, Derby DE22 1GB, UK

² University of Virginia, 110 Bayly Dr, Charlottesville, VA 22903, USA

³ Muni-Pomadze Ramsar Site, Wildlife Division (Forestry Commission), P.O. Box 202, Winneba, Ghana

intervention seeks to maintain an opening between the lagoon and ocean, often for boat access and navigation (Duck and de Silva 2012). Direct intervention may include dredging, either as part of a coastal management plan or on a more ad hoc basis, and the construction of hard engineering structures. Indirect impacts involve changes in the sediment budget, which may be associated with damming of rivers (Boateng 2012a) or emplacement of hard engineering structures that block longshore currents. The nature of the connection between a lagoon and the ocean is critical for communities that are directly reliant upon these coastal environments for their economic livelihood and welfare (Moreno et al. 2010). Coastal communities in less economically developed countries (LEDCs) located around lagoons are especially dependent on them (Hollis et al. 1988). However, in many LEDCs coastal management plans are lacking and coastal management takes an ad hoc approach (Linham and Nicholls 2012). In some coastal communities in LEDCs, indigenous customs also influence management of the coastline (Ntiamao-Baidu 1991).

Lagoon environments are common along the low-lying, sandy coastline of West Africa on the Gulf of Guinea. Here, coastal populations are dependent on lagoons for subsistence and small-scale economic enterprise. A tropical climate strongly influenced by the seasonal movement of the ITCZ causes strongly seasonal rains and storms that can cause natural breaching of lagoon barriers. The many lagoon-barrier systems on Ghana's low-lying coastline and recent research on coastal change in the country (for examples see Appeaning Addo 2011; Sagoe-Addy and Appeaning Addo 2013; Appeaning Addo 2014; Boateng 2012b) make it an appropriate West African location to study these environments. More than 70% of Ghana's population live along the coastal strip with maximum population densities occurring at the coast (Ghana Embassy 2014). Resultant population pressure at the coast has caused increasing impact on coastal resources.

In this study, we use a combination of digital image analysis, GPS mapping and field evidence to document physical changes that took place at the Muni-Pomadze lagoon in Ghana during an unusually lengthy period of lagoon opening between 2014 and 2016. We consider how these changes impacted the local community as well as how they might influence future evolution of the lagoon. Finally, we suggest how this case study might be used to inform management practices at similar coastal environments.

Study area

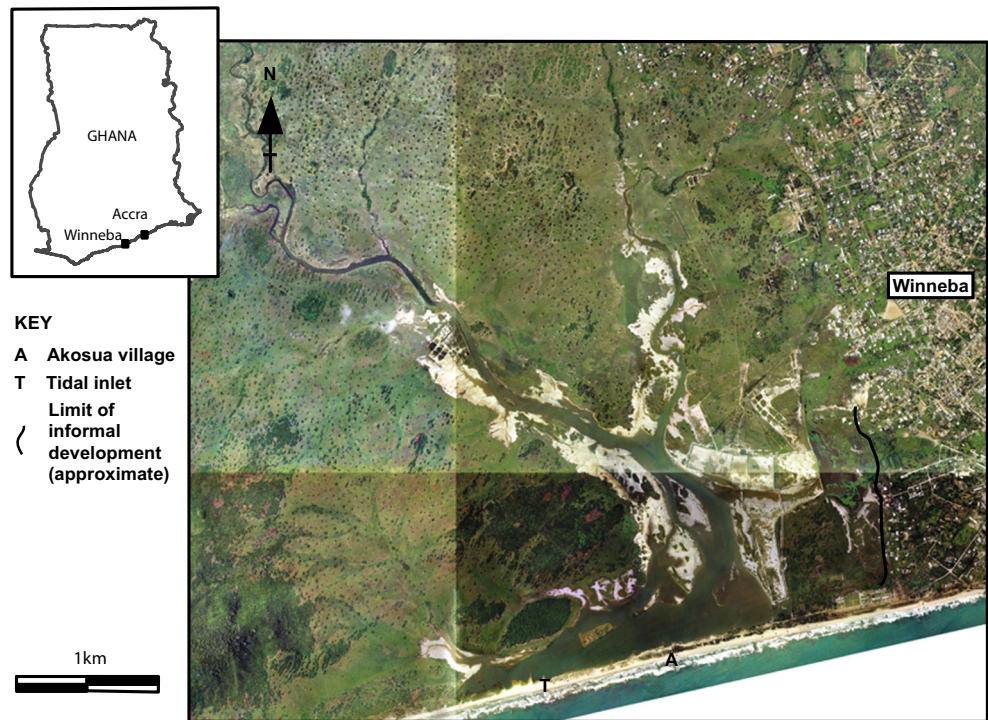
The Muni Pomadze lagoon (MPL) is situated on Ghana's central coastline on the western edge of the town of Winneba, 60 km west of Accra (Fig. 1). This coastline experiences medium wave energy (Wellens-Mensah et al. 2002) and is mesotidal with an average tidal range of approximately 1 m (Boateng 2012a). The average rate of sea level rise over

the twentieth century from measurements taken at the Takoradi tidal station in W. Ghana (the nearest station to Winneba) is 3.34 mm/year (Sagoe-Addy and Appeaning Addo 2014) although the country's Environmental protection Agency (EPA) has predicted that sea levels will rise by 1 m during the twenty-first century (Mensah and Fitzgibbon 2013). The Winneba area experiences a major wet season from March to July and a minor wet season from September to November (Gordon et al. 2000). The lagoon is separated from the ocean by a 2 km long beach barrier that is permanently connected to land at its eastern side (Fig. 1). Three small rivers drain into the lagoon with a catchment area of approximately 90 km² (Wuver and Attuquayefio 2006). The discharge of these rivers fluctuates greatly between wet and dry seasons. At the end of the major wet season (late June) the height of the water in the lagoon can reach a maximum of 2 m and the lagoon covers approximately 1000 ha but by the end of the dry season the area covered by water shrinks to as little as 100 ha and salinity can reach 165‰ (Gordon et al. 2000). Breaching and the creation of a tidal inlet at the western end of the barrier take place at the end of the heaviest rainy seasons, approximately once every ten years (Gordon et al. 2000) when water levels in the lagoon are at maximum height. Once the fresh water is released the inlet is rapidly sealed by deposition of sand transported by longshore currents from the west (Ly 1980). The lagoon is of global significance as a staging post for migratory birds (Ntiamao-Baidu et al. 2000) and received Ramsar designation in 1992 for its importance as a coastal wetland (Ryan and Ntiamao-Baidu 2000). Compared to other lagoon settings in Ghana, MPL has relatively high quality water (Nixon et al. 2007) and was noted as having the greatest habitat diversity and least human encroachment of any of Ghana's five Ramsar designated coastal wetlands (Ryan and Ntiamao-Baidu 2000). The Ramsar designation as well as practices based on indigenous traditions (Wuver and Attuquayefio 2006) afford some management of the lagoon. A small fishing community (Akosua village) is located directly on the barrier and its inhabitants are dependent on the lagoon and coastal waters for their livelihood. In addition, townspeople living on the edge of the lagoon use its resources. Sometime between November 2013 and July 2014 the lagoon barrier was breached at its western end and remained open until at least July 2016.

Materials and methods

We used a combination of field observations, photographic evidence, GPS mapping and Google image analysis, as well as lagoon salinity and depth measurements, to document the physical changes to the barrier and lagoon during the 2014–2016 opening. In January 2017, a focus group discussion with the Akosua village was conducted that included questions about the lagoon opening. Field observations were made between

Fig. 1 Location of Muni-Pomadze lagoon showing location of tidal inlet, Akosua village and approximate extent of development on eastern edge of lagoon. Aerial image from 2005



July 2014 and July 2016 and recorded photographically. Changes in the morphology of the breach region and location of the stable end of the barrier were mapped in July 2014, January 2016 and July 2016 using a Garmin GPS unit. A study of Google Earth images dating from 2000 to the present, aerial photos from 2005 and topographic mapping from 2005 supplemented field observations and provided a longer-term context for the nature of the connection between the ocean and lagoon. Water salinity and depth were recorded monthly by the local Forestry Commission from 2011 to 2016 at the south of the lagoon, close to the tidal inlet. Salinity of surface water was measured using a hand-held refractometer. Water depth measurements were taken from fixed stations using a depth pole graduated in cm. General information on resource use and human activity in the lagoon area was obtained from the local Forestry Commission, who oversee the Muni Pomadze Ramsar site. Specific information regarding resource use and traditional lagoon management practices of the inhabitants of the Akosua village was gathered during the focus group discussion.

Results

Status of ocean-lagoon connection

The combination of Google Earth imagery and field observations shows that the lagoon-ocean connection has remained open during both wet and dry seasons between July 2014 and July 2016 (Table 1). Google Earth data from 2000 to 2013 is only for the dry season and shows the lagoon as closed

(Table 1). There is no image data for the period November 2013 to July 2014 but anecdotal evidence from local residents suggests that the lagoon was open early in 2014.

Geomorphological change along the barrier

For most of its length the lagoon barrier is stable and vegetated with a height of up to 2.5 m above sea level. At its western end where breaching occurs and a tidal inlet develops (Fig. 1), the barrier lacks stabilising vegetation and is of a lower elevation. Google Earth images from 2000 and 2013, together with aerial imagery from 2005, are very similar showing the lagoon closed by a sand accumulation that narrows to the east (Fig. 2). Google Earth images from November 2013 to July 2016, together with field observations, show changes that

Table 1 Status of lagoon-ocean connection

Date	Source of information	Lagoon-ocean connection
July 2016	Field observations	Open
February 2016	Google Earth image	Open
January 2016	Field observations	Open
July 2015	Field observations	Open
May 2015	Google Earth image	Open
July 2014	Field observations	Open
November 2013	Google Earth image	Closed
January 2013	Google Earth image	Closed
December 2000	Google Earth image	Closed

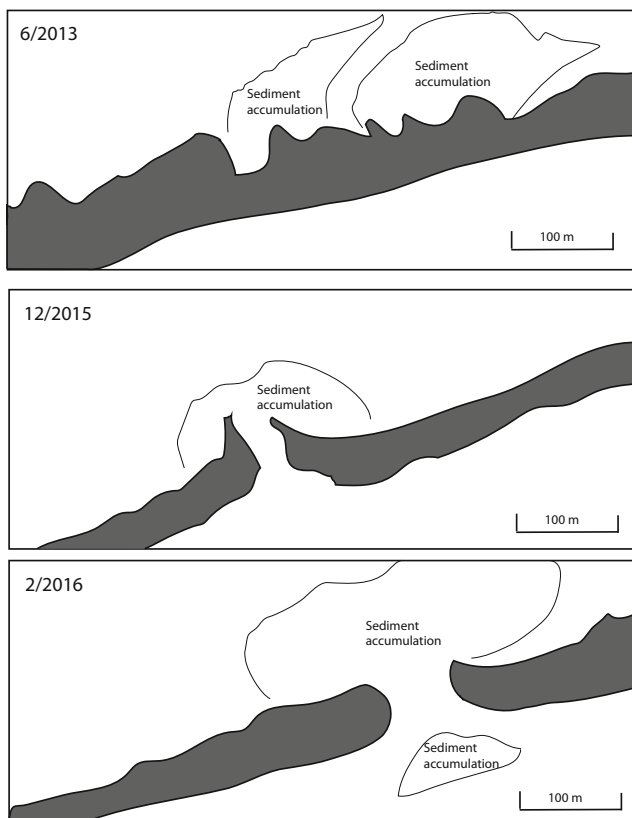


Fig. 2 Geomorphological changes at the barrier breach. Sketches are made from overlay of Google Earth images. Dates of images are given on the figure

occurred during lagoon opening. The image from November 2013, prior to the extended opening, reveals evidence of sediment transport into the lagoon during previous openings. The development of a tidal inlet delta as well as asymmetric, eastern trending shoals and small spits on the lagoon-side of the barrier can be seen.

Sedimentation Observations from July 2014 reveal an open breach with active transport and sediment accretion in the lagoon. Imagery from 2015 is poor but reveals a tidal inlet with small spits on either side that taper into the lagoon. Images from February 2016 show accretion of sediment along the unstable barrier to the west of the tidal inlet and in the lagoon, east of the tidal inlet (Fig. 2). Field observations in July 2016 reveal further accretion of sand to the west of the inlet and continued sand transport into the lagoon evidenced by the development of sand shoals to the east of the tidal inlet (Fig. 3).

Location of tidal inlet GPS mapping reveals that during the 2014–2016 opening there was a shift eastwards of the tidal inlet. Figure 4 shows the positions of the eastern (barrier) side of the inlet in July 2014, January 2016 and July 2016 superimposed on aerial image from 2005. Between July 2014 and January 2016 the eastern side of the inlet shifted 98.5 m eastward; between January 2016 and July 2016 it shifted a further 85 m to the east.

There was no evidence of tidal inlets forming or any wash-over occurring elsewhere along the barrier.

Erosion During opening, erosion of the end of the stable, vegetated barrier was minimal as evidenced by palm trees at the barrier end remaining in place (Fig. 5). However, there was erosion of the unstable barrier below it with a stepped profile and berm forming (Fig. 5). Although the stable barrier did not lose any of its length to erosion, it narrowed by approximately 2 m due to erosion on its lagoon side. Narrowing caused the toppling of palm trees into the lagoon and created a near vertical cliff of 2.5 m maximum height (Fig. 5).

Salinity and water depth

Figure 6 shows monthly salinity and water depth measurements for the period 2011–2015 in the lagoon, close to the inlet. The annual salinity and depth variations between wet and dry season can be seen for all years. The influx of river water during the main wet season (March to July) decreases salinity and increases water depth. Minimum water depth and highest salinity occur during the dry season (December to February). There are no clear salinity and water depth trends over this time. However, the maximum average water depth occurred in 2011 and the minimum was in 2015 indicating a general shallowing of the lagoon over time. The maximum average salinity over the five year period was recorded in 2011, and the minimum during 2015 indicating a general reduction in salinity extremes when the lagoon remained open.

Local practices influencing lagoon opening

There are both traditional and ad hoc local practices that influence lagoon opening. Information from the focus group discussion confirmed that traditional opening ceremonies have taken place at the end of the rainy season to prevent rising lagoon water from flooding homes on the lagoon barrier and eastern shore. The ceremonies involve dredging of the low, unstable barrier to create an outlet to the ocean that allows impounded lagoon waters to drain. However, it seems that there was not an opening ceremony in 2014 and that natural breaching of the sand barrier formed the tidal inlet. Once the lagoon is breached, the openings can be maintained by individual ad hoc actions of fishermen, who drive canoes through the tidal inlet during low tide. According to the Forestry Commission, the driving of canoes through the inlet at MPL occurred throughout the period of lagoon opening from 2014 to 2016.

Discussion

Between 2014 and 2016, the connection between MPL and the ocean persisted for longer than previous research

Fig. 3 Barrier breach (a) and accumulation of sand on lagoon side of breach (b). Both images taken July 2016



(Gordon et al. 2000) and observations have indicated. The opening of the lagoon occurred through natural breaching of the barrier at the end of the 2014 rainy season. Reasons for the extended opening of the lagoon are unclear. There is no evidence for coastal engineering to the west of MPL, which would disrupt longshore currents and reduce sediment transport to the area. However, the ad hoc intervention of fishermen driving canoes through the tidal inlet helped to maintain the connection between the ocean and lagoon. The major shoreline changes associated with long-term lagoon opening were the narrowing of the stable barrier with

associated loss of stabilising trees, a shift in the location of the tidal inlet towards the stable barrier and the accretion of sand bars and shoals in the lagoon. These changes have reduced the stability of the barrier in the area of the tidal inlet and thus increase the incidence of future opening.

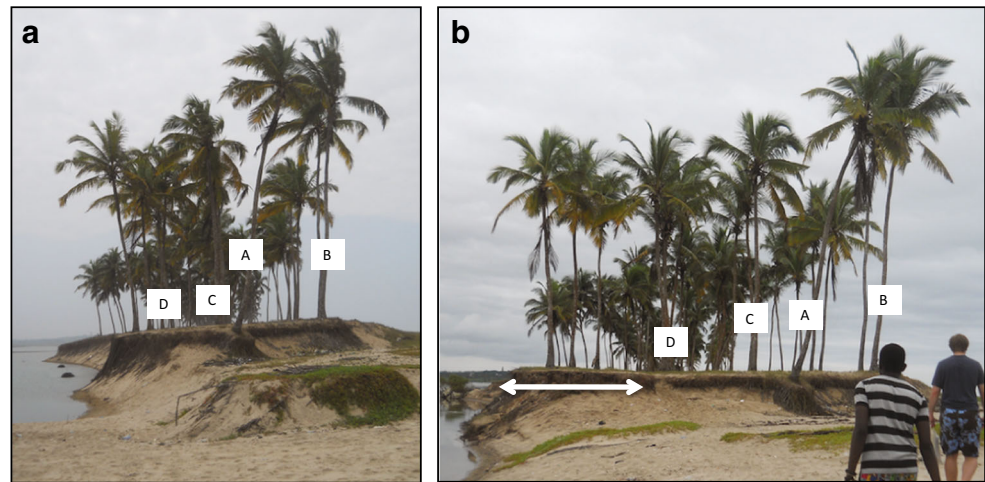
Shoreline change during lagoon opening

The continual lagoon opening from 2014 to 2016 changed the locus of erosion resulting in barrier narrowing rather than shortening. In 2014, recent erosion at the end of the barrier



Fig. 4 Positions of the eastern (barrier) side of the breach in July 2014, January 2016 and July 2016 plotted onto 2005 aerial image

Fig. 5 Erosion at barrier breach. Photo (a) was taken July 2016. Photo (b) was taken July 2014. Letter labels identify the same coconut palm at each date. The loss of trees on the lagoon side and narrowing of the barrier can be seen



is apparent from the exposure of roots at the barrier tip (Fig. 5). However in 2015 and 2016, during lagoon opening, the loss of trees and root exposure is on the lagoon side of the barrier. Here, the barrier narrowed by 2 m and erosion has also produced a steep cliff face. During this time, trees at the barrier end have remained stable as noted by the presence of same coconut palm with roots exposed labelled 'A' in Fig. 5. The shift in site of erosion may be due to prevailing winds from the west driving waves against the backside of the barrier as well as eddies, associated with incoming tides, forming behind the barrier. Erosion of 2 m in two years is similar to average coastal recession rates of 1.5 m/year for the Ghana coastline (Wiawe 2010). However, it is lower than the average barrier erosion rate at MPL of 4 m/year. observed between 2005 and 2014 (Davies-Vollum and West 2015) and lower than maximum erosion rates observed in Ghana of 5.5 m/year. (Boateng 2012a). The 2014–

2016 lagoon opening has not increased rates of erosion; instead it has resulted in a shift in the location of erosion. Such shifts in erosion 'hot spots' are significant for understanding threats to dwellings or infrastructure on barriers. Consideration of average recession and erosion rates might mask this complexity. In addition to barrier narrowing, the tidal inlet moved 183.5 m eastwards, towards the stable, vegetated barrier (Fig. 4). The shift in the location of the inlet closer to the stable barrier base increases the potential for further barrier erosion. Future lagoon openings are likely to result in further encroachment of the tidal inlet on the stable barrier and continued erosion, increasing the potential for more frequent opening.

During opening there has been transport of sediment into the lagoon and sand shoals have formed on the eastern, lagoon side of the tidal inlet (Fig. 3) resulting in shallowing. Monthly water depth measurements made close to the tidal inlet also reveal an

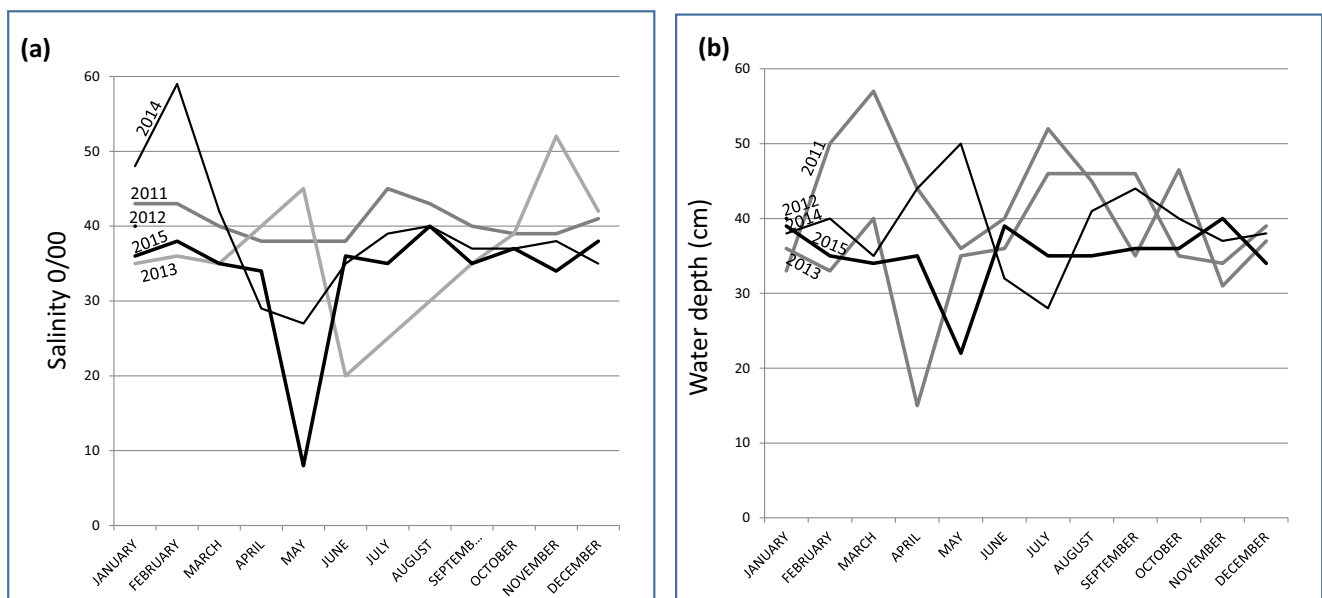


Fig. 6 Monthly (a) salinity (in parts per thousand) and (b) water depth (in centimetres) measurements for the period 2011–2015. Data courtesy of MPL Forestry Commission

average depth decrease between 2011 and 2015. The process of rapid infilling of a lagoon as it transitioned from intermittently open to open was observed by Morris and Turner (2010) at lagoon-barrier sites in Australia and the general consensus is that open lagoons act as natural sediment sinks, evolving by infilling (Boyd et al. 1992; Nichols and Boon 1994). If transport of sand into MPL continues during open periods it has the potential to fill the lagoon and seal the lagoon inlet. Boateng (2006) compared Ghana's coastal surveys in 1945 and 1972 and noted that sites of sediment accretion occurred where longshore drift had been intercepted. The transport and accumulation of sediment into the lagoon has the potential to impact the longshore transport of sand eastward. Continued accumulation of sediment in the lagoon may thus reduce the longshore sediment budget to the east of MPL with associated potential for beach erosion along Winneba's shoreline. There is no evidence for breaching or wash-over along the barrier other than at the site of the current tidal inlet. There are a few very small wash-over fans but these are vegetated and have remained the same size and shape in all visual records dating from 1970s to the present.

Projected shoreline change

Consideration of future change to the barrier has to take into account the complex interplay of short-term physical changes due to lagoon opening and the longer-term impact of sea level rise (SLR). Davies-Vollum and West (2015) looked at the impact of projected SLR on the MPL barrier and predicted barrier fragmentation with breaching at multiple barrier low points. However, given recent observations of erosion and geomorphological changes during the 2014–2016 opening, it is likely that in the short term, opening of the barrier will be focused in the area of the recent tidal inlet rather than at multiple low points. If extended lagoon openings continue to occur, the shift to more open lagoon conditions is also likely to occur earlier than predicted by Davies-Vollum and West (2015). Any coastal development and engineering to the west of MPL would contribute to extended opening by reducing longshore transport of sediment and decreasing the potential for closure of the lagoon. In the longer term, future SLR might be expected to increase the incidence of wash-over at low points along the barrier as predicted (Davies-Vollum and West 2015) causing barrier break-up. This is particularly likely if SLR is rapid such that over-washing and accretion of sand in the lagoon does not keep up with erosion at the barrier shore face (Moore et al. 2014). Implications of both observed short term and predicted longer term physical changes along the barrier are important for forming part of coastal management plans and management of ecosystem services.

Ecosystem services

Populations reliant on lagoons for resources have controlled the extent of water exchange with the ocean to manipulate

ecosystem services. The control of the ocean-lagoon connections can ensure salinities that favour certain species and depths that facilitate food production (Chapman 2012). Lagoon openings have also been created to manage floods and water quality (Schallenberg et al. 2010). The opening at MPL has multiple impacts on the lagoon's ecosystem services, most notably related to biodiversity and flooding.

The physical impact of maintaining a more permanent connection to the ocean is to potentially create more stable salinity and water depth in the lagoon. Gordon (2000) observed that breaching occurring as part of the lagoon flood cycle resulted in a five-fold drop in salinity. Although salinity data from 2011 to 2015 do not show any obvious trends, the annual minimum average salinity for this period occurred in 2015 suggesting that lagoon opening may have some stabilizing effects on salinity. The stabilization of salinity levels has a rapid and significant increase on lagoon biodiversity. Maintaining an open inlet allows movement of organisms between the ocean and the lagoon resulting in increases to the invertebrate and fish populations. This was observed during a breach event at MPL in the 1990s (Gordon and Ankrah 1999). The increase in fish and shellfish in the lagoon in turn impacts organisms higher up the food chain. For example, during a breach event in 1994, Ntiama-Baidu et al. (2000) noted a 40% increase in migrating birds visiting the site. Local inhabitants may take advantage of the increased biodiversity during lagoon opening to harvest shellfish and fish.

The creation of a long term opening at MPL impacts inundation of coastal settlements on the barrier community that live on the eastern shore of the lagoon (Fig. 1) as well as in the Akosua village. During the rainy season, waters impounded in the lagoon impinge on settlements on the low-lying eastern edge of the lagoon and the barrier (Fig. 1). This flood risk may have had the effect of preventing development in this area and encroachment of dwellings onto the lagoon. However, this side of the lagoon is adjacent to the town of Winneba (Fig. 1) and there is much pressure for expansion. With an open connection to the ocean, the lagoon drains during the rainy season and flood risk to the community decreases. With reduced flood risk the lagoon shoreline becomes a more attractive location for settlement. Development is already taking place with unplanned, informal construction of dwellings observed in 2016. However, any reduced flood risk realised by lagoon opening is likely to be short term as rising sea levels bring increased incidence of inundation from the ocean.

Implications for coastal management

There has been much debate regarding best management practices for lagoons and of the advantages and disadvantages of human intervention (Schallenberg et al. 2010). The practice of opening a lagoon as part of a coastal management strategy has

been discussed as a viable option. Wainwright and Baldock (2013) noted that management of lagoon barrier systems often requires artificial entrance opening and Korateng et al. (2000) suggested keeping a permanent link between sea and lagoon as a way to maintain physical and chemical properties of lagoon water. At MPL it is unclear whether maintaining an open the lagoon has sufficient benefits to warrant this as part of a management strategy. Lagoon opening has the potential to improve the economic livelihoods of the local communities through the prospect of increased fishing and it can reduce the risk of flooding to dwellings on the MPL barrier and shore. However, a more permanent opening has resulted in sediment accretion in the lagoon and barrier erosion, which may be perceived as disadvantages. Sediment accretion can impact longshore transport of sediment while barrier erosion can increase the likelihood of future opening as well as damage infrastructure and dwellings. In addition, the decreased flood risk associated with an open lagoon may encourage unmanaged development on the lagoon shores, which can result in resource depletion and environmental degradation.

Coastal management at lagoons must also consider SLR (Chapman 2012). Davies-Vollum and West (2015) considered maintaining a permanent lagoon opening as a management strategy to deal with SLR at MPL. However, the recent observed physical changes associated with a two-year lagoon opening make this management strategy less attractive. The complex impacts of lagoon opening suggest that there is no clear management strategy for these environments but that any strategy needs to take into account physical and ecological changes associated with opening, the longer-term repercussions of SLR and the needs of coastal communities. Monitoring ocean connectivity and the specific physical and biological changes associated with it is recommended for future planning at lagoons.

Lagoon-barrier systems are widespread, found not just in Ghana but along the West African coastline. The impacts of more open lagoons, as evidenced by the situation described herein for MPL, are of relevance to coastal settlements across West Africa. Modification of the lagoon-ocean connection can lead to shifts in patterns of erosion and sedimentation and alteration of ecosystem services. Understanding the nature of these changes is key to managing the dynamic lagoon environment and can help elucidate possible future changes associated with SLR and the vulnerability of lagoon-barrier communities. This is particularly critical for African coastlines that are experiencing rapid population growth and immigration (Hinkel et al. 2012), which brings increased pressure on coastal resources and ecosystem services together with a need to manage them effectively.

Conclusion

The Muni-Pomadze lagoon experienced an extended open connection to the ocean between 2014 and 2016. The opening

was caused by natural breaching processes that occurred at the end of the rainy seasons. Reasons for the extended period of lagoon opening are uncertain although it was facilitated by local people driving boats through the tidal inlet at low tide. The open connection between the lagoon and ocean resulted in increased sedimentation in the lagoon, narrowing of the lagoon barrier and shifts in the location of the tidal inlet and sites of erosion. These changes have the potential to destabilize the barrier and increase the likelihood and extent of future lagoon opening. During lagoon opening changes to ecosystem services included an increase in fishing prospects and a decrease in flood risk. Local studies such as this one are important in understanding how lagoons respond to an increased connection to the ocean and how local communities may manipulate and react to lagoon opening. With concurrent pressures of increasing populations and physical changes associated with sea level rise, an increased understanding of ongoing and projected changes to lagoons and the communities they support is important in developing integrated management plans. This is particularly true in LEDCs, where coastal communities are dependent on resources at the subsistence level.

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