A Rapid Ecohydrological Assessment of the Ruvu River Estuary, Tanzania

Tanzania Integrated Water, Sanitation and Hygiene (iWASH) Program

Mouth of the Ruvu Estuary looking out towards the Indian Ocean, photographed at high tide in June.

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Executive Summary

This report describes the results of the first rapid ecohydrological assessment of the Ruvu River estuary (June 18-28, 2013). The specific objective was to begin understanding how the plant and animal communities are related with the salinity and flow regime in the estuary. To do so, baseline data was gathered on estuary channel depth, flow velocity, salinity and water quality, riparian vegetation community structure, marine vegetation and fish species and the presence/absence of large terrestrial and marine predators in the estuary. These baseline data are a subset of the inputs necessary to ultimately determine the minimum freshwater inflows required in the Ruvu river to maintain the estuarine ecosystem and the human communities that have been depending on them for millennia.

The survey results presented in this report provide a snapshot of the wet-dry season transition. Because salinity in the estuary varies not just with location and tide but also with the seasons, additional baseline salinity data in other seasons are necessary for obtaining the salinity profile of the Ruvu estuary over a year. This report proposes a monitoring program to obtain this additional data as well as the studies necessary for a detailed understanding of the connections between freshwater flows, salinity and the ecosystem communities.

Background

Freshwater inflows via rivers maintain estuarine plant and animal communities, which provide a range of valuable ecosystem services such as maintaining fisheries, providing timber and forest products for coastal communities, protecting shorelines against wave erosion and resisting seawater intrusion into coastal aquifers in the vicinity of estuaries. However, the increasing demand for water upstream from the Ruvu River, as well as increasing uncertainty of rainfall due to climate change and runoff resulting from land cover change implies that decreasing freshwater inflows to Ruvu estuary is a very real possibility. Decreasing freshwater inflows will result in increasing salinity over the usual seasonal range and duration; conditions that negatively affect both aquatic and riparian communities.

Specific guidelines on seasonal minimum inflows into the estuaries are required for sustainable management of estuaries and coastal areas. Developing these flow guidelines in turn requires an understanding of the ecosystem communities (aquatic and riparian) and their functioning in relation to hydrology, primarily salinity, flooding duration and water depth.

- The first task therefore is to characterize the ecosystem communities as well as the salinity regime in the estuary.
- The second task is to establish connections between estuarine communities and salinity.

Results from this survey

<u>Hydrology and water quality:</u> The latter half of June sees the transition from the wet to dry season, with the river flow magnitude being in between the seasonal high and low flows. Based upon limited sampling about 4-6 km upriver from the mouth, the freshwater discharge over the sampling period in June was computed to be around 30 m^3/s. There was no clear unidirectional flow at the estuary mouth owing to the opposing mix of tides and freshwater, hindered by wind; surface flow was 0 m/s. Seawater was found to extend about 12 km upriver from the river mouth at high tide, and up to 8 km at low tide; spring tides corresponding to the full moon phase occurred over the survey and were 3-4 m at the mouth of the Ruvu River. Channel depth ranges from 1-3 m at the mouth of the river with presence of sandbanks and mudflats, and increases upstream, reaching 8 m at the scouring sides at river bends. Dissolved oxygen, critical to aquatic life, varied from 7.40 mg/l at the mouth (well mixed with ocean waves) and decreased upstream to 6.2 mg/l. Turbidity was high in the river (less than 8 cm), intermediate at the mouth while seawater was clear.

Riparian vegetation and salinity: Mangroves are the only group of trees able to tolerate salinity, and hence the mangrove to palm (*Phoenix reclinata*) transition zone indicates the extent of average seawater ingress into the Ruvu River, seen to be 8-10 km upriver from the mouth. Salinity measurements at both low and high tides in this zone indicated fresh and slightly brackish values respectively (the furthest upstream where values > 0.5 ppt were observed). However it is likely that seawater intrudes further upstream in the dry season coinciding with the lowest freshwater inflow and spring tide combination.

Mangrove species are known to vary in their salinity and flood tolerance (eg Semesi 1991). This leads to species with the highest flood and salinity tolerance (*Sonneratia* and *Rhizophora*) to occur at the edges of the bank that are flooded at high tide followed by *Avicennia* with intermediate tolerance while mangroves with less tolerant of flooding such as *Ceriops, Xylocarpus* and *Hereteria* occupy higher ground inland, that also have sandier soil while the shores have more loam and organic content. This horizontal zonation of mangroves can be monitored periodically along with salinity measurements to constitute a long-term seawater intrusion monitoring program. This report includes resources to both identify mangrove species in the Ruvu estuary as well as the locations and descriptions of different mangrove communities that constitute the 2013 baseline reference for future monitoring.

Aquatic communities: Fishing surveys were conducted throughout the Ruvu River estuary and adjacent waters. An attempt to sample all associated habitat types was made and thus fishing was conducted in freshwater upstream, brackish estuary, river mouth, coastal mangrove, seagrass, and coral reef habitats. Nine 550 m benthic longlines with 40 – 70 baited hooks of various sizes were set and soaked for 1-2 hours. Any animals caught were measured and sampled for stable isotope analysis. Although this widely accepted fishing method and variations thereof are used to catch a variety of shark, ray, and bony fish species, African catfish (*Arius africanus*) were the only species caught throughout the entire sampling effort. It is possible that low catch rates could reflect a low abundance of predatory fish in the system at the time of survey, however, we suggest complementing these surveys using gillnets and working in close collaboration with local fishermen to undertake additional fishing surveys in the Ruvu as well as in the Wami.. No marine mammals or sea turtles were observed over 8 days of journeys along the coast from Bagamoyo to the mouth of the Ruvu.

Surveys of fish catches from fish markets, seine and overnight dhow trip landings indicated a diverse group of bony fish species and communities that currently occur along the coast (photographic key in appendix). However conversations with the local fishing community indicated decreasing numbers of sharks, rays and large fish. Fish constitute the main source of protein and income for local communities; hence their ecology needs to be understood in relation to salinity and habitat types in the estuary and coastal littoral zone. Mangrove root zones and seagrass beds are the breeding sites and nurseries to the majority of the fish and invertebrate (crabs, shrimps) species present. Awareness generation must be continued amongst fishing communities on reducing fish by-catch mortality.

Terrestrial wildlife: Unlike the lack of marine mammal sightings, a fair amount of terrestrial wildlife (birds, mammals and reptiles) was observed in the mangrove forests of the Ruvu estuary. The existence of wildlife, especially big animals such as hippos, crocodiles, baboons and monkeys in forests that do not have any protected status like a National Park was a heartening surprise. The mangrove and palm forests still exist owing to the unsuitability of agriculture in saline areas. Hippos were seen at low tide in the river, when the water is fresh. These remaining mangrove forests constitute the only habitat for wildlife, and hence need protection from over-harvesting of mangrove trees. Protection of the mangrove forests fringing the estuary by formation in a National Park is strongly urged.

Up next: Steps for determining minimum freshwater inflows

The salinity profile of the estuary is required by estuarine salinity and water balance models to calculate how much freshwater inflow is necessary to maintain the salinity regime. Because salinity in the estuary changes seasonally with changes in freshwater river inflows and also diurnally with the tidal regime, additional salinity profiles corresponding to different seasons are needed. This survey has collected data that is a snapshot of conditions over June 18-26 that corresponds to the transition from the wet to the dry seasons (decreasing inflows). Ideally, a continuous set of salinity measurements over a decade would provide a robust data set. However, this being the beginning of such an effort, at a minimum, 5 more salinity measurement surveys over the year similar to this survey need to be carried out. Such a sampling set (every 2 months, for 2 days / survey) would yield the seasonal variation in estuary salinity over a year. The Wami Ruvu Basin Water Office could be the institution best placed for this role especially as they have helped organize and have actively participated in this survey.

Basin-level perspective: we all live downstream

Water abstraction, deforestation, afforestation, agricultural and industrial activities in upstream areas of the Ruvu River Basin have the potential to substantially affect the ecology of the estuary as well as the goods and services it provides to local human populations. With respect to the Ruvu Basin as a whole, if maintenance of freshwater flows to the estuary is important to stakeholders, then water management tools such as the Ruvu Environmental Flow Assessment can be applied to balance freshwater needs for humans and nature, and provide guidelines for future water resources development as well as for coastal zone management. The formation of a functioning monitoring program that is also able to disseminate results aids the success of other coastal resource management initiatives in the ultimate objective of sustainable coastal management and habitat protection.

Acknowledgements

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We are grateful to the fishing community of Bagamoyo for sharing with us their stories, perspectives and enthusiasm in showing their catch and allowing us to photograph the fish for this report. We also acknowledge the cheerful help by locals in helping launch the boat from the beach every morning.

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This report and the maps have been prepared by Amartya Saha. Photographs have been provided by Kirk Gastric, Jeremy Kiszka, Shelard Mukama and Amartya Saha. Phil Matich analyzed the stable isotope samples in the laboratory and helped interpret the data .

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1 Introduction: Estuaries and Ecosystem Services

1.1 Healthy estuaries: their role in fisheries and resisting seawater intrusion

An estuary is defined as a partly enclosed body of brackish water with at least one freshwater river flowing into it and having a free connection to the sea (Pritchard 1967). The major estuaries in Tanzania occur where the rivers Pangani, Wami, Ruvu and Rufiji flow into the Indian Ocean. Estuaries have a unique environment with a constantly varying mix of freshwater and seawater. This mix varies seasonally from a pulse of freshwater flowing far out to sea during the rainy season, to very saline conditions in the estuary during the dry season when the freshwater flow in the river has decreased. The mix of freshwater and saline seawater also varies diurnally with tides; at high tide, the seawater opposes the freshwater and moves into the river as a wedge of denser water flowing in underneath the freshwater that is flowing seaward in the opposite direction.

This ever-changing environment of fresh and saline water along with the nutrients brought by both water pools provides one of the world's most productive ecosystems - the estuarine and coastal ecosystems. In the tropics, seagrass beds cover the estuary and coastal offshore muddy/sandy bottom, where marine fish come to breed, the seagrass providing both shelter for juvenile fish from larger marine predators of the open sea, as well as food in the form of submerged aquatic vegetation and marine invertebrates (Bwathondi & Mwamsojo 1993). Several species of mangroves frequently are found growing on the river banks and coasts of tropical and subtropical estuarine environments. Their roots protect the coast from erosion and from tropical storms, and also slow down flow thereby facilitating sedimentation and nutrient deposition (Semesi 1991). Mangroves and seagrass beds are critical nursery areas for marine fish, and coastal fisheries depend on these habitats remaining in a healthy condition. Semesi *et al.*(2000) described in detail the natural resources in the mangrove forests and the seagrasses and their uses by the local communities. The livelihoods of local human populations often are largely dependent on these resources such as fish and mangrove poles that have been exported for centuries throughout Tanzania and beyond (Martin 1978).

Rainy and dry seasons in Tanzanian river basins cause a seasonal fluctuation in freshwater inflows into estuaries to which local ecosystems have adapted. However a decrease in freshwater inflow to levels lower than the natural seasonal flow regime results in increased seawater intrusion into the estuary (Nguyen & Savenije 2006). Prolonged exposure to high salinity reduces water uptake in mangroves by stressing the salt-exclusion mechanisms in roots and leaves (Parida & Das 2000). Even though mangrove species differ in their tolerances to salinity, high levels of flooding with saline water can stress even the most salinity-resistant species, resulting in eventual mangrove dieback. Similarly, hyper-saline conditions in bays stress seagrasses, as well as the various organisms that reside in these habitats. Not much is known upon the impacts of prolonged high salinity on biogeochemical decomposition cycles, growth and metabolism of juvenile crustaceans and fish. Decreased river inflows into estuaries also lead to decreased nutrient and sediment inputs; decreased sediment inputs can lead to accelerated erosion of the estuary by ocean waves, that has been noticed in the Pangani river estuary (Sotthewes 2008). At the same time, very high freshwater flows can also disrupt lifecycle process of estuarine ecosystems (Powell *et al.*2002, Tolley *et al.*2012). Keeping all this in mind, there is an optimal range of freshwater inflows into estuaries necessary to maintain estuarine ecosystems.

Freshwater flows to the estuary thus balance seawater coming in with the tide. Hence, any large decrease in freshwater inflows leads to seawater intrusion into the estuary, and possibly into coastal aquifers near the estuary in areas where the estuary and underlying aquifers are hydrologically connected, or in low elevation flat areas along the riverbanks where seawater floods in overland during low tide. Once shallow well water gets saline, wells often have to be abandoned. This is already happening in Bagamoyo district, Tanzania, as evident from coastal village wells that had to be relocated on account of salinization (Tobey 2008). While coastal salinization is reportedly occurring over a wider section of coastline in Tanzania, maintaining the seasonal freshwater flows into estuaries can resist the salinization of aquifers underlying the estuary. Sotthewes (2008) notes increasing saltwater intrusion occurring in the Pangani estuary over the past several decades and attributes it to two major factors: decreasing freshwater discharge on account of irrigation and hydropower reservoir abstractions and increasing erosion at the marine end on the account of less deposition of river sediment.

1.2 Sustainable estuary/coastal management and freshwater inflows

Physicochemical characteristics, biological structure, and productivity of estuaries are closely linked to seasonal changes in timing and volume of freshwater inflow (Drinkwater and Frank 1994, Sklar & Browder 1998, Alber 2002, Powell *et al.*2002, Estevez 2002). Maintaining an adequate freshwater inflow regime is critical for maintaining fisheries, the ecosystem and surrounding connected environments.

Policymakers thus are faced with the difficult task of developing water resource management programs that allocate freshwater between changing human and ecosystem needs in a sustainable manner (Pielou 1998).

An Environmental Flow Assessment, as related to an estuary, aims to determine the quality, quantity, and timing of freshwater flow required to maintain the estuarine ecosystems in a desired state. The determination of these freshwater inflow requirements would need to answer the following questions:

1. How are the plants and animal communities in the estuarine ecosystem influenced by salinity levels?
2. How does the salinity profile into the estuary and up the river vary with freshwater river flows, tides, seasons and weather events?

1.3 Scope and objectives of present survey

In this study, baseline data were gathered to start characterizing the Ruvu estuary ecosystem communities along with physical hydrology and water quality. This report details the findings from the first survey carried out in June 18-28, 2013, corresponding to the transition between wet and dry seasons, with freshwater flows in the Ruvu in between the wet season high and the dry season low.

The fieldwork focused on the following areas:

1. Estuary hydrology and water quality: Mapping estuary channel depth, width, flow measurements and discharge calculations at high tide. Salinity, Dissolved Oxygen, temperature measurements from marine end to freshwater end.
2. Riparian Vegetation surveys along the estuarine and freshwater sections of the Ruvu, relating community composition with river salinity as well as species zonation with local topography (flooding extent) and soil types
3. Terrestrial Wildlife sightings and habitat extent observations, which provide additional idea on the health of the terrestrial ecosystem in the estuary.
4. Aquatic ecosystem surveys: Recording seagrass, macroalgae and fish species present by surveying mudflats and local fishing community catches in markets and beach landings. Longline-based survey of teleosts (bony fish) and elasmobranchs (sharks and rays) in the estuary, coastal and adjacent freshwater sections. Tissue samples of fish, invertebrate and seagrass taken for stable isotope analysis that will yield trophic level information for understanding the community structure. The report also includes recommendations for future monitoring to add to the understanding of the Ruvu estuarine ecosystem and data on the hydrology/salinity regime. This understanding will enable the ultimate development of a set of minimum river flows in the Ruvu necessary to maintain the estuarine aquatic ecosystem and the mangrove forests.

2. The Ruvu estuary: setting, hydrology and water quality

2.1 The Ruvu River Basin: physical setting, land use and threats to water

The Ruvu River, whose watershed provides much of the water for Dar Es Salaam, arises in the southern flanks of the Uluguru Mountains that form part of the biodiversity-rich Eastern Arc Mountains (Fig.2-1). It is joined by its major tributary, the Mgeta River, which drains the western Ulugurus (IUCN 2010 Ruvu Basin report). The Ruvu thereafter flows northeastwards and is joined by the River Ngerengere, which drains the eastern parts of the Uluguru Mountains. It continues flowing northeast through agricultural and pastoral landscapes, crossed by the TANZAM highway and rail artery, and past industrial centers to drain into the Indian Ocean north of Bagamoyo, forming the Ruvu estuary (Figure 2-1).

The Ruvu River Basin (11,789 km^2 – JICA 2013) lies between latitudes 6° 05’ and 7° 45’ south and longitudes 37° 15’ and 39° 00’ east. The Ruvu River Basin and the Wami River Basin are jointly managed by the Wami Ruvu Basin Water Office of the Ministry of Water, Tanzania.

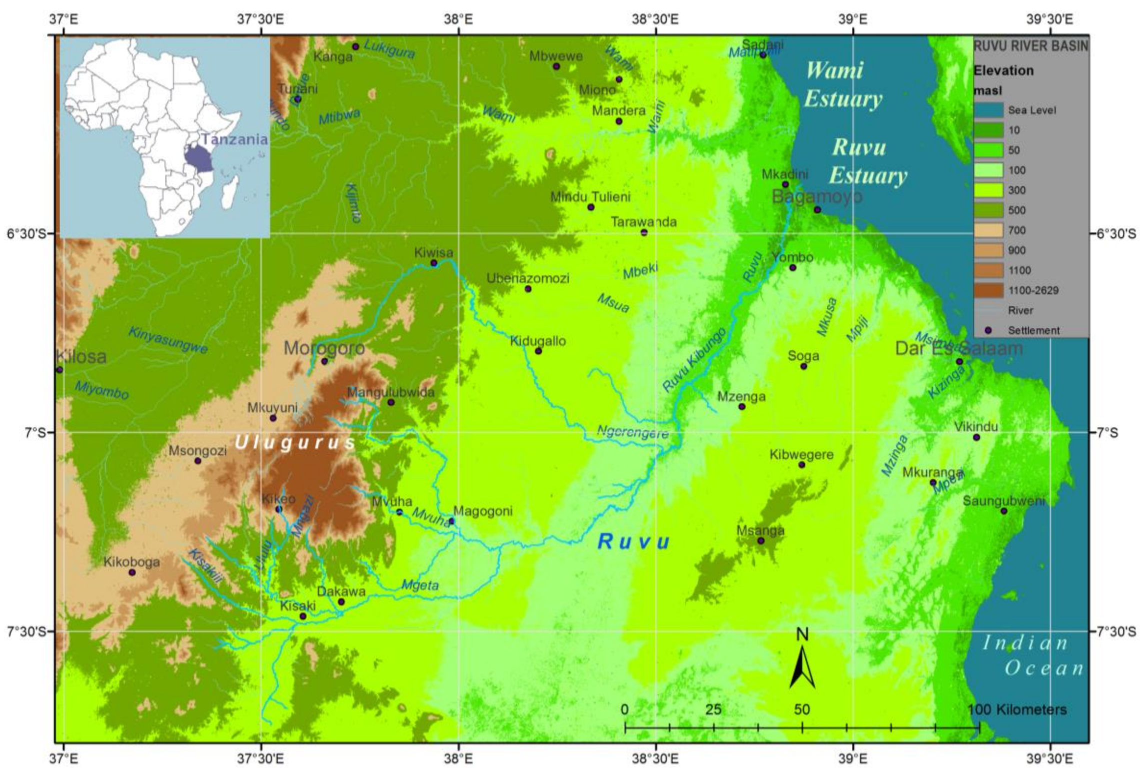


Figure 2-1: Ruvu river arising in the Uluguru mountains south of Morogoro, with the Ruvu Estuary located on the Indian Ocean just north of Bagamoyo.

Climate and river flow: The climate of the Ruvu basin has been described in detail in several publications (IUCN 2010, JICA 2013). The major rainy season occurs between March-May while a smaller season occurs between November-January. The highest rainfall in the Ruvu basin is consistently observed in the higher elevations of the Ulugurus (average annual rainfall > 2000 mm) while in the plains it drops to 1000-1200 mm per year (Yanda & Munishi 2007, WRWBO data, GLOWS 2014). The Annual Hydrological Reports by the Wami Ruvu Basin Water Office (WRWBO 2010) describe the flow in streams in the headwater Mgeta and Ngerengere catchments as being very responsive to rainfall. In comparison the

Lower Ruvu catchment has a relatively stable flow regime. The period of high discharge in all tributaries of the Ruvu drainage, April and May, coincides with the main rainy season (March- May) as seen in Figure 2-2.

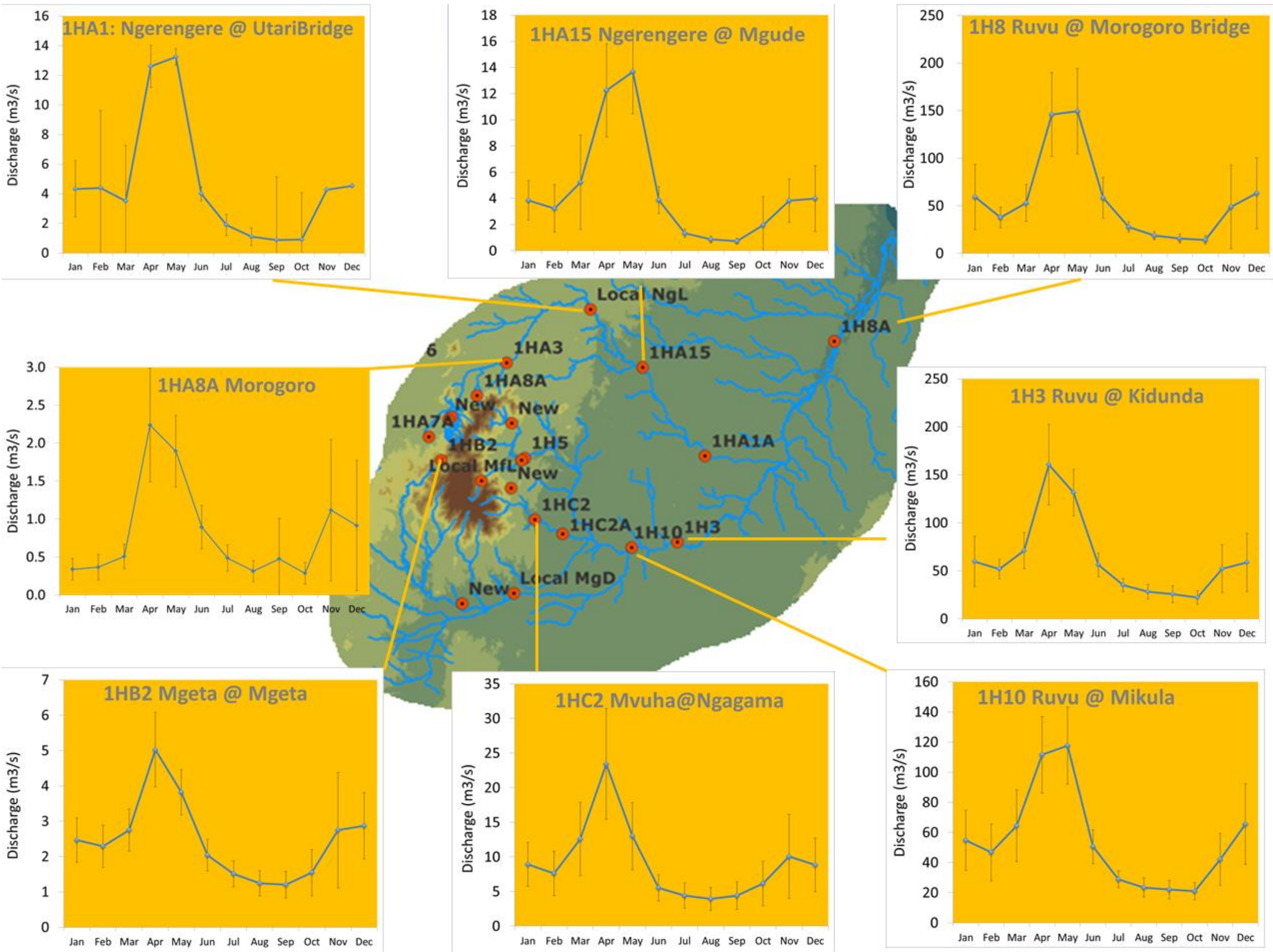


Figure 2-2: Monthly discharge (m^3/s) in select tributaries and sections of the Ruvu river, averaged over 1950-2010. Error bars depict 0.5 standard deviation on either side of plot. Data source: WRBWO.

However there is no published flow information for the Ruvu estuary; the monitoring station on the Ruvu River closest to the estuary is about 45 km upriver from the estuary, at the Morogoro Road Bridge named 1H8A (Figure 2-2 upper right).

*Land use in the basin: L*and cover/land use in the basin has a direct connection with water quality in the estuary (Yanda & Munishi 2007). Agricultural activities in the Upper Ruvu are primarily rain-fed. Many farms extend up mountain slopes and become sources of soil erosion. There are several irrigation projects in the lowlands. The Lower Ruvu basin also has various industries in the hinterland of Dar Es Salaam including textiles, sisal production, beverage, brewery, tobacco processing, pharmaceutical, soaps (JICA 2013) and service industries such as slaughter houses and garages discharging effluents. Waste streams from these industries, along with domestic sewage, ultimately end up in the Ruvu River. The prospects for growth of irrigated agriculture and industrialization in the Ruvu River basin not only increase the potential for pollution but also could lead to increased water demands. For instance, the National Development Corporation is developing an oil palm plantation on 10,000 ha of land at Kimala Misale and Dutumi villages in Kisarawe and Kibaha district (http://ndc.go.tz/agro-industries/); palm plantations typically require irrigation over the dry season to optimize growth.

Figure 2-3: Location of the Ruvu River estuary northwest of Bagamoyo. Orange circles denote the extent of the present survey from the estuary mouth, past the palm-mangrove transition zone upto the bridge on the Mtoni-Kigongoni road. Map source: Google Earth.

The Ruvu River estuary, situated just north of Bagamoyo (Fig. 2-1, 2-3) is fringed by mangrove forests at the mouth of the river. Rice farms and scattered rural settlements occur along the Ruvu river upto a few kilometers downstream of the bridge on the Mtoni-Kigongoni road. Thereafter, mangrove forests lie along the banks of the last 10-12 kilometers of the Ruvu until the mouth of the river at the Indian Ocean. Semesi *et al.* (2000) have reported the status of the coastal natural resources (mangroves, fisheries and saltworks) along with their uses in Bagamoyo district. Unlike the Wami estuary to the north that is protected within Saadani National Park (Anderson et al. 2007), no such protection is afforded the Ruvu River estuary. That fact that mangrove forests still exist in the Ruvu estuary despite lack of any official protection, and despite the centuries-old exploitation for mangrove poles, is encouraging. However, the increasing pressure on natural resources together with the dangers of increasing salinization resulting from a combination of decreased freshwater inflows and sea level rise could compromise the health of these forests and ecosystem services provided.

The present survey was carried out over June 18–27, 2013. It commenced from the marine end into the mouth of the Ruvu River and proceeded upstream till the bridge on the road from Bagamoyo between Mtoni and Kigongoni (Fig. 2-3). The survey included the range of vegetation, from salt tolerant mangroves at the mouth to farms and natural vegetation that is known to be totally intolerant of saltwater at the bridge end. The river is ~20 m wide at the Mtoni bridge end and remains within ~20-30m width until about 4 km from the mouth of the river when the channel begins to widen until reaching 1-1.5 km wide at the mouth.

2.2 Estuary depth profiles

Depth to river bottom was taken using a Depthmate SM5 (Laylin, VA, USA), a handheld depth reader with a range of 0.6 – 70 m. Depth measurements were taken at high tide conditions throughout the estuary, river channel upstream and open sea at locations where water quality parameters were measured as well as elsewhere (Appendix 1 for data). Fig.2-4 (left) shows the measurement locations along with interpolated depths from these spot measurements taken on June 21, 2013. The Inverse Distance Weighting (IDW) procedure in the Spatial Analyst toolkit of ArcGIS 10.2 was used with the default parameters of square power to generate this map of depth gradients. In addition, this report also includes a depth profile of just the Estuary taken by the sediment source study team on August 24, 2013 (Fig.2-4 right). Depth readings here were taken along two downstream-upstream transects, and the map has been generated using IDW interpolation.

In general the estuary mouth ranges from 1-4 meters in depth depending on location and tide, and gets deeper upriver, especially on the scouring banks at channel bends (evident in Fig.2-4 right). The next section on channel profiles depicts these trends in the data. There are sandbanks deposited at the mouth of the estuary, one of which also supports a monospecific stand of the mangrove *Sonneratia alba*.

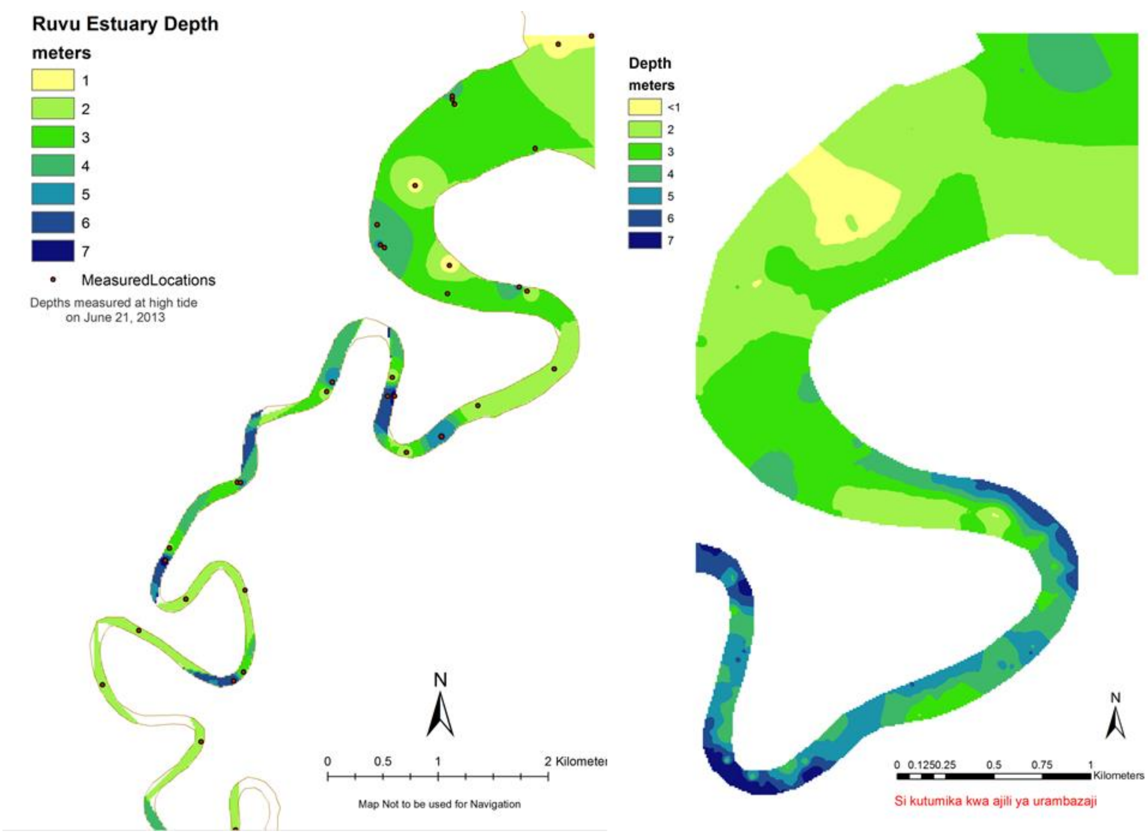


Figure 2-4: (Left) Water depth of the Ruvu Estuary and adjacent upstream river under flood tide conditions on June 21, 2013. Measurement locations are shown by tiny circles. (Right) Continuous water depth profile of a close-up of the Ruvu estuary taken on August 24, 2013. Data Courtesy Chris Dutton (right plot).

In general, estuarine hydrology is well-known to be complex owing to the mix of opposing freshwater and seawater inflows. Seawater that has a higher density than freshwater flows into the estuary as a wedge underneath the less dense freshwater that flows seaward, introducing shearing turbulences that change with the water column depth. Freshwater and seawater flows also change continually with time and space. Freshwater inflows change with the season as well as with human abstractions, while seawater inflows change twice a day with the tide, and monthly and seasonally with the magnitudes of the tides. In addition, in periods of high tide at the mouth, wind direction opposing the tidal inflow constitutes another difficulty in measuring flow. Flow measurements were still carried out despite the above challenges to attempt to get an estimate in the transition between the wet and dry season.

Flow measurements were obtained on different days mostly under high tide conditions, from 3 hours following the morning low tide to 3 hours after the noon high tide. Flow was measured at different locations starting from the mouth to 10 km upriver. Table 2-1 shows a selected set of locations and measurements. A mechanical flow meter with a propeller was used to measure velocity (General Oceanics Model 2030, FL, USA) along with a 3m extensible rod. Readings were taken at the surface, at 1 m and 2 m.

Date	Tide	Salinity extent	Latitude	Longitude	Depth	Speed (m/s)	Remark
19/6/2013	Flood	saline section	6 22.459	38 52.279	1m	0.1145	
19/6/2013	Flood	saline section	6 24.387	38 51.479	1m	0.0855	
19/6/2013	Flood	saline-fresh	6 24.406	38 50.937	1m	0.1095	
*19/6/2013	flood	fresh	6.4035	38.85	surface	0.2376	Deep-end
*19/6/2013	flood	fresh	6.4035	38.85	1m	0.1944	Deep-end
*19/6/2013	flood	fresh	6.4035	38.85	2m	0.0938	Deep-end
19/6/2013	flood	fresh	6.4035	38.85	surface	0.1921	Mid-channel
19/6/2013	flood	fresh	6.4035	38.85	1m	0.1615	Mid-channel
19/6/2013	flood	fresh	6.4035	38.85	2m	0.0554	Mid-channel
18/6/2013	flood	fresh	6.4035	38.85	surface	0.1548	Shallow-end
19/6/2013	flood	fresh	6.4035	38.85	1m	0.1222	Shallow-end
19/6/2013	flood	fresh	6.4035	38.85	2m	0.0457	Shallow-end
19/6/2013	Flood	fresh-saline	6 25.02	38 50.068	surface	0.0643	Shallow-end
19/6/2013	Flood	fresh-saline	6 22.916	38 51.958	surface	0.0318	Shallow-end
20/6/2013	Ebb	saline	6 22.663	38 51.535	surface	0.00	
23/6/2013	Ebb	na	6 25.414	38 49.986	surface	0.00	
23/6/2013	Ebb	na	6 25.414	38 49.986	1m	0.00	
*21/6/2013	Flood	fresh	6.4241	38.8342	surface	0.8015	
*21/6/2013	Flood	fresh	6.4241	38.8342	1m	0.8590	
*21/6/2013	Flood	fresh	6.4241	38.8342	2m	0.1861	

Table 2-1: Selected flow data measurements over the Ruvu estuary survey, from the mouth to upriver. Rows with stars signify sections where freshwater discharge has been calculated.

As can be seen from Table 2-1, the velocity varies from 0 m/s (where the propeller is almost stationary) in the estuary to strong flows (0.8 m/s) upriver, based upon location and tidal regime. There were spring tides (coinciding with full moon phase) over the sampling duration, with the difference between low and high tides being as much as 3.5 m as measured on the shore banks at the estuary mouth.

From the estuary mouth to about 2 km upriver, flow velocities measured at numerous locations were nearly zero on both the surface and at 1 m depth during high tide. This was probably on account of the opposing fresh water and seawater flows. Wind blowing in from the Indian Ocean also pushed surface water in small waves upstream. At about 2 m depth flow was still often zero (no propeller turns); however at times eddies were detected by the flow meter propeller slowly turning upon altering flow meter orientation to catch the current. The current was transient in most cases, as inferred from the propeller turning for a while then stopping. These eddies likely arise from turbulence caused by the shearing action of a wedge of seawater moving upriver against the downriver freshwater flow (tidal mixing) as illustrated in Fig.2-5.

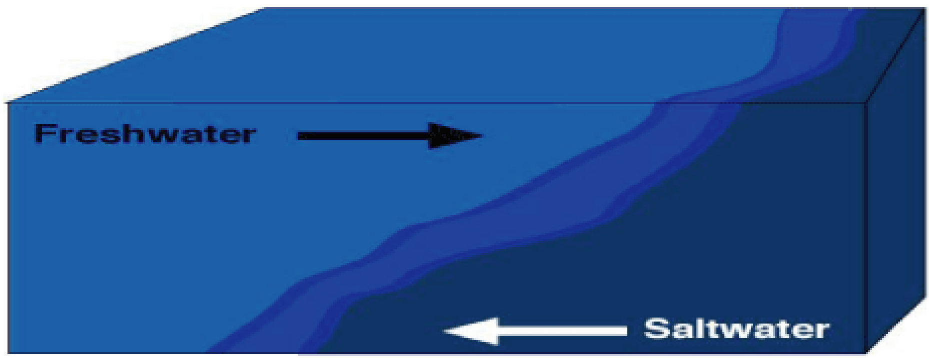


Figure 2-5: Seawater typically advances into a river as a wedge under inflowing freshwater. Source: http://www.ldeo.columbia.edu/edu/k12/snapshotday/Parameters.html.

Further upriver, the downstream flow velocity begin to increase; these flow measurements were made on the surface and 1 m depth, and hence represent the freshwater outflow, and not the inflowing seawater which occurs beneath, as evident from the increasing salinity with depth. Likely there is laminar freshwater outflow towards the sea on top, then a turbulent mixing zone of fresh and seawater (intermediate salinities), with seawater at the bottom.

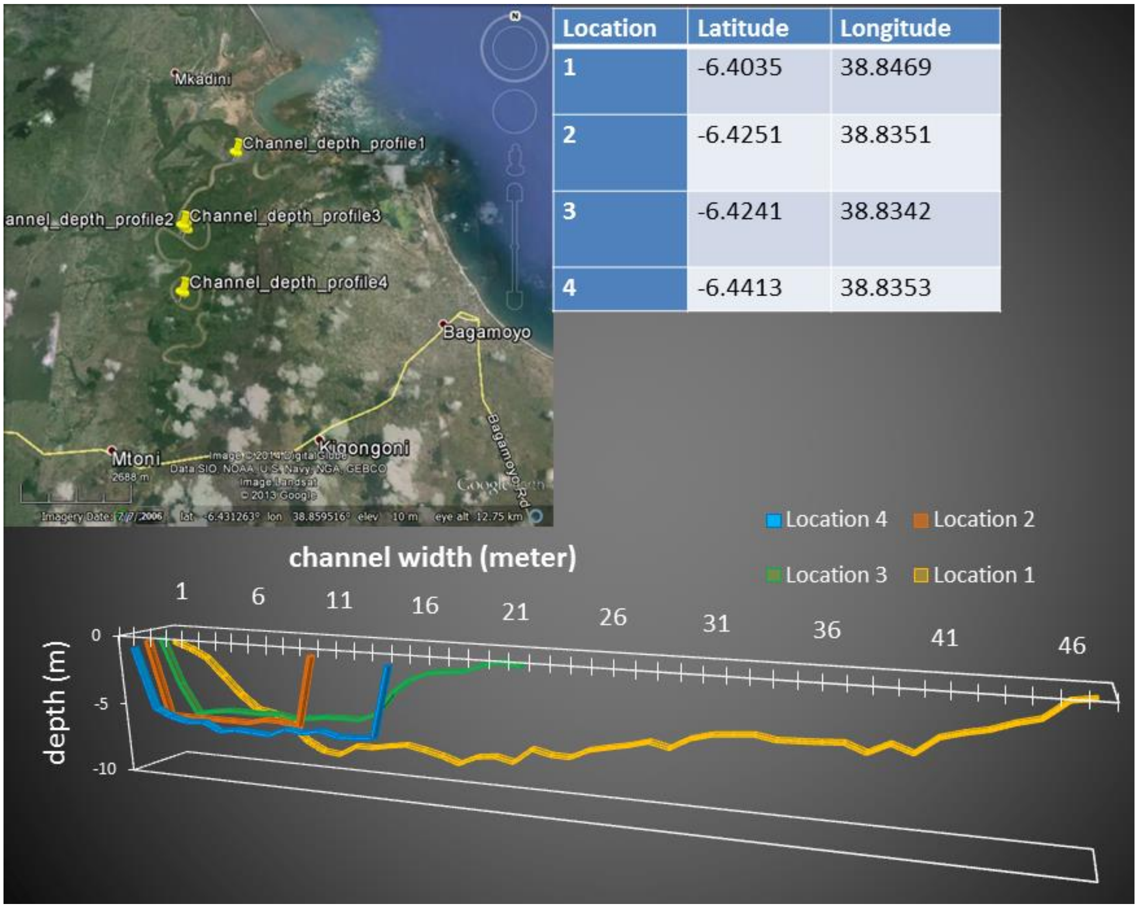
Velocities of 0.8 m/s were observed about 10 km upriver from the mouth, where the channel is quite constricted (20 m width) in comparison with the estuary mouth (800-1700 m wide). The widening of the estuary together with incoming tides opposing freshwater outflow results in a big decrease in velocity. In addition, the 0.8 m/s measurements were taken at low tide with the high tide still a couple hours away.

2.3 Discharge

On account of near-zero flow velocities being observed in the top 1-2 meters depth all across the estuary mouth up to 2 km upstream, it was not possible to accurately estimate discharge at the mouth of the estuary. Hence we compute discharge at two sites 7 and 11 km upriver (6.4035 S and 38.8469 E) and (6.4241 S and 38.8342 E) where unidirectional flow was observed in the top 2 meters of the water column and where channel depth profiles were obtained. Units of discharge are cubic meters per second or cumecs as used in engineering literature.

2.3.1 Selected channel cross-sectional area profiles

Depth measurements were taken every meter along four transects across the width of the river (Figure 2-6) on June 21, 2012. This data was then used to reconstruct channel cross sectional area profiles at these locations that can then be used along with flow velocity measurements to estimate instantaneous discharge.



Location	Latitude	Longitude
1	-6.4035	38.8469
2	-6.4251	38.8351
3	-6.4241	38.8342
4	-6.4413	38.8353

Figure 2-6: Top: Map of channel depth profile locations. Bottom: Channel depth profiles of the four locations on the Ruvu river shown along the river width (x axis) and depth (y axis).

The river follows a continually meandering path between the Mtoni_Kigongoni road bridge and the estuary mouth (Fig.2-3), a result of the extremely flat terrain. Abandoned channels are also visible in Fig 2-3. This meandering results in channels having a scouring zone on one side and a depositional zone on the opposite bank as is evident in the channel depth profiles at sites 1 and 3 (Fig.2-6 bottom). The region has very dynamic channels indicating that the depth profile changes often on account of the soft muddy river bed, seasonally / interannually varying flows and interactions with vegetation.

2.3.2 Discharge calculations

Two locations were chosen for discharge calculations based upon the availability of flow data; these are locations 1 and 3 in Fig.2-7. Velocity profile with depth at each section is shown for these two locations. Location 1 (Fig.2-7, red or left plot) is situated the furthest downriver about 7.8 km from the estuary mouth shows decreasing velocities with depth (0-2 m). This is similar to a parabolic velocity profile that is typical of rivers and channels with unidirectional flow.

Location 3 (Fig.2-9, right plot) is located 13 km from the estuary mouth showed faster flow than the downriver location 1 at all 3 depths. However, the velocity was higher at 1 m depth than the surface (0.86 m/s vs 0.81 m/s); this could be caused by opposing wind drag slowing down the surface water layer. An abrupt decrease in velocity was recorded from 1 m to 2 m depth (from 0.86 m/s to 0.19 m/s – Fig.2-9, blue plot). This abrupt decrease could be caused by a wedge of seawater flowing in underneath at high tide, that can change the typical parabolic velocity profile by further lowering the observed velocity because the seawater wedge opposes the freshwater flow.

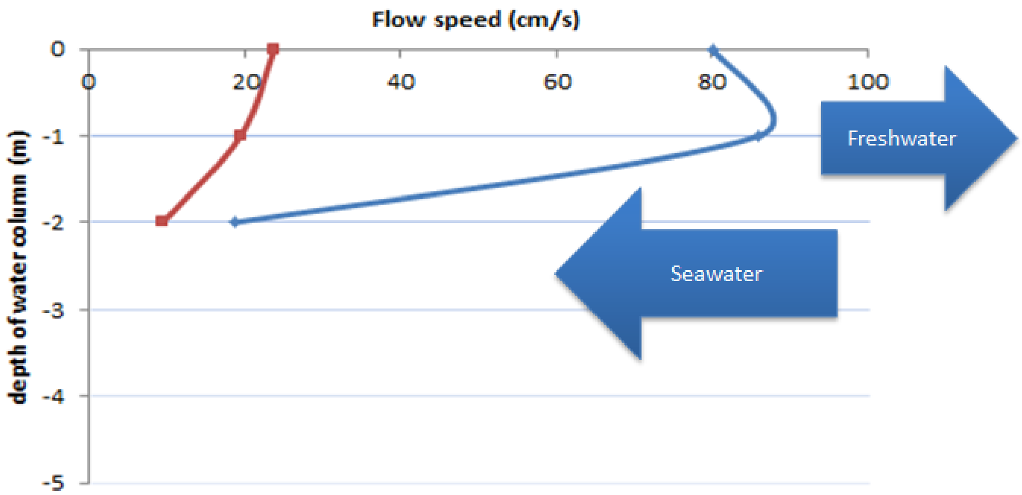


Figure 2-7: velocity profile with depth at locations 1 (6.4035 S and 38.8469 E, red, LEFT plot) and 3 (6.4241 S and 38.8342 E, blue, RIGHT plot).

With the assumption that an inflowing seawater layer causes this abrupt decrease in flow speed from 1 m depth to 2 m depth (Fig 2-10), the depth of the freshwater layer at location 3 is assumed to be 2 m. The mean velocity of this overlying freshwater layer is then computed by averaging the velocities at the surface, 1m and 2m that works out to around 0.60 m/s.

Current speed can vary across channel width. Flow velocity was measured at three points along a channel width transect - the deep section end, channel middle and shallow section end (1 meter offshore). However given the multiple survey activities happening simultaneously, there was not adequate time to measure the flow at every meter segment along the channel width; hence we assume the flow in the deeper side to represent the bulk of the flow in the river.

Although the channel cross-sectional area for location 3 works out to 81 m^2, our velocity measurements primarily represent the freshwater section, which, as explained, is estimated to be 2.5 m thick. Hence the cross-sectional area for the freshwater layer in the river is taken as:
2.5 m (depth) * 19 m (width) = 47.5 m^2
Given that Discharge = Mean Velocity * Cross-sectional Area, the discharge of freshwater at location 3 at the time of flow measurement works out to be 47.5 m^2 * 0.6 m/s = 28.5 m^3/s or can be taken to be about 30 m^3/s

Similarly, the discharge at location 1 (orange plot in Fig 2-9, Location 6.4035 S and 38.8469 E) is calculated as shown below. Taking the average of the surface, 1m and 2 m speeds from Table 2-1, the mean velocity of the top 2 meters = 17.53 cm/s
Looking at the velocity profile with depth (Fig 2-10, red plot), it can be assumed that the layer of freshwater is 3 m thick. Note that in both cases we are not considering the brackish mixing zone in discharge calculations, owing to the very slow velocities caused by the interaction of two opposing flows.
Cross Sectional Area of freshwater section at location 1 = 3 m * 47m
Hence Discharge at Location 1 = Cross Sectional Area * Mean Velocity = 24.675 m^3/s that is approximately 25 m^3/s .

Discharge estimates at both locations 1 and 3 are within the same order of magnitude (25-30 m^3/s). This is expected by the river continuum as these locations are just 5 km apart. However, additional flow and cross sectional data from other locations along the river will improve the confidence of the estimates of net discharge in the Ruvu.

Figure 2-8: Discharge calculations for locations 1 and 3 in the Ruvu river near the estuary.

The methodology and assumptions along with the calculations are included in Figure 2-8. It must also be noted that these discharge estimates are reflective of the flow occurring over the dates of the survey (June 18-27, 2013) under prevailing tide conditions. Flow varies diurnally, seasonally and inter-annually, and hence these estimates are reflective of conditions between the wet and dry seasons. For instance, the average annual discharge noted in the Ruvu at Morogoro Road Bridge is around 61 m^3/s (WRWBO Annual Hydrological Report 2009-2010)*;* this station is the closest regular monitoring station managed by the WRWBO, about 45 km upstream of the estuary mouth. Fig.2-9 shows the variability of flows measured and averaged over the month of June at Morogoro Rd Bridge since 1965 (with gaps in between). Average flows (in m^3/s) for June range from 15 m^3/s to over 200 m^3/s with an average computed under 50 m^3/s. It should be noted from the presence of meandering abandoned channels that channel depth changes over decades due to streambed and bank erosion/deposition, which requires rating curves at a site to be updated periodically. Lack of recent updates can increase the uncertainty of recent data.

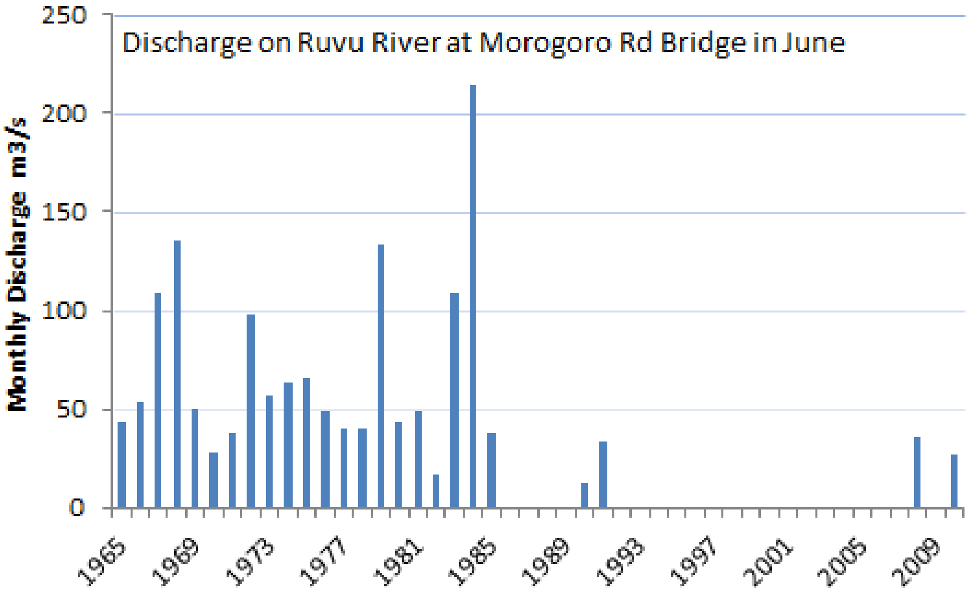


Figure 2-9: Monthly Discharge for the month of June, measured on the Ruvu River at Morogoro Rd Bridge. Data: WRWBO. Data is unavailable for years between 1986-1989, 1992-2007 and 2009.

2.4 Water quality measurements in the Ruvu estuary

Salinity is the water quality parameter that governs aquatic and riparian ecosystem structure and function in estuaries. Other water quality parameters relevant to estuarine ecosystem processes include temperature, dissolved oxygen, turbidity and nutrient levels. Aquatic organisms differ in their tolerance of low dissolved oxygen (DO) conditions, which can arise due to either slow flow conditions or the presence of nutrient pollution from upstream waters leading to hypoxia in estuaries. DO is also inversely related to water temperature

Water quality parameters were measured along the marine to freshwater section of the Ruvu River, starting from the marine end (1 kilometer out to sea from the mouth of the river), through the estuary and extending upstream past the mangrove-palm transition into the agricultural areas until the road bridge (Figure 2-3).

2.4.1 Salinity

A conductivity probe (YSI EC 300A, YSI, USA) with a 10 m cable was used to measure salinity and temperature along the marine-freshwater transect. Salinity and temperature were measured at different depths (surface, 1, 2 and 3 meters) under different tidal conditions, i.e. flood and ebb tides. In places with strong flow, the cable at 3 m moved off at an angle and hence 3 m readings under these conditions are not included. The bridge (Fig.2-3) was chosen as the starting point to serve as a fixed geographical reference for future salinity measurements which change with season. At high tide, seawater was found to extend almost 11 km upstream from the mouth of the river (5.5 km as the crow flies), with the furthest inland salinity being noticed at (-6.417 S, 38.8344 E) under high tide conditions, measuring about 5 ppt. Salinity values in the freshwater-seawater mixing zone at the surface (Fig 2-10) were lower than at values at 1m, 2 m and 3 m depth (Fig 2-11). Data has been included in Annex 1.

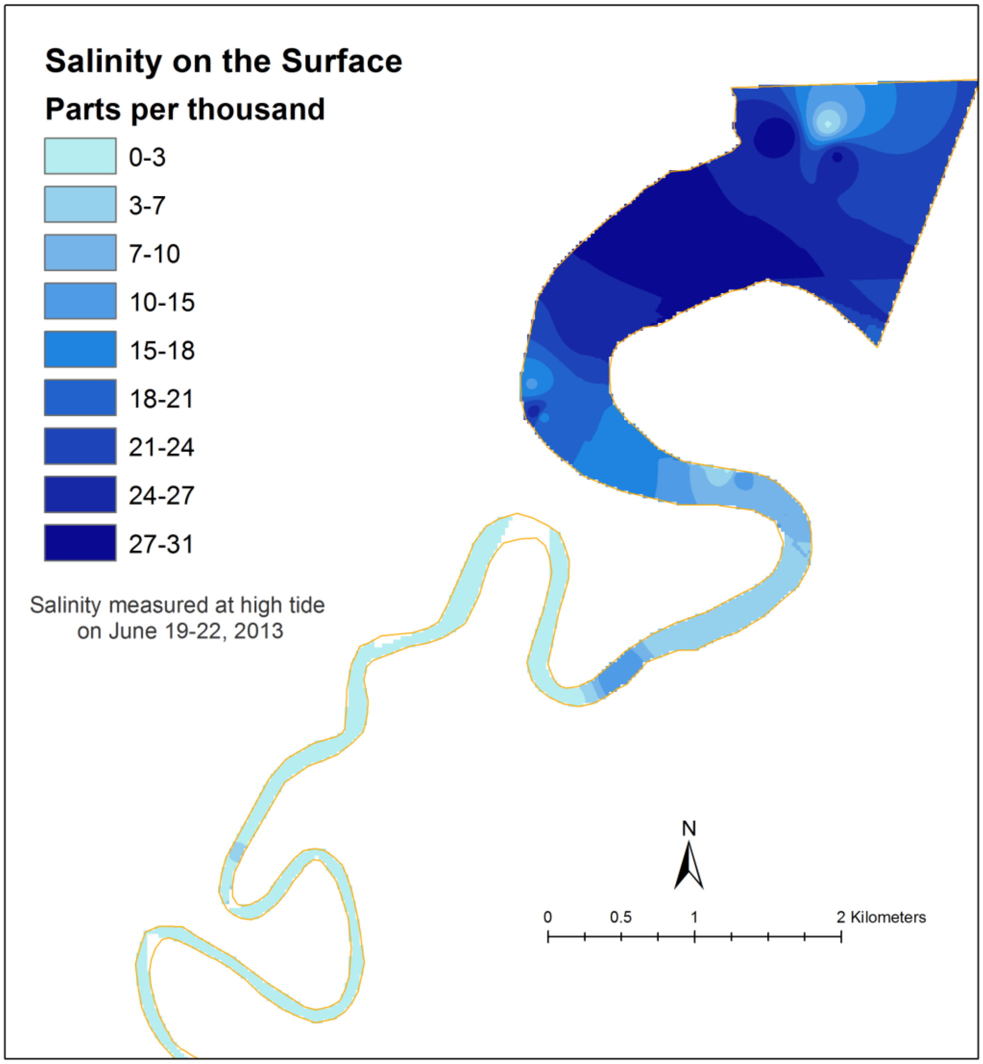


Figure 2-10: Surface Salinity gradient in the Ruvu estuary between June 18-26, 2013 corresponding to the wet-dry season transition.

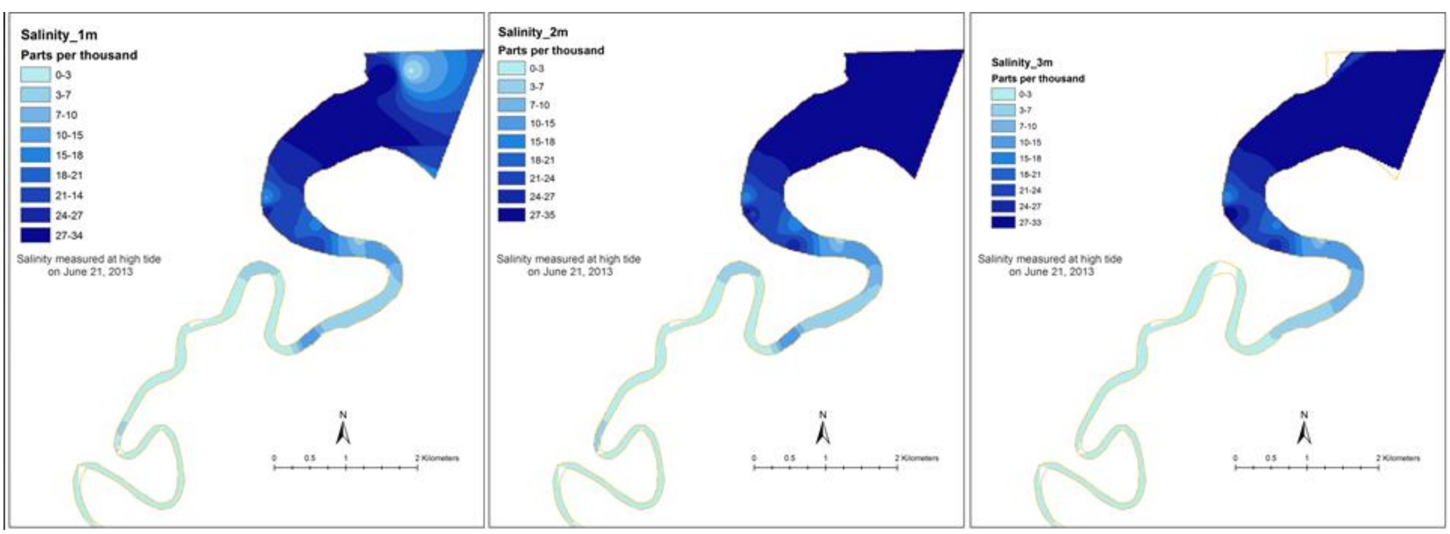


Figure 2-11: Salinity profiles of the Ruvu estuary at 1m, 2m and 3m depths under high tide conditions over June 19-22, 2013.

This survey noted that the Ruvu River estuary mouth up to 2 km inland had full marine salinity at high tide and lower salinity values at low tide. Figure 2-12 shows the salinity values plotted with distance (in km) from the bridge to the river mouth. The bridge was chosen as the origin as it represents a fixed spot for future sampling, unlike the mouth which has no clear landmark. The water at the bridge was entirely fresh even at peak high tide. It remained fresh 15 km downstream when the first slightly brackish water was observed (~5 ppt) at high tide at 2m depth. Similar salinity values were observed until about 22 km downstream from the bridge when the salinity began to increase until by 25 km downstream, values reached 25 ppt at high tide. The mouth lay at 28 km downstream.

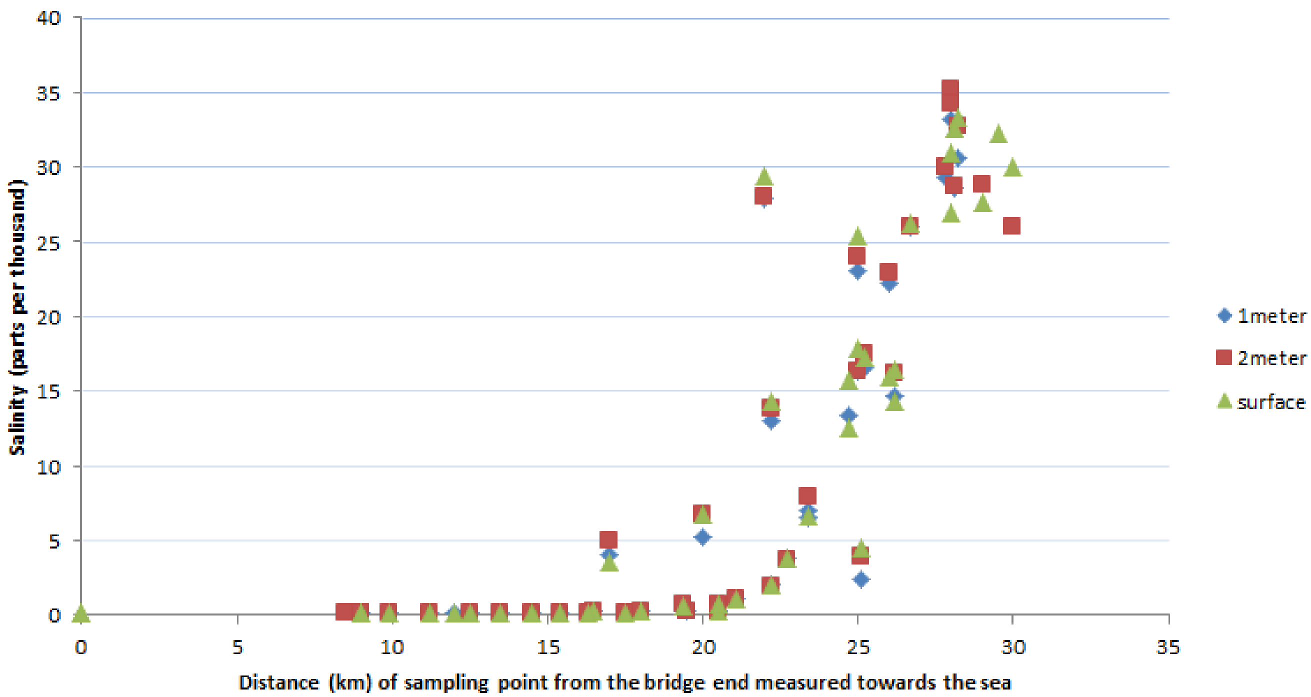


Figure 2-12: Salinity measurements at surface, 1 and 2 m depth carried out over both low and high tide conditions from the freshwater to the marine end of the Ruvu.

In places where the current was strong, it was difficult to measure salinity at 3 m or deeper, on account of the current carrying the probe away from the vertical. Hence for future measurements, the use of a rope and weight is recommended, to which the probe can be attached, to avoid the drift away from the vertical.

2.4.2 Dissolved oxygen

A Dissolved Oxygen (DO) probe (YSI DO 300, YSI, USA) with a 10 m cable was used to measure DO (in mg/l and %) as well as the temperature (°C) at the same depths as the salinity measurements. The dissolved oxygen profile of the estuary is shown in Figures 2-13 (left and right) taken in June and August respectively, the latter by the team studying sediment sources in the Ruvu. The same spatial pattern was present in both surveys. In general, the DO level decreases upriver from the mouth of the estuary, from turbulent well-mixed conditions at the mouth (ocean wave action) to lesser turbulence upstream. There also may be a higher biochemical oxygen demand upstream owing to organic matter inputs in runoff from farms and decaying leaf litter. Within the estuary mouth, the southeastern bank has a lower DO than the northwestern bank. There was no clear relationship between DO and depth in the first 2 meters of water.

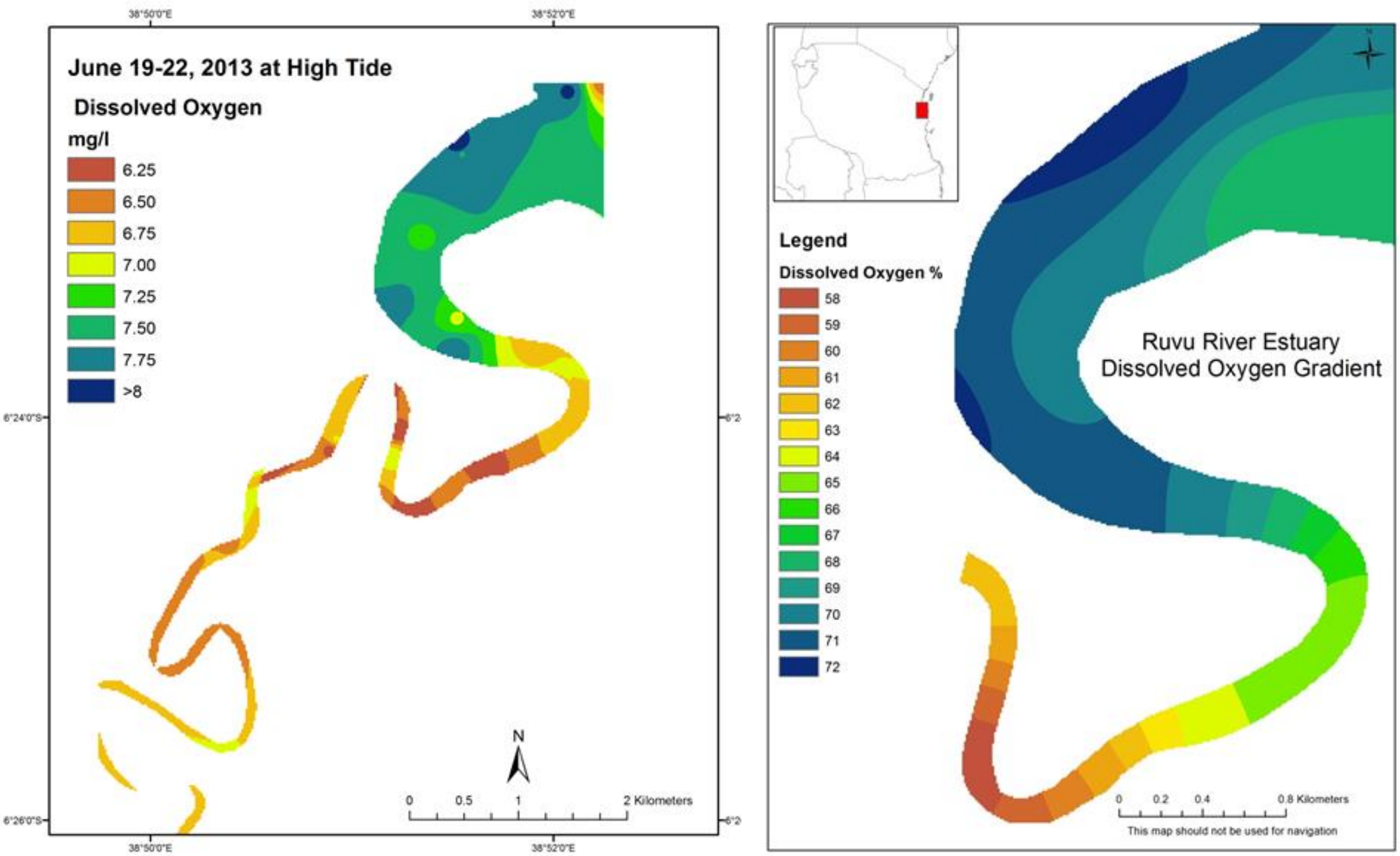


Figure 2-13: (Left) Dissolved Oxygen gradient in the Ruvu River Estuary as of June 19, 2013 (daytime). (Right) DO profile (in %) of the Ruvu Estuary obtained in August 27, 2013 (daytime). Courtesy: Chris Dutton for the plot on the right.

2.4.3 Turbidity:

The survey over June 19-22 noted highly turbid water in the Ruvu river from the Mtoni bridge that decreased only at the estuary mouth. This is illustrated by the series of photographs (Figs 2-14 to 2-18) showing muddy brown water. Turbidity was visually examined by filling an 8 cm diameter transparent bottle with river water, looking along the diameter cross-section from one side of the bottle and by noting if letters on the other side were legible. Turbidity measurements were qualitative, but in no case visibility extended beyond 8 centimeters except at the estuary mouth where the water was clearer at high tide on account of mixing with clear seawater. Water in the Indian Ocean 1 km away from the mouth was very clear, with a blue surface appearance as was seawater off the coastline south of the estuary (Fig.2-22), away from the direct outflow from the Ruvu.

Figure 2-14: Turbid water in the freshwater section of Ruvu river, 20 km upriver from estuary mouth.

Figure 2-15: High turbidity in mangrove-palm transition zone, 14 km upriver from estuary mouth.

Figure 2-16: (Left) (Right)Turbidity from inflowing sediment-laden freshwater in the mangrove-forested section 4 km upstream from the mouth.

Figure 2-17: Turbidity persisting in Ruvu estuary mouth, June 21, 2013

Figure 2-18: Clear seawater off the coast south of the estuary

3. Vegetation composition and relationship to salinity

It is well known that mangrove species differ in their tolerance of flooding duration and salinity, which leads to horizontal zonation of mangroves as has been reported in the literature for East Africa and elsewhere (e.g. Semesi 1991, 2001, Richmond 2011, Punwong 2013).

3.1 Methods

3.1.1 Vegetation Composition: In this survey, the tree species composition on the banks of the Ruvu river as well as the canopy was recorded visually from the boat, extending from the mouth of the river (the estuary) past the mangrove-palm transition into the agricultural areas to the bridge on the Mtoni-Kigongoni road (Figure 2-3). For the first 5 km in the estuary, photographs were taken every 15 seconds from the moving boat (about 25 meters apart) that were subsequently examined to add to visual observations of riverbank mangrove species composition. In addition to riverbank vegetation observations from the boat, a survey was conducted ashore on a high sandbank with high mangrove diversity (-6.378786°S, 38.854517°E, Fig.3-1, Table 3-1), to observe how mangrove community composition varied inland from the bank, and to visually relate species composition with habitat characteristics such as local topography, extent of flooding and soil type. All mangrove species (adults and saplings) occurring 2 meters on either side of a random line transect (approximately 100 meters in length) were noted, along with notes on local topography, high tide flooding evidence and soil type, whether clayey or sandy.

3.1.2 Salinity measurements: As mentioned in Chapter 2, salinity measurements were taken along the same marine-freshwater journeys at different depths (surface, 1 and 2 meters) under different tidal conditions (Ch 2, Appendix 1). Salinity values over the high tide phase at 2 m depth are included in Fig.3-2 and have been related with the occurrence of different plant communities.

3.2 Vegetation composition

A variety of plant communities exist from the estuary mouth all the way to the freshwater section (Fig.3-1, Table 3-1). They can be broadly classified based upon their degree of salinity and/or flood tolerance as:

(i) communities composed of mangroves that are very tolerant of salinity and flooding duration
(ii) communities composed of mangrove species with lower tolerance of flood duration
(iii) communities with mangroves and palms with very low tolerance
(iv) plant communities intolerant of salinity.

The zone within 9 km upstream from the river mouth has different mangrove communities (Fig.3-1, 3-2), followed by the mangrove – palm transition zone for about 2 km and thereafter paddy farms and freshwater-source using trees (such as *Acacia senna*) on the bank. The distribution of species into these distinct communities is likely a direct outcome of the duration of flooding and the salinity of the water in the root zone. To sample water from the root zone, wells would be required to be installed; however, in the absence of wells, we relate vegetation distribution with adjacent river salinity.

Figure 3-1: Woody vegetation composition in the Ruvu estuary, June 2013. Mangrove species abbreviations: SA: *Sonneratia alba*; RM: *Rhizophora mucronata*; AM: *Avicennia marina*; BG: *Brugeria gymnorrosa*; CT: *Ceriops Tagal*; HL: *Hereteria littoralis*.

Community	Latitude	Longitude	Remarks
Sonneratia	**-6.368287°**	**38.871491°**	**Sandbar jutting out into sea, completely inundated at high tide.**
Sonneratia, Rhizophora	**-6.375122°**	**38.858313°**	**North bank, estuary mouth**
Rhizophora, Avicennia, Ceriops, Brugeria, Hereteria	**-6.378841°**	**38.852970°**	**Diverse high sandy bank in estuary, floods from behind**
Sonneratia	**-6.390415°**	**38.853958°**	**Island in river channel**
Avicennia, Rhizophora, Sonneratia	**-6.386967°**	**38.860841°**	**South bank in estuary mouth**
Avicennia	**-6.396982°**	**38.861010°**	**Avicennia forest on north bank**
Hereteria, Rhizophora, Ceriops, Avicennia	**-6.398293°**	**38.871330°**	**High bank on south side**
Brugeria, Ceriops, Avicennia	**-6.407859°**	**38.858598°**	**High bank on south side further upriver**
Phoenix palm, Avicennia	**-6.409481°**	**38.845097°**	**First palms appear on banks in upriver**
Phoenix palm, Avicennia	**-6.416805°**	**38.835464°**	**Mangrove-palm transition zone**
Paddy farms	**-6.425406°**	**38.845945°**	**Paddy farm situated a few meters away inland**

Table 3-1: Plant communities in Ruvu estuary along with representative GPS locations.

In all, seven species of mangroves were observed in the mangrove forests in the Ruvu estuary (Table 3-2 and Appendix 2 photographic key), similar to what has been reported for coastal Tanzania (Semesi 2001, Richmond 2011). Semesi (1991, 2001) has a very comprehensive description of the ecology and ethnobotany of mangroves in coastal Tanzania. A detailed description of the communities and the environment along the Ruvu estuary shoreline is given below.

Species	*local name*	*Relative Salinity/flood tolerance*
Sonneratia alba	**Mpira, Mlilane, Evening blossom mangrove**	**High, monospecific stands on flooded sandbanks**
Rhizophora mucronata	**Mkoko, red mangrove**	**High, on coastal margins flooded at high tide**
Avicennia marina	**Mchu, white mangrove**	**Medium-high**
Ceriops tagal	**Mkandaa**	**Medium-low, occurs on high sandbanks**
Hereteria littoralis	**Mkungu, silver mangrove**	**Medium-low, occurs on high sandbanks**
Bruguiera gymnorrhiza	**Mshinzi**	**Medium-low**
Xylocarpus granatum	**Mkomafi**	**Medium-low, occurs on high sandbanks**

Table 3-2: List of mangrove species observed in the Ruvu estuary. See appendix 2 for a photographic key.

3.2.1 Estuary mouth:

The mouth of the river has sandbanks extending > 100 m from the coastline into the Indian Ocean (Fig.3-3, 3-4). The landward portions of these sandbanks have stunted *Rhizophora mucronata* and *Sonneratia alba* on account of being entirely submerged during high tide (Fig.3-3, 3-4, 3-5). The almost monospecific stands would indicate that these are the only mangrove species able to tolerate prolonged flooding by seawater on a diurnal basis.

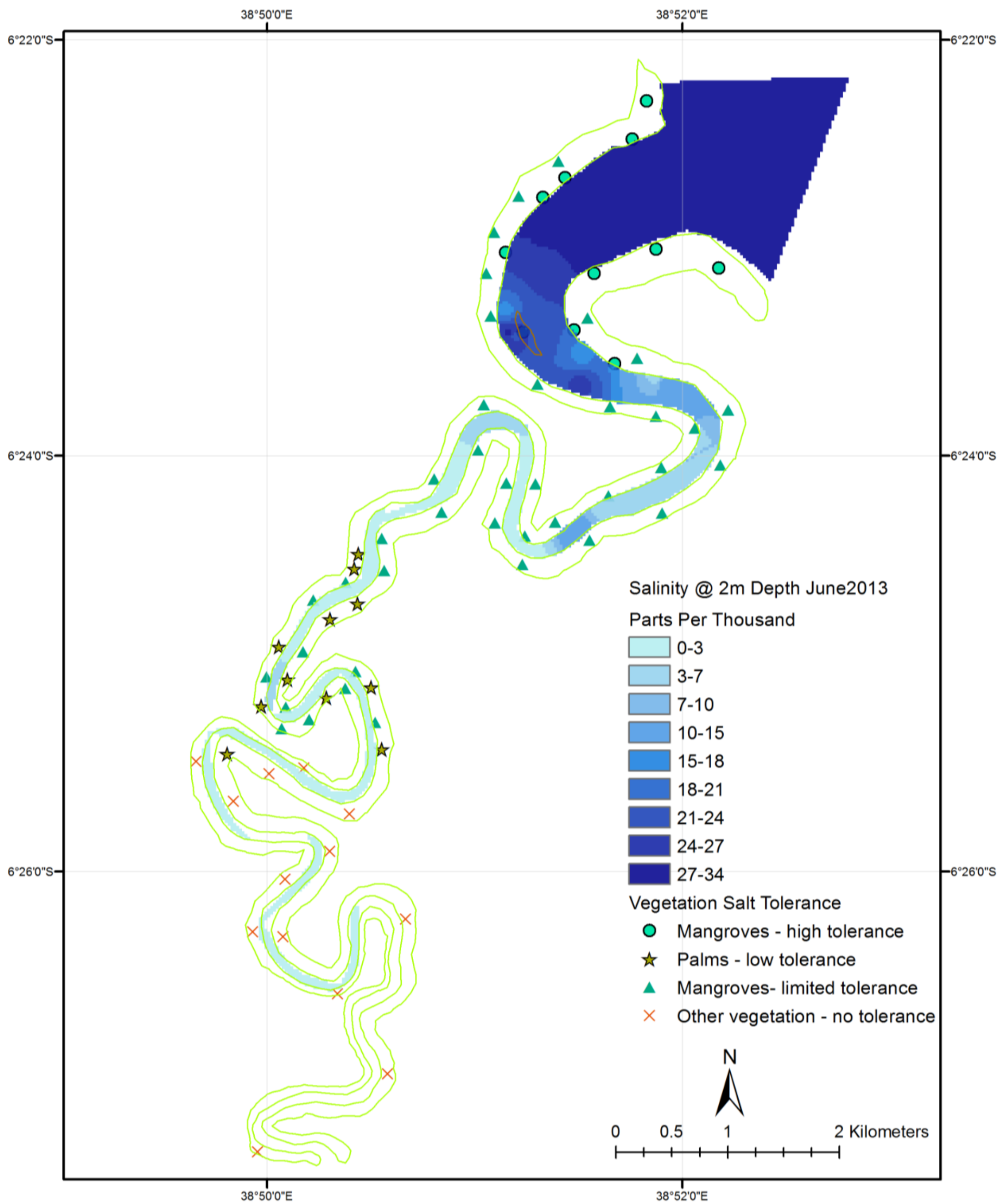


Figure 3-2: Riparian vegetation in the Ruvu estuary (freshwater to marine end) classified by salinity tolerance and shown along with salinity measurements in the Ruvu river (high tide phase at 2 m depth over June 19-22, 2013).

Figure 3-3: *Sonneratia alba* on a sandbank at low tide at the mouth of the Ruvu; the Indian Ocean is to the right.

Figure 3-4: *Sonneratia alba* on sandbanks in the mouth immersed at high tide

Figure 3-5: Pure stand of *Sonneratia alba* on island that gets inundated at high tide

3.2.2 Low-lying riverbanks – fully inundated at high tide

Entering the river, low lying banks and islands have monospecific stands of *Sonneratia* with a few individuals of *Avicennia*. These banks were observed to be totally inundated by the high tide (Fig.3-4, 3-5). *Sonneratia* has been reported as being the most flood-tolerant of the mangroves along the East African coast (Semesi 1991). Both *Sonneratia* and *Avicennia* have pneumatophores as root respiratory adaptations to flooded conditions, while *Rhizophora* has stilt or prop roots (refer Appendix 2). A physiological description of mangrove function in flooding and saline environments is found in the literature (Semesi 2001, Richmond 2011). The coastlines have *Rhizophora* and *Sonneratia* along the banks, with stands of *Avicennia marina* inland (Fig.3-6).

Figure 3-6: Rhizophora (stilt roots), Sonneratia (right) in the foreground, inundated at high tide, with Avicennia in the back, inundated to a lesser extent.

3.2.3 Elevated sandy banks

The western river bank gets noticeably higher upriver from the mouth with an accompanying increase in mangrove species present. *Ceriops tagal* is noticed with its characteristic bunched roots at the base of the trunk, along with *Rhizophora* and *Avicennia,* while *Sonneratia* is absent (Fig.3-7), probably outcompeted by other mangrove species.

Figure 3-7: *Rhizophora* (left), *Ceriops* on sandbank (centre) with *Avicennia* on higher ground. Salinity varies between brackish and marine.

In order to observe what species exist inland away from the riverbank and to examine how community composition is related to distance from the bank, local topography and soil type, shore-based investigations were undertaken. Banks that were up to 0.5 m higher than the high tide level (such as in Figure 3-8 left) showed a diverse assemblage of mangroves, including *Ceriops tagal*, *Brugeria gymnorrhiza*, *Hereteria littoralis* and *Xylocarpus granatum* apart from *Avicennia marina* and *Rhizophora mucronata (Fig.3-9)*. Soils under these diverse mangrove communities were sandy thereby allowing free drainage at low tide; the availability of well-aerated conditions is an important factor in permitting these other mangrove species to exist that are not as tolerant of prolonged flooding as *Sonneratia* and *Rhizophora* are.

On the bank there were also relatively-low lying areas with little vegetation and with cracked soil indicating periodic flooding and drying (Fig.3-10). During the survey, the tide began entering inland along these low-lying areas, not from the riverbank which was still higher than the river level but from other small channels that came in from the coastline. These stream flow channels are visible on the Google Earth map (Fig. 3-8 right). This map shows this bank at high tide with clusters of mangroves flooded off the bank shore that are mainly *Rhizophora.* Salinity in the river varied between

23 ppt (surface) -35 ppt (2 m depth) at high tide. About a kilometer inland, the north bank is dominated by *Avicennia* while the south bank has a diverse assemblage. Salinity varied from 14 – 22 ppt.

Figure 3-8: (Left) High sandy bank on an incoming tide with an Avicennia marina tree on left and smaller *Avicennia* on the bank. **(Right)** Google Earth satellite image taken at high tide, showing *Rhizophora* and *Sonneratia* trees inundated at the edge of the bank as well as presence of channels that flood at high tide.

Figure 3-9: Diversity of mangroves on high bank. Ceriops (left), Xylocarpus (centre), and Avicennia (right) in the back, with a relatively low-lying area (darker soil on the right).

Figure 3-10: Low-lying area with cracked soil indicating periodic wetting and drying

3.2.4 Mangrove – palm transition zone

About 9 km inland the first palms appear (Figs. 3-2, 3-11), and then get more numerous. Unlike *Cocos nucifera* (coconut palm found on coasts) or *Nypa fruticans* (toddy or mangrove palm not found in East Africa, but that may have been introduced), the palms in these forests, such as *Phoenix reclinata* are not known to be tolerant of salinity, although they can withstand some degree of soil anoxia from flooding. Hence the presence of palms on riverbanks indicates water conditions that are largely fresh throughout the year. This is corroborated by this study's salinity measurements which at low tide were 0 ppt while at high tide were 0, 0.3 and 0.6 ppt at the surface, 1 and 2 m depths. The mangrove-palm transition thus can be reasonable assumed to indicate the average extent of seawater intrusion into the Ruvu. A similar transition zone has been observed in the Wami estuary (Anderson et al. 2007). Note that the palms have to be on the riverbank in order to be considered as indicators; inland palms may be located on higher ground that may have a layer of entrapped rainwater (freshwater lens, Saha *et al.* 2009) serving as the water source.

Figure 3-11: *Phoenix reclinata* palms (left) coexisting with *Avicennia marina* (center) in the mangrove-palm transition zone

Figure 3-12: Palms get more numerous, and paddy farms appear up to the bank

3.2.5 Freshwater - dependant vegetation zone

Palms (primarily *Phoenix reclinata*) become more dominant, until acacias and other terrestrial evergreen and deciduous trees appear, interspersed in today's landscape with rice fields (Fig.3-12). The water is completely fresh in these regions. Hydrologists from the Wami Ruvu Basin Water Office have observed saline water past the bridge that is 5 km further upstream from the mangrove-palm transition zone. It is possible that seawater extends further upriver when spring tides coincide with the lowest freshwater flow in the dry season. However, the vegetation is dominated by freshwater-dependent plants, and also paddy farms. This is because the banks are high enough to avoid prolonged flooding by the river, the top water layer is fresh and, eventually upon wet season flows, the freshwater pulse can flush saline water in river bed soil interstices. Also the high banks collect rainwater that constitutes the main water source for plants.

4 Wildlife observations in the Ruvu Estuary

Figure 4-1: Nile crocodile entering the river within the mangrove forest zone.

4.1 Terrestrial wildlife

The Ruvu estuary, with its diverse habitat—including different mangrove forests, mangrove-palm forests, grasslands, rice paddy and banana farmlands, wooded grassland and thick shrub-land with several micro-habitats—supports different populations of birds, reptiles and mammals. This is despite any official form of protection such as that afforded to the Wami estuary by its inclusion in Saadani National Park. The only wildlands and wooded habitat remain along the river banks in the brackish region of the estuary, where the saline water does not permit agriculture. However, indiscriminate mangrove tree felling can be expected to significantly degrade this habitat to the point where wildlife populations may no longer be supported in the future. Mammal, bird and reptile observations were recorded from the boat during transects and journeys along the river. The species was identified as far as possible to the lowest taxonomic level, and GPS coordinates noted, as well as the salinity of the river at that point. Amphibians and invertebrates were not seen in this boat-based survey.

Reptiles: Nile crocodiles (*Crocodylus niloticus*), were observed at several locations crawling to the brackish water from the mud along the river bank (Fig.4-1). A green monitor lizard (*Varanus prasinus)* climbed and perched on shrubs along the river. The table below indicates just the larger reptile species observed. Lizards have not been included and no snakes were seen.

Birds**:** Around 30 species of birds were seen (Table 4-1), including many species of waterbirds. The depth of the river favors some species like Kingfisher (Pied Kingfisher and Woodland Kingfisher) to be adapted to catching both freshwater and brackish fishes. The island isolated due to deposition on the river mouth is dominated by *Sonneratia alba* and few individuals of *Avicennia marina* and is a roosting ground for herons, sacred ibises and African spoonbills as well as little egrets and long-tailed cormorants. A large population of yellow-billed storks and woody-billed storks were observed in a brackish environment around 6.4265 S and 38.841133 E with many *Sinnea* trees. Little bee eaters darted across the river feeding on insects flying on the surface of water. African fish eagles and a brown snake eagle were seen, the latter chased away by herons (especially Grey herons). Flamingoes (group of more than ten individuals) were seen in flight at the river mouth. Associated bird species around Bagamoyo area from salt pans and other terrestrial birds nearby the estuary were Indian house crows, nightjar, three-banded plover, black-winged stilt, spur-winged plover, crowned plover and Eurasian swifts.

COMMON NAME	SCIENTIFIC NAME
Roseate tern	***Sterna dougalii***
Little egret	***Egretta garzetta***
African spoonbill	***Platalea alba***
African Fish Eagle	***Haliaeetus vocifer***
Grey heron	***Ardea cinerea***
Brown Snake Eagle	***Circaetus cinereus***
Woolly-necked stork	***Ciconia episcopus microecelis***
Sacred ibis	***Threskiornis aethiopicus***
Egyptian Vulture	***Neophron percnopterus***
Little bee eater	***Merops pusillus***
Purple heron	***Ardea purpurea***
African Paradise Flycatcher	***Terpsiphone viridis***
Spur-winged Plover	***Vanellus spinosus***
Black-winged Stilt	***Himantopus himantopus***
Crowned Plover	***Vanellus coronatus***
Three banded Plover	***Charadrius tricollaris***
Striped Kingfisher	***Halcyon chelicuti***
Pied Kingfisher	***Ceryle rudis***
Long-tailed Cormorant	***Phalacrocorax africanus***
Yellow-billed Stork	***Mycteria ibis***
Lesser flamingo	***Phoeniconaias minor***
Eurasian Swift	***Apus apus***
Indian House Crow	***Corvus splendens***
Woodland kingfisher	***Halcyon senegalensis***
Palm-nut vulture	***Gypohierax angolensis***
Dimorphic egret	***Egreta dimorpha***

Table 4-1: Birds seen in Ruvu Estuary during June survey and identified using Stevenson & Fanshawe(2002) and Williams & Arlott (1993).

Mammals: Blue monkeys (*Cercopithecus mitis)* were encountered in palms and other trees around 6.3943 S and 38.8585 E but not on mangroves, thus suggesting the possibility that these monkeys occur in vegetation associated with freshwater. Yellow baboons (*Papio cynocephalus)* observed on the river bank of more than 10 individuals as a group, some of them uprooting grass stems and feeding on them. Several Hippopotamus (*Hippopotamus amphibious*) were observed in the river (Fig.4-2) near the mouth at low tide when the water was not saline (< 3 ppt).

4.1.1 Challenges of Wildlife conservation in the Ruvu River Estuary

Unlike the Wami River estuary, which is protected by inclusion within Saadani National Park, there is no official protected status for the mangrove forests bordering the Ruvu River or for the river itself. This survey has observed megafauna (hippos, crocodiles, primates) and a diversity of bird species that depend upon these mangrove forests for

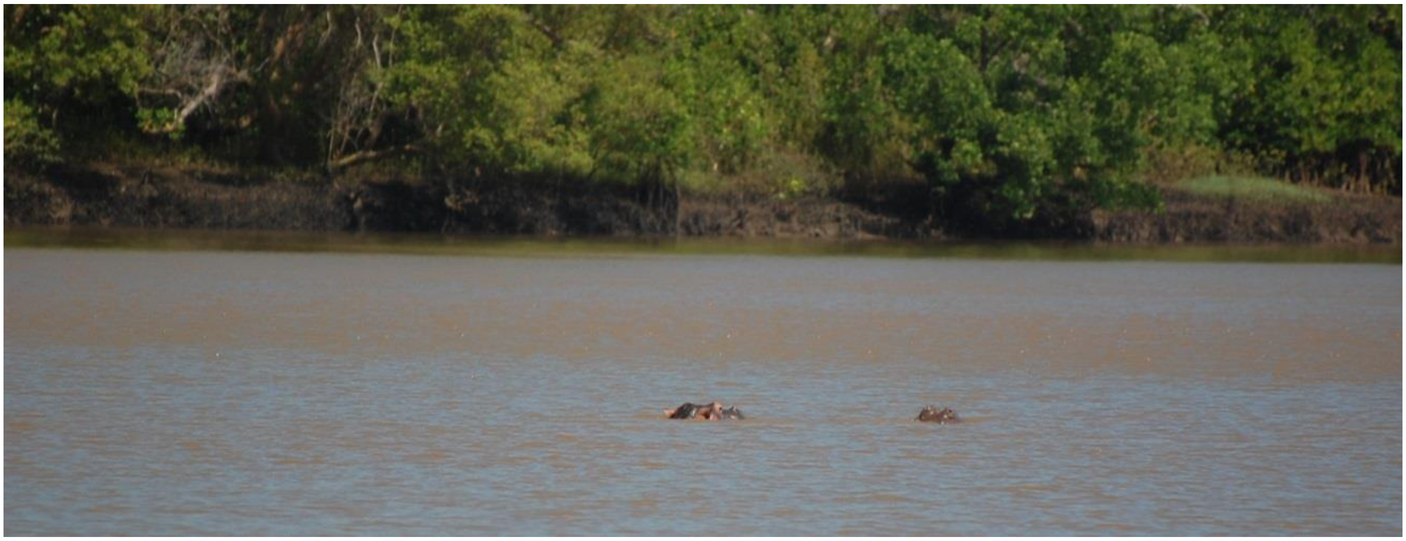


Figure 4-2: Hippos a few kilometers from the river mouth at low tide when channel is largely freshwater

from these forests for the Indian Ocean trade (Martin & Martin 1978, Stedman-Edwards *et al.* 2013). However, increasing pressures are threatening mangrove forests through indiscriminate cutting of mangroves for timber (Stedman-Edwards *et al.* 2013). This survey noticed areas on higher banks that were clear-cut (Fig. 4-3). Clear-cutting sections decreases habitat for bird communities that roost and breed in these trees. Another environmental issue involves plastic bags and garbage that are washed up with the tides in increasing amounts, covering mangrove propagules, roots and pneumatophores. Plastic bags also pose a serious danger to turtles, fish and birds by choking them. Efforts are required to increase protection for these forests, as well as to work with communities for mangrove restoration programs while simultaneously exploring other avenues for sustainable income generation for local communities.

Figure 4-3: Mangrove stumps poke out over the high tide waves on a clear-cut bank

4.2 Aquatic ecosystem characterization

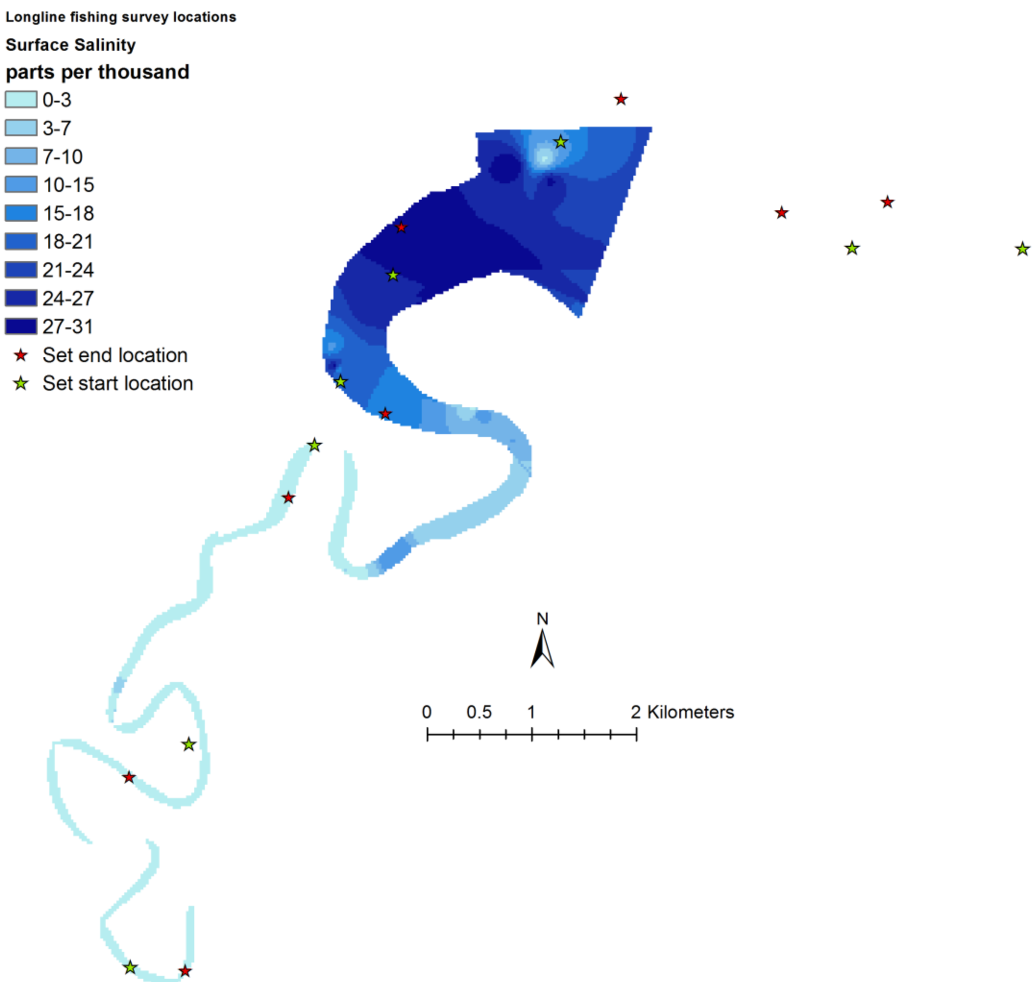


Figure 4-4: Longline fishing locations with start (green star) and end (red star) for each longline set, corresponding to the anchor and buoy locations. Also shown are surface salinity as of June 2013 (shades of green) and salinity values measured at the time of fishing.

Estuaries have assemblages of freshwater, brackish water and marine fish and invertebrates whose movements depend upon the tides and the seasons. However not much is known about the relationship between salinity, flow and the metabolic, prey and reproductive aspects of the aquatic organisms in the Ruvu estuary, or along the coastline of this part of East Africa. In order to acquire a baseline benchmark of what species currently exist in different seasons, two approaches were taken simultaneously: fishing campaigns targeting large fish, sharks and rays and surveying fish catches by the local fishing community. This report includes the results of the fishing campaign conducted over June 23-27, 2013.

4.2.1 Longline-based survey for bony fish, sharks and rays

Small-scale bottom longline fishing surveys were initiated to assess the relative abundance and community structure of bony fish (teleosts) and sharks/rays (elasmobranchs) across the main habitats in the river and adjacent waters (including the mouth of the estuary and coastal waters). An attempt to sample all associated habitat types was made and thus fishing was conducted in freshwater upstream, brackish estuary, river mouth, coastal mangrove, seagrass, and coral reef habitats (Fig. 4-4). In brief, nine 550 m benthic longlines with 40 – 70 baited hooks of various sizes were set and soaked for one – two hours (Fig. 4-5). Any animals caught were measured and sampled for stable isotope analysis (Table 4-2). Although this widely accepted fishing method and variations thereof are used to catch a variety of sharks, rays and large bony fishes, African catfish (*Arius africanus*) were the only species caught throughout the entire sampling effort, with a total of 9 individuals caught and sampled for stable isotope analyses.

Figure 4-5: (Left) (Right) Longline nylon rope, hooks and anchor. Two sea catfishes (*Arius africanus*) caught on the longline.

Surprisingly, no sharks were caught, while bull sharks (*Carcharhinus leucas*) were expected to be captured. It is also important to note that bait depredation (by crabs and catfish) was a major issue, potentially altering catch results. Bull sharks are found to swim up rivers in many parts of the world, including the Florida Everglades, the Mississippi, the Amazon, the Ganges-Brahmaputra, the Zambezi, other rivers along the coasts from Morocco to Angola, from South Africa to Kenya and Australia. They prefer warm shallow waters and are associated with estuaries. No marine mammals or sea turtles were recorded during sea journeys between Bagamoyo (village where field team was based) and the Ruvu River (~10 km) on all 6 days.   While the amount of observation effort was low, at least a few sightings were expected. Past hunting and current poaching/by-catch might highlight the existence of serious conservation problems for these species in the area.

4.2.2 Community trophic structure via stable isotope analysis

Stable isotopes of nitrogen and carbon in the tissue of an organism can indicate what the organism feeds upon (eg. Bouillon, Connolly and Gillikin 2011). While carbon stable isotope ratios do not change between primary producers (macroalgae, seagrasses), invertebrates and fish, the nitrogen stable isotope ratio does change, with an increase on the heavier nitrogen isotope (N^{15}) resulting from metabolic fractionation (retention of the heavier N^{15} in tissue of the consumer). This generally results in an increase of around 3 parts per thousand (ppmil) of the N isotopic ratio in the tissue of a predator when compared with that of the prey. This is the basis for determining trophic levels and food webs. In order to understand the trophic connections or dietary connections between various species in the estuarine community, tissue samples were taken from seagrasses, macroalgae and fish (Table 4-2).

Seagrasses are a group of rooted flowering plants belonging to the monocotyledon group that occur in shallow bays and lagoons in the tropics and subtropics. Seagrass beds provide shelter and food for numerous species of aquatic invertebrates, fish, juveniles of larger marine fish, sea turtles and dugongs (Semesi 2001). Seagrasses are sensitive to flow alterations, hypersalinity, turbidity increases and nutrient reductions (Doehring 2002, Fourqurean *et al.*2003) and are globally threatened ecosystems on account of changes in water quality and introductions of invasive species. Increased sediment can increase turbidity, thereby decreasing sunlight penetration, as well as eventually smother seagrass beds. Doehring *et al.*(2002) used salinity tolerance data from field and laboratory studies of submerged aquatic vegetation in the Caloosahatchee estuary, Florida to estimate a minimum flow required to maintain the salt-tolerant freshwater species, *Vallisneria americana,* at the head of the estuary and a maximum flow required to prevent mortality of the marine species *Halodule wrightii* at its mouth.

A total of 7 seagrass species and 5 macroalgae species were sampled north of Bagamoyo village from the coastal flats at low tide (Fig 4-6). The seagrass species identified were *Thalassodendron ciliatum, Haladule wrightii, Haladule uninervis, Halophila ovalis, Syringodium isoetifolium and Cymodocea species*

Figure 4-6: Seagrass beds along the coast at high tide (left) and low tide (right) with some degree of sedimentation.

A total of 34 species of fish were collected and sampled (fin and muscle tissues) for stable carbon and nitrogen isotope analyses (Table 4-2) in order to investigate community structure, trophic redundancy and individual foraging specialization. A subset of the species sampled was analyzed, based upon the replicates taken.

Fig 4-7 shows the stable isotope values of primary producers (seagrasses and macroalgae) clustered at the bottom of the plot and those of the secondary consumers on top. The nitrogen stable isotope ratio (Y –axis) shows a very clear trophic separation between the primary producers (0-4 ppmil) and the fish (8-13 ppmil). Assuming the typical 3 parts per thousand (ppmil) separation between marine/estuarine trophic levels, this shows that perhaps invertebrates (crustaceans, worms, small algae and detritus-eating fish) would have a delta N in between, in the 4-8 ppmil range. Primary producers have a wide range in the stable isotope ratio of carbon, while the secondary consumers show a subset of that range. This indicates that most teleost fishes in coastal ecosystems of the Ruvu estuary region rely on prey that feed in macroalgal and seagrass food webs. Furthermore, most fish species appear to exhibit some trophic overlap with other species found in the same geographic region, thereby suggesting the importance of each component of coastal food webs, especially primary producers that are affected by changes in water quality (e.g. salinity, turbidity, and nutrients).

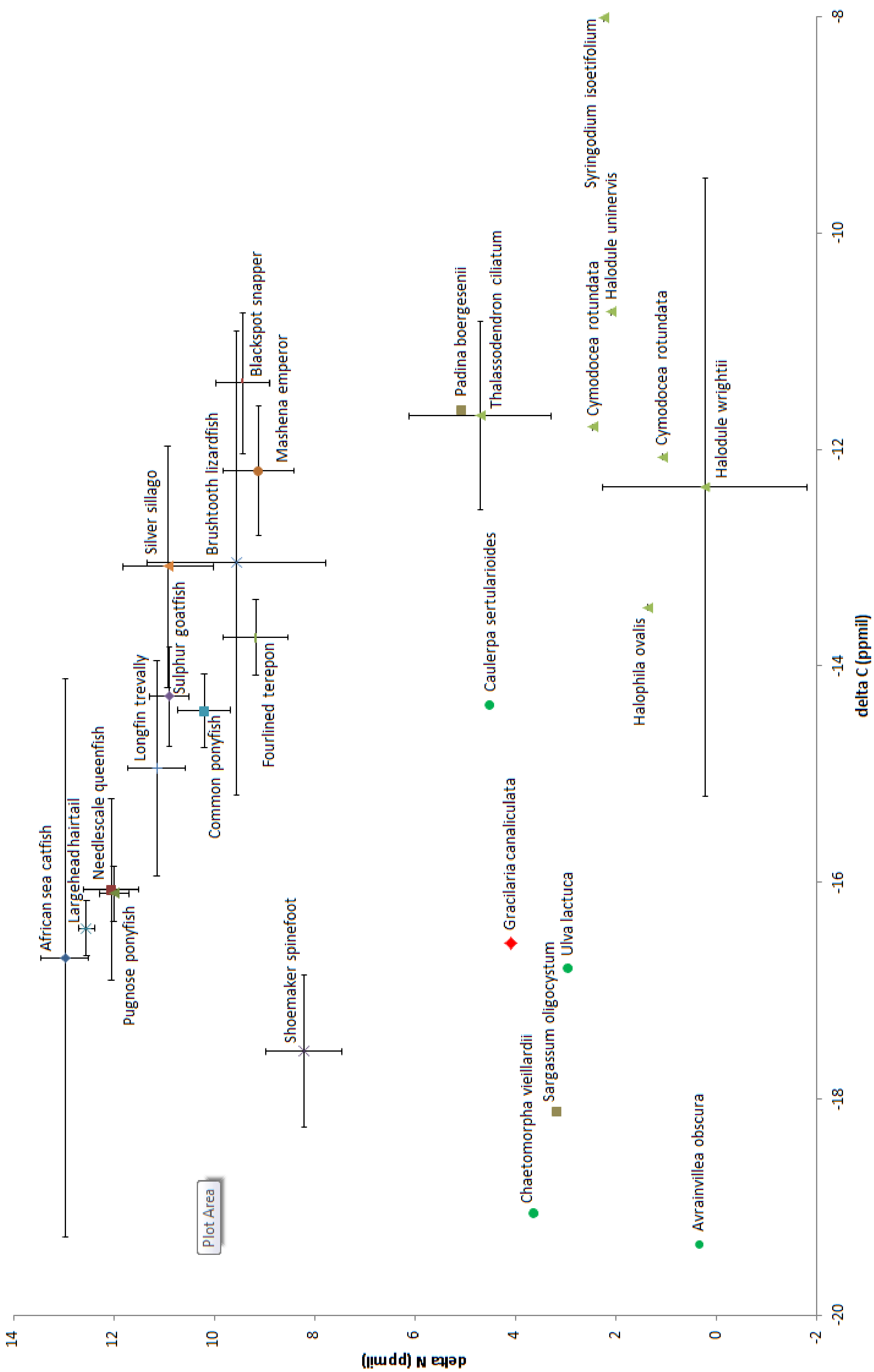


Figure 4-7: Trophic levels of secondary consumers (fish - above) and primary producers (seagrasses and macrolagae-bottom) obtained from a plot of Carbon and Nitrogen stable isotopes for the Ruvu Estuary

Species	n	sample	Common name	Swahili local name
Scomberoides tol	**9**	**epaxial muscle biopsy and caudal fin clip**	**needlescaled queenfish**	**pandu**
Tylosaurus crocodilus	**4**	**epaxial muscle biopsy and caudal fin clip**	**hound needlefish**	**mkule**
Sphryraena obtusata	**5**	**epaxial muscle biopsy and caudal fin clip**	**obtuse barracuda**	**msusa**
Sillago sihama	**15**	**epaxial muscle biopsy and caudal fin clip**	**silver sillago**	**mtambaanchi**
Psettodes erumei	**1**	**epaxial muscle biopsy and caudal fin clip**	**indian spiny turbot**	**gayo gayo**
Upeneus sulphureus	**30**	**epaxial muscle biopsy and caudal fin clip**	**sulphor goatfish**	**mkundaji**
Leiognathus equulus	**32**	**epaxial muscle biopsy and caudal fin clip**	**common ponyfish**	**kotwe**
Secutor insiditor	**8**	**epaxial muscle biopsy and caudal fin clip**	**pugnose ponyfish**	**kotwe**
Gerres acinaces	**2**	**epaxial muscle biopsy and caudal fin clip**	**longtail siver biddy**	**chae**
Thryssa vitrirostris	**2**	**epaxial muscle biopsy and caudal fin clip**	**orangemouth anchovy**	**dagaa**
Pellona ditchela	**3**	**epaxial muscle biopsy and caudal fin clip**	**indian pellona**	**dagaa**
Sardinella albella	**4**	**epaxial muscle biopsy and caudal fin clip**	**white sardinella**	**dagaa papa**
Sardinella gibbosa	**1**	**epaxial muscle biopsy and caudal fin clip**	**goldstripe sardinella**	**dagaa papa**
Trichiurus lepturus	**7**	**epaxial muscle biopsy and caudal fin clip**	**largehead hairtail**	**antepa**
Plectorhincus flavoma	**1**	**epaxial muscle biopsy and caudal fin clip**	**dusky rubberlip**	**mchone**
Saurida undosquamis	**21**	**epaxial muscle biopsy and caudal fin clip**	**brushtooth lizardfish**	**mbumbura**
Otolithes ruber	**3**	**epaxial muscle biopsy and caudal fin clip**	**tigertooth croaker**	**pooza**
Chirocentrus dorab	**1**	**epaxial muscle biopsy and caudal fin clip**	**dorab wolfherring**	**mkonge**
Caranx papuensis	**2**	**epaxial muscle biopsy and caudal fin clip**	**brassy trevally**	**kolekole**
Rastrelliger kanagurta	**1**	**epaxial muscle biopsy and caudal fin clip**	**indian mackerel**	**kibua**
Plolynemus sextarius	**1**	**epaxial muscle biopsy and caudal fin clip**	**blackspot threadfin**	**kupe**
Gerres filamentosus	**1**	**epaxial muscle biopsy and caudal fin clip**	**lontail siverbiddy**	**chaa**
Johnius dussumieri	**1**	**epaxial muscle biopsy and caudal fin clip**	**bearded croaker**	**pooza**
Gazza minuta	**2**	**epaxial muscle biopsy and caudal fin clip**	**toothpony**	**kotwe**
Carangoides armatus	**12**	**epaxial muscle biopsy and caudal fin clip**	**longfin trevally**	**kolekole**
Pomadasys kaakan	**1**	**epaxial muscle biopsy and caudal fin clip**	**javelin grunter**	**karamamba**
Drepane puctata	**1**	**epaxial muscle biopsy and caudal fin clip**	**spotted sicklefishl**	**kipepeo**
Panulirus ornatus	**1**	**epaxial muscle biopsy and caudal fin clip**	**ornate spiny lobster**	**kamba koche**
Carangoides oblongus	**1**	**epaxial muscle biopsy and caudal fin clip**	**coachwhip trevally**	**kolekole**
Lutjanus fulviflamma	**13**	**epaxial muscle biopsy and caudal fin clip**	**blackspot snapper**	**tembo**
Signatus sutor	**8**	**epaxial muscle biopsy and caudal fin clip**	**shoemaker spinefoot**	**tasi**
Lethrinus mahsena	**11**	**epaxial muscle biopsy and caudal fin clip**	**mahsena emperor**	**changu**
Pelates quadrilineatus	**26**	**epaxial muscle biopsy and caudal fin clip**	**fourlined terepon**	**kui**
Terapon puta	**3**	**epaxial muscle biopsy and caudal fin clip**	**smallscalled terepon**	**kui**
Arius africanus	**9**	**epaxial muscle biopsy and caudal fin clip**	**african sea catfish**	**hongwe**

Table 4-2: List of marine and estuarine fish species sampled for tissue to create trophic webs.

4.2.3 Local fishermen catch survey

The major landings of the coast include snappers, groupers, catfish, sardines, rabbitfish, sharks, lobsters and prawns. The common fish found in the mangrove and estuarine habitats include milkfish, catfish and file fish. There are more than 30 species of prawns in Tanzanian waters, but the economically important ones include *Penaeus monodon, P. indicus, P. semisulcatus* and *P. latisulcatus*. The largest and most valuable prawn is *P. monodon*, whereas *P. indicus* is the most abundant in Tanzanian waters. Seagrass beds provide nursery and feeding grounds for herbivorous fish, such as parrotfish (*Scarus*), rabbitfish (*Siganus*) and habitat for marine invertebrates such as sea cucumber (Holothoroidea) and the bivalve *Anadara antiquata*. Men usually catch fish using seine nets, while *A. antiquata* and sea cucumbers are collected by women who regularly search the beaches for edible marine life and seaweed.

Overnight dhow fishing trips: the larger fishes in the market are brought in by dhows (ocean-going sailboats) which fish overnight in waters 5-8 km out in the Indian Ocean by hook and line as well as by nets (Fig 4-8).

Figure 4-8: (Top left) A fisherman brings in the catch from an overnight offshore dhow fishing trip. (Bottom left) The fish atop the basket includes (from top) - tuna, milk shark, catfish, tarpon, sea catfish and another milk shark. (Right) the catch also contained (from top) sea catfishes, tarpon, sole, grouper and mackerels.

Beach seine landings: The majority of fish in seine nets are small in size, many of them juvenile snappers, grunts and wrasses; crabs are also caught (Fig 4-9, 4-10). Seine nets corral together both pelagic and bottom-dwelling fish. Inedible fish like puffers are usually tossed back into the sea, however mortality results if too much time elapses in sorting fish from the net. If the fish are gathered together in a canoe, chances of by-catch being released alive appears greater than if the net were to be drawn up and examined on the beach.

Figure 4-9: Catch from a seine net placed into a canoe before sorting out inedible fish such as puffers which are often tossed back into the sea.

Figure 4-10: Bottom-dwelling Flathead catfish in the seine catch

Fish markets: A wide variety of species and sizes were seen at the Bagamoyo Customs House Beach fish market (Fig 4-11 to 4-14). Catches brought in by boat range from small jacks, scats, snapper and pomfrets to larger halfbeaks, ballyhoo, needlefish, catfish and mullets, to mackerel, barracuda, grouper and tuna all the way to shark and rays. In addition, there are also seine catches, small coastal fish that are sorted and usually deep fried (Fig 4-13). Additional photographs are included in Appendix 3

Figure 4-11: (Left) Jacks and scats for sale at Bagamoyo beach fish market. (Right) Ballyhoos (*Tylosurus crocodilus*) for sale.

Figure 4-12: Extensive sheds where fish are deep-fried using mangrove firewood for preservation and export throughout Tanzania.

Figure 4-13: (Top) (Bottom) A variety of fish are deep-fried after having their digestive organs removed that can otherwise spoil earlier. Small fish and shrimp are fried straightway.

Figure 4-14: (Left) sorting of small fish. (Right) cuts of shark and skates as well as (from top right) marine catfishes, jacks and pompanos on sale.

4.2.4 Conservation issues in the coastal and marine ecosystem

Fish are the main protein source as well as the major income source for coastal communities; a large part of the catch is sent to Dar es Salaam as well as inland towns such as Morogoro and Dodoma. The bigger fish are sent on ice, while smaller fish are deep fried for preservation (Fig 4-13). Local fishing communities mention a marked decrease in the numbers of large fish over the past 1-2 decades as well as the volume of smaller fish; reasons include overfishing and use of destructive fishing practices that are resulting from the greater demand on fisheries (Julius 2005). Jiddawi (2003) mentions that environmental factors also affect fish reproduction and populations; any negative impact on estuarine water quality impacts seagrass beds, with negative feedback effects cascading up the marine coastal ecosystem trophic levels. However, beyond generalizations such as sedimentation and nutrient pollution harming coastal ecosystems, not much is known about the prey, metabolic and reproductive requirements of the various species groups, or the interactions between them.

Numerous inedible fish species and fish too small to eat were seen discarded on the beach (Fig.4-15). While many fishermen consider toxic puffers as nuisance species, awareness generation is needed that puffers (and other fish species that aren't eaten) are part of the coastal marine ecosystem, and that efforts should be taken to return these commercially unwanted fish alive as far as possible. Encouraging fishermen in Bagamoyo to collect information on fish catches and observed trends in fish abundance, distribution, and habitat availability will provide information about the status and sustainability of the coastal fishery.

In 1991, Bwathondi and Mwamsojo reported on the problem of fish by-catch in prawn trawlers (up to 70% of the catch) at the seminar on Tanzanian Wetlands (published in 1993). Due to limited storage space on board most trawlers, the fish were often discarded. They also mentioned that TAFIRI (Tanzania Fisheries Research Institute), in collaboration with experts from NORAD was involved in designing a method to separate prawns from fish and reduce by-catch waste.

Figure 4-15: (Left) inedible puffer fish discarded on the beach. (Right) dried-up juvenile nurse shark - discarded as by-catch probably because of its small size.

5 Improving understanding of the Ruvu estuary and coastline – the steps ahead

The current rapid assessment over June 18-27, 2013 has obtained initial data on estuary depth, hydrology, salinity and the communities present. These data pertain to the spring tide phase in the transition from the rainy season (March-May) to the dry season (July-September). Further data and studies over an entire year are necessary in order to develop a detailed understanding of how estuarine aquatic and terrestrial communities are connected to seasonally varying salinity, flow and nutrient regimes. These regimes result from the seasonal balance between freshwater inflows and sea tides. This chapter suggests a monitoring plan to obtain the necessary data. Apart from obtaining the minimum dataset necessary to begin understanding the ecosystem, a monitoring program provides feedback on the current ecological and environmental state of the ecosystem on which fisheries depend on. As a local example, Julius (2005) describes a proposed monitoring program for Mnazi Bay Ruvuma Estuary Marine Park as a step to increase the effectiveness of government initiatives to protect coastal ecosystems and livelhoods. Information from monitoring programs can point out the degree of success of management initiatives and suggest adaptive changes in management plans. This chapter also lists research directions to develop the ecohydrological understanding necessary in order to maintain flows that can support healthy, diverse and functioning communities. Finally, the chapter briefly indicates how salinity and flow data is used in models to obtain estimates of minimum freshwater inflows.

5.1 Recommendations for future data monitoring

The data required to understand the ecosystem is divided into a hydrological/water quality dataset and an ecological data set having data on the biology and ecology of communities and species as they relate to the estuarine environment.

5.1.1 Hydrological/water quality data monitoring

Parameter	Frequency	Methods
Flow/water level *	**Continuous/every 2 months**	**Current meter from boat**
Channel depth/bathymetry	**Every 2 months/once a year**	**Depth finder from boat**
Channel width	**Once a year**	**Google Earth**
Turbidity	**Continous/every 2 months**	**Turbidity tube from boat**
Salinity *	**Continous/every 2 months**	**Continuous measurement probe/Salinity and conductivity meter from boat/sonde**
Dissolved Oxygen (DO) and temperature	**Continous/every 2 months**	**DO meter from boat**

Table 5.1: Hydrological/water quality data parameters to be monitored. Parameters marked with an asterisk are critical parameters to be measured.

5.1.1.1 Flow/water level:

How often: Ideally, flow should be measured continuously in order to know the diurnal, lunar phase tidal, and seasonal variation. This data can then be related to rainfall and other water balance parameters to understand the hydrology of the Ruvu basin and estuary, which is a pre-requisite to managing flows year-round that maintain the ecosystem. While flow can be directly measured by devices like Acoustic Doppler Velocity (ADV) units, they are very expensive and require a fair amount of regular maintenance. Hence the most widespread approach is the continuous monitoring of water level together with developing a station calibration or flow rating curve (EPA Ireland 2013). However, in the event that the use of a continuous water level monitoring recorder is unfeasible, flow and accompanying channel depth profile measurements are recommended on at least 6 sampling events spread uniformly throughout the year (every two months), to capture some sense of seasonal variability.

Where: Flow can be measured at the locations from the June 2013 survey (Fig.2-9), in order to add to the dataset at those locations as well as observe any changes in the depth profile. It was seen that measuring flows in the estuary mouth was extremely challenging owing to the numerous pools of water (freshwater and seawater), some merging and some flowing separately in different directions. Hence it is recommended that flow measurements be carried out upriver of the mouth. Steady downstream flows on the surface over the sampling period in June were encountered 7 km and further upriver. This is likely to change with season. Since the objective is to monitor the freshwater inflows, an apt approach is to measure flow in the river in places where there is net downstream freshwater flow.

Flow measurements should be carried out in at least two locations:

1. Location closest to the estuary mouth that has net downstream freshwater flow together with underlying seawater flowing in opposite direction (upriver) as inferred by salinity measurements

2. Location upriver at freshwater end that has net downstream freshwater flow with no salinity at any depth.

These datasets can finally be compared against the discharge measurements obtained at the station closest to the estuary (50 km upriver from estuary mouth at Morogoro Bridge, Fig.2-3) by the Wami Ruvu Basin Water Board station to examine for a relationship between flows at the two locations.

5.1.1.2 Bathymetry:

Channel morphology and depths are ever-changing in estuarine environments on account of soft muddy bottoms that are continually shaped by deposition of upstream sediment as well as erosion from the interplay of freshwater and tidal currents. Google Earth images of the Ruvu estuary reveal the existence of numerous abandoned river channels, while the Pangani estuary has been reported to be subject to significant erosion over the past several decades (Sotthewes 2008). Hence channel depths can be determined from a boat-based depth finder to read the depth at fixed distance intervals on transects along the river length as well as across the channel at selected places. Whether the interval is 10 m or 1 m depends upon the time available. However, a 10 m interval should offer sufficient resolution for hydrological discharge estimation purposes. Depth profiles at flow measurement locations should be done at least annually, and twice a year if possible, to look at whether there is any significant erosion and deposition, and are these related with seasonal freshwater inflows.

5.1.1.3 Width:

Channel width can be measured from Google Earth. The present survey used a range finder (with a max range of 300 m) that worked well except in the estuary mouth where the distance between opposite shores was too large. Rangefinder results compare well with estimates obtained by using the Ruler tool in Google Earth.

5.1.1.4 Turbidity:

Caused by the presence of suspended and dissolved particulate matter, turbidity is of direct significance to seagrass beds and other primary producers as it can affect the amount of sunlight transmitted through the estuarine water to the bottom. Turbidity can be measured by the use of a turbidity tube, which is a clear glass tube with a Secchi disk at the bottom as shown by the painted disk in Fig.5-1. Alternatively, a Secchi disk can be tied to a weighted rope and immersed until the lines are not clear, and the depth of immersion measured and recorded.

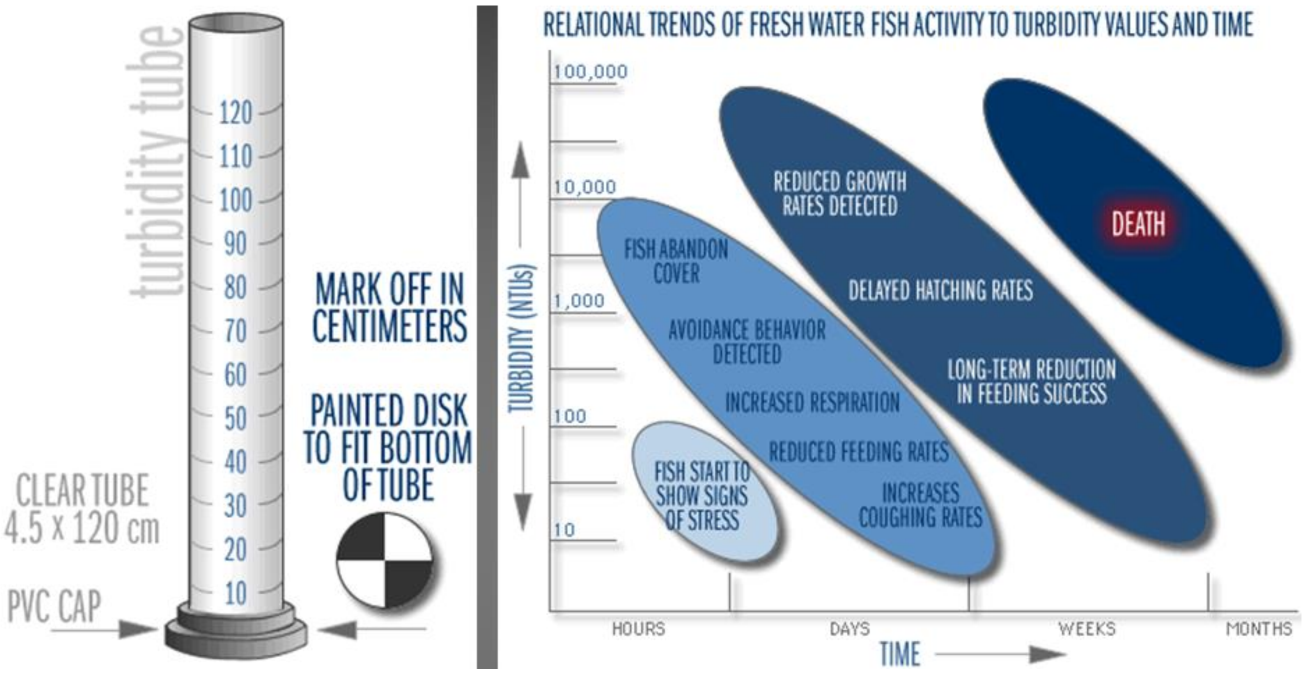


Figure 5-1: (Left) Turbidity tube and (Right) a schematic showing relationship between turbidity and fish. Source: http://steinhardtapps.es.its.nyu.edu/nyuhudson/?page_id=168

5.1.1.5 Salinity:

This present survey has characterized the salinity over a 9-day period encompassing spring tides (full moon phase) in the wet to dry season transition. Additional data collection in different seasons is necessary to obtain the full range of estuarine salinity conditions likely to exist. This basic information is necessary for simple estuarine models to recommend minimum freshwater inflows required to maintain this salinity regime. Ideally, a continuous measurement of salinity would provide a comprehensive picture of salinity conditions throughout the year. There are numerous commercially-available probes that record salinity, conductivity and temperature data at user-specified time intervals and store that in an internal memory. However if the use of a continuous measurement probe is impractical for logistical reasons, at the very least, 6 salinity sampling events spaced evenly over the year are necessary. Accordingly it is recommended that salinity, temperature and DO measurements be carried out at the same locations (Appendix 1) in different seasons. With a motor boat, each sampling should take 2-3 days, in order to measure data at the same spot at least twice, under two different tidal regimes. However, it can be logistically unfeasible to go to the Ruvu estuary at low tide on account of the reefs fringing the mouth of the estuary. Hence, to obtain salinity and other measurements under low tide conditions, the crew will have to remain in the estuary between two successive high tides. This can be problematic if the first high tide occurs late in the morning, as that would necessitate returning to Bagamoyo after sunset in the dark. An alternative would be to deploy a sonde over the entire sampling 2-3 day period with the purpose of recording data every 30 minutes and thereby obtain a continuous time series of salinity measurements over the 48 hour period. This time series captures tidal variability (seawater movement) over four tide cycles. A year's data can then be used as inputs for a salinity estuarine model to arrive at estimates of minimum freshwater inflows.

5.1.1.6 Dissolved Oxygen and Temperature:

Dissolved Oxygen is inversely related to temperature; higher the water temperature, lower is the dissolved oxygen available for fish to breathe. Hence these two parameters are always measured and recorded at the same time. Monitoring schedule for these two can accompany salinity measurements.

5.1.1.7 Additional parameters:

Nutrient concentrations (Ammonia, Nitrates and Total Phosphorus) were not measured in the Ruvu River as that was beyond the scope of the June 2013 survey. However, given the possible increase of irrigated agriculture and plantations as well as the significant industrial activity in the Ruvu River Basin (JICA 2013), future monitoring should include nutrients (agrochemicals) as well as chemicals that have been observed in industrial effluent discharges upstream.

5.1.2 Ecological parameters

Parameter	Frequency	Methods
Mangrove species Composition	**1-5 years**	**Boat and shore transect-based survey; note GPS**
Mangrove-Palm transition zone species composition	**1-5 years**	**Boat based survey; note GPS points of first palms on shore encountered moving upriver**
Seagrass composition and health	**1 year**	**Coastal beach walk at low tide; boat over shallow seagrass beds.**
Local fishing community surveys on fish catch	**Seasonal: 6 months - year**	**Community/market surveys**

Table 5.2: Ecological data parameters to be monitored.

5.1.2.1 Changing conditions in the estuary

Mangrove species composition along river banks and on high sandbanks inland can change with altered long-term groundwater salinity as well as tidal soil erosion (eg Sotthewes 2008) that increases flooding along the riverbanks. Periodic monitoring of mangrove composition can systematically detect these changes; in addition, monitoring also detects instances of indiscriminate tree-cutting.

Approach: The species composition of mangrove communities along both banks of the river can be ascertained from the boat while taking measurements of hydrological data. Figures 3-2 and 3-3 can be used as a reference guide for seeing where mangrove species and palms were present in 2013.

Mapping the species composition in selected plots in the estuary (GPS locations of trees, diameter at breast height, and species for each individual in plots or line transects) and monitoring that periodically (every 5 years) could form a component of a long-term monitoring program to assess changes in the estuarine ecosystem caused by changing salinity arising from both reduced freshwater inflows as well as sea level rise.

5.1.2.2 Extent of seawater intrusion upriver

Another region that can be monitored is the mangrove-palm transition zone (Figure 3-2) which as mentioned before, indicates the extent of significant seawater intrusion upstream along the river. The GPS coordinates of *Phoenix reclinata* palms should be noted and mapped. Mapping can be done annually or every few years, and compared. The palms should occur on the river bank or close to shore as long as the elevation is not more than 25-30 cm. Higher elevations can result in rainwater storage in the soil that can be the main water source for the palms; this is why elevations even 0.5 m higher can support species that are less salinity or flood-tolerant than those on the banks where river water is accessed by roots.

5.2 Studies for understanding ecosystem-hydrology linkages

5.2.1 Cataloguing / basic ecology of species in the Ruvu estuary

Ecosystems are understood by examining their structure and function. To understand structure, the first step is to catalogue the species and communities that exist in the estuary and surrounding environs as well as observe which of these are yearlong residents and seasonal visitors. Survey efforts should be focused on estuarine and coastal communities because local fisheries depend upon these communities functioning in a healthy manner. Basic ecology on the functioning of these communities can be gleaned from a literature survey. The excellent guide to the seashores of East Africa and the Western Indian Ocean (Richmond MD 2012) has very useful identification guides as well as a large set of pertinent references to the literature of the ecology and natural history of the region.

Studies are needed to understand the connections between different estuarine species/communities and the physical environment; in particular, salinity, turbidity and dissolved oxygen. These studies are more involved, taking several years and are ideally undertaken by university and government institution researchers and can be suitable as university student projects.

5.2.2 Seagrass species composition and links to salinity

Not much information is available on linking seagrass species composition to salinity. A study can be performed along the lines of Madden *et al*. 2009 who devised a set of seagrass indicator metrics for water quality and flow management from a multi-year monitoring study of seagrass communities in Florida Bay. Shokri and Gladstone (2013) investigated vulnerability of seagrass beds and their invertebrate populations to threats arising from land use patterns in the catchment. A similar approach can be utilized to link seagrass species and their respective marine invertebrate and fish communities to water quality (salinity, dissolved oxygen, temperature and turbidity), that can then be used to formulate flow criteria to maintain seagrass ecosystems.

5.2.3 Mangrove species water uptake, groundwater salinity and level dynamics, indicators of changing hydrological and salinity conditions

It is hypothesized that mangrove species growing on higher elevations in the estuary have a lower tolerance of salinity and/or flooding extent than *Sonneratia* and *Rhizophora.* Knowing the water sources of upland mangrove species can identify species that can serve as indicators of hydrologic/salinity change in the estuary, that accompany changes in inflow as well as sea level rise. The water sources of plants can be determined from the stable isotope signature (oxygen) of local rainwater, groundwater and plant stem water (Saha *et al.* 2009). Rainwater can be collected while groundwater wells can be installed on the higher sandbanks and samples taken for stable isotopes and salinity during different times of the year. In addition, a piezometric water level indicator can be installed inside a well to obtain a continuous record of the water table. Higher elevations often have a rainwater pool (called a freshwater lens) sitting atop the saline groundwater that can be the principal water source for especially those plants that cannot tolerate prolonged salinity. Increasing sea level can result in shrinking of this freshwater lens, with eventual replacement of less-tolerant mangroves with higher salinity/flood tolerant mangroves.

5.2.4 Extent of average sea-water intrusion upriver:

The mangrove palm interface as described in Chapter 3 can serve as an indicator of mostly freshwater conditions prevailing throughout the year, although occasional forays of seawater as an underwater layer can occur further upstream. A map can be made of the transition zone showing GPS locations of palms on riverbanks over the first kilometer upriver from the estuary. This map can then serve as a dated reference against which future maps or samplings can be compared, to see whether the average extent of seawater intrusion upriver is changing.

5.2.5 The effect of protected area status on estuarine wildlife:

The Ruvu estuary is impacted by human activities (including fishing, water extraction, habitat degradation, deforestation and agriculture), while the Wami estuary is protected by being included within Saadani National Park, Tanzania's only coastal and marine national park. There is an opportunity to compare the effect of these activities on key and emblematic species, such as crocodiles, hippos, fish, sea turtles and marine mammal populations in the Wami-Ruvu region. The Wami is likely to be a significantly less impacted area, with important large vertebrate populations. A comparative analysis of the Ruvu and Wami communities (abundance, distribution and trophic ecology) could potentially enable assessment of the effect of human activities on these species, and how human activities might disrupt their function in these ecosystems.

5.3 Estuarine salinity modeling approach

Freshwater inflows into estuaries are essential for the survival and reproduction of plant and animal communities as well as for resisting seawater intrusion into coastal aquifers (Ngusaru 2000, Alber 2002, Powell *et al.*2002). Given that demands for water abstraction from the Ruvu Basin are escalating at a time of increasing uncertainty in rainfall and disruption of runoff patterns on account of land cover change, ensuring a minimum supply of freshwater into the estuary as per seasonal requirements of the estuarine ecosystem is all the more critical. Determining the minimum inflows at different times of the year is thus necessary. This section explains how this estimate can be obtained by estuarine modeling and collecting data needed to calibrate the models.

Estuarine hydrology is complicated by the interaction of opposing freshwater and seawater inflows. In addition, both inflows continually vary with time and space. Freshwater inflows vary seasonally, with precipitation, land cover and abstractions, while seawater changes with tides and the lunar cycle. Because of the continually changing seawater and freshwater inflows, the salinity distribution throughout the estuary (from river mouth to up the river channel up to where seawater manages to reach) is both spatially and temporally variable. For instance, as indicated in Fig.5-2, in the dry season, saline water is noted further upstream, while in the wet season it's the opposite whereby a freshwater plume is expected to extend beyond the mouth of the river, similar to that being observed at Wami River estuary (Anderson and McNally 2007) and which is generally the case with river estuaries worldwide.

Several publications (Powell *et al.*2002, Flannery *et al.*2008) detail the steps involved in obtaining minimum freshwater inflows into estuaries. There have been free, open source estuarine circulation and salinity models developed for estuaries such as SELFE, a circulation model for oceans and estuaries developed by Center for Coastal Margin Observation and Prediction (http://www.stccmop.org/knowledge_transfer/software/selfe) that are being widely used worldwide. One of the users, the Texas Water Development Board has a website describing data needs and computational resources of this model (http://www.stccmop.org/knowledge_transfer/software/selfe.)These models offer spatially detailed solutions as long as they are provided with a rigorous data set. In the absence of highly detailed spatiotemporal data on flows and salinity, simple two-member models can be used to start the process of estimating minimum freshwater inflows required to maintain a certain salinity regime in the estuary.

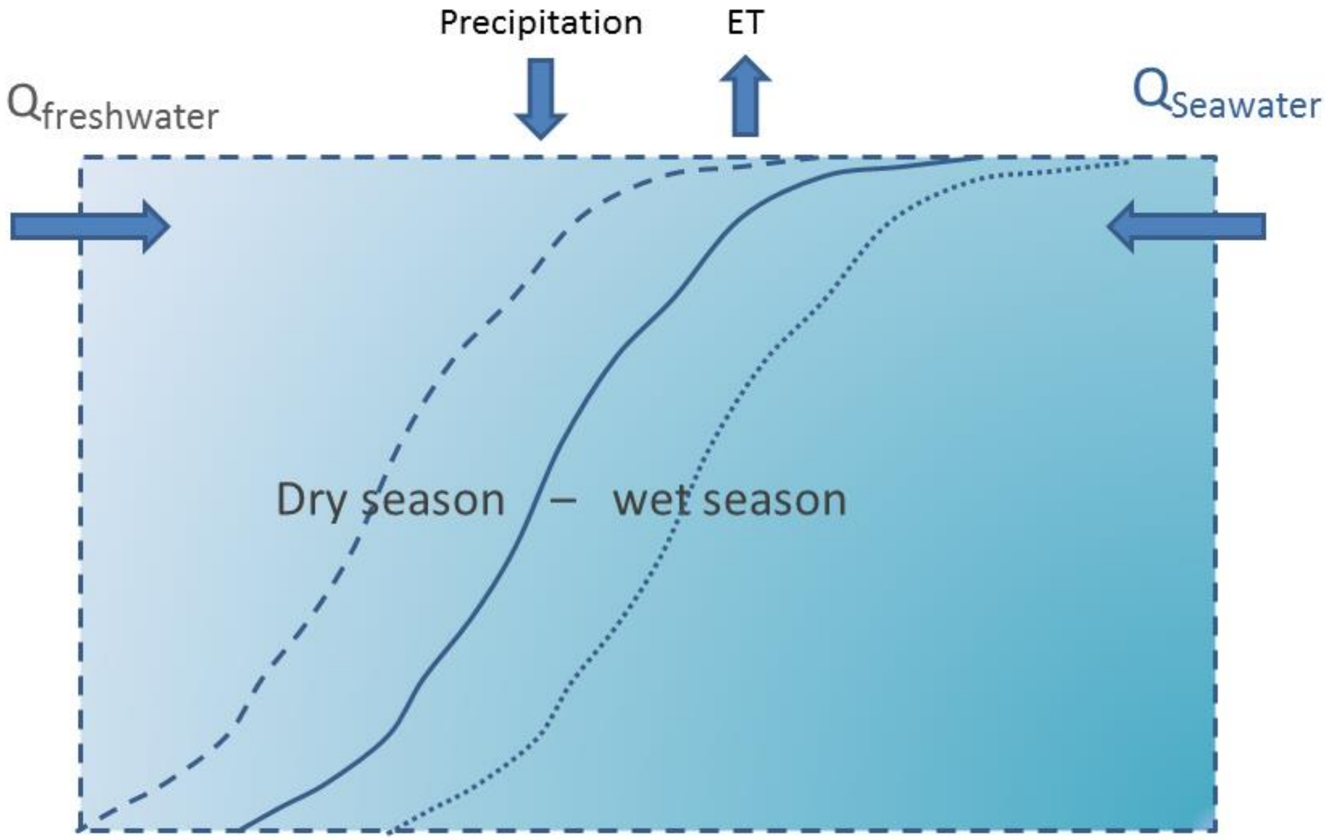


Figure 5-2: Water inputs and outputs in an estuary. $Q_{freshwater}$ (representing freshwater inflows, both surface and groundwater), rainfall, evapotranspiration and $Q_{seawater}$, ie seawater inflows. The set of S-shaped curved lines indicate the diffuse boundary between freshwater and seawater pools.

Freshwater and seawater inflows ($Q_{freshwater}$ and $Q_{seawater}$ in Figure 5-2) constitute the two end-members to which precipitation and evaporation can be added, to obtain a water budget of an estuary. The salinity of different fluxes is known, and with knowledge of the salinity composition of the estuary, an unknown flux (freshwater in this case) can be estimated. It is thus necessary to know the salinity composition of the estuary and how this composition varies with season.

Actions taken over the next five to ten years in upstream areas of the Ruvu River Basin have the potential to substantially affect the ecology of the estuary as well as the goods and services it provides to local human populations. With respect to the Ruvu Basin as a whole, if maintenance of freshwater flows to the estuary is important to stakeholders, then water management tools such as environmental flow recommendations can be applied to balance freshwater needs for humans and nature, and provide guidelines for future water resources development.

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Annex 1: Water quality survey data

The following table lists the locations and the time of collection of salinity, DO, temperature and water depth.

Date	Time	Latitude	Longitude	depth(ft)	depth(m)	Measuring depth	Temp (oC)	Salinity	DO(mg/l)	DO (%)
6/18/2013	1630	-6.54333	38.89935			Surface	27.7	30	16	
6/18/2013		-6.54333	38.89935			2m	25.2	26	26	
6/19/2013	9:07:00 AM	-6.37432	38.87132	6.3	1.92	surface	25.2	27.7		
6/19/2013		-6.37432	38.87132			2m	25.5	28.8		
6/19/2013	9:18:00 AM	-6.37815	38.85908	9.6	2.93	surface	25.1	26.92	7.6	
6/19/2013		-6.37815	38.85908			2m	25.2	35.18	7.38	
6/19/2013	9:50:00 AM	-6.39037	38.85313	11.3	3.44	surface	25.2	16	7.54	
6/19/2013		-6.39037	38.85313			1m	25.4	22.2	6.9	
6/19/2013		-6.39037	38.85313			2m	25.4	22.9		
6/19/2013	10:14:00 AM	-6.40645	38.85798	16.6	5.06	surface	26.1	14.37	6.38	
6/19/2013		-6.40645	38.85798			1m	26.1	13.02	6.02	
6/19/2013		-6.40645	38.85798			2m	25.9	13.84	6.31	
6/19/2013		-6.39707	38.85027							
6/19/2013	10:30:00 AM	-6.40677	38.84895	13.7	4.18	surface	26.5	6.71	5.7	
6/19/2013		-6.40677	38.84895			1m	26.5	5.21	6.1	
6/19/2013		-6.40677	38.84895			2m	26.4	6.71	6.22	
6/19/2013	10:45:00 AM	-6.57785	38.8387			surface	26	0.5		
6/19/2013		-6.58862	38.82982							
6/19/2013	11:43:00 AM	-6.47843	38.828	12.2	3.72	surface	26.5	0.1	6.1	
6/19/2013		-6.47843	38.828			1m	26.5	0.1		
6/19/2013		-6.47843	38.828			2m	26.4	0.1		
6/19/2013	1:22:00 PM	-6.417	38.83447	21.1	6.43	surface	26.9	3.6	6.27	
6/19/2013		-6.417	38.83447			1m	26.7	4	6.46	
6/19/2013		-6.417	38.83447			2m	26.6	5	6.46	
6/19/2013	1:52:00 PM	-6.38193	38.86597	7.8	2.38	surface	26.4	31	7.6	
6/19/2013		-6.38193	38.86597			1m	26.2	33.2	7.2	
6/19/2013		-6.38193	38.86597			2m	26	34.2	7.26	
6/20/2013	10:21	-6.38842	38.8525	12	3.66	surface	25.8	14.3	7.41	
6/20/2013		-6.38842	38.8525			1m	25.6	14.7	7.3	
6/20/2013		-6.38842	38.8525			2m	25.5	16.2	7.25	
6/20/2013		-6.38842	38.8525			3m	25.4	16.4	7.19	
6/20/2013	11:20	-6.3943	38.8585	9	2.74	surface	25.6	16.3	7.56	
6/20/2013		-6.3943	38.8585			1m	25.6	16.3	7.15	87.9
6/20/2013		-6.3943	38.8585			2m	25.4	17.7	7.37	89.6
6/20/2013		-6.3943	38.8585			3m	25.4	17.8	7.43	89.8
6/20/2013	12:16	-6.3943	38.8585	10.7	3.26	surface	25.8	23	7.51	91.7
6/20/2013	1230 high tide	-6.3943	38.8585			1m	25.4	24	7.8	89.2
6/20/2013		-6.3943	38.8585			2m	25.2	25.7	7.71	94

Date	Time	Latitude	Longitude	depth(ft)	depth(m)	Measuring depth	Temp (oC)	Salinity	DO(mg/l)	DO (%)
6/20/2013		-6.3943	38.8585			3m	25.2	25.4	7.82	94.9
6/20/2013	12:50	-6.39013	38.85278	14	4.27	surface	25.7	27.9	8	97.4
6/20/2013		-6.39013	38.85278			1m	25.5	28	7.79	95.4
6/20/2013		-6.39013	38.85278			2m	25.3	28.7	7.76	94.6
6/20/2013		-6.39013	38.85278			3m	25.3	29.4	7.79	94.7
6/20/2013	13:57	-6.37747	38.85892	13.7	4.18	surface	25.6	30.6	8	97.2
6/20/2013		-6.37747	38.85892			1m	25.7	32.7	7.87	96.8
6/20/2013		-6.37747	38.85892			2m	25.9	33.3	7.78	95.2
6/20/2013		-6.37747	38.85892			3m	25.9	33.3	7.6	94.3
6/20/2013	16:04	-6.37772	38.85892	10.1	3.08	surface	25.7	28.6	8.06	97.8
6/20/2013		-6.37772	38.85892			1m	25.6	28.7		
6/20/2013		-6.37772	38.85892			2m	25.5	31.1		
6/20/2013		-6.37772	38.85892			3m	25.5	32.6		
6/21/2013	11:07	-6.39373	38.86462	14.5	4.42	surface	26.6	2.4	6.9	26.6
6/21/2013	low tide 8:30 am	-6.39373	38.86462			1m	26.1	3.9	6.79	26.5
6/21/2013	sunny	-6.39373	38.86462			2m	26.2	4.5	6.61	26.3
6/21/2013		-6.39373	38.86462			3m	26.2	4.5	6.61	26.2
6/21/2013	11:37	-6.40302	38.8534	18-23.8		surface	26.4	0.3	7	85
6/21/2013	channel width 170m	-6.40302	38.8534			1m	26.3	0.3	6.8	84.5
6/21/2013		-6.40302	38.8534			2m	26.3	0.3	6.82	84.2
6/21/2013		-6.40302	38.8534			3m	26.3	0.3	6.88	84.5
6/21/2013		-6.39853	38.85422							
6/21/2013	12:00	-6.40182	38.84867	16	4.88	surface	26.5	0.3	6.8	85.6
6/21/2013	channel width 160m	-6.40182	38.84867			1m	26.4	0.3	6.79	84.1
6/21/2013		-6.40182	38.84867			2m	26.4	0.3	6.82	86
6/21/2013		-6.40182	38.84867			3m	26.3	0.3	6.84	83.3
6/21/2013	13:15	-6.40998	38.84137							
6/21/2013		-6.41055	38.8398							
6/22/2013	12:28	-6.38028	38.89935	17	5.18	surface	26.5	34.2	7.9	108
6/22/2013		-6.38028	38.89935			1m	26.4	34.6	7.7	99
6/22/2013		-6.38028	38.89935			2m	26.3	34.6	7.7	98.5
6/22/2013		-6.38028	38.89935			3m	26.3	34.6	7.94	98.5
6/22/2013	15:41	-6.38	38.91185	15	4.57	surface	26.4	34.4	7.92	
6/22/2013		-6.38	38.91185			1m	26.4	34.7	7.95	
6/22/2013		-6.38	38.91185			2m	26.4	34.6	7.91	
6/22/2013		-6.38	38.91185			3m	26.4	34.6	7.94	
6/22/2013		-6.38417	38.90702	29	8.84					
6/23/2013	1330	-6.41038	38.84088	17.1	5.21	surface	26.3	0.2	6.78	82.2
6/23/2013		-6.41038	38.84088			1m	26.3	0.2	6.5	79.1
6/23/2013		-6.41038	38.84088			2m	26.2	0.2	6.83	82.3

Date	Time	Latitude	Longitude	depth(ft)	depth(m)	Measuring depth	Temp (oC)	Salinity	DO(mg/l)	DO (%)
6/23/2013		-6.41038	38.84088			3m	26.2	0.2	6.79	83.5
6/23/2013		-6.40632	38.84183							
6/23/2013	1402	-6.42725	38.84028	20	6.10	surface	26.2	0.2	6.61	82.8
6/23/2013		-6.42725	38.84028			1m	26.2	0.2	6.8	84.1
6/23/2013		-6.42725	38.84028			2m	26.2	0.2	6.84	84.1
6/23/2013		-6.42725	38.84028			3m	26.2	0.2	6.84	84.9
6/23/2013		-6.42672	38.83723							
6/23/2013	1557	-6.44128	38.83527	20	6.10	surface	26.3	0.2	6.86	84.5
6/23/2013		-6.44128	38.83527			1m	26.3	0.2	6.5	82.1
6/23/2013		-6.44128	38.83527			2m	26.3	0.2	6.84	85.9
6/23/2013		-6.44128	38.83527			3m	26.2	0.2	6.81	82.9
6/23/2013		-6.44128	38.83527	19.5	5.94	surface	26.3	0.2	6.98	85.1
6/23/2013		-6.44128	38.83527			1m	26.3	0.2	6.81	84.8
6/26/2013	0830	-6.37305	38.86793	2.56	0.78	Surface	25.1	30.3	7.81	93.7
6/26/2013		-6.37305	38.86793			1m	25.1	32.3	7.62	
6/26/2013	0842	-6.37818	38.85913	3.14	0.96	Surface	25.2	29.3	7.6	91
6/26/2013		-6.37818	38.85913			1m	25.2	30	7.52	90.9
6/26/2013		-6.37818	38.85913			2m	25.2	31	7.48	90.1
6/26/2013		-6.37818	38.85913			3m	25.1	32	7.2	90
6/26/2013	0855	-6.3851	38.85573	2.71	0.83	Surface	25.3	26.2	7.2	88.9
6/26/2013		-6.3851	38.85573			1m	25.3	26	7.18	87.4
6/26/2013		-6.3851	38.85573			2m	25.3	26	7.26	88
6/26/2013		-6.3851	38.85573			3m	25.3	25.7	7.2	87.7
6/26/2013	0905	-6.39188	38.85867	2.23	0.68	Surface	25.6	16.2	7.1	86.5
6/26/2013		-6.39188	38.85867			1m	25.6	17.3	6.95	84.7
6/26/2013		-6.39188	38.85867			2m	25.4	16.5	6.88	83.9
6/26/2013		-6.39188	38.85867			3m	25.4	17.5	6.86	83.6
6/26/2013	0916	-6.39408	38.86527	3.63	1.11	Surface	25.6	12.4	6.83	83
6/26/2013		-6.39408	38.86527			1m	25.6	12.6	6.73	82.4
6/26/2013		-6.39408	38.86527			2m	25.6	13.4	6.7	81.9
6/26/2013		-6.39408	38.86527			3m	25.5	15.7	6.73	82.3
6/26/2013	0927	-6.4007	38.86758	3.38	1.03	Surface	26	6.5	6.6	80.1
6/26/2013		-6.4007	38.86758			1m	25.7	6.7	6.39	78.4
6/26/2013		-6.4007	38.86758			2m	25.7	7	6.35	77.7
6/26/2013		-6.4007	38.86758			3m	25.7	8	6.37	77.7
6/26/2013	0938	-6.40383	38.86108	3.6	1.10	Surface	25.8	3.8	6.45	71.1
6/26/2013		-6.40383	38.86108			1m	25.7	3.8	6.25	76.2
6/26/2013		-6.40383	38.86108			2m	25.7	3.8	6.21	76.2
6/26/2013		-6.40383	38.86108			3m	25.7	3.7	6.19	75.7
6/26/2013	0947	-6.4078	38.855	6.19	1.89	Surface	25.9	2	6.25	76.1
6/26/2013		-6.4078	38.855			1m	25.8	2	6.15	75.4

Date	Time	Latitude	Longitude	depth(ft)	depth(m)	Measuring depth	Temp (oC)	Salinity	DO(mg/l)	DO (%)
6/26/2013		-6.4078	38.855			2m	25.8	2	6.11	75
6/26/2013		-6.4078	38.855			3m	25.8	1.9	6.12	75.3
6/26/2013	0956	-6.40142	38.85378	3.9	1.19	Surface	25.9	1.1	6.3	76.4
6/26/2013		-6.40142	38.85378			1m	25.8	1.1	6.13	75.3
6/26/2013		-6.40142	38.85378			2m	25.8	1.1	6.12	75.1
6/26/2013		-6.40142	38.85378			3m	25.8	1.1	6.12	75
6/26/2013	1010	-6.39782	38.85	3.66	1.12	Surface	25.9	0.8	6.74	77
6/26/2013		-6.39782	38.85			1m	25.8	0.8	6.14	75.5
6/26/2013		-6.39782	38.85			2m	25.8	0.8	6.14	74.9
6/26/2013	1019	-6.40263	38.84822	4.66	1.42	Surface	25.8	0.6	6.27	76
6/26/2013		-6.40263	38.84822			1m	25.8	0.6	6.18	76
6/26/2013		-6.40263	38.84822			2m	25.8	0.6	6.15	75.4
6/26/2013		-6.40263	38.84822			3m	25.8	0.7	6.16	75.5
6/26/2013	1035	-6.39782	38.842	3.66	1.12	Surface	25.9	0.4	6.14	75.7
6/26/2013		-6.39782	38.842			1m	25.8	0.4	6.07	75.9
6/26/2013		-6.39782	38.842			2m	25.8	0.4	6.2	76.1
6/26/2013		-6.39782	38.842			3m	25.8	0.4	6.18	76
6/26/2013	1045	-6.41035	38.84058	3.6	1.10	Surface	25.8	0.3	6.33	77.1
6/26/2013		-6.41035	38.84058			1m	25.8	0.3	6.29	77
6/26/2013		-6.41035	38.84058			2m	25.8	0.3	6.25	76.7
6/26/2013		-6.41035	38.84058			3m	25.8	0.3	6.23	76.5
6/26/2013	1055	-6.41593	38.83482	5.52	1.68	Surface	25.9	0.3	6.44	79.5
6/26/2013		-6.41593	38.83482			1m	25.9	0.3	6.36	78.1
6/26/2013		-6.41593	38.83482			2m	25.9	0.3	6.31	77.6
6/26/2013		-6.41593	38.83482			3m	25.8	0.3	6.32	77.6
6/26/2013	1106	-6.42028	38.83622	4.57	1.39	Surface	26	0.2	6.38	78.8
6/26/2013		-6.42028	38.83622			1m	25.9	0.2	6.44	79.1
6/26/2013		-6.42028	38.83622			2m	25.8	0.2	6.41	79
6/26/2013		-6.42028	38.83622			3m	25.8	0.2	6.41	78.6
6/26/2013	1115	-6.41955	38.84127	5.97	1.82	Surface	26.1	0.2	6.66	81.6
6/26/2013		-6.41955	38.84127			1m	25.9	0.2	6.54	80.4
6/26/2013		-6.41955	38.84127			2m	25.9	0.2	6.5	80.4
6/26/2013		-6.41955	38.84127			3m	25.9	0.2	6.47	79.6
6/26/2013	1124	-6.4265	38.84113	6.61	2.01	Surface	25.9	0.2	6.62	91.2
6/26/2013		-6.4265	38.84113			2m	25.9	0.2	6.52	80.7
6/26/2013		-6.4265	38.84113			3m	25.9	0.2	6.25	79.9
6/26/2013	1135	-6.42295	38.83222	4.94	1.51	Surface	25.9	0.2	6.67	81.6
6/26/2013		-6.42295	38.83222			1m	25.9	0.2	6.62	81.3
6/26/2013		-6.42295	38.83222			2m	25.9	0.2	6.61	81.1
6/26/2013		-6.42295	38.83222			3m	25.9	0.2	6.57	81
6/26/2013	1145	-6.42758	38.82912	4.63	1.41	Surface	26	0.2	6.7	83.2

Date	Time	Latitude	Longitude	depth(ft)	depth(m)	Measuring depth	Temp (oC)	Salinity	DO(mg/l)	DO (%)
6/26/2013		-6.42758	38.82912			1m	26	0.2	6.71	82.2
6/26/2013		-6.42758	38.82912			2m	26	0.2	6.66	82
6/26/2013		-6.42758	38.82912			3m	26	0.2	6.65	81.9
6/26/2013	1155	-6.43243	38.83752	4.57	1.39	Surface	26	0.1	6.91	84.8
6/26/2013		-6.43243	38.83752			1m	26	0.1	6.76	82.7
6/26/2013		-6.43243	38.83752			2m	26	0.1	6.76	83.3
6/26/2013		-6.43243	38.83752			3m	26	0.1	6.75	83.2
6/26/2013	1208	-6.44152	38.83533	3.05	0.93	Surface	26.3	0.1	6.96	86.1
6/26/2013		-6.44152	38.83533			1m	26.3	0.1	6.91	85.2
6/26/2013		-6.44152	38.83533			2m	26.3	0.1	6.88	84.9
6/26/2013		-6.44152	38.83533			3m	26.3	0.1	6.88	85
6/26/2013	1210	-6.37235	38.87075	1.06	0.32	Surface	26.5	2.5	6.3	77.3
6/26/2013		-6.37235	38.87075			1m	26.5	2.6	6.3	77.3
6/26/2013	1216	-6.43993	38.84047	3.99	1.22	Surface	26.2	0.1	6.97	85.8
6/26/2013		-6.43993	38.84047			1m	26.1	0.1	6.92	84.3
6/26/2013		-6.43993	38.84047			2m	26.2	0.1	6.86	84.9
6/26/2013		-6.43993	38.84047			3m	26.1	0.1	6.88	85

Annex 2: Photographic guide to mangrove species of the Ruvu estuary

Sonneratia alba, evening bloom mangrove, blossoms and pneumatophores.

Left :*Rhizophora mucronata* with prop or stilt roots

Above: propagules and sharp pointed tips of leaves of *Rhizophora mucronata*

Silvery underside leaves of *Hereteria littoralis*, silver mangrove

Two individuals of *Hereteria littoralis* on a high bank (0.5 m above high tide), with *Avicennia marina* in the background.

Above: leaves of *Avicennia marina* (white mangrove) with salt exudates

Left: *Avicennia marina* inundated at high tide.

Yong JWH. 2013.
https://www.researchgate.net/publication/236000095_Comparative_Guide_to_Asian_mangroves?ev=prf_pub

Annex 3: Marine fish species encountered in local fishermen catch

From left to right *: Himantura uarnak, Carcharhinus sorrah, Himantura fai*

Several species of sharks in the catch

Crabs (left) and a large marine conger eel (right) are part of the catch.

Clockwise from top left: groupers and snappers, wrasse, prawn, mullets and goatfish. Octopus, cutlass fish, mantis shrimp and center – cuttlefish.

Annex 4: Participants in the Rapid Ecohydrology Assessment of Ruvu Estuary, June 18-28 2013

Kirk Gastrich - marine and estuarine ecology (sharks, rays, bony fish and seagrasses); Staff Scientist, Marine Community and Behavioral Ecology Lab, Department of Biology, Florida International University, Miami FL 33181 USA. Email:kgastric@fiu.edu

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Michael Kimaro – wildlife ecology of Tanzania. Research assistant, Ruaha Carnvore Program, Ruaha National Park, Tanzania. Email: mbebekimaro@gmail.com

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