SIERRA RUTILE PROJECT AREA 1

ENVIRONMENTAL, SOCIAL AND HEALTH IMPACT ASSESSMENT:

SPECIALIST ESTUARINE STUDY

Anchor Environmental Consultants Report No. 1598/2

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EXECUTIVE SUMMARY

This report presents results of an estuarine and marine specialists study conducted as part of an Environmental, Social and Health Impact Assessment (ESHIA) conducted for proposed expansions to Sierra Rutile Limited's mining operations in Area 1, in the Moyamba and Bonthe District in the Southern Province of Sierra Leone. The purpose of the study was to assess the current state of health and conservation importance of these estuarine and marine habitats downstream of, and potentially affected by mining operations, their sensitivity and significance, their contribution to local livelihoods, the extent to which all of these aspects have been affected by mining operations past and present, how they might be affected by mining activities in the future, and how potential impacts of future mining activities can be mitigated. Field surveys of the affected estuarine and marine habitats were conducted in the wet season (August) of 2017 and during the dry season in January 2018. These ecological surveys included the collection of physical water quality data, water samples, sediment samples, benthic[1] macrofauna[2], fish and vegetation at 26 and 33 sampling sites during the wet and dry season surveys respectively. Birds, reptiles, and mammals encountered were also noted as was any use of natural resources in the area by local people. At a number of sites, vegetation transects were surveyed and the species and status of mangroves and other plants were recorded. Findings of these surveys are presented in this report along with an assessment of future proposed mining operations.

Description of the affected Environment

Water quality

Water temperature across all sampling sites varied between 26.3 and 28.2°C (wet season) and 26.3-29.1°C (dry season) and on average was slightly higher 28.1 vs. 27.0°C. No evidence of vertical stratification[3] was evident in the temperature data from any of the sampling sites. Salinity varied between 0.10 and 18.95 Practical Salinity Units (PSU)[4] in the wet season (average = 3.0) but was markedly higher in the dry season (4.8-32.8, average = 19.7). In the three creeks that drain directly from the Sierra Rutile (SR) Area 1 (Kangama, Gbangbaia and Teso Creeks) PSU was very low (<1.0) in both the surface and bottom waters, but this was much higher in the dry season when run-off was much lower (K1 = 11.1, G1 = 15.0, T1 = 4.8). Salinity in Motevo Creek, which is closer to the mouth of the estuary, was higher than the Kangama or Gbangbaia Creeks in the dry (2.60-3.17) and wet seasons (21.3-29.4), but also displayed no evidence of stratification. Telo Creek was only sampled in

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[1] The ecological region at the lowest level of a body of water.

[2] Invertebrates that live on or in sediment, or attached to hard substrates, larger than 1 mm in size.

[3] Layering or separation between cooler and/or denser, saltier water on the bottom and lighter/warmer freshwater above.

[4] The Practical Salinity Scale 1978 (PSS-78) has been considered by the Joint Panel on Oceanographic Tables and Standards and is recommended by all oceanographic organizations as the scale in which to report future salinity data. The PSS scale has replaced the older PPT or Parts Per Thousand scale since electrical conductivity measurements became the most common method used to estimate the ionic content of seawater. By convention, practical salinity is expressed as a dimensionless number only and should be written as, e.g. S = 35.034.

the dry season, drains into Bagru Creek from the north, and had a salinity range from 12.7-15.4. Bagru Creek, into which Kangama and Gbangbaia Creeks drain, exhibited a clear salinity gradient from almost fresh at the top (0.05) to brackish at the lower end near Sherbro Island in the wet season (surface: 3.82, bottom: 8.26) and was also correspondingly more saline in the dry season (13.6-25.1). Some evidence of stratification was evident in the lower reaches of this creek in the wet but not in the dry season. Salinity levels in Sherbro Creek, which is closest to the mouth of the estuary, were not surprising, higher than the other creeks, and ranged from 5.06-22.50 in the wet season and 31.7-32.8 in the dry season. Clear evidence of stratification was also evident in this area, with higher salinity readings on the bottom than at the surface.

pH showed little variation across the various survey sites, ranging from slightly acidic (6.68) to slightly alkaline (8.20) in the wet season, and was slightly more alkaline in the dry season (6.86-8.66). Levels of dissolved oxygen (DO) were moderate to high at all sites in both seasons, but were slightly higher in the wet compared with the dry season. Wet season values ranged from 5.72-8.02 mg/l (average = 6.76 mg/l) while dry season values ranged from 4.35-7.68 (average = 6.07 mg/l). Where there was some evidence of stratification in the water column, DO levels at the bottom tended to be higher than at the surface. DO levels also tended to be higher near the mouth of the estuary compared with the upper reaches of the creeks. Sechii depth, a measure of the distance that light is able to penetrate through the water column, varied from 24-121 cm in the wet season but was considerably higher (i.e. indicative of clearer waters) in the dry season (50-198 cm). There were no clear patterns with distance downstream in either season, with peak Sechii depth often recorded at stations mid-way between the top and bottom. Total Suspended Solids (TSS) differed strongly between the wet and dry season being considerably elevated in the latter season, this is counter intuitive inasmuch as one would normally expect that TSS to be correlated closely with turbidity (higher suspended sediment loads generally result in reduced water clarity). However, in this instance it is thought that the higher TSS levels in the dry season are linked to elevated phytoplankton abundance. The relationship between Sechii depth and TSS was poor but that between Sechii depth and Chlorophyll-a (Chl-a) concentration was more clear, suggesting that phytoplankton[5] were making a greater contribution to light attenuation than the inorganic material (sediment). All physiochemical measurements were within what can be considered “normal” limits and are likely to be typical of conditions in the study area.

Primary productivity

Chlorophyll-a (Chl-a) concentration in surface water samples was highly variable during the wet season and ranged from 4.5-105.0 $\mu g.l^{-1}$. During the dry season survey Chl-a concentrations were less variable ranging between 9 and 81.9 $\mu g.l^{-1}$. Although the maximum recorded value during the dry season was lower than that recorded during the wet season, overall, the Chl-a concentrations were elevated. In the dry season elevated Chl-a was evident throughout the creeks surveyed especially at the sampling sites in the upper creeks furthest from the sea, while Chl-a concentrations at Sherbro Island were comparable to those recorded during the wet season. There was a trend of lower Chl-a values at sampling sites in the upper creeks furthest from the sea (Kangama, Gbangbaia, upper Bagru and Teso Creeks) with higher values recorded in the lower Bagru, Motevo Creeks and

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[5] Plankton consisting of microscopic plants.

Sherbro Island during the wet season. Chl-a concentration at many stations were high compared to those reported in the literature for other West African estuaries. Higher values mostly associated with marine influence, suggests that phytoplankton blooms are developing in the wider areas of the estuary in the vicinity of Sherbro Island where nutrient levels, light penetration and retention support phytoplankton growth. During the dry season there was likely a greater water retention time in the upper creeks due to decreased flow through of fresh water and a greater tidal influence allowing longer residence time for phytoplankton. The increased retention times in conjunction with greater water clarity (increased Sechii depths) would have increased primary production and resulted in phytoplankton blooms and the elevated Chl-a values.

Sediment quality

Intertidal sediments in the study area are composed mostly of silt (i.e. extremely fine sediment) but included some coarser material (coarse, medium, fine and very fine sand) as well. Sub-tidal sediments were generally coarser, most likely as a result of more intense scouring in the channel. Silt also formed an important component of the sub-tidal sediment indicating a constant supply of fine material passing through the creeks. Total Organic Content (TOC) in intertidal sediments was high, averaging 26%. The lowest values were recorded close to the sea, at the lower Bagru Creek and Sherbro Island sites, where coarser marine sediments dominated. Intertidal sediments within the mangrove creeks showed no clear spatial trend in TOC that was nearly always greater than 20%. Mangroves are known to trap fine sediment within their root structure, thereby acting as a sedimentary sink for organic carbon, as well as acting as a source of organic carbon from the constant organic input from the trees themselves. TOC in sub-tidal sediments was much lower on average (8.8%) than that observed in the intertidal sediments. TOC in sub-tidal sediments was highly variable with no clear longitudinal spatial trend from river to marine dominated areas, with across channel variability exceeded any longitudinal gradient throughout the study area.

Trace metal concentrations in sub-tidal sediment samples were generally low, and none exceeded commonly accepted levels of serious concern. The concentrations of three trace metals (arsenic (As), chromium (Cr) and nickel (Ni)) in sub-tidal sediment samples did exceed the level where toxicity may begin to be observed in sensitive species (the National Oceanic and Atmospheric Administration (NOAA) Effects Range Low guideline, Long & Morgan 1990, Long *et al.* 1995) at some stations, but there were no clear spatial patterns that suggest anthropogenic[6] pollutant sources. Poly-Aromatic Hydrocarbon (PAH)[7] concentrations were below the laboratory detection limits in all sub-tidal sediment samples.

Biomonitoring

Trace metal concentrations in oyster flesh exceeded the median recommended levels for human consumption at at least one sampling station for five of the six metals for which guidelines are available. Zinc (Zn) concentrations exceeded the NOAA Effects Range Low guideline at 20 sites,

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[6] Environmental pollution and pollutants originating in human activity.

[7] Polycyclic Aromatic Hydrocarbons (PAHs) are hydrocarbons—organic compounds containing only carbon and hydrogen—that are composed of multiple aromatic rings (organic rings in which the electrons are delocalized).

arsenic (As) at 16 sites, copper at seven sites, lead and cadmium at three sites each. These results suggest either naturally high levels of some trace metals in the estuarine environment and bioaccumulation by oysters (particularly Zn and As), or anthropogenic enrichment from a source other than the Area 1 mining activities. Ongoing biomonitoring is recommended and this should provide a more comprehensive picture of trace metal levels and potential risks these pose to local people who consume the oysters.

Vegetation

The total mangrove area for the extent of this study stands at an estimated 681.9 km^2. Mangrove habitat lost to mining activities is currently estimated to be 1.25 km^2 or 0.18% of the mangrove forest area in the Sherbro River Estuary with a total 3.00 km^2 or 0.44% to be lost with future mining plans in the Kangama Creek area. Eight mangrove[8] species were identified during the wet and dry season surveys and included *Avicennia germinans (*Black mangrove)*, Conocarpus erectus* (Button wood)*, Dodonaea viscosa (*Hopbush)*, Guilandina bonduc* (Grey nicker), *Laguncularia racemosa* (White mangrove)*, Rhizophora racemosa, Rhizophora harrisonii* (both Red mangrove), and *Phoenix reclinata* (a palm). These species are typical of West African mangrove ecosystems. The sites surveyed were predominately composed of *R. racemosa* which is characteristic of the zone closest to the river channels. *A. marina* occurred in small clumps in places and was likely due to a change to topography or sediment characteristics of that specific site. Sites surveyed within the delta were mostly similar to one another in terms of species composition and tree densities, while sites surveyed at Sherbro Island exhibited differences to their river delta counterparts. Transects walked through the mangroves on each of the sample creeks (Bagru, Gbangbaia, Kangama and Motevo Creeks) revealed different species compositions and vegetation structure. The Gbangbaia Creek mangrove had the greatest total forest density (117.61 trees/0.1ha) but the lowest basal area overall (0.49 m^2/0.1ha). The Motevo Creek transect had a high total forest density (117.61 trees/0.1ha) and high basal area (1.39m^2/0.1ha). Both the Kangama and Bagru Creeks transects had similar basal areas (1.25m^2/0.1ha) but different total forest density, 78.97 and 41.58 trees/0.1ha trees respectively.

Macrobenthic invertebrates

A total of 324 invertebrates representing 43 species and 36 families were collected during the wet season field survey from intertidal cores and sub-tidal grabs, an additional 13 species from 12 families were collected from local fishermen or by other means from the sub-tidal and intertidal environments. The dry season yielded a greater number invertebrate with 419 being collected representing 56 species from 39 families identified from sub-tidal grabs and intertidal cores. Overall 106 invertebrate species from 70 families were recorded from all methods of sampling in SR Area 1. The invertebrate species diversity from the combined wet and dry season surveys far exceeds those of surveys conducted for the region. The sub-tidal invertebrate communities were more diverse and

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[8] Mangroves comprise of a group of shrubs and small tree that grows in coastal saline or brackish water and have specific adaptations for dealing with saline, muddy and oxygen poor environments where they live. Only a few mangroves are from the iconic mangrove plant genus, *Rhizophora.*

had greater abundances compared to the intertidal invertebrate communities. Overall the wet season had greater abundances and diversity of invertebrates compared to the wet season.

Fish

A total of 1 273 fish representing 55 species from 28 families were collected during the wet and dry season field surveys. The diversity of fish sampled during these surveys is lower than that reported in other fish surveys in the region. The dry season survey recorded an additional 10 species, mostly marine taxa (9 out of the 10) that were not found during the wet season survey, however the catch diversity for both surveys was similar with 44 and 45 species recorded during the wet and dry season surveys respectively. Fish abundance during the dry season was however greater with more than double the number of fish caught (1 273) compared to during the wet season (544). Combining the data for both surveys, the most diverse fish families in the samples were the Carangidae (jacks) represented by six species, Clupeidae (herring and sardines) represented by five species, the Haemulidae (grunts), Cichlidae (cichlids) and Sciaenidae (croakers and drums) with four species each. In terms of abundance, four families dominated numerically with Mugilidae (59%), Pristigasteridae (31%), Clupeidae (14%) and Poeciliidae (4%) contributing 87% of the total catch. There were noticeable seasonal changes in the fish community composition between surveys with the wet season survey catches having similar contributions by three families, Pristigasteridae (31%), Clupeidae (22%) and Mugilidae (21%), and a noticeable proportion of the catch comprising species of Poeciliidae (8%) and Sciaenidae (5%); dry season catches on the other hand were dominated by Mugilidae (76%), and Clupeidae (11%). The surveys of the estuaries downstream of the Area 1 mining area indicated an estuarine fish community dominated by marine species that contributed 39 of the 55 species, whilst more freshwater species (10) were recorded then strictly estuarine species (6). During the wet season survey, the marine guild was also dominant in terms of fish abundance (69%) but the freshwater group contributed a significant 28% numerically to the total catch. The dry season survey saw a shift in relative abundance, with the marine guild contributing 90% to the total catch and a substantial reduction in the numerical contribution of freshwater taxa to just 7 % of the total catch. The estuarine fish community was dominated by carnivorous and omnivorous species with only one species classified as herbivorous (the phytoplanktivorous Bonga shad). Most species present in the wet season fish community were first level predators consuming mainly benthic invertebrates, zooplankton, macro-crustaceans and insects; or second level generalist predators consuming mainly fish, shrimps and crabs. In terms of abundance, the phytoplanktivorous mullets dominated, whilst the mainly zooplanktivorous predators that included the three *Sardinella* species and *Ilisha africana* were the next most common trophic group.

Fish diversity in samples collected from the Bagru, Gbangbaia and Kangama Creeks increased noticeably between the wet and dry season surveys, whilst small decreases in the number of species caught were observed in the Motevo and Teso Creeks samples. Similarly fish abundance in all creeks, with the exception of Kangama Creek and the Sherbro Island sites, was higher during the dry season surveys. Wet season fish diversity was higher at the Motevo Creek and Sherbro Island sites compared to other sampled creeks, whilst dry season diversity was similar across all sites except for Telo creek, where only one species of mullet was caught. Total catches (fish abundance) was similar across most creeks, with the exception of high catches at Sherbro Island during the wet season and in Motevo Creek during the dry season. Fish samples collected from creeks potentially adversely impacted by mining activities in SR Area 1 (Gbangbaia, Kangama and Teso Creeks) did not have markedly different diversity or abundance from samples collected in the Bagru, Telo and Motevo Creeks and Sherbro Island that are unlikely to be impacted by mining. A loss of the freshwater component (including catadromous[9] species) of the fish community is a potential impact of dams created by the current and historical SRL operations. This impact would have been most evident during the dry season survey when freshwater flows are at their lowest. However both surveys indicated seasonal diversity and abundance of freshwater species that is comparable to other studies in the region. Based on these two fish surveys it appears that the estuarine fish community in terms of diversity and composition is typical of a "normal" West Africa estuary, however, the relatively low number of fish caught, the small size of individuals (relative to the reported maximum sizes) and the relatively low mean trophic level of the fish community, does indicate anthropogenic impacts. It is suspected that the constant high levels of fishing effort by artisanal and commercial fishers using both long lines and gill nets is having a significant impact on the estuarine fish stocks.

Birds, reptiles and mammals

In all, 20 species of water birds were recorded during the wet season survey and more than double (50) during the dry season. Numbers of birds recorded was highest in Bagru and Sherbro Creeks in both seasons and is believed to be linked to the much greater sand and mudflat habitat availability as feeding areas for many water birds in these two areas. Species that were encountered most frequently included *Calidris minuta* (Little stint), *Thalasseus maximus* (Royal tern), *Sternula albifrons* (Little tern), *Ardea alba* (Great white egret), and *Egretta gularis* (Western reef heron). Historical bird surveys conducted during the dry season (northern summer) in the vicinity of Sherbro Island (but excluding the mangrove creeks) recorded a total of 14 515 birds from 56 species (Van der Winden *et al.* 2007). Species that were highlighted as being particularly important (in terms of the numbers recorded) included *Tringa totanus* (Common redshank), *Gelochelidon nilotica* (Gull-billed tern), *Thalasseus bengalensis* (Lesser crested tern), *Sternula albifrons* (Little tern) and *Rynchops flavirostris* (African skimmer). It has been recommended that Sherbro Island be designated as a Wetland of International Importance in terms of the Ramsar Convention, and as an Important Bird Area (COP11 National Report for Ramsar: Sierra Leone, 2011; Van der Winden *et al. 2007*). No aquatic reptiles or mammals were recorded during this survey.

Although no mammals were encountered in the mangroves during the dry season survey, several mammal tracks were evident in some of mangrove transects. Otter and monkey tracks were abundant in the Motevo and Bagru Creeks transects and a single feline track was further noted in the Motevo Creek transect. The otter track is likely to be that of *Aonyx capensis* (African clawless otter) as this species has previously been recorded in Sierra Leone estuaries (Van der Winden *et al*. 2007). The monkey tracks could be from several different species (*Chlorocebus sabaeus* (Green Monkey), *Cercopithecus campbelli* (Campbell's Monkey), or *Procolobus badius* (Western Red Colobus) which utilise mangroves for refuge and food resources.

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[9] Applied to migratory behavior of organisms that spend most of their lives in freshwater but travel to the sea to breed.

Human use

Extensive fishing activity or evidence of fishing was observed in all the creeks surveyed during this study. Three main types of fishing gear were observed: gill nets, long lines and purse-seine nets. Gill net fishing was practised throughout the study area, but the highest densities of fishers were encountered near the mouth of Bagru Creek in the lee of Sherbro Island, and in the lower stretches of Motevo Creek. These gill nets mostly target pelagic species[10] such as clupeids (sardinellas) and mullets, although bentho-pelagic sciaenids (croakers) and Polynemidae (threadfins) were also present in the gill net catches. Longlines predominantly target and catch demersal fish[11] such as catfish, tonguesole and grunts. Observed catches by both gill net fishers and long liners were modest, ranging from nothing to a few kilograms per boat. This suggests that most of this fishing is of a subsistence nature, although it was observed that fishers sold their catch for cash when the opportunity arose. Purse-seine fishing was only observed near the open sea adjacent to Sherbro Island during the wet season, but in the dry season two purse-seine vessels were observed operating in the lower Bagru Creek, inland of Sherbro Island. This type of fishing involved the use of a large planked canoe around 10 m in length and powered by an outboard motor. The net was hauled manually by approximately 15 fishers and the catch was dominated by clupeids, although some large croakers were also caught in the haul observed. Large oyster shell middens were noted at many small villages along the mangrove creeks and provided evidence of extensive oyster harvesting for subsistence purposes. Mangrove trees are harvested for wood poles used to provide moorings for boats at villages and to create barriers across the upper reaches of the creeks (probably also in house construction although this was not investigated). The estuaries and rivers themselves serve as an important access route for the transport of people, goods and produce. Observed fishing effort during the dry season survey was substantially lower than that seen during the wet season survey and individual vessel catches were greater in the former season.

Impact assessment

The estuarine environmental and social impact assessment was informed by the wet and dry season estuary field surveys that were successfully undertaken during August 2017 and January 2018 respectively and has assisted in providing a comprehensive picture of the potential impacts of the SR Area 1 mining operations (current and future) on downstream estuarine habitats.

The assessment identified five potential impacts on the estuarine socio-environmental system:

1. Direct loss of estuarine habitat and biota within mining footprint;
2. Modification of remaining estuarine habitat;
3. Fragmentation of habitats and alteration of ecosystem functioning;
4. Changes in the community composition and distribution of estuarine biota; and
5. Impacts on livelihoods, and/or loss or alteration of ecosystem services.

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[10] Those that inhabit the water column, not near the bottom or the shore.

[11] Those that live near the bottom.

Without implementation of any management, loss of estuarine habitat was assessed as being of medium overall significance, whilst the remaining four identified impacts were assessed as being of high negative significance (Impacts 2-5). All of these impacts however, can be managed to achieve at least a medium overall significance.

Identified cumulative impacts on the estuarine ecosystems include those associated with export of bauxite from Nitti port and the consumptive use of living estuarine resources by local communities. Impacts associated with the mine closure phase are expected to be initially similar as during active mining, and then reduced as rehabilitation is implemented. The assessment of mine closure impacts are therefore the same as those assessed "with management".

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LIST OF ABBREVIATIONS

Al	Aluminium
As	Arsenic
BAF	Basal Area Factor
Cd	Cadmium
Chl-a	Chlorophyll-a
Cr	Chromium
Cu	Copper
DBH	Diameter at Breast Height
DO	Dissolved oxygen
EISIA	Environmental and Social Impact Assessment
ERL	Effects Range Low
ERM	Effects Range Median
Fe	Iron
GBH	Girth at Breast Height
GIS	Geographic Information System
Hg	Mercury
ICP-OES	Inductively Coupled Plasma Atomic Emission Spectroscopy
Mn	Manganese
NASA	National Aeronautics and Space Administration, USA
ND	not detected
NH_4	Ammonia
Ni	Nickel
NO_3	Nitrate
NO_2	Nitrite
NOAA	National Oceanic and Atmospheric Administration, USA
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PO_4	Phosphate
Ppm	parts per million
PSU	Practical Salinity Units
SRL	Sierra Rutile Limited
SRTM	Shuttle Radar Topographic Mission
TOC	Total Organic Content
kt	kilo ton
tph	tons per hour
TPH	Total Petroleum Hydrocarbons
TSS	Total suspended solids
UNCC	University of North Carolina, Charlotte
WoRMS	World Register of Marine Species
USGS	United States Geological Survey
Zn	Zinc

1 INTRODUCTION

Sierra Rutile Limited (SRL) mining area is located in the Southern Province of Sierra Leone approximately 135 km southeast of the capital Freetown and approximately 30 km east from the Atlantic Ocean. The Mine Lease Area spans ten separate surface water catchments, three of which (Lanti, Kangama, and Gbangbaia) are under tidal influence and are likely to support estuarine communities. Mining commenced in the area in 1967 and an Environmental and Social Impact Assessment (ESIA) was completed for the owner and operator of the mine, SRL by Knight Piesold in 2001. This original ESIA was updated by a local company CEMMATS Group Ltd in 2012.

Limited information was provided on estuarine or marine resources in the mining area and at Nitti Port from where the products are exported during these assessments. It was noted, for example, in the updated 2012 ESIA report, that mangrove swamps dominate in areas under tidal influence, and that these were made up mostly of red mangrove *Rhizophora* spp. Other flora or fauna (invertebrates, fish, amphibians, reptiles and birds) inhabiting these areas were not described. It was however noted that these wetland habitats are clearly important for local people. The 2012 ESIA highlighted the fact that local residents regularly use water bodies (including the swamps) as a source of building materials (thatch, poles) and food (mostly fish and oysters).

The original 2001 ESIA also noted that surface water resources have been altered by the mining activity, notably surface water flows and water quality, groundwater table elevations, and domestic water supplies. Surface waters were highlighted as being more acidic than natural, and this was attributed to the oxidation of trace sulfide residues that emerge from land plants and effluent from the mine.

For the purposes of this study, and as part of the process of preparing a new Environmental, Social and Health Impact Assessment (ESHIA), a detailed assessment was undertaken of estuarine habitats in the mining area and the marine environment between Nitti Port and Sherbro Island where transhipment of product takes place, and the associated fauna and flora in each habitat. This included results from a wet season field survey completed in August 2017 with a corresponding set of results from a dry season survey conducted in January 2018. The purpose of the study (and this report) was to assess the current state of health and conservation importance of these estuarine and marine habitats, their sensitivity and significance; their contribution to local livelihoods, the extent to which all of these aspects have been affected by mining operations past and present; how they might be affected by mining activities in the future; and how potential impacts of future mining activities can be mitigated.

2 PROJECT DESCRIPTION

The following description of existing and proposed future mining operations within the Sierra Rutile Limited Mine Lease Area 1 (Area 1) was extracted from the Final Scoping Report (SRK 2017) for this study.

2.1 Site area

The SRL operation is located in the Moyamba and Bonthe District in the Southern Province of Sierra Leone. It is situated 30 km inland from the Atlantic Ocean and 135 km south east (geodesic distance) of Freetown (Figure 1). SRL has undertaken dry and dredge mining activities to extract rutile deposits intermittently since 1967. SRL currently holds seven mining leases covering 559 km^2 with a total of 16 mineral deposits identified. SRL's Area 1 covers an area of 290 km^2. These deposits, alluvial in nature, are mainly located around the Gbangbama Hills and the Moyamba Hills. SRL's mining leases cover one of the world's largest known rutile deposits, with a Joint Ore Reserves Committee (JORC) compliant resource of 900 million tonnes (Mt) of high-grade ore. The SRL operation has sensitive receptors within and adjacent to their current and proposed operations, including an extensive mangrove and estuarine system; wetlands (marshes and swamps); watercourses; subsistence agriculture; settlements; and cultural practices.

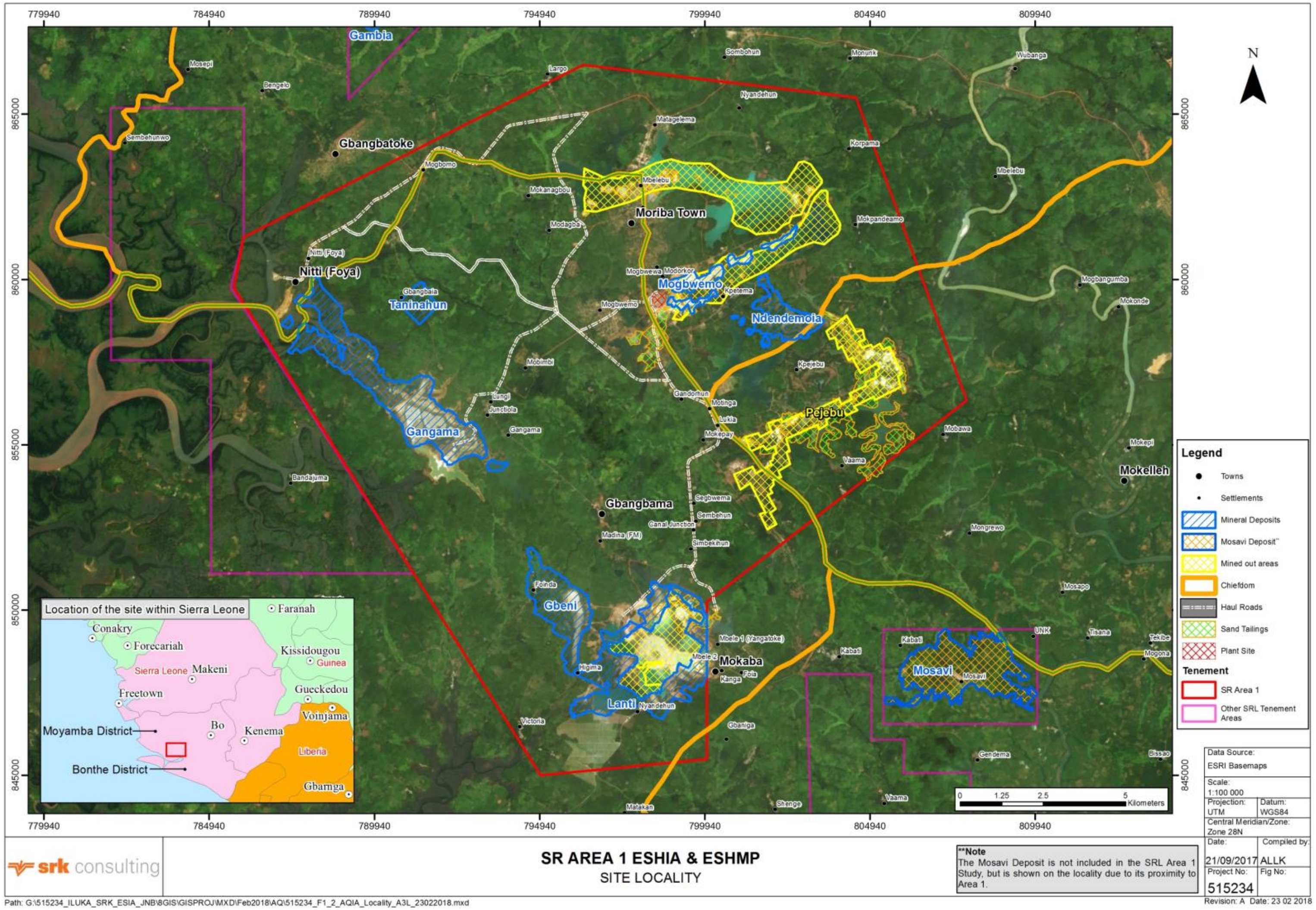

Figure 1. **General locality map of Sierra Rutile Limited operations in Area 1**

2.2 Current and proposed future activities

Currently, SRL's primary operations consist of Lanti mining operations (both dredge and dry mining), processing operations (floating and land based concentrators), Gangama dry mining operation (dry mining and land based concentrator), Mineral Separation Plant (MSP) and the transport and export of product through the Nitti Port facilities (Table 1). In addition, the mine maintains an extensive network of ponds and has power generation facilities, accommodation, offices, a clinic and roads.

Mining, scrubbing and screening is undertaken on board the Lanti dredge, with mineral concentrate produced on board the floating concentrator. The dry mines produce run of mine ore for their respective concentrators, where de-sliming and primary heavy mineral concentration takes place. The separation of mineral concentrate into the various products takes place at the MSP.

The SRL operation intends to amend their current operations by implementing a more cost-effective mining method as well as by doubling the throughput of Lanti and Gangama dry mining operations and increasing the throughput capacity of the MSP. The latter expansion is driven by capacity constraints as well as occupational health and safety related considerations, and will coincide with the planned closure of the Lanti dredge during 2018.

Table 1. Current and proposed activities within Mining Lease Area 1

Stage	Activities
Current (operational)	• Site clearing; • Dredging; • Dam construction; • Ore extraction (earth moving); • Primary mineral processing; • Secondary mineral processing; • Tailings management; • Transporting and storage of ore and product; • Port handling and shipping; • Access road building and maintenance; • Waste management; • Power generation facility and transmission of power; • Potable water services; • Mine offices, workshops storage, accommodation and associated facilities; and • Rehabilitation.
Planned (construction and operational)	• Site clearing; • Ore extraction (earth moving); • Access road building and maintenance; • Primary mineral processing; • Tailings management; • Transporting of ore • Waste management; • Power transmission services; • Potable water services; • Mine offices, workshops and storage; • Rehabilitation.

2.2.1 Lanti Dry Mine

It is proposed that the current excavate-and-haul mining method be modified by constructing an in-pit mining unit, followed by an ex-pit scrubber, before ore is pumped to the existing concentrator. Lanti Dry Mine currently has a nameplate capacity of 500 tonnes per hour (tph), and the intent is to increase throughput to 1 000 tph.

This proposal will see the addition of the following infrastructure:

- In-pit mining unit;
- Ex-pit scrubber;
- Additional tailings containment facilities;
- Potential extensions to or new borrow pits;
- Potential extensions to roads; and
- Potential extensions to transmission lines.

2.2.2 Gangama Dry Mine

Construction of the Gangama Dry Mine commenced in April 2015 after the man-made dredge pond was drained. The construction activities focused on a dry mining concentrator plant and associated infrastructure such as roads. The plant was commissioned in May 2016. Similar to Lanti Dry Mine, the intention is to modify the mining method and increase the current throughput from 500 tph to 1 000 tph.

This proposal will see the addition of the following infrastructure:

- In-pit mining unit;
- Ex-pit scrubber;
- Additional tailings containment facilities;
- Potential extensions to or new borrow pits;
- Potential extensions to roads; and
- Potential extensions to transmission lines.

2.2.3 Mogbwemo Tailings

The Mogbwemo dry mine operates on the fringes of the Pejebu deposit that was historically wet mined. The process will be similar to the Lanti and Gangama dry mining operations, with the exception that ore would be transferred to an existing concentrator.

2.2.4 Mineral Separation Plant

The MSP consists of a feed preparation plant and a dry plant. Flotation and completion of heavy mineral concentration will continue to be carried out in the feed preparation plant. The dry plant will be rebuilt to modern health and safety standards. Throughput will be increased from the current nominal 165-175 kilo tonne (kt) to 250-275 kt per annum.

3 METHODOLOGY EMPLOYED FOR FIELD SAMPLING

The description of the affected estuarine and marine environment is based on a field survey undertaken during the wet season (August) of 2017 and the dry season (January) of 2018 in addition to the limited available scientific literature.

3.1 Sampling schedule, sites and activities undertaken

The schedule of sampling activities that were undertaken during the wet (August 2017) and dry season (January 2018) surveys is shown in Table 2. A total of 27 sites were sampled on the Gbangbaia, Kangama, Teso and Motevo Creeks, along the Bagru Creek and the northern shore of Sherbro Island near the mouth of the Bagru Creek in the wet season (Figure 2). These sites were sampled again in the dry season along with an additional four sites on Teso Creek (T1, T2, T4, T5) and two sites in Telo Creek (C1, C2, Figure 2). Teso Creek is very remote from Nitti Port and sampling was thus conducted from the shore at one station only in the wet season using a small inflatable boat. Location of a launch site on this creek in the dry season enabled the team to sample additional stations during this sampling trip. Two additional sites in Telo Creek were added in the dry season to bolster the number of control stations (i.e. those unlikely to be affected by mining) in the dataset.

In situ water quality measurements and water and sub-tidal sediment were collected at all sites in the wet and dry seasons (Table 3). Intertidal sediment and macrofauna samples, vegetation transects and fish samples were collected at alternate sites (2-3 samples per creek). Oysters were collected at all sites where they were present (this was the case for many more sites in the wet compared with the dry season); the tissue was removed and was analysed for trace metal content. Bird counts, observations of other wildlife and human use of natural resources was noted and recorded at all times during the field survey.

Table 2. Schedule of sampling activities

Season	Date	Activity
Wet season	11 August 2017	• Field sampling in Gbangbaia Creek (G1, G2 and G4)
	12 August 2017	• Field sampling in Gbangbaia Creek (Site G5), and Kangama Creek (Site K1, K2, K3)
	13 August 2017	• Field sampling in Gbangbaia Creek (Site G6), and Kangama Creek (Site K4 and K5,)
	14 August 2017	• Field sampling at Nitti Port, Gbangbia Creek (G3),
	15 August 2017	• Bagru Creek (B3, B4) and Motevo Creek (M5)
	16 August 2017	• Field sampling at Motevo Creek (M1, M2, M3, M4)
	17 August 2017	• Field sampling at Bagru Creek (B5) and Sherbro Island (S1, S2, S3, S4)
	18 August 2017	• Field sampling at Teso Creek (T3)
	19 August 2017	• Field sampling at Kangama Creek (K1, K2, K3, K4, K5)
Dry season	20 January 2018	• Field sampling in Gbangbaia Creek – sites G1, G2 and G4
	21 January 2018	• Field sampling in Kangama Creek (Site K1, K2, K3, K4)
	22 January 2018	• Field sampling in Gbangbaia Creek (Site G6), Kangama Creek (Site K5) and Bagru Creek (B2)
	23 January 2018	• Field sampling in Bagru Creek (B3 and B4) and Telo Creek (C1 and C2)
	24 January 2018	• Field sampling in Sherbro Creek (S1, S2, S2 and S4)
	25 January 2018	• Field sampling at Motevo Creek (M1, M2, M3, M4, M5)
	26 January 2018	• Field sampling in Gbangbaia Creek (G3 and G5) and Bagru Creek (B1, B3 and B5)
	27 January 2018	• Process samples from Gbangbaia, Kangama, Bagru, Telo and Sherbro Creeks
	28 January 2018	• Field sampling in Teso Creek (T1, T2, T3, T4 and T5)

Table 3. **Sample log showing sampling activities undertaken at each sampling station**

Sampling conducted	G1	G2	G3	G4	G5	G6	K1	K2	K3	K4	K5	B1	B2	B3	B4	B5	M1	M2	M3	M4	M5	C1	C2	T1	T2	T3	T4	T5	S1	S2	S3	S4	Nitti Port
In situ water quality (Temp, Cond, Dissolved oxygen, pH, turbidity)	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	D	D	W D	D	D	W D	W D	W D	W D	
Water samples for nutrients (NO_2, NO_3, NH_4)	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	D	D	D	D	W D	D	D	W D	W D	W D	W D	
Water samples for Chl-a and TSS	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	D	D	D	D	W D	D	D	W D	W D	W D	W D	
Biomonitoring (oyster) samples		W	W	W	W	W	W	W	W	W	W D	W	W D	W D	W D	W D		D	W D	W D	W D								W D	W D	W D	W D	W
Sediment samples for trace metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, Mn, Al, Fe)	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	D	D	D	D	W D	D	D	W D	W D	W D	W D	W D
Sediment samples for grain size and TOC	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	D	D	D	D	W D	D	D	W D	W D	W D	W D	
Grab samples for macrofauna	W D	W	W	W D	W	W D	W D	W	W D	W	W D	W	W D	W	W D	W	W D	W	W D	W	W D	D	D	D		W D	D	D	W D	W D	W D	W D	
Seine net (fish)	W D			W D		W D	W D		W D		W D		W D		W D	W	W D		W D		W D	D	D	D		W D		D		W D		W D	
Gill net (fish)	W D			W D		W D	W D		W D		W D		W D		W D	W	W D		W D		W D	D	D	D		W D		D		W D		W D	
Fyke net (fish)	W			W		W D	W		W		W D		W D		W D	W	W D		W		W												
Intertidal core samples (grain size, TOC)	W D			W D		W D	W D		W D		W D		W D		W D	W	W D		W D		W D	D	D	D		W D		D		W D		W D	
Intertidal core samples (macrofauna)	W D			W D		W D	W D		W D		W D		W D		W D	W	W D		W D		W D	D	D	D		W D		D		W D		W D	
Mangrove composition and density	W	D		W		W	W		W D		W		W	D	W	W	W		W D		W					W				W		W	
Bird counts (species composition and abundance)	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	W D	D	D	D	D	W D	D	D	W D	W D	W D	W D	W D

W = wet season; D = dry season

Figure 2. Map of SR Area 1 and downstream estuarine and marine habitats showing individual sampling stations for both wet and dry seasons.

3.2 Study area

The estuarine ecological survey focussed on estuarine habitats between SRL's Area 1 operation and the coast in the vicinity of Sherbro Island. Sampling was undertaken in Gbangbaia, Kangama, Bagru, Telo, Motevo and Teso Creeks (Blocks 2, 3, 4, 5 and 6 in Figure 3), and between Sherbro Island and the mainland (Block 7). Between 1 and 6 sites were sampled in each creek (Table 3, Figure 2). The study area as a whole will be referred to as the Sherbro River Estuary (SRE) when necessary.

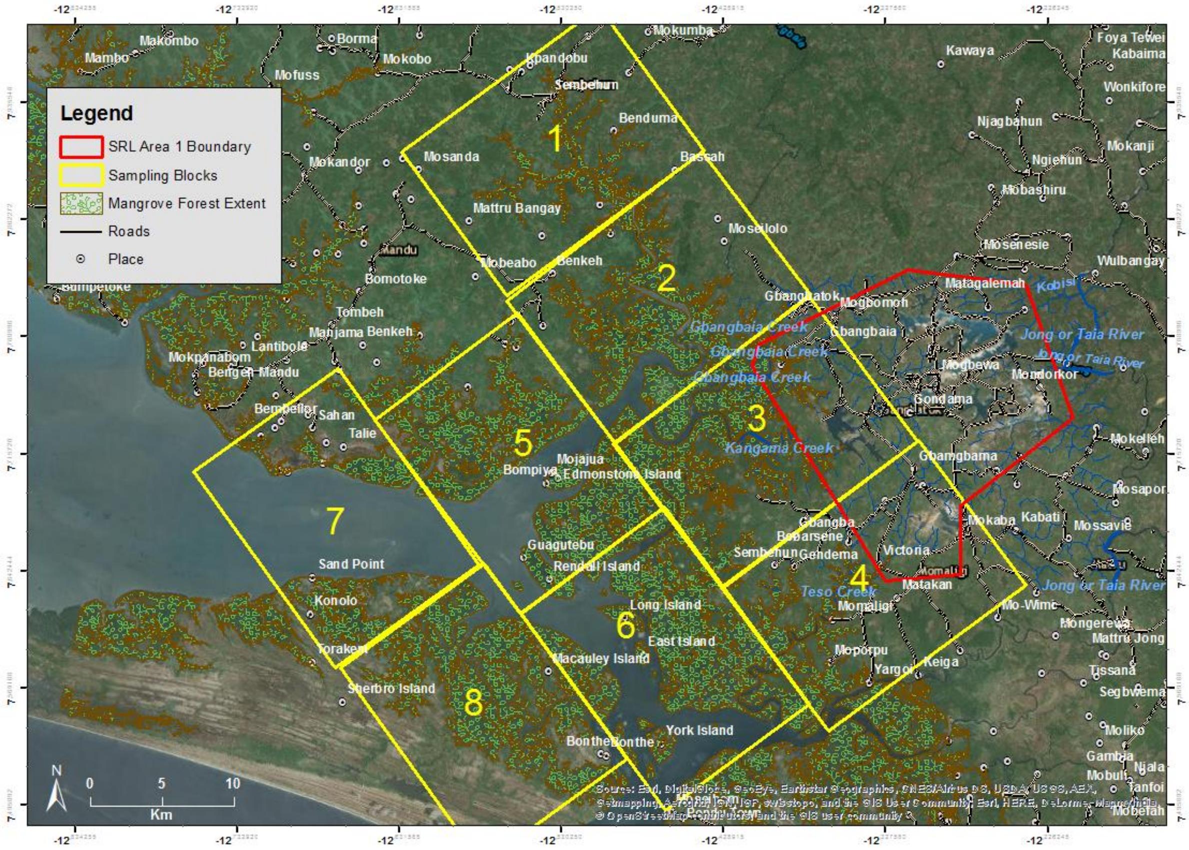

Figure 3. **Map of Area 1 and downstream estuarine and marine habitats where the ecological surveys were undertaken. The extent of the mining concession area is delineated by a red line. Mangrove extent layer provided by Giri *et al.* (2011).**

3.3 Survey protocol

The ecological survey included the collection of physical water quality data, water samples, sediment samples, benthic macrofauna, fish and vegetation at 33 sampling sites. Birds, reptiles, and mammals encountered were also noted as was any use of natural resources in the area by local people. At a number of sites, vegetation transects (perpendicular to the channel to just beyond the high water mark) were surveyed and the species and status of mangroves and other plants were recorded. Detailed method statements employed for each of these components is provided below.

3.4 Water quality measurements

Sampling was conducted during daylight hours over a period of eight days (12-19 August 2017) in the wet season and nine days (20-28 January 2018) in the dry season. This resulted in sites being sampled at different times of the day and at different states of the tide (Figure 4). This is typical of a survey of this nature and must be taken into account during interpretation of the results. In both cases (wet and dry seasons), sampling started at the peak of the spring tide portion of the tidal cycle and extended through to the start of the next spring tide cycle (19 August 2017 and 29 January 2018, Figure 4).

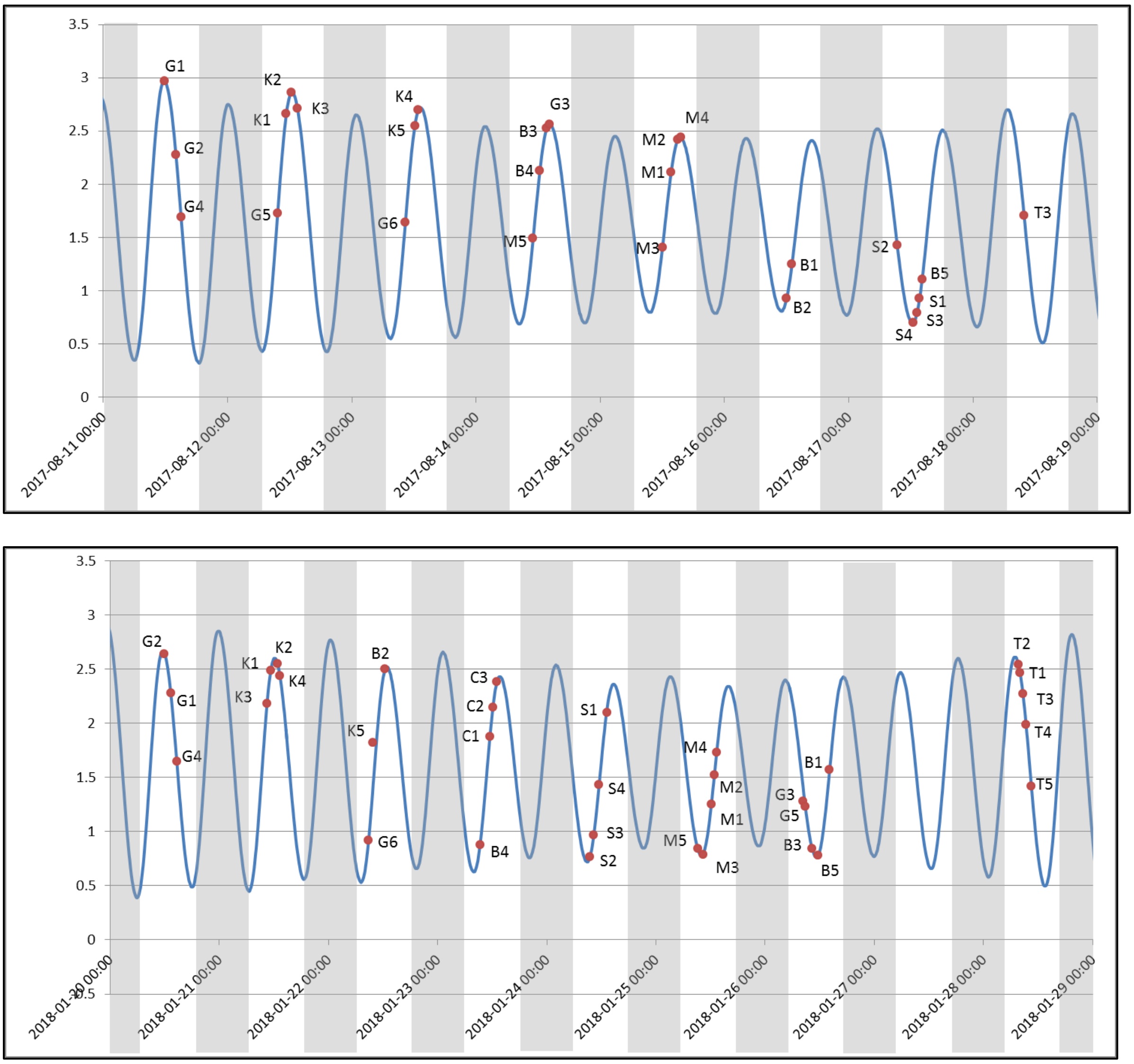

Figure 4. **State of the tide at which each of the sampling sites were visited in the wet season (top) and dry season (bottom).**[12]

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[12] Source: WXTides, Sherbro Island. Light and dark shading indicates day and night. Locations of the sampling sites are shown on Figure 2.

Temperature, salinity and dissolved oxygen (DO) of the surface and bottom water at each site was measured using a Hach HQ40d water quality meter (Figure 5). Bottom water samples were collected using a Niskin bottle. Surface water samples were filtered through glass fibre filter paper for measurement of suspended solids and chlorophyll-a (Chl-a) (a measure of phytoplankton abundance). Total suspended solids (TSS) in water samples were determined by oven drying a pre-weighed filter paper and weighing on a three point balance, and subtracting the weight of the filter paper from the total weight to obtain the mass of material suspended in the water column. Turbidity (water clarity) was also measured using a Sechii disk. Chl-a was analysed by acetone extraction and fluorometry according to the methods prescribed by APHA *et al*. (2014).

Approximately 150 ml of surface water was collected in an opaque plastic bottle at each site, and was submitted to Jones Environmental Laboratories in the United Kingdom (UK) for analysis of dissolved nutrients (ammonia, nitrate, nitrite and phosphate). Nutrient concentrations were determined using a Kone analyser.

Figure 5. Measuring water quality parameters (temperature, salinity, DO and pH) using a HachHQ40d water quality meter (left) and mangrove oysters used for biomonitoring (right).

3.5 Sediment quality

Sediment samples (250 g each) were collected both sub-tidally and intertidally. The sub-tidal samples were collected using a stainless steel Van Veen grab deployed from the survey vessel, whilst the intertidal sediment were collected by hand, using a hand corer (Figure 6, Figure 7). Immediately after collection, sediments samples were placed in a cooler with ice and later frozen before being sent to the laboratory for analysis. Particle size analysis of the sediment samples was undertaken by Scientific Services and University of Cape Town. Standard geotechnical techniques (Test Reference: ASTM D 422-63 (1990), ASTM D854-58, TMH1 A2-A4 (1986)) were applied in each case, which involved the use of 18 different sieve sizes (7 500-75 µm). A High Performance Laser Diffraction Analyser (the Horiba LA-960) was used to determine the percentage contribution of a further 11 different particle size diameters below 75 µm in size. The results were pooled into eight commonly recognised size fractions: gravel (>2 000 µm), sand (subdivided into very coarse sand 1 000-2 000 µm, coarse sand 500-1 000 µm, medium sand 250-500 µm, fine sand 125-250 µm and very fine sand

63-125 µm), and mud (silt 2-63 µm and clay <2 µm). Sub-tidal samples were also analysed for trace metal content and Polycyclic-Aromatic Hydrocarbons (PAHs) by Jones Environmental Laboratories in the UK.

The London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972), and the 1996 Protocol to the London Convention regulate the deliberate disposal of waste materials in the marine environment. Sierra Leone is a signatory to the London Protocol as of 2013. The London Convention and Protocol requires that participating countries develop national action lists that include sediment quality guidelines to assess if sediment identified for dredging is of a suitable quality for unconfined open water disposal. Sierra Leone has not yet developed such sediment quality guidelines, so the median Level I and Level II values from 12 participating countries that have developed guidelines, was calculated for the eight trace metals of primary concern in the marine environment (Table 4). Sediment with trace metal concentrations at or below the Level I guideline is considered not toxic, whilst sediment with trace metal concentrations above the Level II value is considered unsuitable for disposal (i.e. toxic). Sediment with metal concentrations falling between the two levels requires further testing (e.g. bioavailability or acute toxicity testing). Although SRL does not undertake the disposal of dredged sediment in the marine or estuarine environment, these guidelines were used to screen sediment samples collected during the estuarine survey - with the rationale being that sediments suitable for disposal are not contaminated by trace metals due to anthropogenic activities (including mining).

The United States (US) National Oceanic and Atmospheric Administration (NOAA) has also published a series of sediment screening values, which cover a broad spectrum of trace metal concentrations from toxic to non-toxic levels as shown in Table 4. The Effects Range Low (ERL) represents the concentration at which toxicity may begin to be observed in sensitive species. The ERL is calculated as the lower 10th percentile of sediment concentrations reported in literature that co-occur with any biological effect. The Effects Range Median (ERM) is the median concentration of available toxicity data. It is calculated as the lower 50th percentile of sediment concentrations reported in literature that co-occur with a biological effect (Buchman 1999). Comparing the sediment results from the estuarine survey to the NOAA guidelines and the median Level I and Level II values for 12 participatory countries to the London Convention and Protocol provides a useful indication of areas in the estuary where the sediments may be toxic to living organisms. However, this comparison does not provide an indication of whether the build-up of a trace metal is due directly to anthropogenic contamination of the environment, or whether it is an indirect result of other environmental influences, for example a high concentration of mud, as concentrations of metals in sediments are affected by grain size, total organic content and mineralogy. Comparisons with natural background levels from areas that are known to be unpolluted, or historical concentrations, are required to conclusively demonstrate anthropogenic enrichment. Another noteworthy caveat, the ERL guideline corresponds roughly to a 10% likelihood of toxicity, so this guideline represents a conservative (precautionary) approach (O’Connor 2004).

Table 4. **Sediment quality guidelines used to assess potential toxicity from elevated trace metal levels in this study. Concentrations are parts per million dry weight, ERL = Effects Range Low, ERM = Effects Range Median.**

Metal	Median value[1]		NOAA	
	Level I	**Level II**	**ERL**	**ERM**
Arsenic (As)	20	70	8.2	70
Cadmium (Cd)	1.35	4.6	1.2	9.6
Chromium (Cr)	80	320	81	370
Copper (Cu)	47.5	155	34	270
Mercury (Hg)	0.35	1	0.15	0.71
Lead (Pb)	72.5	310	46.7	218
Nickel (Ni)	50	150	20.9	51.6
Zinc (Zn)	185	552	150	410

1. Median values calculated from sediment quality guidelines from Belgium, Denmark, Finland, France, Germany, Ireland, Spain, UK, US (Pacific NW), Australia, Hong Kong and South Africa (DEA 2012) and the Effects Range Low (ERL) and Effects Range Medium (ERM) values published by the US National Oceanic and Atmospheric Administration (NOAA) (Long & Morgan 1990, Long *et al.* 1995).

3.6 Biomonitoring

At all sampling sites where oysters were found, samples (20-30 oysters) were collected for trace metal analysis (Figure 5). The oyster tissue was removed from the shell and submitted to Scientific Services Analytical Laboratories in South Africa for determination of trace metal content (aluminium (Al), As, Cd, cobalt (Co), Cr, Cu, iron (Fe), manganese (Mn), Ni, Pb, Zn, Hg) using ICP-OES.

Trace metal levels in oysters collected from sites in the creeks draining Area 1 were compared with the median maximum legal limits prescribed for each contaminant in shellfish for human consumption sourced from those for 13 different countries/jurisdictions (South Africa, Canada, Australia & New Zealand, European Union, Japan, Switzerland, Russia, South Korea, USA, China, Brazil, Israel, Table 5) in the absence of values specifically for Sierra Leone. Where different values from different countries were available, the median value was taken to screen the oyster samples collected from the estuary downstream of Area 1.

Table 5. **Guidelines relating to maximum concentrations for metals in molluscs in different countries.**

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Africa$_1$		0.5		3.0	3.0	0.5
Canada$_2$	70.0	2.5		1.0	2.0	
Australia & NZ$_3$		2.0	1 000		2.0	0.5
European Union$_4$		1.5			1.0	0.5
Japan$_5$		10.0			2.0	0.2
Switzerland$_2$		1.0			0.6	0.5
Russia$_6$		10.0			2.0	

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Korea$_{2}$		0.3				
USA$_{7,8}$		1.7			4.0	
China$_{9}$					2.0	
Brazil$_{10}$						0.5
Israel$_{10}$						1.0

1. Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972)
2. Fish Products Standard Method Manual, Fisheries & Oceans, Canada (1995)
3. Food Standard Australia and New Zealand (http://www.foodstandards.gov.au/Pages/default.aspx)
4. Commission Regulation (EC) No. 221/2002
5. Specifications and Standards for Foods. Food Additives, etc. Under the Food Sanitation Law JETRO (Dec 1999)
6. Food Journal of Thailand. National Food Institute (2002)
7. FDA Guidance Documents
8. Compliance Policy Guide 540.600
9. Food and Agricultural Import Regulations and Standards.
10. Fish Products Inspection Manual, Fisheries and Oceans, Canada, Chapter 10, Amend. No. 5 BR-1, 1995.

3.7 Benthic macrofauna

At each site samples of sub-tidal and intertidal benthic invertebrate macrofauna (organisms >1.0 mm) were collected. Sub-tidal samples were collected using a Van Veen grab and intertidal samples using a hand core (Figure 6, Figure 7). Invertebrates were separated from the sediment by sieving in a 1 mm mesh bag and preserved in 5% formalin (Figure 7). These samples were returned to South Africa for identification to species level as far as possible.

In the laboratory, samples were rinsed on a 1 mm sieve with fresh water to remove formalin. The samples were then hand sorted and all fauna was removed and preserved in 1% phenoxytol (Ethylene glycol monophenyl ether) solution. Limited taxonomic work has been conducted in Sierra Leone previously and there are few identification keys available for the invertebrate fauna of the region and many species may remain undescribed. Organisms were identified to the lowest possible taxonomic level possible using available taxonomic keys (e.g. Day 1967a, b, 1974, Carpenter & De Angelis 2014a, 2016) for the 68 intertidal and sub-tidal samples collected. The validity of each species was then checked on The World Register of Marine Species (WoRMS, www.marinespecies.org).

Figure 6. Sub-tidal macrofauna and sediment samples were collected using a Van Veen grab. Typically this was done in the channel from a boat but the action of the grab is demonstrated here on the edge of the bank.

Figure 7. Collection of intertidal macrofauna samples with a hand held corer (1), transfer to a 1 mm mesh bag (2), rinsing to remove fine sediment (3) and transferring the residual material to a sample jar (4).

3.8 Fish

Fish were sampled using a combination of gill nets (28-145 mm stretch mesh, 4 m depth, 200 m length), fyke nets (25 m wing length, 1 m depth) and a seine net (12 mm stretch mesh, 25 m length, 2 m depth) (Figure 8). Fish sampling gear was deployed at alternate sites in each creek where practically feasible. Gill and seine net deployments were conducted at most sites, and fyke net deployments were restricted to the upper sites and some side creeks where flow rates were not too high. Samples of fish were also obtained from local fishers and a record kept of species caught. All fish collected were identified on site and photographed. For identification of fish species, *The Fresh and Brackish Water Fishes of West Africa* (Paugy *et al* .2003) taxonomic guide and the *Field Guide to the Commercial Marine Resources of the Gulf of Guinea* (Schneider 1990) were used. Species names were checked for synonymy using FishBase (www.fishbase.org).

The fish fauna sampled in the study area was compared to that reported for other West African tropical estuaries, particularly that reported by Whitfield (2005), who included data from studies in Nigeria, Guinea, Senegal, Ivory Coast and Benin, as well as that recorded in the Gambia River Estuary by Vidy *et al.* (2004) and Simier *et al.* (2006). Simier *et al.* (2006) state that the data emanating from the Gambia surveys in particular represent a good "natural reference point" for other West African estuarine fish surveys, due to the extensive seasonal sampling effort undertaken and the limited anthropogenic impacts on the Gambia estuary. The degree of marine, estuarine and freshwater affinity of each fish species recorded was determined using the ecological categories defined by Albaret (1999, also used in Simier *et al.* 2006 and others) (Table 7). For the purposes of this study, the eight bio-ecological categories estuarine association of Albaret (1999) were reduced to three categories, namely a freshwater, an estuarine and a marine group. This is similar to, but also represents a reduction to the classification used by Whitfield (2005), who defined two estuarine (estuarine residents and estuarine migrants), two marine (marine immigrants and marine stragglers), and three freshwater guilds (freshwater immigrants, freshwater stragglers and catadromous migrants) when comparing estuarine fish communities in Sub Saharan Africa (Table 7). Life history information on many of the species encountered is insufficient to determine the degree of estuarine association or dependence as per Whitfield's (1998) and (2005) classifications.

Figure 8. Setting a gill net (left) and a beach seine net (centre, right).

Table 6. Bio-ecological categories of fish found in West African estuaries (after Simier *et al*. 2006).

Bio-ecological category	Description
Co	Freshwater species occasional in estuaries
Ce	Freshwater species with estuarine affinities
Ec	Estuarine species of freshwater origin
Es	Strictly estuarine species
Em	Estuarine species of marine origin
ME	Marine-estuarine species
Ma	Marine species accessory in estuaries
M	Marine species occasional in estuaries

Table 7. Adapted estuarine associated categories for fish used in this study.

Category (this study)	Description	Bio-ecological category (Simier *et al.* 2006)	Estuarine guilds (Whitfield 2005)
Fresh water guild (F)	Freshwater and catadromous species occurring in estuaries	Co, Ce, Ec	Freshwater immigrants, freshwater stragglers and catadromous migrants
Estuarine species (E)	True estuarine species that can breed in estuaries	Es	Estuarine residents and estuarine migrants
Marine guild (M)	Marine-estuarine species (May be dependent on estuaries for juvenile habitat)	Em, Me, Ma , M	Marine immigrants and marine stragglers

Available life history information on the fish species caught, namely the maximum recorded size, prey types and trophic level of each species was extracted from FishBase (www.fishbase.org). Based on dietary information available in FishBase, species were categorised as herbivores, omnivores or carnivores. Fish species were also assigned to one of seven trophic groups as defined by Écoutin *et al.* (2014) (Table 8). This life history information facilitated assessment of any anthropogenic impacts on the fish communities inhabiting the estuary downstream of Area 1. Comparisons of the fish communities found at different sites were undertaken using multivariate statistical analysis of combined (average catch at each sampled site) seine net data for the wet and the dry season surveys. Multivariate statistical analysis was conducted using the PRIMER software. Fish abundance data were fourth-root transformed and the Bay-Curtis similarity index was used to create similarity matrices. Relationships between sites were represented using dendrograms and multidimensional scaling and the statistical significance of groupings was tested using SIMPROF test. This spatial analysis (comparisons of fish communities sampled at increasing distances from mining activities) informed the assessment of potential current and future mining impacts.

Table 8. Trophic groups assigned to fish species (From Écoutin *et al.* 2014)

Code	Description
he-de	Scavenger or grazer herbivores
he-ph	Herbivores mainly feeding on phytoplankton or micro-phytoplankton
p1-zo	First level predators mainly feeding on zooplankton
p1-bt	First level predators mainly benthophagous (molluscs, cockles, marine worms)
p1-mc	First level generalist predators mainly feeding on macro-crustacean or insects
p2-ge	Second level generalist predators mainly feeding on fish, shrimps and crabs
p2-pi	Second level piscivorous predators mainly feeding on fish

3.9 Vegetation

Total mangrove area (km^2) was estimated for the Sherbro River Estuary area in the vicinity of Area 1 using the mangrove extent layer and metadata from a study undertaken by Giri *et al*. (2011) in ESRI ArcGIS 10.3. Giri *et al.* used approximately 1 000 Landsat scenes and employed hybrid supervised and unsupervised digital image classification techniques. Each image was normalized for variation in solar angle and earth-sun distance by converting the digital number values to the top-of-the-atmosphere reflectance. Canopy height classifications and above and below ground biomass for the same region was obtained from a study undertaken by Fatoyinbo & Simard (2013). Mangrove distribution data was also sourced from the Centre for Applied Geographic Information Science, University of North Carolina, Charlotte (CAGIS) and NASA Shuttle Radar Topographic Mission (SRTM) data downloaded from US Geological Survey (USGS) EROS Data Centre (UNCC; CAGIS accessed August 2017). Both of these data sets are considered to be historic, dating from 1997-2000, and were compared with contemporary mangrove area coverage provided by Mondal *et al*. 2017 in order to determine any loss or gain in habitat or community structure over time. An indication of losses or gains in biomass and carbon for the study area were also estimated using newly structured height classification data based on the current dominant indicator species. Ground truth data and existing maps and databases were used to select training samples and also for iterative labelling. Results were validated using existing GIS data and the published literature to map ‘true mangroves’ (Giri *et al*. 2011, Fatoyinbo & Simard 2013, Mondal *et al.* 2017).

Rhizophora spp. generally obtain a greater height (up to 40 m) and are restricted to areas that are regularly inundated, while *Avicennia germinans* (up to 20 m, but usually smaller) and *Laguncularia* spp. (2-4 m respectively) are usually found in the tidally flooded area behind the *Rhizophora* spp. band (Beentje & Bandeira 2007). Using the aforementioned information, in conjunction with canopy height class data, the percentage of mangrove area composed of *Rhizophora* spp. and *Avicennia*/*Laguncularia* spp. was estimated. Calculations were to be based on the assumption that the 90 x 90 m blocks where canopy heights are >8 m, are composed of *Rhizophora* spp., while 90 x 90 m blocks where canopy heights are <8 m, are composed of *Avicennia/Laguncularia* spp.

Distinct vegetation bands of *Rhizophora* spp. and *Avicennia/Laguncularia* spp. within the mangrove communities surrounding Area 1 were thought to be visible in satellite imagery. However, through ground truthing during two field excursions it was determined that size classes were not distinct to species (e.g. *Rhizophora* spp. is present in both > 8 m and 5 – 7 m size classes). In order to determine mangrove cover down to species, finer scale resolution imagery would be required (e. g. drone footage of the study area).

The mangrove ecosystem inhabiting the delta below Area 1 was sampled in August 2017. Two sites were sampled on Bagru Creek (B2 and B4) and Sherbro Island (S2 and S4), three sites were sampled on Gbangbaia Creek (G1, G4 and G6), Kangama Creek (K1, K3 and K5) and Moteva Creek (M1, M3 and M5), and a single site was sampled on Teso Creek (T3). The inaccessibility of the mangrove areas made it difficult to sample gradients along transects. Thus, tree density and basal area was assessed in plots located 5-10 metres into the mangrove area away from the waters' edge at each site. The objective of this was to establish if there were any differences in density and basal area between creeks that have potentially been impacted by mining activities (Gbangbaia, Kangama and Teso Creeks) relative to those where no mining impact is anticipated (Bagru, Moteva Creeks and Sherbro Island). Where possible, a minimum of three plots were assessed using a Cruise Master 10M wedge prism. Plots were selected at random and did not overlap one another. Within each of the plots, a centre point was selected and a visual sweep of the surrounding mangrove trees was done, and trees were counted as per typical cruise counting methodology (Bell & Alexander 1957, English *et al.* 1997). The species of each tree counted was recorded and the Girth at Breast Height (GBH) measured.

Basal area (m^2 per hectare) was calculated by multiplying the number of trees in each size class counted by the Basal Area Factor (BAF) of the Cruise Master 10M wedge prism. Diameter at Breast Height (DBH) was calculated by dividing GBH by Pi. The DBH in conjunction with forestry tables (English *et al.* 1997, Cintrón & Novelli 1984) were used to estimate the number of stems per hectare. The tree density (stems per hectare) was adjusted from to stems per ha to stems per 0.1ha.

In each of the four creeks, Gbangbaia, Kangama, Bagru and Motevo Creeks, a transect was walked through the mangroves from the channel to the landward margin. Due to time constraints it was not always possible to reach the landward margin of the mangrove. Starting from the channel margin, stem density (stems/0.1ha) and basal area (m^2/0.1ha) was assessed using the Point-Centred Quarter Method+ (PCQM+) outlined by Dahdouh-Guebas and Koedam (2006) transect points were taken at 10 m intervals for the first 4 points, 20 m intervals for next seven points and 50 m intervals thereafter.

3.10 Birds, reptiles and mammals

All birds, reptiles and mammals encountered on the estuarine creeks draining from the Area 1 during the survey were identified and counted (and photographed where possible) in the field using binoculars and guides. This was done opportunistically whilst travelling from Nitti Port to the various sampling sites, between sites, and on the return journey to the port. Sampling effort was not equitably distributed across the study area, therefore, with maximum effort being expended on the area close to Nitti Port (Gbangbaia Creek and Bagru Creeks).

4 DESCRIPTION OF THE AFFECTED ENVIRONMENT

This description of the affected environment is based on data collected during the two field surveys undertaken during the wet season (August 2017) and the dry season (January 2018). Data from these surveys is presented below in the context of available literature on West African estuarine ecosystems.

4.1 Water quality

4.1.1 Physical properties (Temperature, salinity, DO, TSS)

Data on temperature, salinity, pH, dissolved oxygen (DO) and turbidity levels in surface and bottom waters at each sampling site in the wet (August 2017) and dry seasons (January 2018) are presented in Figure 9 below. In the wet season, water temperature varied between 26.3 and 28.2°C and was generally slightly cooler (0.1-0.5°C) at the bottom than at the surface at most sites survey (Figure 9). There was a trend of increasing temperature with distance downstream on most creeks, but this was confounded by time of day, with samples taken early in the day being cooler than those taken later in the day. No evidence of stratification[13] was evident in the temperature data from any of the sampling sites. The pattern was similar in the dry season (range = 26.3-29.1°C) except that water temperature was on average slightly higher (average = 28.1 vs. 27.0°C).

Salinity varied between 0.10 and 18.95 Practical Salinity Units (PSU)[14] in the wet season (average = 3.0) but was markedly higher in the dry season (4.8-32.8, average = 19.7) (Figure 9). In the wet season, salinity in three creeks that drain directly from Area 1 (Kangama, Gbangbaia and Teso Creeks) was very low (<1.0) in both the surface and bottom waters due to strong freshwater outflow which restricted ingress of salt water up to the top of these creeks. In the dry season when run-off was much lower however, salinity measured at the upper stations of these creeks was higher (K1 = 11.1, G1 = 15.0, T1 = 4.8). Salinity in Moteva Creek, which is closer to the mouth of the estuary, was higher than the Kangama or Gbangbaia Creeks in the dry (2.60-3.17) and wet seasons (21.3-29.4), but also displayed little or no evidence of stratification. Telo Creek was only sampled in the dry season and drains into Bagru Creek from the north. Salinity in this creek ranged from 12.7-15.4. Bagru Creek, into which Kangama and Gbangbaia Creeks also drain, exhibited a clear salinity gradient from almost fresh at the top (0.05) to brackish at the lower end near Sherbro Island in the wet season (surface: 3.82, bottom: 8.26) and was also correspondingly more saline in the dry season (13.6-25.1). Some evidence of stratification was evident in the lower reaches of this creek (Site B3,

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[13] Layering or separation between cooler and/or denser, saltier water on the bottom and lighter/warmer freshwater above.

[14] The Practical Salinity Scale 1978 (PSS-78) has been considered by the Joint Panel on Oceanographic Tables and Standards and is recommended by all oceanographic organizations as the scale in which to report future salinity data. The PSS scale has replaced the older PPT or Parts Per Thousand scale since electrical conductivity measurements became the most common method used to estimate the ionic content of seawater. By convention, practical salinity is expressed as a dimensionless number only and should be written as, e.g. S = 35.034.

B4 and B5) in the wet, but not in the dry season. Salinity levels in Sherbro Creek, which is closest to the mouth of the estuary, were as expected higher than the other creeks, and ranged from 5.06-22.50 in the wet season and 31.7-32.8 in the dry season. Clear evidence of stratification was also evident in this area, with higher salinity readings on the bottom than at the surface.

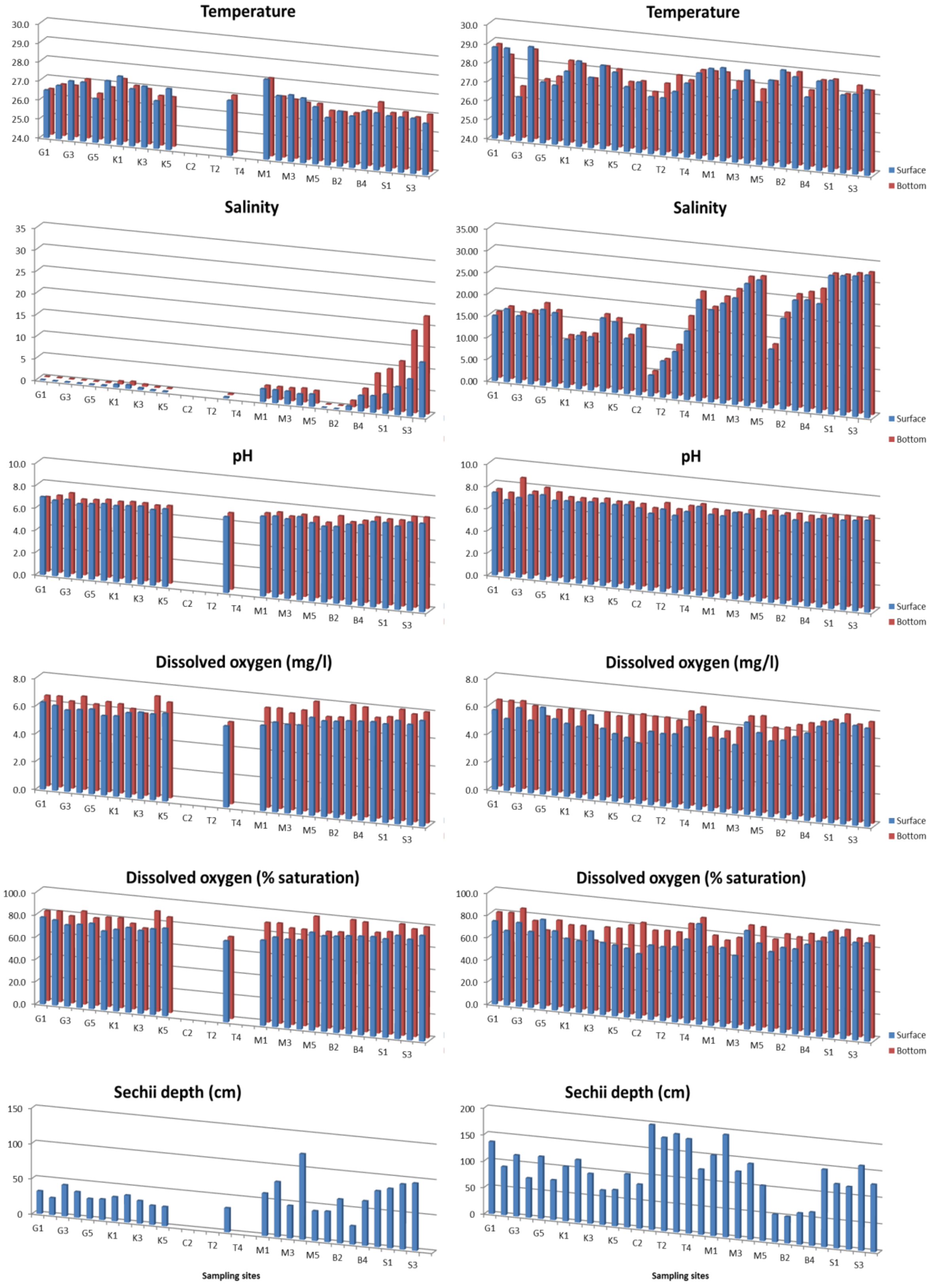

Figure 9. Temperature (°C), salinity (PSU) and pH in surface and bottom at each sampling site during the wet season (left) and dry season (right).

pH showed little variation across the survey sites, ranging from slightly acidic (6.68) to slightly alkaline (8.20) in the wet season, and was slightly more alkaline in the dry season (6.86-8.66) (Figure 9). Almost without exception, surface waters were slightly more acidic than bottom waters, except where there was a marked difference in salinity between the surface and bottom water, in which case the salt content served to buffer the water, driving pH to towards a neutral 7.0.

Levels of DO were moderate to high at all sites in both seasons, but were slightly higher in the wet compared with the dry season. Wet seasons values ranged from 5.72-8.02 mg/l (average = 6.76 mg/l) while dry season values ranged from 4.35-7.68 (average = 6.07 mg/l) (Figure 9). Saturation levels were also high, ranging from 58.0-99.9%. Where there was some evidence of stratification in the water column, DO levels at the bottom tended to be higher than at the surface. Oxygen levels also tended to be higher near the mouth compared with the upper reaches of the creeks.

Sechii depth, a measure of the distance that light is able to penetrate through the water column, varied from 24-121 cm in the wet season but was considerable higher (i.e. indicative of clearer waters) in the dry season (50-198 cm) (Figure 9). There were no clear patterns with distance downstream in either season, with peak Sechii depth often recorded at stations mid-way between the top and bottom. Total Suspended Solid levels (TSS, derived by filtering a sample of water and weighing the filtrate) differed strongly between the wet and dry season being considerably elevated in the latter season (Figure 10). This is counter intuitive inasmuch as one would normally expect that TSS to be correlated closely with turbidity (higher suspended sediment loads generally result in reduced water clarity). However, in this instance it is thought that the higher TSS levels in the dry season are linked to elevated phytoplankton abundance at this time (see Section 4.1.2 for more details) which reduces light penetration much less than suspended sediment does.

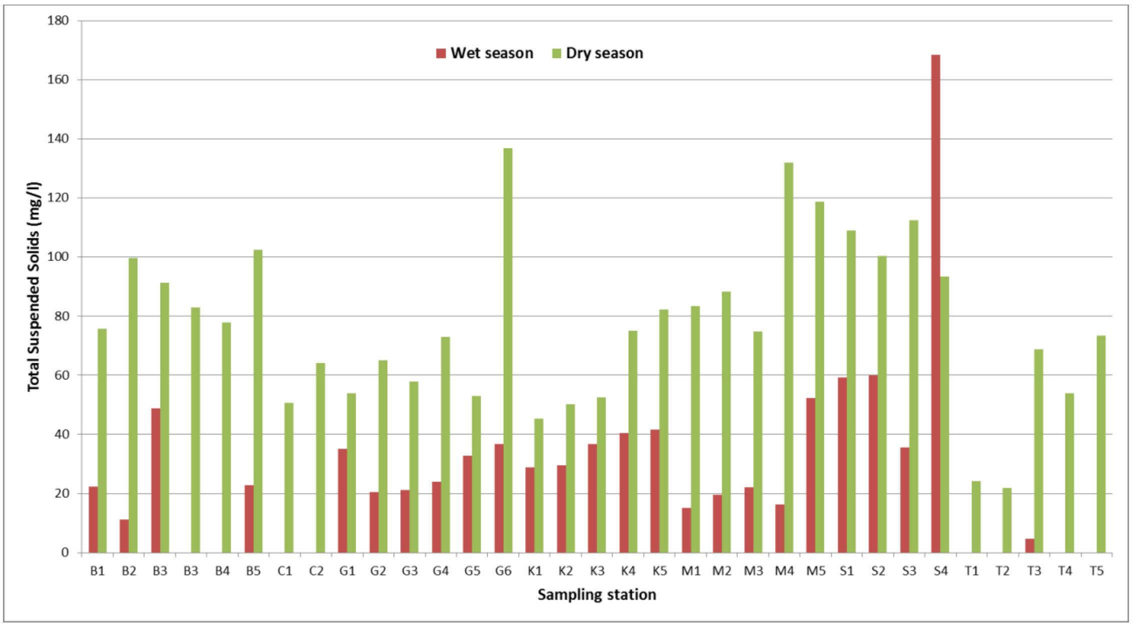

Figure 10. Total Suspended Solids (TSS) at each sampling station in the wet and dry season.

4.1.2 Dissolved inorganic nutrients

Nutrients as ammonia, nitrate, nitrite and phosphate were analysed from surface water collected at each site for the dry season survey and are presented in Table 9 and Figure 11. Analyses on water samples did not detect any nitrate in the water samples collected throughout the study area. Phosphate was not detectable by laboratory methods at all sites except M4, K1 and T4. Nixon *et al.* (2007) recorded low phosphate levels in their study of lagoons in Ghana with levels generally being < 0.031 mg/l, levels in the Sherbro River Estuary, were mostly comparable. Ammonical nitrogen levels were fairly consistent throughout the creeks sampled with low levels being recorded at sites M1, S1 and T4. Free ammonia levels were variable throughout with no clear spatial trend in concentration levels. Nitrite was mostly undetectable in the different sample creeks, except in Telo Creek (C1 and C2) which flows in Bagru Creek which also recorded Nitrite as being present (B3, B4 and B5) in the water column . Nixon *et al.* (2007) recorded low nitrite levels in their study in Ghana. Nitrite was also present in the lower portion of Motevo Creek (M4 and M5) as well as Kangama Creek (K3 and K2). Sites G3 and G5 in Gbangbaia Creek, also recorded nitrite as being present.

Table 9. Concentration of nutrients ammonia, nitrate, nitrite and phosphate in surface water samples collected from stations sampled during the dry season survey.

	Phosphate	Ammoniacal Nitrogen as N	Free Ammonia as N	Nitrate	Nitrite
	mg/l	mg/l	mg/l	mg/l	mg/l
G1	<0.06	0.62	0.008	<0.05	<0.006
G2	<0.06	0.53	0.011	<0.05	<0.006
G4	<0.06	0.51	<0.006	<0.05	<0.006
S3	<0.06	0.51	0.036	<0.05	<0.006
K3	<0.06	0.48	<0.006	<0.05	0.011
C2	<0.06	0.5	0.034	<0.05	0.043
M1	<0.06	0.23	<0.006	<0.05	<0.006
B3	<0.06	0.5	0.009	<0.05	<0.006
K5	<0.06	0.45	0.01	<0.05	<0.006
S1	<0.06	0.05	<0.006	<0.05	<0.006
M4	0.1	0.49	0.009	<0.05	0.008
K3	<0.06	0.5	0.02	<0.05	0.023
K2	<0.06	0.47	0.008	<0.05	0.015
G5	<0.06	0.47	0.007	<0.05	0.019
K4	<0.06	0.5	0.02	<0.05	<0.006
M5	<0.06	0.51	0.034	<0.05	0.006
B2	<0.06	0.5	0.034	<0.05	<0.006
C1	<0.06	0.5	0.014	<0.05	0.035
M2	<0.06	0.48	0.008	<0.05	<0.006
K1	0.13	0.49	0.019	<0.05	<0.006
S4	<0.06	0.46	0.028	<0.05	<0.006
G6	<0.06	0.46	0.008	<0.05	<0.006
B4	<0.06	0.47	0.007	<0.05	0.008
S2	<0.06	0.49	0.009	<0.05	<0.006

	Phosphate	Ammoniacal Nitrogen as N	Free Ammonia as N	Nitrate	Nitrite
B3	<0.06	0.54	0.033	<0.05	0.017
G3	<0.06	0.49	0.033	<0.05	0.008
T3	<0.06	0.43	0.028	<0.05	0.009
T5	<0.06	0.57	0.006	<0.05	<0.006
T2	<0.06	0.43	0.006	<0.05	<0.006
T1	<0.06	0.51	0.009	<0.05	<0.006
T4	0.18	0.34	0.006	<0.05	0.012
B5	<0.06	0.44	0.017	<0.05	0.012
B1	<0.06	0.56	0.012	<0.05	<0.006

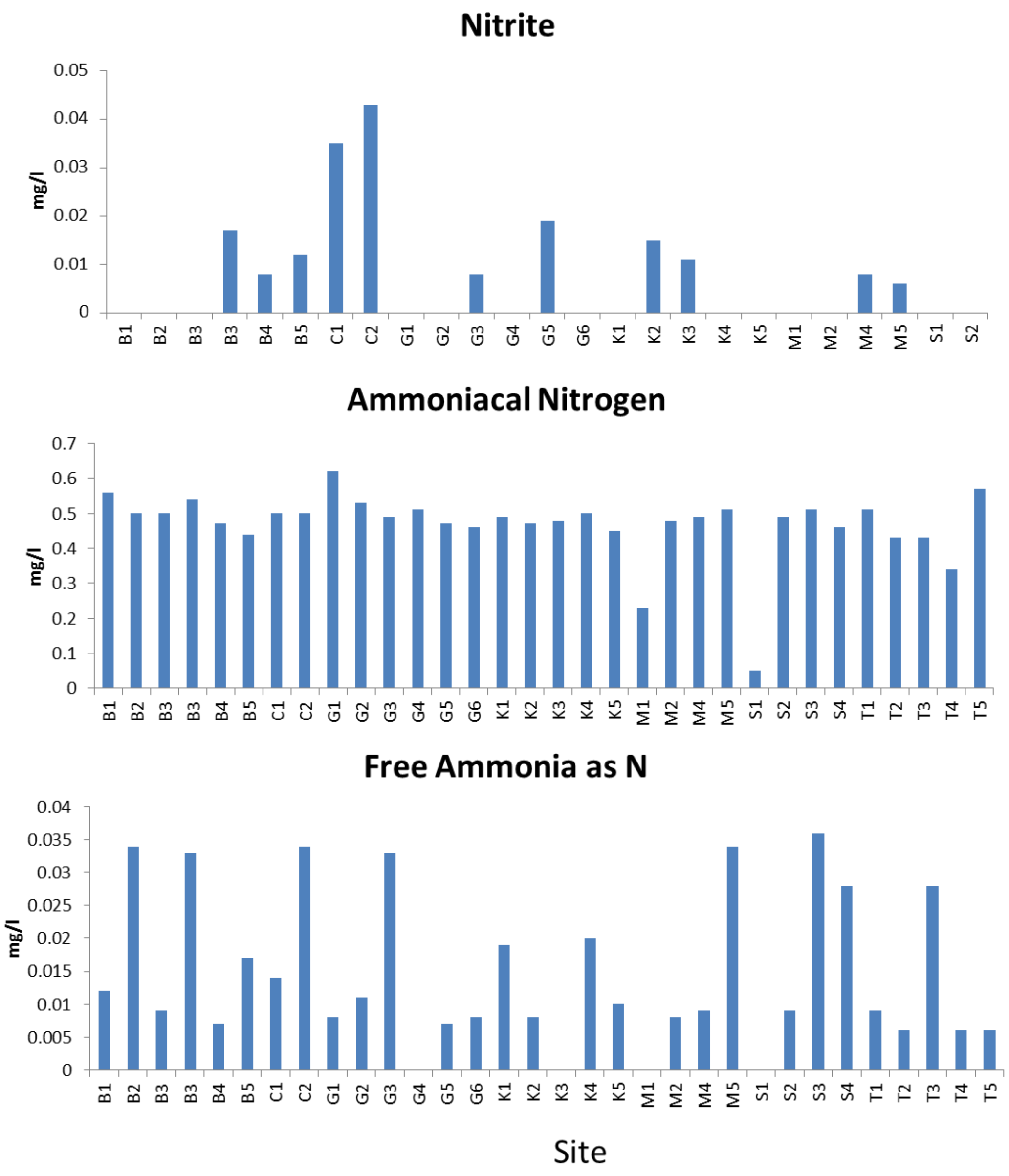

Figure 11. **Nutrient concentrations in surface water samples collected from the estuaries below Area 1 during the dry season field survey.**

4.1.3 Chlorophyll-a

During the wet season survey Chl-a concentration in surface water samples was highly variable and ranged from 4.5-105.0 µg/l (Figure 12). There was a trend of lower Chl-a values at sampling sites in the upper creeks furthest from the sea (Kangama, Gbangbaia, upper Bagru and Teso Creeks), with higher values recorded in the lower Bagru and Motevo Creeks and Sherbro Island. During the dry season survey Chl-a concentrations were much less variable ranging between 9 and 81.9 µg.l^{-1} (Figure 12). Although the maximum recorded value recorded in the dry season is lower than that recorded during wet season, overall the Chl-a concentrations were elevated compared to those recorded during the wet season. Elevated Chl-a was prominent throughout the creeks surveyed especially at the sampling sites in the upper creeks furthest from the sea, while Chl-a concentrations at Sherbro Island were comparable to those recorded during the wet season.

Chl-a concentration at many stations were high compared to those reported in the literature for other West African estuaries. For example, upper Chl-a values of 8 µg.l^{-1} for the Bia River, 2 µg.l^{-1} for the Tanoe River, 2.5 µg.l^{-1} for the Comoe River and 5 µg.l^{-1} for the Ebrie Lagoon in the Ivory Coast were reported by Kone *et al*. (2009), a maximum value of 10.1 µg.l^{-1} was reported for the marine dominated Sine Saloum estuary (Simier *et al.* 2004), and an average value of 9.6 µg.l^{-1} was reported by Troussellier *et al.* (2005) for the Senegal River. The high Chl-a values reported in the study area during the wet season appear to be mostly associated with marine influence, suggesting that phytoplankton blooms are developing in the wider areas of the estuary in the vicinity of Sherbro Island where nutrient levels, light penetration and retention support phytoplankton growth. During the dry season water retention time in the upper creeks increases due to decreased flow-through of fresh water and a greater tidal influence. This longer residence time during the dry season allows for phytoplankton blooms to develop further up the estuary. The increased retention times in conjunction with greater water clarity and light penetration (increased Sechii depths, Section 4.1.1) would have allowed for increased primary production and the elevated Chl-a values recorded during the dry season (Allanson & Baird 1999).

Overall the Chl-a values recorded for the estuary suggests that primary productivity is high compared to several other West African systems. Low light penetration due to the high turbidity and low retention times in the upper creeks probably limits phytoplankton growth during the wet season, but these levels are comparable to other estuaries in West Africa. The exception to this pattern was the K1 site at the start of the Kangama Creek where the highest Chl-a value of 104.0 µg.l^{-1} was recorded (Figure 12). This appears to be related to the proximity of this site to a large artificial impoundment used for mining operations, immediately upstream (Figure 2). This impoundment probably provides suitably increased retention times and water clarity for phytoplankton blooms to form, and due to spill-over during the wet season, results in elevated Chl-a levels at this site. Nutrients released from the soil when the ore is mined may also contribute. Greater retention times due to hydrodynamics of the estuary and tidal influence and greater light penetration during the dry season resulted in elevated primary production and higher Chl-a results.

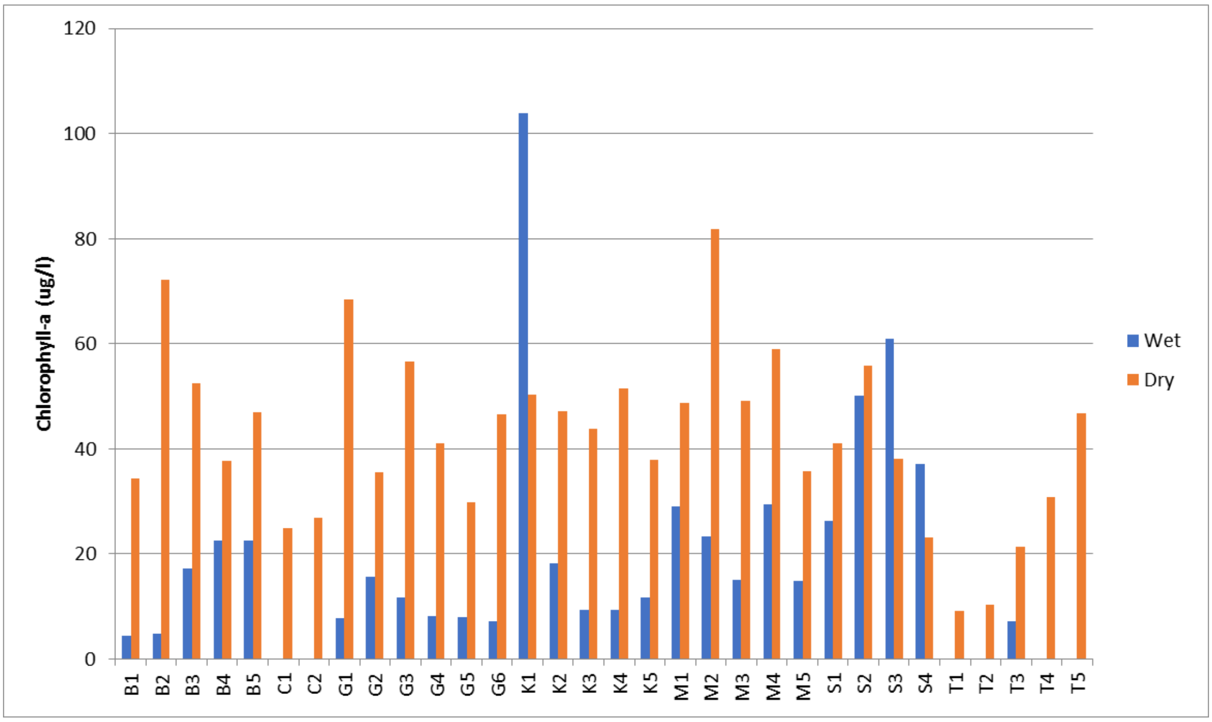

Figure 12. **Chlorophyll-a concentration in surface water samples collected from sites below Area 1 during the wet and dry season field surveys.**

4.2 Sediment quality

4.2.1 Grain size composition

Grain size composition results for intertidal and subtidal sediment samples collected during the wet and dry season surveys are represented on Figures 12 and 13. Bagru Creek sub-tidal sediment profiles at sites B1 and B2 in the wet season were similar being mostly composed of medium sand (Figure 13). However, in the dry season both sub-tidal profiles shifted from medium sand to high quantities of coarse gravel; yet they still held their silt component. In the wet season, the B3, B4 and B5 sub-tidal soil profiles indicated large compositions of very fine sand along with low silt components (Figure 13). This pattern was reversed in the dry season, where fine silt sediment fractions dominated the sediment composition for all three of these lower Bagru Creek subtidal sites. The inter-tidal sediment profiles at sites B2 and B4 remained relatively constant and fine silt dominated the sediment composition both in the wet and the dry season (Figure 13). However, gravel contributed more than a third to B2 intertidal sediment profile in the dry season as opposed to zero in the wet season.

Subtidal sediments from Gbangbaia Creek were similar throughout with components of coarse, medium, and fine sand predominating in the wet season (Figure 13). Small amounts of gravel, very coarse sand, very fine sand and silt were also recorded at sites G1, G2 and G3. Sub-tidal sites G4 and G6 had fairly high quantities of silt. However in the dry season, four of the subtidal sites had greater quantities of gravel compared to the wet season particularly sites G1 and G6 in which gravel contributed at least 60% to their sediment composition. Subtidal sites G3 and G4 had a lower gravel composition but had greater silt quantities compared to the latter sites. Sites G2 and G5 revealed distinguishingly different patterns from the rest of the sub-tidal profiles, where gravel contributed to less than 1% for both sites. G2 and G5 were dominated by very fine sand and silt in their respective sediment profiles. Silt was a major component at the three intertidal sites sampled in the wet season (G1, G4 and G6). The latter sites were distinguished in their profile by varying amounts of very coarse sand (major contribution for G6), coarse sand (major contribution for G1) and medium sand (major contribution for G4). All three intertidal sites had small quantities of gravel in their profiles in the dry season. Site G1 had a greater gravel contribution and its silt component remained relatively the same in both seasons; whereas sites G4 and G6 had greater quantities of very coarse sand compared to gravel and their silt components were higher in the dry season survey compared to that recorded during the wet season survey (Figure 13).

Subtidal sediment samples from Kangama Creek sites K2, K3, K4 and K5 were similar all being dominated by medium sand and having similar proportions of the remaining size fractions in the wet season survey (Figure 13). The sub-tidal site K1 was dominated by coarse sand and had a larger component of silt compared to the other sub-tidal Kangama sites. All the Kangama Creek intertidal sediment samples revealed similar profiles to the sub-tidal sites, but had greater amounts of very fine sand and silt. Medium sand was the major contributor for intertidal site K1. In the dry season survey, there was a shift from medium sand being a major contributor; to gravel, very coarse sand and silt for subtidal sites K3 and K4 and intertidal site K1. The sediment profile at subtidal site K5 didn’t change substantially between surveys, except for an increase in the medium sand fraction. This increase in the medium sand fraction also occurred at intertidal site K3, however, its silt component decreased. Silt remained the major component of the intertidal profile for site K5, but the medium sand fraction decreased. Subtidal site K1 shifted from coarse sand to medium sand as the major contributor and subtidal K2 site’s major component is coarse sand followed by the fine silt fraction (Figure 13).

The upper two sub-tidal sites in Motevo Creek (M1 and M2) were similar in terms of sediment profile, with fine sand being the dominant component in the wet season (Figure 14). Subtidal site M1 had a similar sediment profile during the dry season and the wet season surveys, but with an increase in fine sediment and silt contribution. A similar trend was seen at sub-tidal sites M3 and M4, where medium sand was the dominant component. Sub-tidal site M5 was dominated by coarse sediment, predominantly medium sand, but also had small elements of very coarse sand, very fine sand and silt. The sediment profile for subtidal site M5 had changed dramatically in the dry season, where gravel and fine silt were the major components. The dry season survey results revealed a shift with the coarser and medium sand size fractions contributing more to the sediment profiles of the intertidal sampled sites (M1 and M5) and the subtidal site M2 as opposed to the finer sediment fractions that were evident in the wet survey. Intertidal sites included a greater proportion of silt compared to the subtidal sites, but also included large amounts of medium sand as well as some very coarse, coarse, fine and very fine sand (Figure 14). At the intertidal and subtidal M3 site, fine sand contributed more than the silt component during the dry season survey.

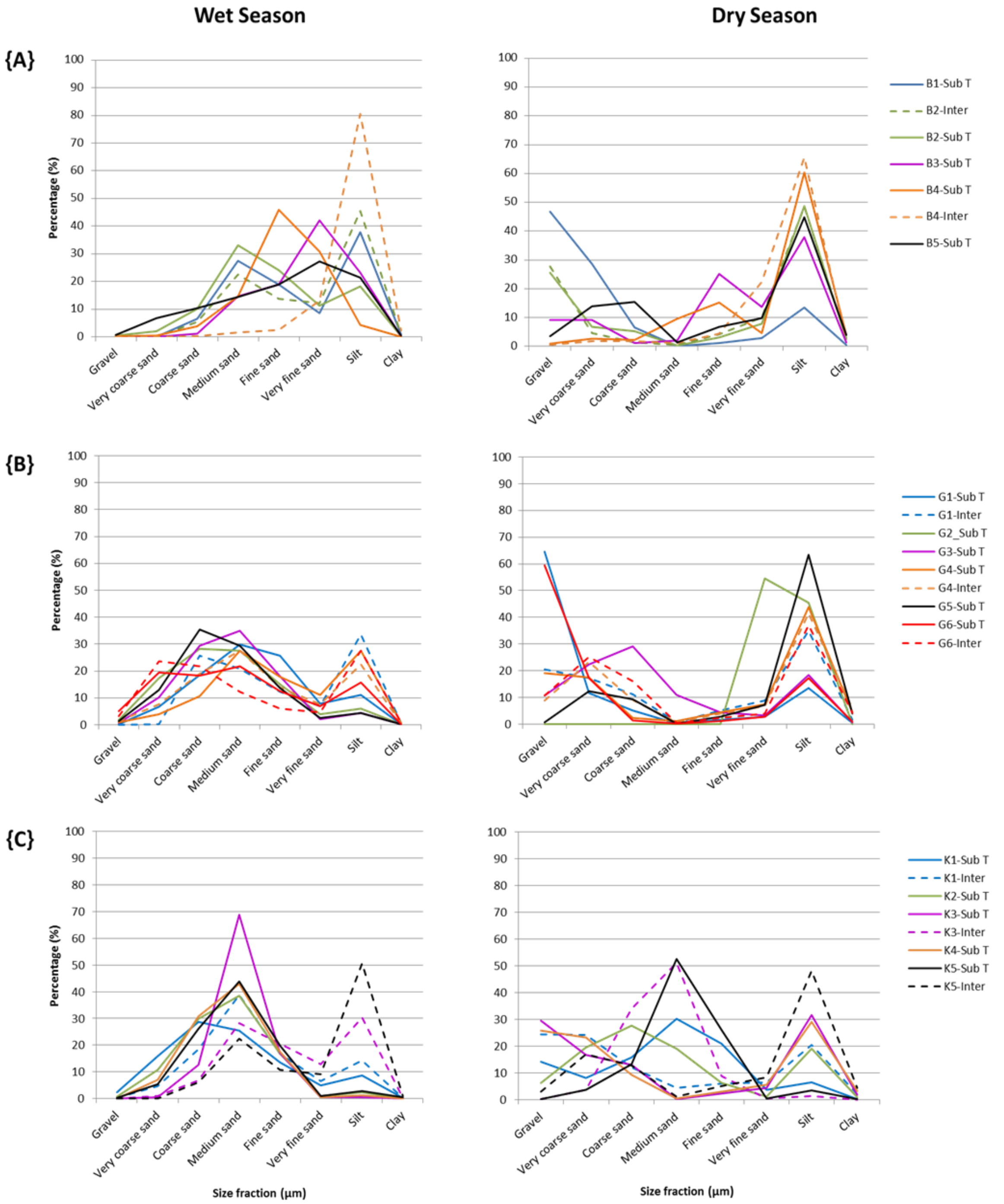

Figure 13. **Relative percentage contribution of the grain size samples to the overall sediment composition at {A} Bagru Creek, {B} Gbangbaia Creek and {C} Kangama Creek which were sampled during both the 2017 wet season (left) and 2018 dry season (right) surveys.**

At Sherbro Island the subtidal site S1 was dominated by fine sand but also included a large portion of very fine sand and silt in the wet season survey (Figure 14). The sediment profiles at the subtidal sites S2 and S3 were similar but had a slightly greater component of coarse and medium sand and a small fraction of fine sand. The sediment profile of subtidal site S4 was similar to the two intertidal sites in this area (S2 and S4) where all three sites included large amounts of coarse, medium and fine sand, as well some silt. The subtidal sites sediment profiles were similar in the dry season where fine sand was still the major contributor; however there was a decrease in gravel, coarse sand, very fine sand and silt components. The intertidal sites had similar profiles both surveys, with coarse and medium the dominant fractions (Figure 14).

The sediment characteristics of the subtidal and intertidal environments in the wet survey at T3 in Teso Creek were markedly different. The sediment in the intertidal sample was mostly composed of fine sediment including medium, fine and very fine sand as well as a large component of silt. The subtidal sediments included mostly coarse material - very coarse, coarse and medium sand. In the dry season survey, the latter sediment profiles were similar with regard to the finer sediment fractions; however there were variations in the coarser grain sizes. Subtidal T3 consisted more of medium sand as opposed to coarse sand; whereas intertidal T3 consisted very coarse sand as opposed to medium sand. Additional sites sampled in Teso Creek in the dry season, revealed that subtidal site T2 shared similarities with subtidal T3 site with medium sand dominating the sediment composition. Furthermore, intertidal site T5 and subtidal site T4 share similar sediment profiles to that of subtidal site T3 in the wet survey with the exception of small fractions of silt present in site T4. Subtidal site T5 sediment consisted mainly of gravel along with silt as a smaller component (Figure 14).

In Telo Creek silt was a major component of subtidal (C1), followed by very coarse and coarse sand whilst, sand and coarse sand dominated the sediment composition at subtidal site C2. The one intertidal site sampled was dominated by coarse sediment fractions (very coarse and coarse sand) (Figure 14).

Overall, there are clear differences between the wet and dry season surveys especially for the subtidal sites across all the creeks sampled. Wet survey results revealed that subtidal sites consisted generally coarse to medium sand components with few finer (fine sand and silt) sediment fractions. Dry survey results show an increase in gravel and very coarse sediment fractions at a few of the subtidal sites sampled but in general the finer (sand silty and clay) sediment fractions contributed more to the sediment profiles compared to the wet survey in all creeks. Intertidal sites did not vary significantly between the two seasons; however, there were still some shifts of finer fractions to coarse sediment fractions in some cases. In all, silt was still a major component for intertidal sites across the creeks sampled. Fine sediment is readily trapped by mangroves (Furukawa *et al.* 1997) in the wet and particularly in the dry season, which accounts for its sustained abundance in the intertidal. Although there is minimal water run-off in the dry season, silt still formed an important component of the subtidal sediment, indicating a small constant supply of fine material passing through the creeks.

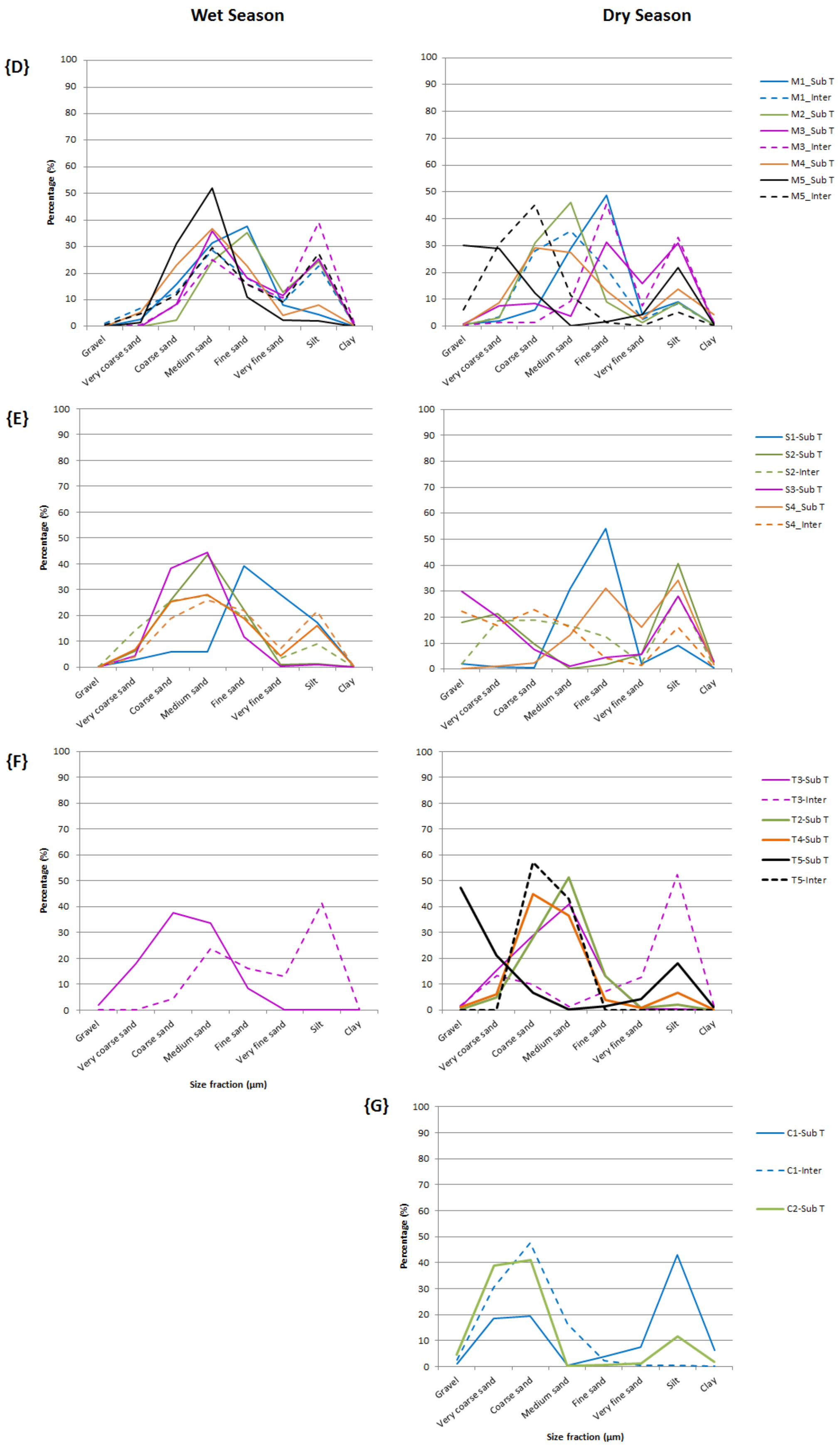

Figure 14. Relative percentage contribution of the grain size samples to the overall sediment composition at {D} Motevo Creek, {E} Sherbro Island, {F} Teso Creek and {G} Telo Creek which were sampled during both the 2017 wet season (left) and 2018 dry season (right) surveys.

4.2.2 Total organic content

Total Organic Content (TOC) in intertidal sediments was high, averaging 23.3% in the wet season, with the lowest values recorded close to the sea on Bagru Creek and Sherbro Island sites where coarser marine sediments dominated. Average TOC was lower in the dry season, 16.0%, with large reductions in TOC at several sites (G1, K3, M1, M3, M5) (Figure 16). Sites closest to the sea (B4, G4, G6, K5 S2 and S4) had the least variation between the wet and dry seasons and this was likely due to constant tidal influence rather than seasonal runoff affecting deposition of organic matter. Motevo Creek had reduced TOC across all three intertidal sites sampled in the dry season compared to the wet season with this trend also being noted at sites G1 and K3. Reduced runoff during the dry season may have reduced the deposition of organic material in the intertidal leading to considerably lower TOC percentages at the aforementioned sites. Overall, greater inter-site variation in TOC was noted in the dry season and in general intertidal sediments within the mangrove creeks showed no clear spatial trend in TOC in either the wet or dry season. This is not unusual as mangroves are known to trap fine sediment within their root structure, thereby acting as a sedimentary sink for organic carbon as well as acting as a source of organic carbon from the constant organic input from the trees themselves (Bouillon *et al.* 2003, Gonneea *et al.* 2004). The sediment trapping function is likely to be enhanced during the wet season when fresh water runoff from the watershed brings addition organic carbon from the surrounding terrestrial environment resulting in the greater and less variable TOC percentages observed. The lack of continual input of TOC into the intertidal during the dry season in conjunction with removal of organic carbon by outgoing tides would likely result in the greater variations in TOC as well as the reduced values in certain areas.

TOC in sub-tidal sediments was much lower on average (8.8% wet season and 12.9% dry season) than that observed in the intertidal sediments (Figure 16). TOC in sub-tidal sediments was even more variable than that observed in the intertidal sediment samples during both the wet and dry seasons. No clear longitudinal spatial trend from river to marine dominated areas was evident, and even sites under greater marine influence on Sherbro Island, had organic content similar to that observed at stations higher up the mangrove creeks across both the wet and dry seasons. The average TOC was however greater in samples collected during the dry season survey. The greater TOC in the dry season was attributed to lower flow-through rates due to decreased runoff from the watershed. The reduced flow rates would result in greater deposition of organic carbon in the sub-tidal environment. However, the system is subject to high flow rates (river and tidally driven) in the river channels and the variability in sub-tidal organic content could have been due to the position of the grab sample relative to the channel centre. It was clear during sampling that there was high, small scale, spatial variability across river channels with sediments in the channel centre and outer bends being coarse (and hence low in organic content), and those close to the river bank or on the inner bend being finer, muddy and with a higher organic content. This across channel variability masks any longitudinal gradient that might exist between the upper estuary and the sea.

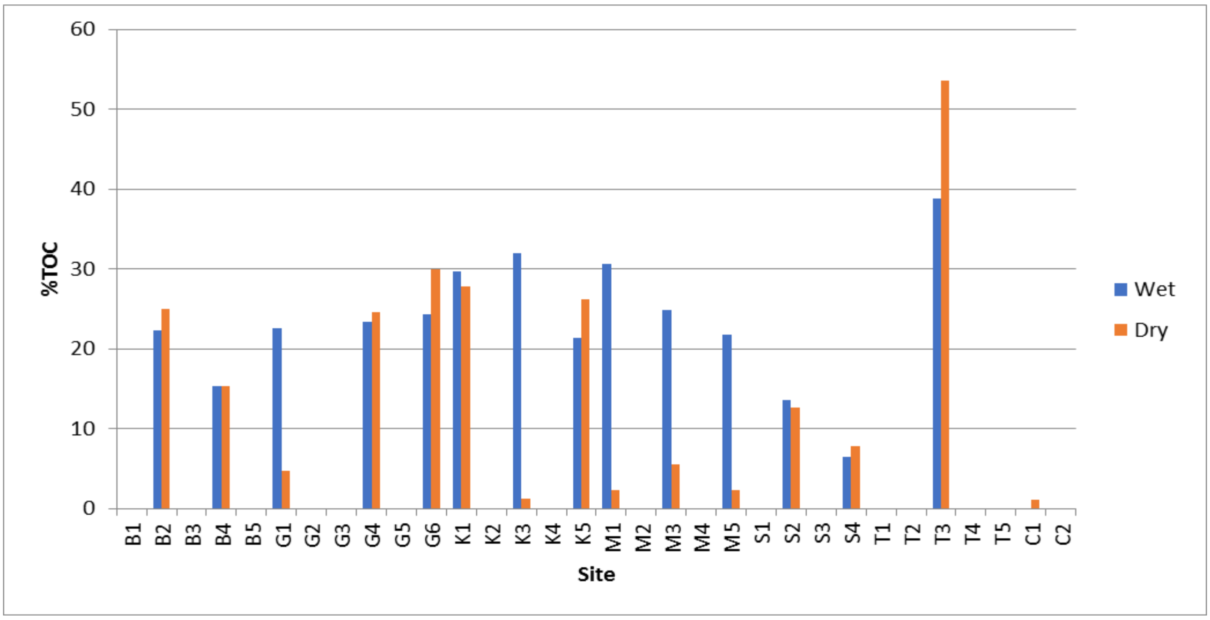

Figure 15. Total organic content (%) of intertidal sediment samples.

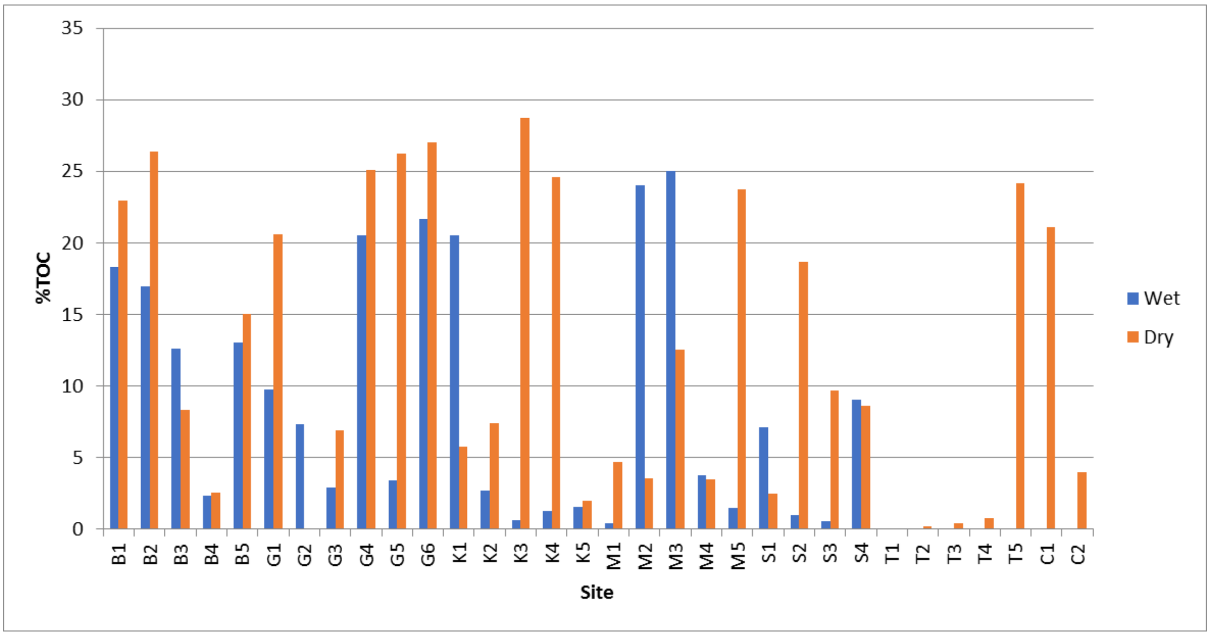

Figure 16. Total organic content (%) of subtidal sediment samples.

4.2.3 Trace metals in sediments

The measured concentrations of trace metals in the estuarine subtidal sediment samples taken during the wet and dry season surveys are shown in Table 10. Only three (arsenic, chromium and nickel) out of the eight trace metals analysed exceeded the median Level 1 concentration as well as the ERL guideline (Figure 15).

There were noticeable differences between the number of sites that exceeded the ERL concentration between the wet and dry season. Six additional sites exceeded the ERL concentration for arsenic and chromium trace metals and three for nickel in the dry season. Furthermore, there are also increases in the concentration of these trace metals at some of the sites surveyed in the dry season. Sites T2, T3, K4, K5, G5 and M4 had substantial increases in all three trace metals in the dry season survey. M5 in Motevo Creek also had a noticeable increase in chromium and nickel concentrations between the wet and dry season surveys.

Due to these distinct increases of trace metal concentration between the wet and the dry season surveys, toxicity may likely be observed in sensitive species. For arsenic, only T3 (Teso Creek) for the wet season and G2 (Gbangbaia Creek) for the dry season exceeded the median Level 1 concentration from available international guidelines. For chromium, 13 and 19 sites exceeded the Level 1 concentration in both the wet and dry season. None of the sites exceeded the level for nickel during either survey. There is some uncertainty as to why sediment samples from many sites had increased trace metal concentrations between the wet and the dry season surveys. It is suspected that the increase in finer sediment particle sizes and increased TOC in sediments observed during the dry season (to which trace metals adhere) are the reason rather than an increase in input from anthropogenic sources. Ongoing monitoring of trace metal levels in sediments and biota is therefore recommended. This will improve understanding of seasonal changes and potential sources of trace metals in the estuarine environments and the associated risk for estuarine biota and people consuming seafood.

Table 10. **Concentration of trace metals (mg/kg) in subtidal sediment samples collected from 27 estuary sampling stations in the 2017 wet and 2018 dry surveys. Values highlighted in red font exceed the Effects Range Low (ERL) NOAA guidelines.**

Site/Metal	Aluminium (Al)		Arsenic (As)		Cadmium (Cd)		Chromium (Cr)		Copper (Cu)		Iron (Fe)		Lead (Pb)		Manganese (Mn)		Mercury (Hg)		Nickel (Ni)		Zinc (Zn)	
ERL			**8.2**		**1.2**		**81**		**34**				**46.7**				**0.15**		**20.9**		**150**	
Median Level I			**20**		**1.35**		**80**		**47.5**				**72.5**				**0.35**		**50**		**185**	
Season	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
S1	16000	5562	5.7	2.4	<0.1	<0.1	38.5	43.6	3	<1	16170	6298	<5	<5	99	64	<0.1	<0.1	9.2	4.1	23	7
S2	2931	39270	1.6	10.8	<0.1	<0.1	21.7	101.3	<1	5	2019	28780	<5	7	52	279	<0.1	<0.1	2	23.1	<5	44
S3	1497	40280	2.9	10.1	<0.1	<0.1	17.2	97	<1	5	6227	29220	<5	8	39	193	<0.1	<0.1	1.5	21.3	<5	43
S4	19720	17550	7.2	11.8	<0.1	<0.1	62.6	62	3	<1	17120	63900	6	7	97	323	<0.1	<0.1	11.7	10.3	23	40
B1	53060	45500	12.5	13.6	<0.1	<0.1	110	106.6	8	6	37810	35530	11	9	568	524	<0.1	<0.1	28.5	24.5	51	51
B2	46400	40900	8.7	11.4	<0.1	<0.1	101	98.4	8	7	31720	31050	11	10	186	196	<0.1	<0.1	24.1	22.6	44	48
B3	24080	4358	7.6	11.2	<0.1	<0.1	66.4	37.6	5	<1	26480	21570	5	<5	230	144	<0.1	<0.1	13.4	3.5	31	14
B4	16350	4415	8.5	11.8	<0.1	<0.1	49.4	44.6	2	<1	23530	26710	<5	<5	215	206	<0.1	<0.1	10.1	4.5	26	19
B5	36030	34580	15.5	13.1	<0.1	<0.1	84.4	93.8	6	5	37660	29320	8	7	241	312	<0.1	<0.1	19.4	19.2	42	39
G1	24010	40010	4.6	8.1	<0.1	<0.1	85.4	147.6	4	7	23110	34510	5	7	185	211	<0.1	<0.1	14.7	22.6	29	49
G2	19370	13840	7	23.6	<0.1	<0.1	106	379.4	7	24	31580	143300	6	7	109	259	<0.1	<0.1	12.1	6.9	30	39
G3	11640	8588	5	2.8	<0.1	<0.1	97.2	144.4	5	4	28810	27890	<5	<5	159	140	<0.1	<0.1	6.7	7.3	21	17

Site/Metal	**Aluminium (Al)**		**Arsenic (As)**		**Cadmium (Cd)**		**Chromium (Cr)**		**Copper (Cu)**		**Iron (Fe)**		**Lead (Pb)**		**Manganese (Mn)**		**Mercury (Hg)**		**Nickel (Ni)**		**Zinc (Zn)**	
ERL			**8.2**		**1.2**		**81**		**34**				**46.7**				**0.15**		**20.9**		**150**	
Median Level I			**20**		**1.35**		**80**		**47.5**				**72.5**				**0.35**		**50**		**185**	
Season	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
G4	50100	45000	10.8	12.4	<0.1	<0.1	117	123.8	10	7	34900	40160	14	7	178	225	<0.1	<0.1	28.6	27.1	57	55
G5	5054	47960	2.9	10.9	<0.1	<0.1	71.4	108.5	2	7	20480	35360	7	8	60	340	<0.1	<0.1	4.6	25.1	9	53
G6	45320	48650	16.5	12.6	<0.1	<0.1	103	102.9	9	7	39860	35450	10	12	266	487	<0.1	<0.1	24.9	25.1	46	54
M1	4488	7554	1.2	2.4	<0.1	<0.1	41.1	58.4	2	2	3725	6037	<5	<5	18	21	<0.1	<0.1	4	4.9	5	8
M2	46410	5139	10.2	2.6	<0.1	<0.1	107	54.7	9	<1	28700	8038	8	<5	171	50	<0.1	<0.1	24.9	4.2	44	7
M3	53590	11400	14.3	5.2	<0.1	<0.1	133	63.6	10	<1	40630	18190	11	<5	216	87	<0.1	<0.1	32.8	6.6	54	16
M4	7361	24880	3.1	10.4	<0.1	<0.1	36.9	87.3	2	4	7984	25820	<5	8	37	137	<0.1	<0.1	5	14.8	9	31
M5	2351	3565	3.5	1.8	<0.1	<0.1	25	391.7	<1	2	6953	19280	<5	<5	32	60	<0.1	<0.1	2.5	16.8	5	6
K1	42830	13230	7.2	1.1	<0.1	<0.1	243	218.7	15	9	41870	37630	9	<5	159	127	<0.1	<0.1	24	6.6	41	15
K2	4403	4963	2.1	2.8	<0.1	<0.1	36.6	56	1	1	5074	8725	<5	<5	104	56	<0.1	<0.1	3.4	3.8	5	7
K3	990	1203	0.6	<0.5	<0.1	<0.1	23.8	47.8	<1	<1	1878	3261	<5	<5	16	34	<0.1	<0.1	1.6	2	<5	<5
K4	1626	43660	1.1	10.1	<0.1	<0.1	20.8	177.1	<1	8	2653	37660	<5	8	20	317	<0.1	<0.1	2.1	28.9	<5	54
K5	3237	7734	1.4	3.3	<0.1	<0.1	29.3	69.2	1	2	3865	8372	<5	<5	19	52	<0.1	<0.1	2.3	5.8	<5	10

Site/Metal	Aluminium (Al)		Arsenic (As)		Cadmium (Cd)		Chromium (Cr)		Copper (Cu)		Iron (Fe)		Lead (Pb)		Manganese (Mn)		Mercury (Hg)		Nickel (Ni)		Zinc (Zn)	
ERL			**8.2**		**1.2**		**81**		**34**				**46.7**				**0.15**		**20.9**		**150**	
Median Level I			**20**		**1.35**		**80**		**47.5**				**72.5**				**0.35**		**50**		**185**	
Season	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
T1	-	1211	-	<0.5	-	<0.1	-	42.5	-	1	-	1531	-	<5	-	6	-	<0.1	-	1.8	-	<5
T2	-	476	-	<0.5	-	<0.1	-	34.9	-	<1	-	736	-	<5	-	6	-	<0.1	-	1.8	-	<5
T3	25960	1064	21.2	<0.5	<0.1	<0.1	226	97	<1	1	65630	1152	<5	<5	26	9	<0.1	<0.1	6.5	3.7	22	<5
T4	-	609	-	1	-	<0.1	-	22.8	-	<1	-	3333	-	<5	-	19	-	<0.1	-	1	-	<5
T5	-	47360	-	14.3	-	<0.1	-	106.4	-	7	-	36370	-	8	-	415	-	<0.1	-	25.8	-	50
C1	-	5814	-	3.3	-	<0.1	-	79.5	-	<1	-	12250	-	<5	-	34	-	<0.1	-	3.8	-	<5
C2	-	5267	-	2.8	-	<0.1	-	141.1	-	2	-	7964	-	<5	-	37	-	<0.1	-	8.3	-	5
Nitti Port	42240	14660	5.2	3.6	<0.1	<0.1	150	128.6	11	15	46450	36760	10	27	207	109	<0.1	<0.1	18.9	9.2	43	37

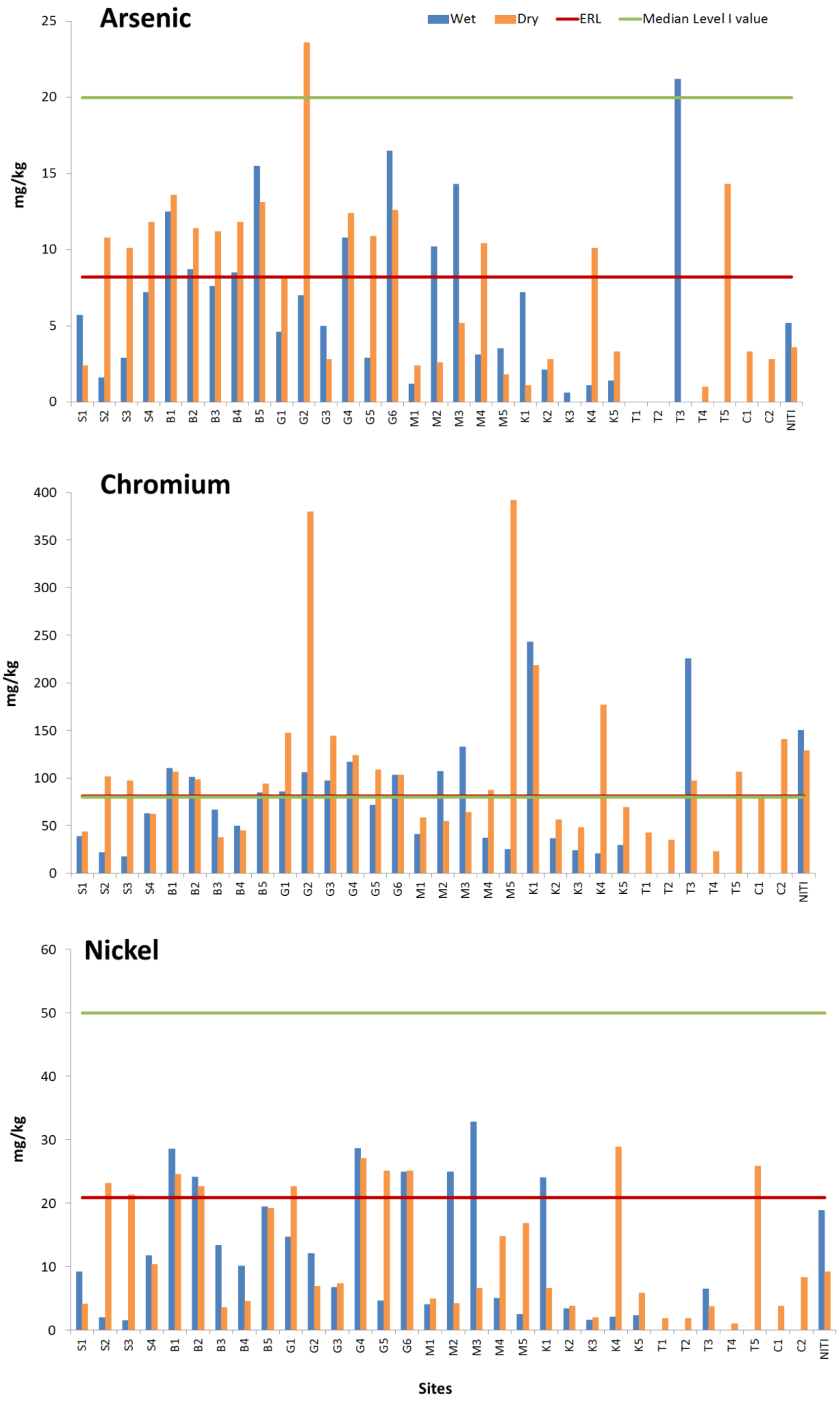

Figure 17. **Trace metal content in subtidal sediment samples taken in the wet and dry surveys as well as showing sediment quality guidelines (ERL: Effects Range Low).**

4.2.4 Hydrocarbons in sediment samples

Poly-aromatic hydrocarbons (PAHs) are present in significant amounts in fossil fuels (natural crude oil and coal deposits), tar and various edible oils. PAHs are also formed through the incomplete combustion of carbon-containing fuels such as wood, fat and fossil fuels. PAHs are one of the most wide-spread organic pollutants and they are of particular concern, as some of the compounds have been identified as carcinogenic for humans (Nikolaou *et al*. 2009). PAHs are introduced to the marine environment by anthropogenic means (combustion of fuels) and by natural means (oil welling up or products of biosynthesis) (Nikolaou *et al*. 2009). PAHs in the environment are found primarily in soil, sediment and oily substances, as opposed to in water or air, as they are lipophilic (mix more easily with oil than water) and the larger particles are less prone to evaporation. The highest values of PAHs recorded in the marine environment have been in estuaries and coastal areas, and in areas with intense vessel traffic and oil treatment (Nikolaou *et al*. 2009).

PAH concentrations were below the laboratory detection limits in the wet season in all sub-tidal sediment samples collected from the estuaries below the Area 1 (Table 11), which suggests that fresh water input from during the wet season disperses any potential PAHs present. During the dry season survey, PAH concentrations were below the laboratory detection limits in all subtidal sediment samples collected except at Nitti Port (Table 12). Of the PAHs detected, Benzo(a)anthracene, Chrysene, Benzo(bk)fluoranthene, Benzo(a)pyrene, Indeno(123cd)pyrene are known to be carcinogenic to humans (Nikolaou *et al*. 2009). However, the levels detected were all well below the NOAA ERM and ERL guidelines (Buchman 1999) indicating that although contamination is occurring it is not at a level to warrant concern. PAHs should continually be monitored at Nitti Port to ensure contamination does not exceed the levels outlined in the NOAA guidelines.

Table 11. Concentrations of Polycyclic Aromatic Hydrocarbons in sub-tidal sediment samples collected during the wet season survey.

	Naphthalene#	Acenaphthylene	Acenaphthene#	Fluorene#	Phenanthrene#	Anthracene#	Fluoranthene#	Pyrene#	Benzo(a)anthracene#	Chrysene#	Benzo(bk)fluoranthene#	Benzo(a)pyrene#	Indeno(123cd)pyrene#	Dibenzo(ah)anthracene#	Benzo(ghi)perylene#	PAH 16 Total	Benzo(b)fluoranthene	Benzo(k)fluoranthene
B1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G6	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02

	Naphthalene$^{\#}$	**Acenaphthylene**	**Acenaphthene$^{\#}$**	**Fluorene$^{\#}$**	**Phenanthrene$^{\#}$**	**Anthracene$^{\#}$**	**Fluoranthene$^{\#}$**	**Pyrene$^{\#}$**	**Benzo(a)anthracene$^{\#}$**	**Chrysene$^{\#}$**	**Benzo(bk)fluoranthene$^{\#}$**	**Benzo(a)pyrene$^{\#}$**	**Indeno(123cd)pyrene$^{\#}$**	**Dibenzo(ah)anthracene$^{\#}$**	**Benzo(ghi)perylene$^{\#}$**	**PAH 16 Total**	**Benzo(b)fluoranthene**	**Benzo(k)fluoranthene**
M2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
Nitti Port	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
S1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
S2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
S3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
S4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
T3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02

Table 12. Concentrations of Polycyclic Aromatic Hydrocarbons in subtidal sediment samples collected during the dry season survey.

	Naphthalene#	Acenaphthylene	Acenaphthene#	Fluorene#	Phenanthrene#	Anthracene#	Fluoranthene#	Pyrene#	Benzo(a)anthracene#	Chrysene#	Benzo(bk)fluoranthene#	Benzo(a)pyrene#	Indeno(123cd)pyrene#	Dibenzo(ah)anthracene#	Benzo(ghi)perylene#	PAH 16 Total	Benzo(b)fluoranthene	Benzo(k)fluoranthene
B1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
B5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
C1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
C2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
G6	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02

	Naphthalene $^{\#}$	Acenaphthylene	Acenaphthene $^{\#}$	Fluorene $^{\#}$	Phenanthrene $^{\#}$	Anthracene $^{\#}$	Fluoranthene $^{\#}$	Pyrene $^{\#}$	Benzo(a)anthracene $^{\#}$	Chrysene $^{\#}$	Benzo(bk)fluoranthene $^{\#}$	Benzo(a)pyrene $^{\#}$	Indeno(123cd)pyrene $^{\#}$	Dibenzo(ah)anthracene $^{\#}$	Benzo(ghi)perylene $^{\#}$	PAH 16 Total	Benzo(b)fluoranthene	Benzo(k)fluoranthene
K4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
K5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
M5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
Nitti Port	<0.04	<0.03	<0.05	<0.04	0.14	<0.04	0.24	0.22	0.14	0.1	0.22	0.11	0.07	<0.04	0.07	1.3	0.16	0.06
S1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
S2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
S3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
S4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
T1	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
T2	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
T3	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
T4	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02
T5	<0.04	<0.03	<0.05	<0.04	<0.03	<0.04	<0.03	<0.03	<0.06	<0.02	<0.07	<0.04	<0.04	<0.04	<0.04	<0.6	<0.05	<0.02

4.3 Biomonitoring

For the wet season survey, trace metal content in oyster flesh exceeded the median recommended levels for human consumption at each sampling station for at least one of the five metal elements for which guidelines are available (Table 13). Zinc concentrations exceeded the guideline at 20 sites, arsenic at 16 sites, copper at seven sites, lead and cadmium at three sites each. Recommended guidelines for three or more trace metals were exceeded at eight sites, three of which were in close proximity to SRL operations at Nitti Port (Nitti Port, G4, G5), but all the other sites where guidelines were exceeded were either upstream of the mining operations (B1) or far downstream (B5, S2 and S4). Lower concentrations of copper and cadmium were observed in the dry season survey results with trace metal content in all samples falling below the guideline level (Figure 18 and **Error! Reference source not found.**). Lead concentration increased at all but two sampling sites (K5 and S2) in comparison to wet season survey results. No significant changes in arsenic and zinc were observed between the two sampling seasons.

The recommended level of Zn in oyster tissue exceeded the Australian and New Zealand standard of 1 000 ppm (ANZECC 2000) at all but one site for the wet season results. Very small decreases in zinc content were observed at all but four sites in the dry season, which resulted in only five samples exceeding the guideline. It must be noted however, that oysters naturally accumulate high levels of Zinc in their tissues and indeed the Australian standard is one of the few that exist specifically for oysters. Published studies typically provide values in excess of 1 000 ppm, e.g. in Hong Kong, Phillips and Yin (1981) provide values ranging from 1 000- 4 000 ppm and Fang *et al.* (2003) provide a range of 1 485-6 645 ppm for the Pearl River delta in China. The higher values reported in both these studies, however, come from areas that can be considered enriched due to industrial development. A study in the less developed Byron Bay, Australia, reported values in the range of 1 806-2 902 ppm of Zinc in oyster tissue (Hayes *et al*. 1998). The higher values (>3 000 ppm) reported during this study do suggest some form of enrichment and the fact that the two highest readings occurred in the vicinity of Nitti Port (Nitti Port and G4), which does suggest an anthropogenic zinc source in the vicinity. Unfortunately, no oysters were found at these sites during the dry season survey.

These results do suggest either naturally high levels of some trace metals in the estuarine environment and bioaccumulation by oysters (particularly zinc and arsenic), or anthropogenic enrichment, but it is not clear what the sources may be as zinc and arsenic are not associated with the SRL mining operations and/or products. Although exceedance of the median value recommended for shellfish consumption was observed for some metals at many sites, the actual concentration of coper, lead, arsenic and cadmium in oyster flesh observed in the wet season either did not exceed the guidelines by a large margin, or in some cases, fell below the guidelines for some countries (e.g. South African guideline for cadmium is 3 ppm and the lead guidelines for Australia, Canada, Japan and Russia are all >2 ppm). However, lead content in oysters collected in the dry season did exceed guideline levels at sites B2, B3, B4 and S4 with the lead concentration increasing by more than double. Significant oyster mortality was observed during the dry season survey at all sites sampled where specimens were previously found during the wet season. It is uncertain whether this might be related to the observed increase in concentration of lead in oysters collected at B2, B3, B4 and S4. This observation is of concern and further biomonitoring is recommended to provide a more comprehensive picture of trace metal levels and potential risks these pose to local people.

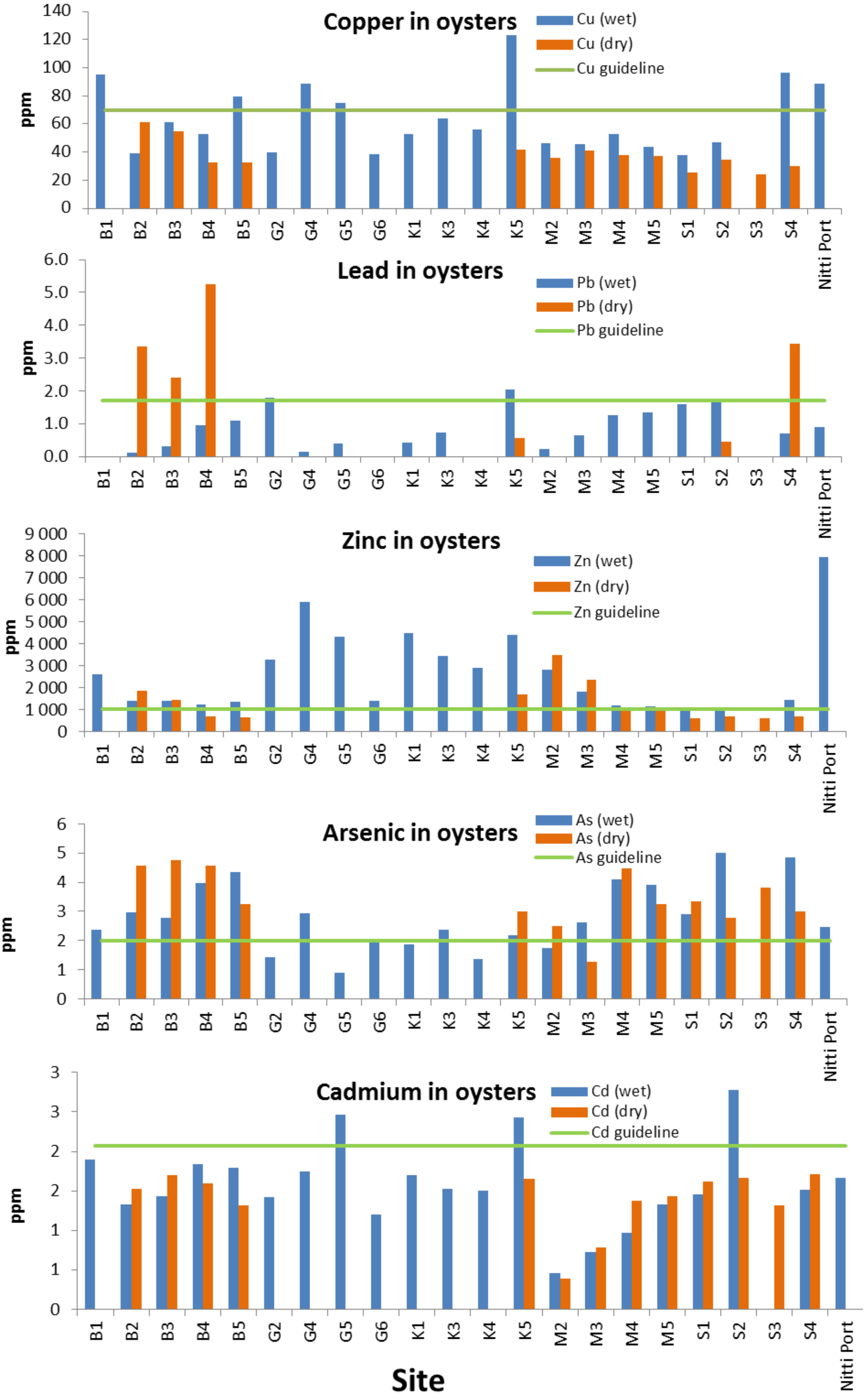

Figure 18. Trace metal content in oyster flesh from both wet and dry seasons for copper, lead, zinc arsenic and cadmium. The median guideline value for the maximum concentration of trace metals in shellfish suitable for human consumption is shown on each graph.

Table 13. **Concentrations of trace metals in oyster tissue collected at different sites in the estuaries of the study area. The median guideline value for the maximum concentration of trace metals in shellfish suitable for human consumption are provided (Table 5), and values exceeding these guidelines are highlighted in red font.**

Sample #	Cu (wet)	Cu (dry)	Pb (wet)	Pb (dry)	Zn (wet)	Zn (dry)	Co (wet)	Co (dry)	Ni (wet)	Ni (dry)	Al (wet)	Al (dry)	As (wet)	As (dry)	Cd (wet)	Cd (dry)	Cr (wet)	Cr (dry)	Fe (wet)	Fe (dry)	Mn (wet)	Mn (dry)	Hg (wet)	Hg (dry)
Median Guideline	**70**	**70**	**1.7**	**1.7**	**1000**	**1000**							**2**	**2**									**0.5**	
B1	95.1	-	ND	-	2609	-	0.5	-	0.4	-	962.4	-	2.4	-	1.9	-	2.0	-	733.8	-	57.8	-	0.1	-
B2	39.3	61.3	0.1	3.3	1387	1844	0.4	0.6	ND	3.0	741.4	1160	3.0	4.6	1.3	1.5	0.2	4.3	560.3	832	13.1	33.1	0.1	0.07
B3	61.5	55.0	0.3	2.4	1378	1446	0.4	0.4	0.5	2.0	631.9	353	2.8	4.7	1.4	1.7	0.9	2.4	622.9	296	20.3	12.1	0.1	0.07
B4	52.6	32.6	0.9	5.3	1209	695	0.4	0.3	0.6	1.9	591.3	253	4.0	4.6	1.8	1.6	7.7	3.3	535.1	363	21.1	14.1	0.1	0.10
B5	79.6	32.5	1.1	ND	1363	639	0.4	0.1	0.5	1.5	465.4	285	4.4	3.2	1.8	1.3	1.0	2.0	466.2	284	25.3	9.3	ND	0.10
G2	39.6	-	1.8	-	3266	-	0.5	-	0.3	-	531.5	-	1.4	-	1.4	-	0.6	-	515.0	-	36.5	-	ND	-
G4	88.6	-	0.2	-	5894	-	0.5	-	0.9	-	268.2	-	2.9	-	1.7	-	2.7	-	372.0	-	24.6	-	ND	-
G5	75.1	-	0.4	-	4326	-	0.5	-	0.5	-	247.0	-	0.9	-	2.5	-	ND	-	322.4	-	21.6	-	ND	-
G6	38.5	-	ND	-	1373	-	0.4	-	ND	-	555.2	-	2.1	-	1.2	-	ND	-	514.6	-	24.9	-	ND	-
K1	53.1	-	0.4	-	4463	-	0.6	-	ND	-	302.2	-	1.9	-	1.7	-	ND	-	377.8	-	56.0	-	ND	-
K3	63.7	-	0.7	-	3416	-	0.5	-	0.3	-	214.6	-	2.4	-	1.5	-	0.8	-	355.6	-	32.8	-	ND	-
K4	55.8	-	ND	-	2901	-	0.3	-	ND	-	121.3	-	1.4	-	1.5	-	ND	-	326.6	-	27.7	-	0.1	-
K5	122.9	41.5	2.0	0.6	4385	1701	0.5	0.3	0.9	2.0	517.9	450	2.2	3.0	2.4	1.7	0.9	3.2	582.4	454	25.0	20.0	0.1	0.04
M2	46.6	36.0	0.2	ND	2799	3498	0.6	0.3	0.3	1.6	483.3	236	1.7	2.5	0.5	0.4	1.5	1.1	486.4	253	20.2	17.5	ND	0.01
M3	45.5	41.2	0.6	ND	1796	2335	0.4	0.1	0.8	1.8	407.3	282	2.6	1.3	0.7	0.8	1.6	2.9	540.9	279	17.5	11.2	ND	0.03
M4	52.5	37.7	1.3	ND	1167	1000	0.4	0.3	ND	2.4	463.6	264	4.1	4.5	1.0	1.4	0.7	2.9	624.1	250	15.2	13.7	ND	0.02
M5	44.0	37.4	1.4	ND	1139	917	0.4	0.1	0.6	1.3	175.1	207	3.9	3.2	1.3	1.4	0.8	2.6	283.3	230	10.4	16.5	ND	0.03
S1	37.6	25.3	1.6	ND	994	597	0.5	0.1	1.2	1.8	576.4	709	2.9	3.3	1.5	1.6	2.7	3.7	779.7	576	19.3	17.8	0.1	0.06
S2	46.7	34.3	1.8	0.5	1002	658	0.7	0.3	1.8	1.8	385.6	370	5.0	2.8	2.8	1.7	1.5	3.6	588.4	357	19.2	8.8	ND	0.04
S3	-	24.3	-	ND	-	612	-	0.3	-	1.6	-	948	-	3.8	-	1.3	-	3.9	-	1237	-	18.0	-	0.07
S4	96.4	29.7	0.7	3.4	1430	691	0.5	0.2	1.0	1.4	487.8	376	4.9	3.0	1.5	1.7	0.8	3.1	505.5	282	16.3	10.5	ND	0.05
Nitti Port	88.8	-	0.9	-	7966	-	0.3	-	0.9	-	155.5	-	2.5	-	1.7	-	1.3	-	297.9	-	17.6	-	ND	-

4.4 Vegetation

Global interest in monitoring and mapping mangrove extent and change over time has increased in tandem with the ongoing destruction of this important ecosystem. Remote sensing tools and techniques combined with geographic information system (GIS) applications have been extensively used in mangrove mapping, and have advanced considerably over the last decade (Mondal *et al*. 2017). Landsat satellite imagery is often the 'go to' mangrove mapping satellite sensor because of its wide spatial and temporal coverage and ease of data accessibility. While global scale studies and monitoring are critical and have come a long way, most only provide a snapshot of mangrove extent due to the enormity in scale of work required for global mapping. Noticeably different estimates are coming out of these global studies, and have thus led to the development of a new global dataset (CGMFC – 21) that combines available global datasets and provides estimates of annual change in mangrove cover over time (Hamilton & Casey 2016, Mondal *et al*. 2017). It is important to note, however, that national/regional estimates (gained by satellite observation and field visits) are still fundamental as these estimates are used for guiding national/regional policies which impacts on local livelihoods (Mondal *et al.* 2017). For the purposes of this study, reference is made to the various global estimates of mangrove extent in the literature as well as more detailed regional estimates of mangrove extent (Giri *et al.* 2014). Spatial data sets (GIS .shp files) and canopy height classification (Fatoyinbo & Simard 2013) are utilized, along with Mondal *et al*. (2017) estimates of mangrove cover in Sierra Leone, which is considered to be the most comprehensive and up-to-date spatial and temporal data set available for this country (Table 14). Findings from the ground truthing work conducted as part of the field studies for this assessment is presented in Section 4.4.2 below.

Table 14. Comparison of mangrove extents in Sierra Leone for 2000 as estimated by the Mangrove Forests of the World (MFW), and the continuous mangrove forest cover for the 21st century (CGMFC-21) (reproduced from and including data from Mondal *et al.* 2017).

Dataset	Source	Brief Description	Area (km^2)
MFW	Giri *et al.*, 2011	Landsat-derived discrete classification	1564.96
-	Fatoyinbo & Simard, 2013	Landsat-derived discrete classification	1024.6
-	FAO, 2007	Country-specific reports based on their own classification system	1053
CGMFC-21—Revised MFW	Hamilton & Casey, 2016	Integration of discrete MFW dataset and continuous Global Forest Cover (GFC) dataset	655.67
CGMFC-21—Revised Terrestrial Ecoregions of the World (TEOW)	Hamilton & Casey, 2016	Integration of discrete TEOW dataset and continuous Global Forest Cover (GFC) dataset	2917.01
-	Mondal *et al.* 2017	Multi-date Landsat derived data and cloud computational technique	1257.91

Mangrove trees grow ubiquitously as a relatively narrow fringe between land and sea, between latitudes 30°N and 30°S. They form forests of salt-tolerant species, with complex food webs and ecosystem dynamics (Valiela *et al.* 2001). Destruction of mangrove forests is occurring globally. Global changes such as increased sea level may also affect mangroves (Ellison 1993, Field 1995), although accretion rates in mangrove forests are often large enough to compensate for the present-day rise in sea level (Field 1995). More important, it is human alterations created by conversion of mangroves to mariculture, agriculture, and urbanization, as well as forestry uses and the effects of warfare, that have led to the remarkable recent losses of mangrove habitat (Valiela *et al.* 2001). New data on mangrove extent, and changes in it, have become more readily available. Moreover, information about the function of mangrove swamps, their importance in the sustainability of the coastal zone, and the effects of human uses on mangrove forests is growing. Mangrove forests make up less than 1% of total tropical forests in the world, yet, are one of the most productive and biologically complex ecosystems. They also store between three and four times more carbon per unit area compared to tropical forests (Murdiyarso *et al.* 2015, Mondal *et al.* 2017). In spite of this, global declines from 18.8 million hectares in 1990 to 15.2 million hectares in 2005 from land competition for agriculture, aquaculture, tourism and infrastructure development has been reported (Mondal *et al.* 2017).

Mangroves consist of a range of functional forms, including trees, shrubs, palms and ferns, all generally greater than half a meter in height, but are considered to have low species richness (Ricklefs & Latham 1993). In order to survive in the harsh intertidal region, a broad range of structural and functional adaptations are exploited (Duke *et al.* 1998). These adaptations include, but are not limited to, pneumatophores[15] (to deal with low oxygen levels e.g. *Avicennia* spp.), prop roots (to deal with low oxygen levels e.g. *Rhizophora* spp.), mechanisms for physiological salt exclusion (e.g. *Rhizophora* spp.) and/or excretion (e.g. *Avicennia* spp.), viviparous[16] propagules (e.g. *Rhizophora* spp.) and sub-viviparous propagules (e.g. *Avicennia* spp. and *Laguncularia* spp.; Passioura *et al.* 1992, Clarke & Allaway 1993, Kathiresan & Bingham 2001, Kitaya *et al.* 2002, Beentje & Bandeira 2007).

Atlantic coast mangroves are less diverse than their Indian Ocean counterparts and are typically characterised by five species of true mangrove trees (Beentje & Bandeira 2007). The trees found within this region generally conform to a zonation pattern from the mean low tide mark to the upper intertidal areas that are flooded only during spring high tides. The first zone, closest to the low tide mark, is typically inhabited by red mangrove trees *Rhizophora* spp., with *Rhizophora racemosa* pioneering colonisation on the water ward edge of the mangrove. *Rhizophora harrisonii* and *Rhizophora mangle* establish in mud accumulated by the root matrix of *R. racemosa* and usually grow behind the pioneering *R. racemosa* (Beentje & Bandeira 2007). Black mangrove *Avicennia germinans* inhabits the next zone which is slightly raised from the low tide mark and is thus inundated less regularly. The higher salinities of this zone (due to evaporation) exclude all three *Rhizophora* species (Beentje & Bandeira 2007). *Avicennia germinans* utilises an increase in salinity

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[15] an aerial root specialized for gaseous exchange

[16] bringing forth live young

tolerance at the expense of growth and competitive ability to inhabit the more saline intertidal areas (Ball 1998a, b, 1996), but are outcompeted closer to the channel and are generally excluded from this zone. The inward zone between the normal high tide mark and spring tide mark is inhabited by White mangrove (*Laguncularia racemosa*) which often acts as a pioneer species allowing the encroachment of, and eventually being replaced by *A. germinans* (Beentje & Bandeira 2007). Button wood (*Conocarpus erectus*) and Hopbush *(Dodonaena viscosa)* inhabit the landward margin and can mix with more inland vegetation types (Beentje & Bandeira 2007).

Mangrove forests provide a range of ecosystem services. They are extremely productive systems, rich in biodiversity, provide important lifelong habitat and nursery grounds for a range of fish, invertebrates, birds, mammals and reptiles, refuge from predation as well as serving as a critical component of commercial coastal and offshore fisheries. In addition to commercially important species, mangroves also support a number of threatened and endangered species. They stabilize sediment being transported down from river systems, protect shorelines from erosion, serve as a buffer during storm and high wind events, maintain water quality and clarity by way of a natural filtration system and are a carbon sink. Mangrove forests are one of the most productive ecosystems in terms of carbon cycling and storages (Jennerjahn & Ittekkot 2002). Of the nine west African countries that are home to mangrove forests, FAO (2007) estimates for 2000, state that Sierra Leone had 105 300 hectares of mangroves, or approximately, 0.007% of the global total.

In Sierra Leone, mangroves are used as a renewable resource. Trunks, bark and leaves are harvested for water-resistant, durable wood used in building houses, boats, pilings, furniture and charcoal, while the bark is used for its tannins in dyes and the leaves in medicine, teas, livestock feed and fodder, and as a substitute for tobacco for smoking. In some places bee hives are set up in close proximity to mangrove forests for the access to nectar in honey production. Fish breeding, coastal protection and a potential source for recreation and tourism are additional uses and benefits.

4.4.1 **Sherbro River Estuary mangrove spatio-temporal assessment**

In an effort to advance coastal conservation and climate resilience building activities, Sierra Leone was selected for the USAID-funded "West Africa Biodiversity and Climate Change Project". Subsequently, for the first time, a long-term (decadal) study of the change in mangrove extent in Sierra Leone has been undertaken by Mondal *et al.* (2017) using remote sensing data to assess the change in extent over time (Table 15, Figure 19). Multi-date Landsat data and cloud computational techniques were used to quantify spatiotemporal changes in land cover, with emphasis on mangrove ecosystems, for 1990-2016 along the Sierra Leone coastline (Figure 20). The Sherbro River Estuary area was included as one of the four focal estuarine environments by Mondal *et al.* (2017), and results from this assessment are included in this report as a historic and current point of reference for mangrove forest condition in the study area. In order to resolve where mangroves have undergone the most change (i.e. closer to the coastline or further away), Mondal *et al.* (2017) delineated a series of zones extending inland of the coast: 1 km, 2.5 km and 5 km from the coastline. Overall change in mangrove cover from 1990 to 2016 in each buffer zone is listed in Table 15. The Sherbro River Estuary area underwent an increase (<10%) in mangrove extent in the 1 km buffer area. Marginal declines (<20%) were, however, observed in the zones further away from the coastline. Change in relative extent of different land covers within the Sherbro River Estuary over time are shown in Figure 21. Mangroves remained the dominant land cover class in this area over time. One exception occurs in the year 2000, in the 5 km buffer zone where ‘other vegetation’ dominates at 46% vs. mangroves at 37%. The relative stability of this area of mangroves is thought to be linked to the size and age of the forest. The Sherbro River Estuary area is covered with the largest and oldest trees, which indicates less degradation over the past decades than in other areas of Sierra Leone.

The area of mangroves in Sierra Leone is estimated to be as much as 1 024.6 km^2, the fourth largest coverage of mangrove forests in West Africa. Similar to Guinea, the majority of mangrove forests in Sierra Leone concentrate in the northernmost and southern river delta areas. In terms of canopy height of mangrove forests, height class 1 (1-4 m) and class 2 (5-7 m) are dominant amongst five canopy height classes (Fatoyinbo & Simard 2013, Figure 22). Compared to Guinea, even though the area of mangroves in Sierra Leone is much smaller, Sierra Leone has larger mean biomass and total carbon of mangroves (125.48 Mg/ha and 62.74 Mg/ha for aboveground biomass, Fatoyinbo & Simard 2013). This is because the averaged canopy height of Sierra Leone is 8.39 m, higher than that in Guinea. Furthermore, the total aboveground biomass and carbon of mangrove forests are 12 856 853 Mg and 6 428 427 Mg (respectively), the fourth largest total biomass and carbon of mangroves out of the nine West African countries assessed (Fatoyinbo & Simard 2013). Biomass estimation is very important to understand carbon storage and cycling (carbon can be estimated from biomass as 50% of the biomass estimate).

Table 15. Summary of mangrove extents (area in km^2) in 1990 and 2016 for the Sherbro River Estuary area within the Sierra Leone coastal landscape complex (SLCLC). Values in bold denote mangrove gain, while values in red italics denote mangrove loss between 1990 and 2016. Note that the SLCLC refers to all the mangroves along the full length of the coast and is not restricted to the zones identified in the more detailed regional assessment.

Zone	**1 km**		**Change (Relative Change)**	**2.5 km**		**Change (Relative Change)**	**5 km**		Change (Relative Change)
	1990	**2016**		**1990**	**2016**		**1990**	**2016**	
Sherbro River Estuary	336.82	355.78	+18.96 (+6%)	591.48	605.54	+14.06 (2%)	768.26	762.99	*-5.27% (-1%)*
			Overall Change (Relative Change)						
SLCLC	2434.82	1834.32	*-660.5 (-25%)*						

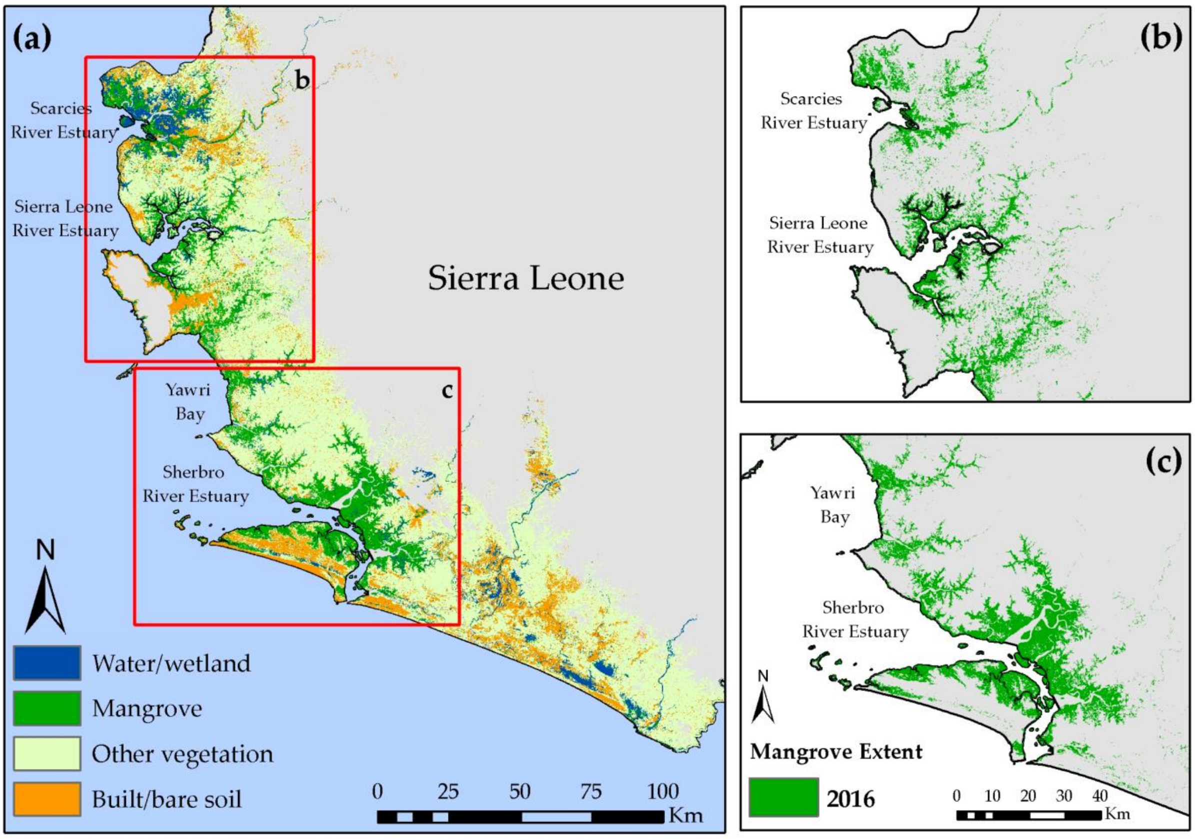

Figure 19. (a) Spatial distribution of four land cover classes across the Sierra Leone coastal landscape complex for 2016. Panels show mangrove extents in northern Sierra Leone (b) Scarcies River Estuary and Sierra Leone River Estuary; and (c) southern Sierra Leone (Yawri Bay and Sherbro River Estuary;Mondal *et al.* (2017)

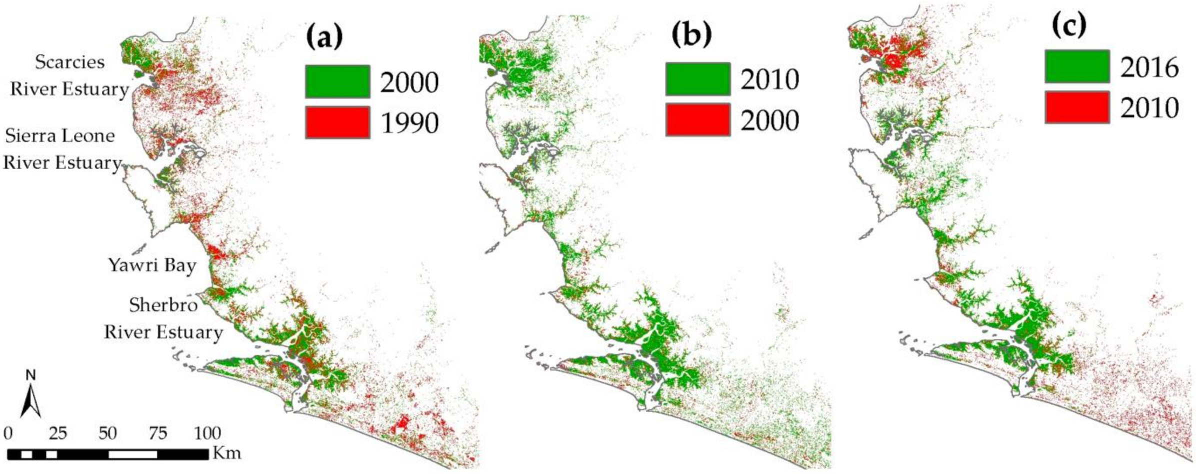

Figure 20. Decadal change in mangrove extents in the Sierra Leone coastal landscape complex (SLCLC) during (a) 1990-2000, (b) 2000-2010, (c) 2010-2016; Mondal *et al.* (2017)

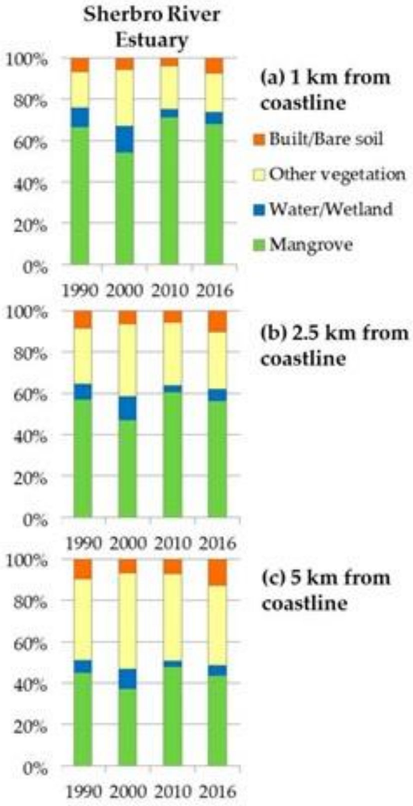

Figure 21. Relative extent of different land covers within the Sherbro River Estuary area during 1990-2016. Panels show mangrove extent within buffers of (a) 1 km, (b) 2.5 km, (c) 5 km extending inland from the coastline. Recreated from Mondal *et al.* 2017

The most apparent land-use related impact on mangrove forests in Sierra Leone comes from clearing land for agricultural purposes. This impact is more severe in the northern part of the country vs. the south where the Sherbro River Estuary is located. Loss of mangrove cover as a result of mining operations in SR Area 1 is estimated at less than 1% (0.44%) of existing mangrove cover around the Sherbro River Estuary area (Figure 23).

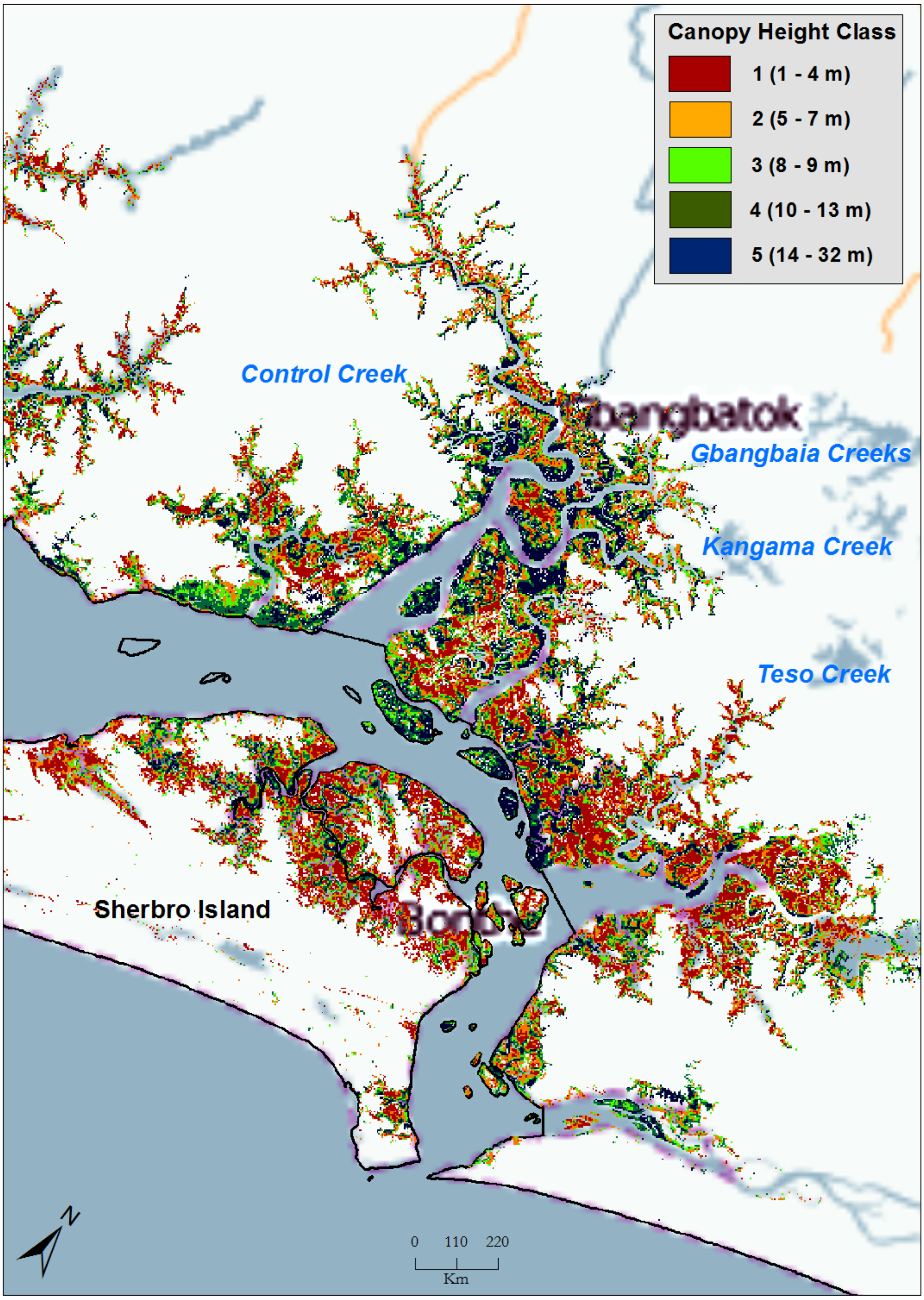

Figure 22. Mangrove canopy height classifications as presented by Fatoyinbo & Simard 2013, and Tang *et al.* 2016, for the Sherbro River Estuary (https://gis.uncc.edu/products/mangrovecarbon).

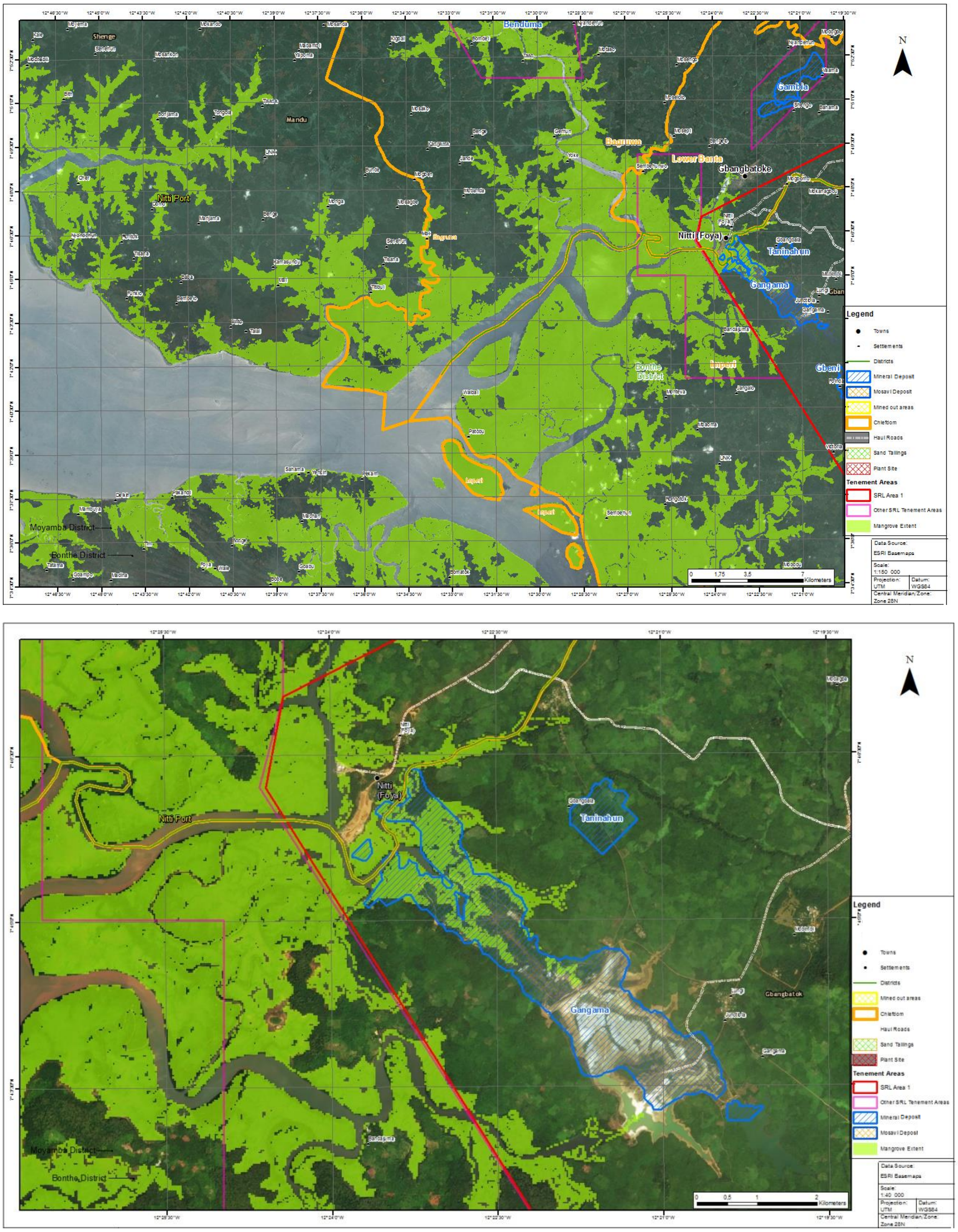

Figure 23 Total mangrove area (km²) for the study area within the Sherbro River Estuary (Top) as calculated from the mangrove extent layer (Giri *et al.* 2011) is 682 km². Total mangrove area (km²) for Gangama Mineral Deposit area (Bottom, blue lined) as calculated from the mangrove extent layer (Giri *et al.* 2011; 3 km², which is estimated at 0.44% of the total mangrove cover in study area to be lost to mining activity.

4.4.2 Wet and dry season mangrove assessment

During the wet and dry field surveys, a total of nine mangrove species were identified, these included black mangrove (*Avicennia germinans*)*,* button wood (*Conocarpus erectus*)*,* hopbush (*Dodonaea viscosa*)*,* grey nicker (*Guilandina bonduc*)*,* white mangrove (*Laguncularia racemosa*)*,* a palm (*Phoenix reclinata*) and red mangrove (*Rhizophora racemosa, Rhizophora harrisonii* and *Rhizophora mangle*). Most of the red mangroves encountered were *R. racemosa,* which is by far the most dominant species in the region. As most of the sites surveyed in this study were located in close proximity to the channel edge, and *R. racemosa* is a pioneer species colonising muddy embankments on the water ward site of the channels, this was not unexpected (Beentje & Bandeira 2007). *Rhizophora harrisonii* were also typically found along the channel edges and usually formed monospecific clumps of trees, while *R. mangle* often present on the mud flats approximately 40 m landward of the channel, *R. racemosa* was characterised by flower stalks that were 3-4 mm long and blunt flower buds (Figure 24) while *R. harrisonii* had flower stalks approximately 6-15 mm long and pointed flower buds.

A. germinans occurred at four sites, including B4, K5, M3 and S2. At sites K5, B4, and M3 the banks were slightly raised indicating that these areas were probably not inundated by tidal flux as regularly as other sites, allowing the encroachment of *A. germinans* into what would typically be the *Rhizophora* spp. zone. Site S2 was characterised by very sandy sediment due to its close proximity to the ocean, characteristics that favour colonisation by *A. germinans* (Beentje & Bandeira 2007). No *A. germinans* was present at site S4 which was surprising, but could be linked to the proximity of this site to a village and *A. germinans* being harvested for building materials. *L. racemosa* was present at sites M3 and S2 where it was dispersed among *A. germinans* trees. *L. racemosa* and *A. germinans* are often found together as *L. racemosa* pioneers colonisation of the upper intertidal zone but is often replaced by *A. germinans* at a later stage (Beentje & Bandeira 2007).

Table 16. List of the seven mangrove species identified during the 2017 and 2018 field surveys and their corresponding common English names and/or local Sierra Leone name with ethnic source of the name in brackets (Beentje & Bandeira 2007). Common and local names for *Rhizophora harisonii* and *Rhizophora mangle* are included as they closely resemble *R. racemosa.*

Species	Common name	Local name
Avicennia germinans	Black mangrove	Ka bure (Temne)
Conocarpus erectus	Button wood	-
Dodonaea viscosa	Hopbush	-
Guilandina bonduc	Grey Nicker	-
Laguncularia racemosa	White mangrove	Chemchem-de (Sherbro)
Phoenix reclinata	Palm	-
Rhizophora racemosa	Red mangrove	Akocur (Temne), Abuma, Kinsii (Kinsu)
Rhizophora harisonii	Red mangrove	Jaia, Jaia-Lelei (Mende), Kinsii (Kinsu)
Rhizophora mangle	Red mangrove	-

Figure 24. Typical *Rhizophora racemosa* inflorescence (top left) with flower stalks 3-4 mm long and blunt flower buds, *Rhizophora harrisonii* inflorescence (top right) with 6-15 mm stalks and pointed flower buds. Comparison of the two types of inflorescence (bottom) showing *R. racemosa* on the left and *R. harrisonii* on the right.

At site G1 an old haul road traverses the mangrove (Figure 25). Along the road, several mangrove species normally associated with the inward terrestrial margin of the mangrove were identified. Their presence as this site is considered anomalous as these species' were present in zones where *Avicennia germinans*, *Laguncularia racemosa* and *Rhizophora* spp. typically occur. The terrestrial associated mangrove species identified included *Conocarpus erectus, Dodonaea viscosa, Guilandina bonduc* and *Phoenix reclinata.* Furthermore at site G1, *A. germinans* and *L. racemosa* were mostly absent, indicating further disturbances to this area, particularly behind the *Rhizophora* spp. zone.

Figure 25. Satellite imagery from 2012 of the mangrove creek below SR Area 1 showing sampling site G1, an old haul road (highlighted in purple) where terrestrial affiliated mangrove species were identified and the impacted area (outlined in red) where *Avicennia germinans, Laguncularia racemosa* and *Rhizophora racemosa* have been affected.

Instances of damage to the mangroves in close proximity to Nitti Port are shown in Figure 26. The damage seems to have occurred when barges carrying product from the mine are swept into the mangrove resulting in *Rhizophora racemosa* being pushed over and damaged. Although this damage is fairly localised, there is a risk that this could lead to further dieback of trees and increased bank erosion in this area.

Data on average stem density for *Rhizophora racemosa* occurring at sampling sites are shown in Figure 27. Basal area was calculated for the same sites but for the sake of briefness, only stem density is presented. Sites from Kangama and Teso Creeks had no *R. racemosa* trees with a diameter at breast height (DBH) less than 5 cm while this size class was present in the remaining creeks sampled. *R. racemosa* with a DBH size class of 5.1 to 10 cm and 10.1 to 15 cm were present in all creeks. In Kangama, Kangama and Motiva Creeks the DBH 5.1 to 10 cm and 10.1 to 15 cm size classes dominated the stem density profile. However, in each of the aforementioned creeks, trees with a DBH greater than 20 cm were also present, indicating stands comprised of both young recruits and older more mature trees. Mangroves sampled on Sherbro Island (S2 and S4) were restricted to *R. racemosa* trees with a DBH smaller than 15 cm with one exception at site S4. The smaller *R. racemosa* trees on Sherbro Island are likely due to the sandy coarse nature of the intertidal zone and the reduced TOC of the sediment (see section 4.2). The exposed nature of this area at the edge of a large lagoon, and associated wave action, is likely to inhibit colonisation of this area (S2 and S4) by *R. racemosa.* This result in overall low densities of this species compared to the relatively sheltered creeks within the Bagru Creek. The single site at Teso Creek had the lowest overall stem density but this coincided with a large number of trees with a DBH greater than 15 cm, indicative of a mature stand of *R. racemosa* with few new recruits. Assessment of the stem density at the two sites on Bagru Creek (B2 and B4) indicated that this section of the delta had a lower density than smaller creeks higher up the system. The channel in this region is quite wide and fairly exposed to wave action, and suggests that increased wave action in conjunction with high tidal and river flow rates, may be inhibiting the deposition of fine mud sediments favoured by *R. racemosa,* resulting in less than ideal habitat for this species.

Figure 26. ***Rhizophora racemosa*** **trees at the edge of the creek adjacent to Nitti Port damaged by barges crashing into the banks.**

Sites that are closer to the main Bagru Creek channel (G6 and M5) tended to have more young recruits (DBH <5cm; Figure 27) than sites situated further up the channels. Sites sampled midway up the creeks (K3, G4 and M3) tended to have the most established young trees (DBH 5.1. to 10 cm, Figure 27). In one instance (M1), there was a high number of small trees (DBH <5 cm; Figure 27) indicating a young stand of *R. racemosa* trees. The presence of young trees at all sites sampled indicates a healthy recruitment of *R. racemosa* into the mangrove systems with no obvious impacts being noted.

Average stem densities for *Avicenna germinans* and *Laguncularia racemosa* measured at the various sampling sites are shown in Figure 27. *A. germinans* occurred at four sites (B4, K5, M3 and S2) as was evident by the distinctive root systems observed. However, *A. germinans* trees only fell in sample plots at sites K5 and S2 and were thus measured and included in stem density plots. *L. racemosa* was present at sites M3 and S2 but again this species only fell in sample plots at site S2. Site K5 included *A. germinans* young recruits with a small DBH, as well as larger more mature specimens with DBHs between 15 cm and 25 cm. The mangroves at S2 were composed of small *L. racemosa* specimens as well as young *A. germinans* recruits. In addition, there were some larger *A. germinans* specimens present with DBHs ranging between 15 cm and 25 cm. The presence of *A. germinans* at sites B4, K5, M3 and *L. racemosa* at site K5 was possibly due to the channel being slightly raised leading to lower inundation frequencies and higher soil salinities causing an encroachment of this vegetation type into the *R. racemosa* zone. The presence of *A. germinans* and *L. racemosa* at site S2 was expected as the coarse sandy sediment favours these species.

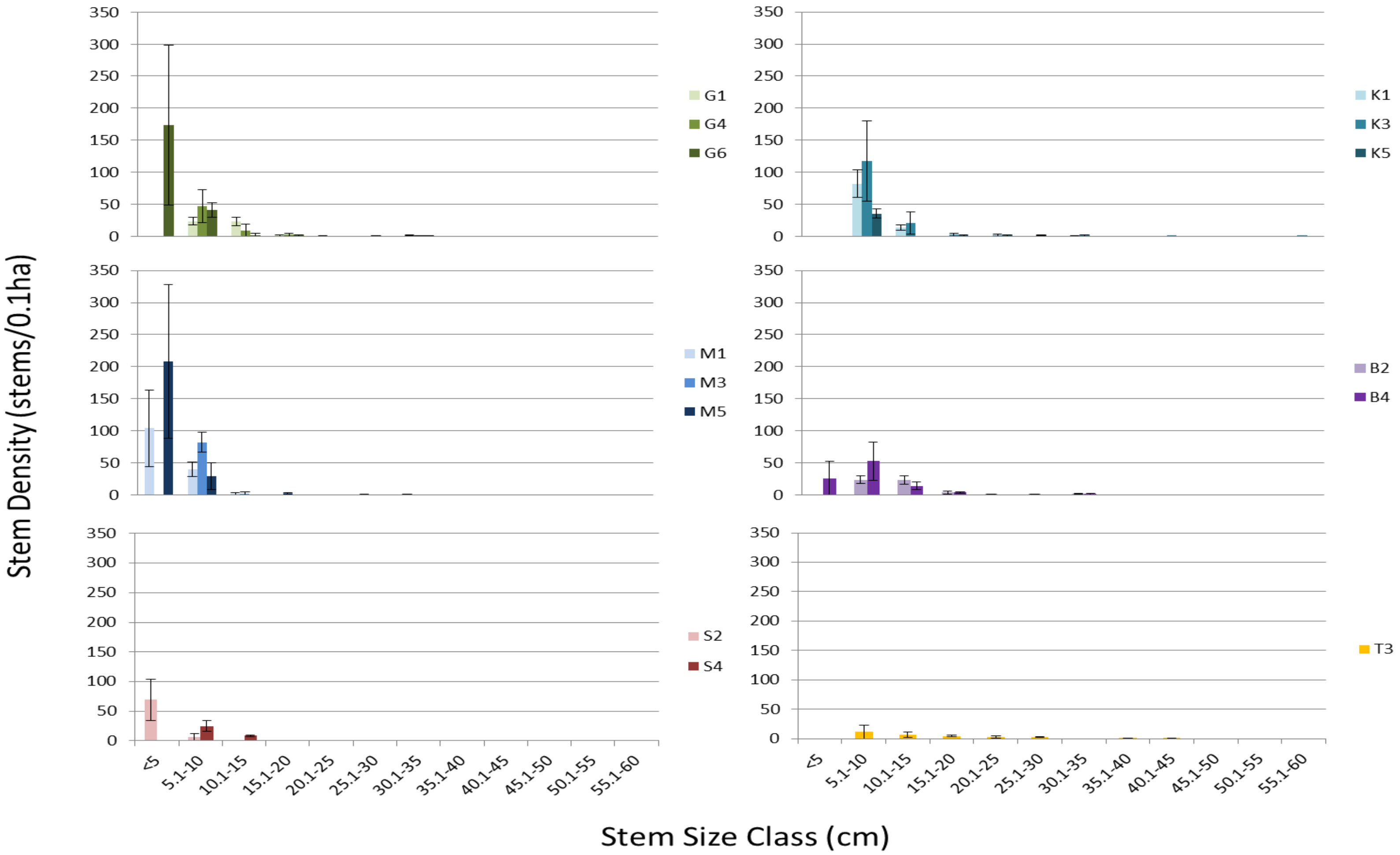

Figure 27. Stem density per 0.1 hectare of *Rhizophora racemosa* at each of the sites sampled during the wet season. Stem size class was based on Diameter at Breast Height (DBH) in centimetres.

Transects surveyed through the mangroves in the dry season (January 2018) were used to assess zonation in the mangrove vegetation from the channel margin to the dry landward edge of the mangroves. The channel margin (channel to approximately 40 m landward) was generally dominated by *Rhizophora racemosa* in all four transects surveyed (Figure 28, Figure 29), and in some cases (e.g. on Bagru Creek) extended even further inland (up to 60 m, Figure 29). Gbangbaia Creek was the least diverse with only two mangrove species encountered (*R. racemosa* and *Rhizophora mangle*). Three mangrove species were encountered in the Kangama and Bagru Creek transects (*R. racemosa*, *R. mangle* and *Avicennia germinans*), but each of these creeks exhibited fundamentally different vegetation structure. *A. germinans* was only encountered at the last (landward) point on the transect in Kangama Creek transect, while *A. germinans* was present from 40 m in from the channel edge mixed with both *R. racemosa* and *R. mangle,* up to 280 m away from the channel. Thereafter *A. germinans* was the only mangrove species present when the landward margin was reached. The transect through the mangrove in Motevo Creek indicated a high mangrove diversity with *R. racemosa*, *R. mangle A. germinans* and *Laguncularia racemosa* all being recorded in the PCQM+[17] counts, as well as *Conocarpus erectus* being noted in the mangrove although it was not counted in the PCQM+ counts.

The Gbangbaia Creek mangrove had the greatest total density but the lowest basal area overall. Within Gbangbaia Creek, *Rhizophora racemosa* had a lower absolute density (De), relative density (De_r) and relative frequency (F_r) than *Rhizophora mangle*, but greater basal area (Ba) and relative Dominance (Do_r), giving *R. racemosa* a higher importance value (I.V.) compared with *R. mangle* (Table 17). In both the Bagru and Kangama Creeks' transects *R. racemosa* ranked second in I.V., having very similar Ba, De_r, Do_r and F_r values (Table 17). However *Avicennia germinans* had the highest I.V. in the Bagru Creek transect while *R. mangle* had the highest I.V. in the Kangama Creek transect (Table 17). The total basal area for these two transects was similar with 1.25 m^2/0.1 ha but the Bagru Creek transect had a much lower total tree density than the Kangama Creek transect - 41.58 trees/0.1ha compared with 78.97 trees/0.1ha, respectively. The mangrove transect in Motevo Creek yielded the greatest total basal area with 1.39 m^2/0.1 ha. Within this transect, *R. racemosa* had the highest I.V., with *R. mangle* having the second highest importance value. *A. germinans* was ranked third in the I.V. while *Laguncularia racemosa* had the lowest importance value.

Overall, the transects indicate similar mangrove vegetation species composition and zonation structuring in the Kangama and Gbangbaia Creeks while the Bagru and Motevo Creeks were essentially different to one another and to the mangroves in the Kangama and Gbangbaia Creeks. The vegetation structure of any areas earmarked for clearing should be considered in detail due to possible different species compositions and zonation structure to ensure rehabilitation efforts match the original mangrove makeup.

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[17] Point-Centred Quarter Method (PCQM+) protocol (measurement of central stem instead of nearest stem)

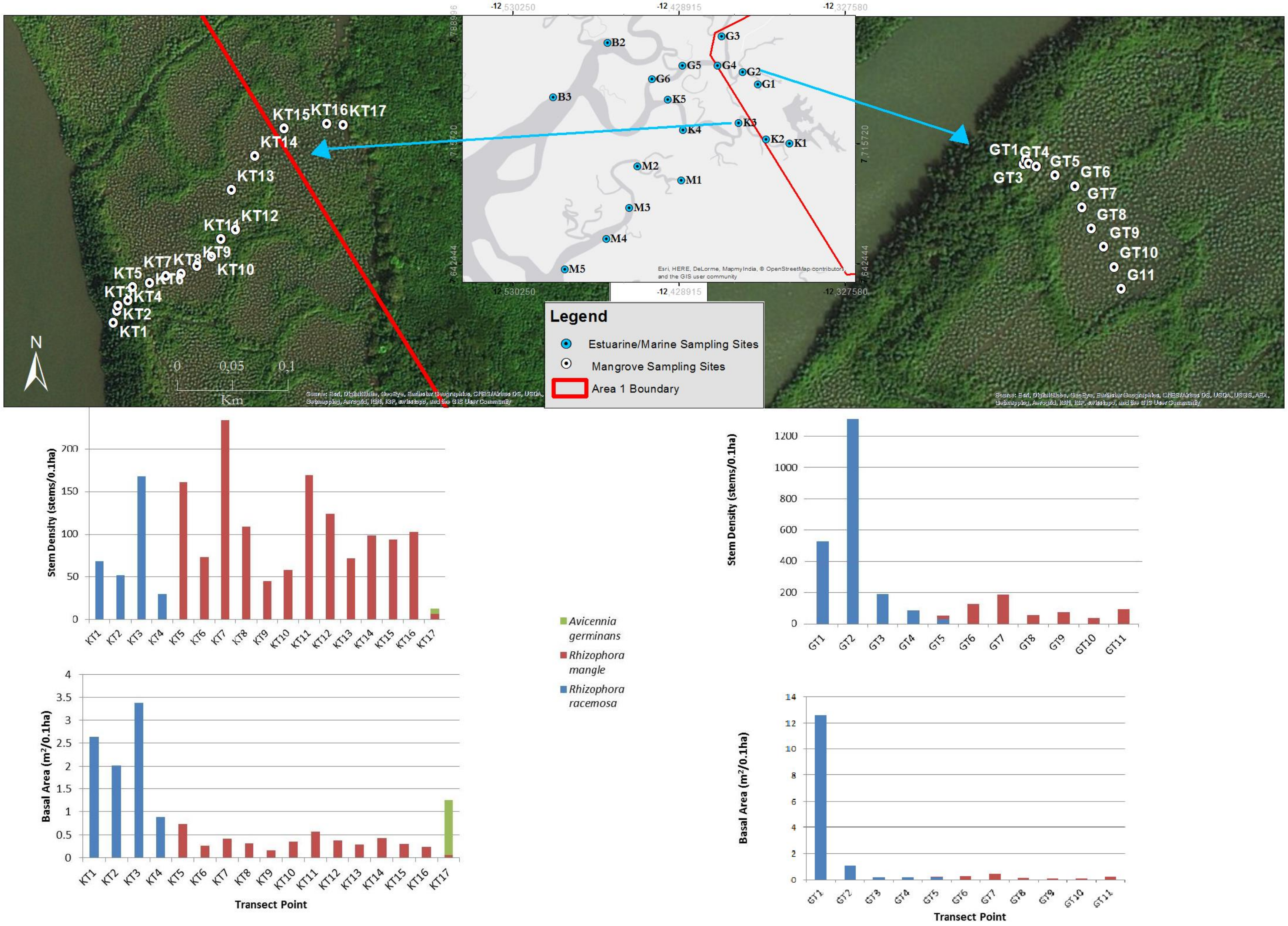


Figure 28. Kangama Creek and Gbangbaia Creek mangrove transects and associated species density and basal area graphs.

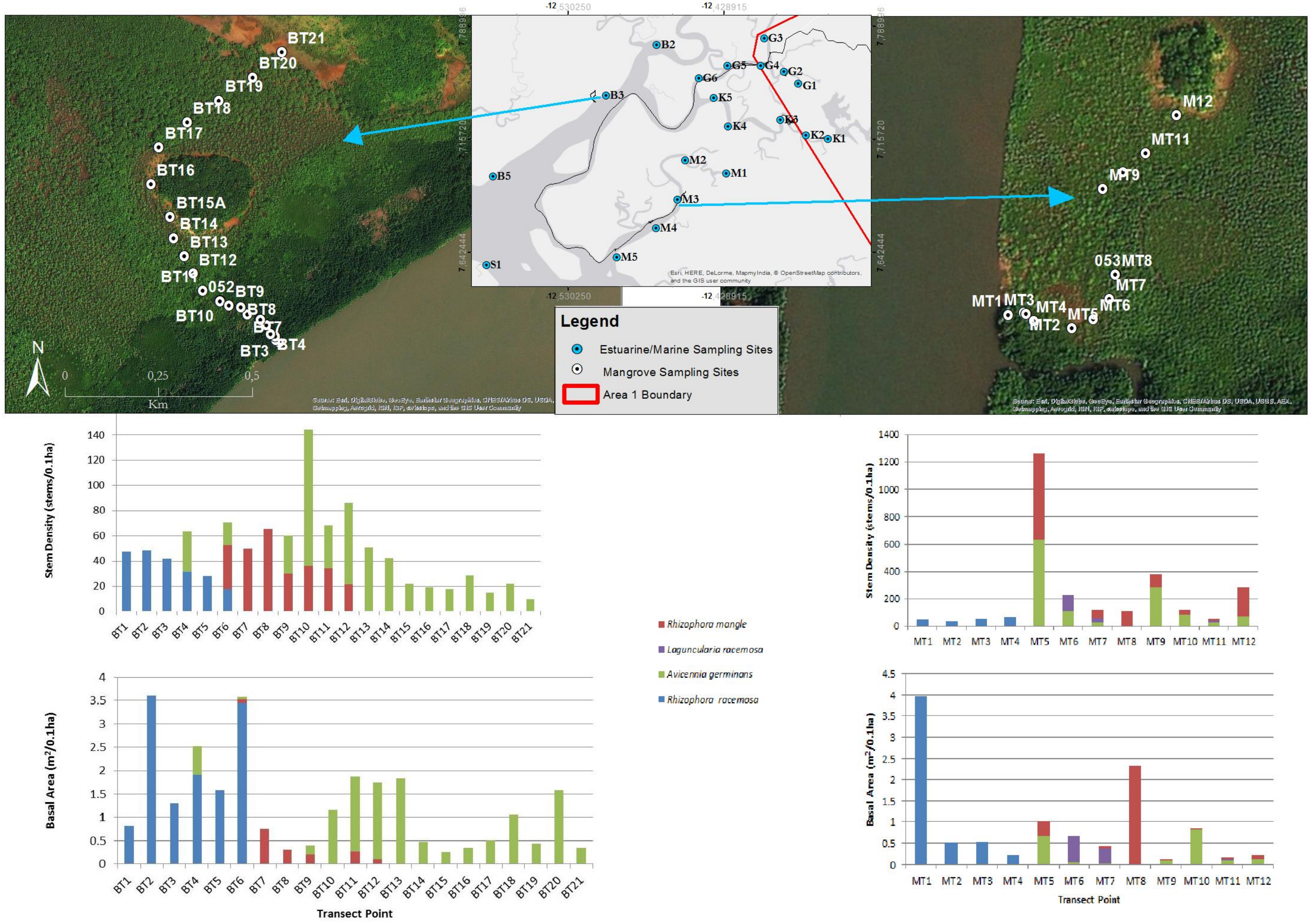


Figure 29. Bagru Creek and Motevo Creek mangrove transects and associated species density and basal area graphs.

Table 17. PCQM+ analysis of the mangrove forest as a result of the transects walked in each of the four study creeks, Bagru, Gbangbaia, Kangama and Motevo. De = absolute density, Ba = absolute Basal area, De$_r$ = relative density, Do$_r$ = relative dominance, F$_r$ = relative frequency, I.V. = importance value (Curtis 1959).

Creek	Species	De (stems/0.1ha)	Ba (m^2/0.1ha)	De$_r$ (%)	Do$_r$ (%)	F$_r$ (%)	I.V.	Rank	Total forest Density trees/0.1ha	Total Basal Area m^2/0.1ha
Bagru	*Rhizophora racemosa*	9.6	0.5244	23.2	42.0	21.4	86.6	2	41.58	1.25
	Rhizophora mangle	8.1	0.0603	19.5	4.8	25.0	49.3	3		
	Avicennia germinans	23.8	0.6641	57.3	53.2	53.6	164.1	1		
Kangama	*Rhizophora racemosa*	18.6	0.5902	23.5	47.4	22.2	93.1	2	78.97	1.25
	Rhizophora mangle	58.1	0.2193	73.5	17.6	72.2	163.4	1		
	Avicennia germinans	2.3	0.4357	2.9	35.0	5.6	43.5	3		
Gbangbaia	*Rhizophora racemosa*	48.1	0.3362	40.9	69.1	41.7	151.7	1	117.61	0.49
	Rhizophora mangle	69.5	0.1502	59.1	30.9	58.3	148.3	2		
Motevo	*Rhizophora racemosa*	39.8	1.0274	35.4	73.7	22.7	131.9	1	112.30	1.39
	Rhizophora mangle	32.8	0.2153	29.2	15.4	31.8	76.4	2		
	Avicennia germinans	30.4	0.0911	27.1	6.5	31.8	65.4	3		
	Laguncularia racemosa	9.4	0.0598	8.3	4.3	13.6	26.3	4		

4.5 Macrofauna

Mangrove ecosystems host diverse macrofaunal assemblages that display a variety of lifestyles from marine to semi-terrestrial to fully terrestrial. These invertebrates take advantage of a multitude of micro-environments found within the mangroves. Invertebrates can be found living on the sediment surface, residing in burrows, on pneumatophores and lower tree trunks or prop roots, burrowing in decaying wood, or in the tree canopies (Sasekumar 1974, Ashton 1999). Typically, the invertebrate community within a mangroves area consists of brachyuran crabs, gastropods, bivalves, hermit crabs, barnacles, sponges, tunicates, polychaetes and sipunculids (Nagelkerken *et al.* 2008, Ravichandran & Wilson 2012, Vannini & Fratini 2012). The importance of these assemblages in mangrove ecosystem functioning has been revised over the past two decades (Cannicci *et al.* 2008, Lee 2008) and their role in ecosystem functioning and mangrove structuring clarified (Smith 1987, Smith *et al.* 1991, Lee 1998, 2008, Kristensen and Alongi 2006, Cannicci *et al.* 2008, Kristensen 2008). Information on the invertebrates of West African mangroves, however, is still very limited (Binder 1968, Zabi & Le Loeuff 1993, Seck 1996, Ngo-Massou *et al.* 2012).

Invertebrates play a vital role within the mangrove ecosystem. Burrowing activities of invertebrates affect sediment properties and biochemical processes, they enhance the porosity water flow through sediment, and assists in flushing toxic substances (Nagelkerken *et al.* 2008). Furthermore, their feeding activities on the sediment surface (deposit feeding) and on plant matter (detritivory), promotes nutrient recycling (Kristensen *et al.* 2008). Mangrove invertebrates form an important food source for vertebrate predators including fish and birds that forage in the mangroves at high and low tide, respectively (Sheaves & Molony 2000).

A total of 324 invertebrates representing 43 species and 36 families were collected during the wet season (August 2017) field survey from intertidal cores and sub-tidal grabs, while an additional 13 species from 12 families were collected from local fishermen or by hand from the sub-tidal and intertidal environments (Table 18, Figure 33). The dry season yielded a greater number of invertebrates: 419 individuals representing 56 species from 39 families. An additional 13 species from 13 families were collected from local fishermen or by hand from the sub-tidal and intertidal environments. Overall, 106 invertebrate species from 70 families were recorded from all methods of sampling in the study area. The invertebrate species diversity from the combined wet and dry season surveys far exceeds those from other surveys conducted in the region. A country wide assessment for Sierra Leone undertaken by the Environmental Protection Agency (2015) recorded 45 invertebrate species while a study of the invertebrates of Wouri River and the associate mangrove ecosystem in Cameroon recorded 60 species (Ngo-Massou *et al.* 2012). In lagoon habitats in Ghana, macrobenthic fauna was found to be low in density and species diversity and numerically dominated by bivalves and capitellid polychaetes (Gordon 2000, Lamptey & Amah 2008). Overall, only 35 species were identified by Lamptey & Amah (2008) and 22 by Gordon (2000). Although the estuarine/mangrove habitat of the Sierra Rutile study area and the Keta Lagoon are fundamentally different, some overlap of invertebrate species is expected.

During the wet season, Motevo Creek yielded the greatest abundance overall (96 invertebrates from five taxonomic classes) while Gbangbaia and Kangama Creeks yielded similar numbers; 67 individuals from four taxonomic classes and 63 from six taxonomic classes, respectively (Figure 30). Sites sampled from Sherbro Island had a similar abundance to the aforementioned creeks, and yielded a total of 59 individuals from eight taxonomic groups. The two remaining creeks, Bagru and Teso, yielded lower numbers of invertebrates (<25 individuals each) and also a lower diversity (five and two taxonomic classes, respectively). The low numbers found in Teso Creek was due to the lower sampling effort in this creek; with only one site sampled here as opposed to a minimum of four sites in the other creeks (Figure 30).

During the dry season Motevo Creek again yielded the greatest overall abundance (142 individuals from nine taxonomic classes), and Kangama Creek the second greatest number of invertebrates (122 individuals from five taxonomic classes. A total of 84 invertebrates from six taxonomic classes were collected from Sherbro Island. The Bagru and Gbangbaia Creeks yielded similar numbers; 27 individuals from four taxonomic classes, and 26 from four taxonomic classes, respectively. The remaining two creeks (Telo and Teso) yielded very low numbers of invertebrates; eight and ten from three and two taxonomic classes, respectively (Figure 30). The low numbers recorded in Telo Creek were likely due to only one site being sampled as the creek was very short in length. Sampling in Teso Creek was initially restricted in the dry season, due to the lack of a suitable launch site for the boat and thus a single site (T3) close to the village was selected and led to the low abunadnces recorded. Sampling effort in Teso Creek was increased during the dry season survey after the identification of a suitable launch site for the boat but this creek still yielded low abundances even with the inclusion of an addirional four sites.

Bagru Creek had consistently low invertebrate numbers in both the wet and dry seasons, with Crustacea dominating the upper sites and Polychaetes and Crustaceans dominating at the lower sites. Ophiuroidea were also important at site B5, near the junction with Sherbro Creek (Figure 30). In Gbangbaia Creek abundance was similar for all sites with the exception of site G1 in the wet season, where a large number of Gastropods was recorded. Bivalves contributed significantly to invertebrate abundance in this creek, while both the Crustaceans and Polychaetes were also present in good numbers. High numbers of invertebrates were present at the head of Kangama Creek in both the wet and dry seasons, with Gastropods and Bivalves being major contributors to these numbers. Polychaetes were present at most sites in Kangama Creek in both the wet and dry seasons, and a large number of Polychaetes were recorded at the lower site (K5) in the dry season. The head of Motevo Creek yielded the highest invertebrate abundances in both the wet and dry seasons, however, the invertebrate community varied substantially between the two seasons in this creek. During the wet season, Gastropods dominated along with Crustaceans and Bivalves, while during the dry season the number of Gastropods decreased, and Bivalves and Polychaetes increased. Site M3 saw marked increases in invertebrate numbers and the greatest invertebrate diversity (7 classes) during the dry season with a large increase in Crustacean numbers. Abundance at the lower sites in Motevo Creek remained low in both the wet and dry season. A diverse community composition including Anthozoa, Bivalvia, Crustacea, Gastropoda, Holothuroidea, Ophiuroidea, Nemertea and Polychaeta was recorded at the Sherbro Island sites. Aside from site S3 in the wet season and S4 in the dry season, numbers of animals recorded were high and is most likely related to greater marine influence at Sherbro Island compared with those further upstream. Invertebrates collected in Teso and Telo Creeks, although low in abundance, were comparable to abundances of similarly positioned sites in the other creeks in the study area (Figure 30).

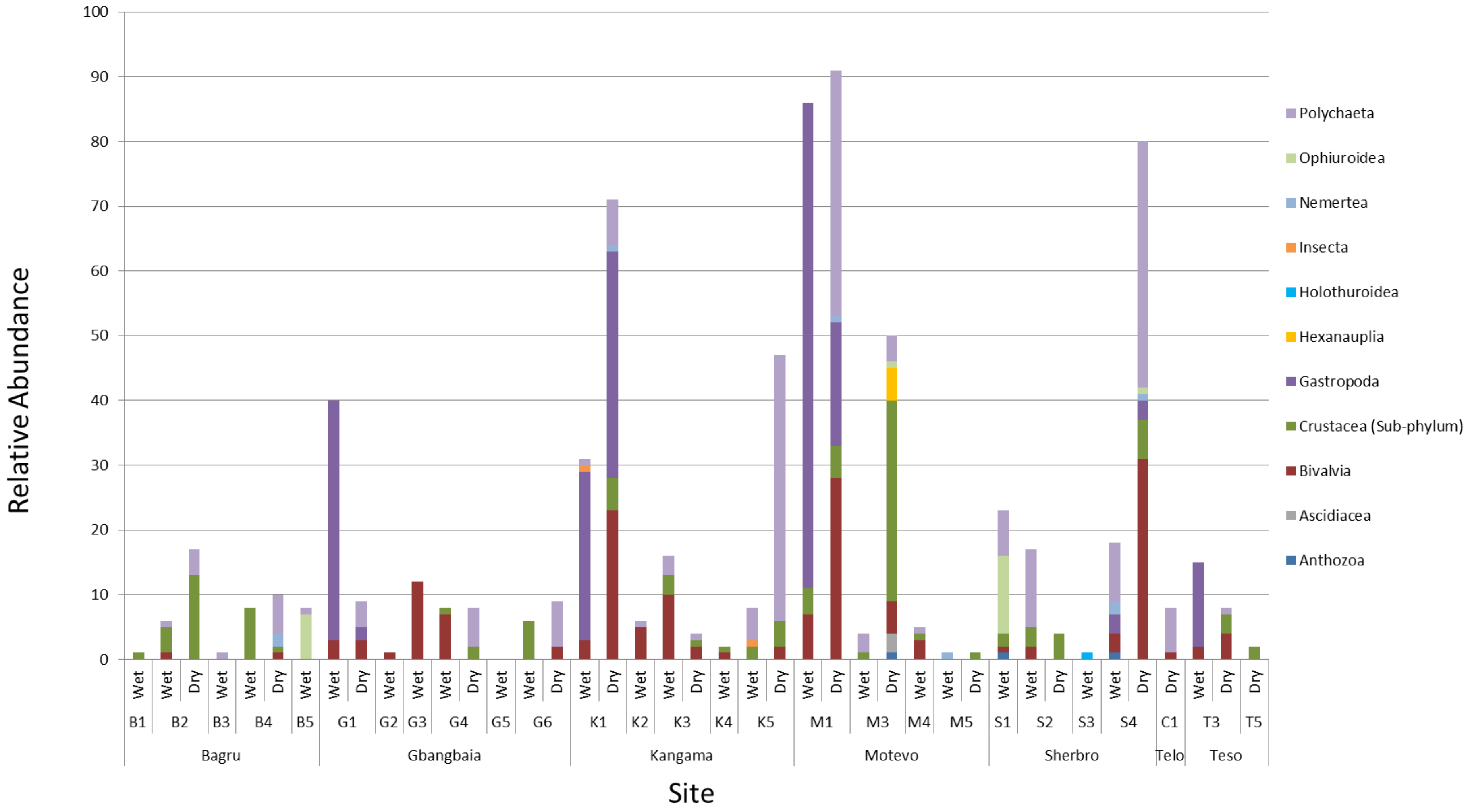


Figure 30. Combined inter- and sub-tidal invertebrate abundance per site indicating relative contribution of different taxonomic classes recorded in the wet and dry season.

Table 18. Number of invertebrates identified in intertidal and subtidal samples collected during the wet season field survey conduct during August 2017 in the estuarine creeks draining Area 1. Species denoted with a + indicates specimens collected other than by grab or hand core, while species denoted with ^ indicates specimens collected from local fishermen. Species recorded in fishers' catches are depicted by asterisks: *: present, **: common, ***: abundant. IT = Intertidal, ST = Sub-tidal

Phyla-Class	Family	Species	Gbangbaia Creek				Kangama Creek				Bagru Creek				Teso Creek				Motevo Creek				Sherbro Island				Telo Creek				TOTAL
			wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		
			IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	
Annelida - Polychaeta	Amphinomidae	*Cryptonome parvecarunculata*																							2						2
	Capitellidae	*Capetellidae sp.*			1		5		19		1								3			1	1								31
	Capitellidae	*Heteromastus filiformis*																			23	1									24
	Capitellidae	*Mediomastus capensis*											3								4										7
	Capitellidae	*Notomastus latriceus*			9	1			21																				27		58
	Capitellidae	*Notomastus sp.*			1				11														11								23
	Cirratulidae	*Cirratulus sp.*																						1							1
	Cossuridae	*Cossura coasta*				1								3																	4
	Glyceridae	*Glycera africana*																							2						2
	Glyceridae	*Glycera tridactyla*																						1							1
	Lumbrineridae	*Lumbrineris heteropoda heteropoda*						1															1								2
	Lumbrineridae	*Lumbrineris meteorana*												1																	1
	Maldanidae	*Maldanidae sp.*																						5		6					11
	Nephtyidae	*Aglaophamus lyrochaeta*																								5					5
	Nephtyidae	*Nephtys hystricis*							8			1	1				3														13
	Nephtyidae	*Micronephthys ambrizettana*+																													*
	Nereididae	*Neanthes sp.*			5				1																						6
	Nereididae	*Nereis lamellosa*								5											9										14

Phyla-Class	Family	Species	Gbangbaia Creek				Kangama Creek				Bagru Creek				Teso Creek				Motevo Creek				Sherbro Island				Telo Creek				TOTAL
			wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		
			IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	
	Nereididae	*Nereis spendida*				2	1	1	1				1																				6
	Onuphidae	*Diopatra cuprea cuprea*				3						1										2	1										7
	Orbiniidae	*Leitoscoloplos fragilis*																			1												1
	Orbiniidae	*Scoloplos madagascariensis*																						1		5							6
	Oweniidae	*Owenia fusiformis*																		1				3									4
	Paraonidae	*Aricidea longobranchiata*																				1											1
	Pectinariidae	*Lagis neapolitana*																								1							1
	Pilargidae	*Hermandura aberrans*																						1									1
	Pilargidae	*Sigambra robusta*											1																				1
	Pilargidae	*Synelmis kirkegaardi*					1																										1
	Spionidae	*Laonice cirrata*																					1										1
	Spionidae	*Polydora sp.*					1																										1
	Sternaspidae	*Sternaspis scutata*																								18							18
	Syllidae	*Syllis sp.*																						1									1
	Terrebelliade	*Nicolea sp.*																								1							1
	Terrebelliade	*Nicolea venustula africana* ⁺																															*
	Processidae	*Processa sp.*										1																					1
	Anthuridae	*Notanthura barnardi*		1				**1**		2											1												5
	-	*Bresiliodea sp.*																			4												4
	-	*Campylonotoidea sp.*																			1												1

Phyla-Class	Family	Species	Gbangbaia Creek				Kangama Creek				Bagru Creek				Teso Creek				Motevo Creek				Sherbro Island				Telo Creek				TOTAL
			wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		
			IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	
Arthropoda - Crustacea (Sub-phylum)	Callianassidae	*Callianassa diaphora*																				1		2							3
	Cirolanidae	*Cirolana sp.* $^{+}$																													**
	Crangonidae	*Philocherus bispinosus bispinosus*						1												1											2
	Diogenidae	*Clibanarius cooki* $^{+}$																													*
	Grapsidae	*Goniopsis cruentata* $^{+\wedge}$																													**
	Grapsidae	*Pachygrapsus gracilis* $^{+}$																													*
	Hexapodidae	*Thaumastoplax anomalipes*											1								6										7
	Ocypodidae	*Ocypode africana*			1				2				1										2								6
	Ocypodidae	*Uca tangeri*																					1		9						10
	Oziidae	*Eupilumnus stridulans*$^{+}$																													**
	Penaeidae	*Penaeidae sp.*											1																		1
	Penaeidae	*Penaeus notialis*$^{+\wedge}$																													***
	Penaeidae	*Penaeus monodon* $^{\wedge}$																													*
	Portunidae	*Callinectes amnicola* $^{+}$																													*
	Portunidae	*Callinectes marginatus* $^{+}$																													**
	Portunidae	*Callinectes pallidus*$^{+}$																													*
	Sesarmidae	*Armases elegans*$^{+}$																													**
	Sesarmidae	*Metagrapsus curvatus*	6		4		4					12	11				12		5			3									57

Phyla-Class	Family	Species	Gbangbaia Creek				Kangama Creek				Bagru Creek				Teso Creek				Motevo Creek				Sherbro Island				Telo Creek				TOTAL
			wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		
			IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	
Arthropoda - Crustacea (Sub-phylum)	Stylodactyloidea	*Stylodactyloidea sp.* ^																													***
	-	*Brachyura larvae*																													0
	Amplescidae	*Ampelisca spinimana*								1																1					2
	Bopyridae	*Bopyridae sp*																			2										2
	Crangonidae	*Crangon Crangon*								1																					1
	Penaeidae	*Parapeneopsis*								2											2										4
	Sphaeromidae	*Platybranchiatae*								1																					1
	Squillidae	*Pterygosquilla*																													**
	Upogebiidae	*Upogebia furcata*								1											23										24
	-	*Phreatoicidea sp*																								4					4
Arthropoda - Hexanauplia	Balanidae	*Amphibalaninae sp*																				5									5
Arthropoda - Insecta	Chironomidae	*Chironomidae sp. larvae*					1																								1
	Tipulidae	*Tupulid sp. larvae*					1																								1
Chordata - Ascidiacea	-	*Ascidian sp*																				3									3
Cnidaria - Anthozoa	Pennatulacea	*Pteroeides sp.*																						2							2
	-	*Actiniaria sp*																			2										2
Echninodermata - Holothuroidea	Holothuriidea	*Holothuroidea sp.*																						1							1
Echninodermata-Ophiuroidea	Amphiuridae	*Amphioplus congensis*										3												6							9
	Amphiuridae	*Amphipholis squamata*										4										1		6		1					12
	Aricidae	*Senilia senilis* ^																													*

Phyla-Class	**Family**	**Species**	**Gbangbaia Creek**				**Kangama Creek**				**Bagru Creek**				**Teso Creek**				**Motevo Creek**				**Sherbro Island**				**Telo Creek**				**TOTAL**
			wet		**dry**		**wet**		**dry**		**wet**		**dry**		**wet**		**dry**		**wet**		**dry**		**wet**		**dry**		**wet**		**dry**		
			IT	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	**IT**	**ST**	
Mollusca – Bivalvia	Cardioidea	*Cardiidae sp.*																		3											3
	Corbulidae	*Corbula gibba*				1				8																					9
	Lucinidae	*Cardiolucina lamothei*																								6					6
	Lucinidae	*Loripes orbiculatus*								3											1										4
	Lucinidae	*Lucinidae sp.*		1								1																			2
	Mactridae	*Mactridae sp.*								1														1							2
	Mytilidae	*Arcuatula sp*																			4										4
	Pharidae	*Sinucultellus atlanticus*																								3					3
	Psammobiidae	*Gari castrensis*		2				11								2		4												1	20
	Tellinidae	*Tellinidae sp.*																		1											1
	Tellinidae	*Austromacoma nymphalis*		2	2	2	1	7	2	13			1							4	3	7		2	27	1					74
	Teredinidae	*Teredo navalis* $^{+}$																													*
	Veneroidea	*Petricolaria sp.*																		2				3							5
	-	*Bivalvia sp*																			9	2									11
Mollusca - Gastropoda	Cerithiidae	*Cerithium atratum* $^{+}$	4																	3											7
	Cerithiidae	*Cerithium guinaicum*																								3					3
	Littorinidae	*Littoraria angulifera +*																													***
	Littorinidae	*Littorinidae sp* $^{+}$																													*
	Muricidae	*Stramonita haemastoma* $^{+}$																													*
	Naticidae	*Natica fulminea*	4																	3											7
	Potamididae	*Tympanotonos fuscatus*	18	14			12	13											3				3								63

Phyla-Class	Family	Species	Gbangbaia Creek				Kangama Creek				Bagru Creek				Teso Creek				Motevo Creek				Sherbro Island				Telo Creek				TOTAL
			wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		wet		dry		
			IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	IT	ST	
	Thiaridae	*Pachymelania aurita*			7					35						13				61	18										134
	Thiaridae	*Pachymelania fusca*		1				1												8	1										11
Nemertea	-	*Nemertea sp.*								1			2							1	1			2	2						9

Overall, invertebrate abundance in the intertidal zone (n = 100 individuals) was less than half the abundance of invertebrates collected from the sub-tidal (n = 224) in the wet season. The invertebrate community in the sub-tidal was also more diverse than the intertidal, and included representatives from all taxonomic classes recorded except Insecta (Table 18, Figure 32). Gbangbaia, Kangama and Motevo Creeks' sub-tidal invertebrate populations were dominated by gastropods and bivalves. Gastropods were restricted to the upper sample sites in all three creeks where they dominated in terms of abundance (Figure 32). The lower sub-tidal sample sites, closest to the sea, had reduced abundances but were more diverse, and included polychaetes, isopods and nemerteans (Figure 32). The sub-tidal invertebrate abundances in Bagru Creek was typically low throughout except at the lowest site which was dominated by the class Ophiuroidea (Figure 32). Site T3 from Teso Creek comprised mostly of bivalves and gastropods, and thus closely resembles the communities from sites at the top of the other creeks. Sub-tidal communities near Sherbro Island were more diverse than those further upstream and were comprised of Anthozoa, Bivalvia, Crustacea, Holothuroidea, Ophiuroidea, Nemertea and Polychaeta (Figure 32). This community, dominated by brittle stars (Class Ophiuroidea), has been identified as the *Amphioplus* sub-community and is a typical community found within lower estuarine habitats of Sierra Leone (Longhurst 1958, Ngo-Massou *et al.* 2012).

Intertidal invertebrate abundance in the dry season was higher than the wet season (n = 235 individuals), while sub-tidal abundance was lower (n = 184 individuals). Lower abundances in the sub-tidal was likely due to the reduced number of sites sampled (Table 18, Figure 32). Sub-tidal communities in the Bagru Creek were comprised solely of polychaetes while Gbangbaia Creek also had low diversity comprising of polychaetes and bivalves only. Kangama Creek sub-tidal communities were fairly diverse at the head of the creek (five classes represented), but were less diverse lower down the creek (Figure 32). Motevo Creek had the greatest sub-tidal diversity with the greatest abundance and diversity being recorded at site M3, the remaining two sites sampled in this creek (M1 and M5) yielding low abundance and diversity. Sub-tidal communities near Sherbro Island were fairly diverse comprising of Bivalvia, Crustacea, Ophiuroidea and Polychaeta (Figure 32). Teso and Telo Creeks both yielded a low abundance of bivalves only.

In addition to having lower abundances, the intertidal invertebrate community was less diverse than the sub-tidal environment in the wet season. Communities were predominantly comprised of Bivalvia, Crustacea, Gastropoda, Insecta and Polychaeta. Bagru Creek was dominated by crustaceans in the form of the mangrove crab (*Metagrapsus curvatus*) and polychaetes (Table 18, Figure 32). Intertidal communities from Motevo Creek and Sherbro Island were similar, being made up of gastropods, polychaetes and crustaceans. Gbangbaia Creek had a monospecific intertidal communities comprising of gastropods at the upper site and crustaceans at the lower sites. The intertidal invertebrate communities of Kangama Creek were the most diverse comprising of Bivalvia, Crustacea, Gastropoda, Insecta and Polychaeta (Table 18, Figure 32). Along with greater abundances in the intertidal during the dry season, greater diversity was also recorded. Upper Bagru Creek comprised solely of crustaceans while samples from the lower reaches included Bivalvia, Crustacea, Nemertea and Polychaeta. Abundance in the intertidal in Gbangbaia Creek increased from the head of the creek to the lowest site, although diversity was low (Table 18, Figure 32). Kangama Creek intertidal communities were dominated by polychaetes throughout with bivalves and crustaceans being present at the lowest site. Diversity and abundance was high at the head of Motevo Creek but decreased along a gradient towards the sea and no invertebrates were found at the lowest site

(M5). Intertidal communities at Sherbro Island were variable with crustaceans occurring at site S2 while the invertebrate community at site S4 comprised of crustaceans, bivalves, polychaetes and nemerteans (Table 18, Figure 32). Invertebrates in the intertidal in Telo Creek comprised solely of polychaetes while in Teso Creek, crustaceans and polychaetes were recorded (Table 18, Figure 32).

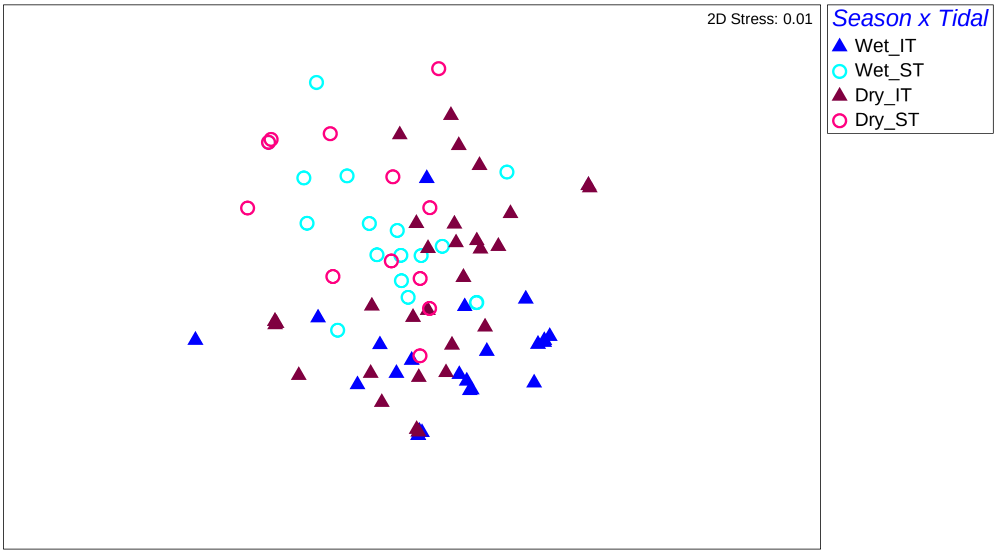


Figure 31. Multi-dimensional scaling plot (MDS) (top) showing Bay Curtis similarity between invertebrates collected in the wet and dry season surveys from the intertidal (IT) and subtidal (ST) environments downstream of SR Area 1.

Multivariate analysis using PERMANOVA (Clarke & Warwick 2001) showed that and an interaction of the factors tested (season x intertidal/sub-tidal) had significant effects (Pseudo-F = 2.47, $p < 0.01$) on the invertebrates collected during the wet and dry season surveys. The MDS plot failed to illustrate the separation of season but some differentiation was evident in intertidal and sub-tidal communities (Figure 31).

Invertebrate fauna were also collected opportunistically from local fishermen and identified to species level where possible (Table 18). Shrimp from the families Penaeidae and Stylodactyloidea were common in scoop net catches and are commonly used as bait by local fishermen (Table 18, Carpenter & De Angelis 2014). The crab, *Callinectes marginatus,* was recorded in our beach seine net and gill net samples and is also targeted by local fishermen (Carpenter & De Angelis 2014). The bivalve, *Senilia senilis,* was collected from a fisherman and the bottom of Bagru Creek during the dry season survey. The crab, *Goniopsis cruentata,* was recorded on mangrove trees at Sherbro Island, is also targeted by local fishers, and has been noted as an edible species often sold in fish markets (Carpenter & De Angelis 2014). *Penaeus monodon* was recorded in catches taken by local fishermen during the 2017 wet season survey. This species is actually native to the Indo-West Pacific, but has been introduced into the Gulf of Mexico (Fuller *et al.* 2014) and has been recorded from several countries in West Africa including Angola (http://www.cabi.org accessed August 2017), Côte d'Ivoire (CAB 2004), Gambia (http://www.cabi.org accessed August 2017), Guinea (Dias 2007), Gabon (Global Biodiversity Information Facility, https://www.gbif.org, accessed August 2017[Discover life]), Senegal, and Côte d'I·voire (http://www.cabi.org accessed August 2017), where it was introduced for aquaculture purposes.

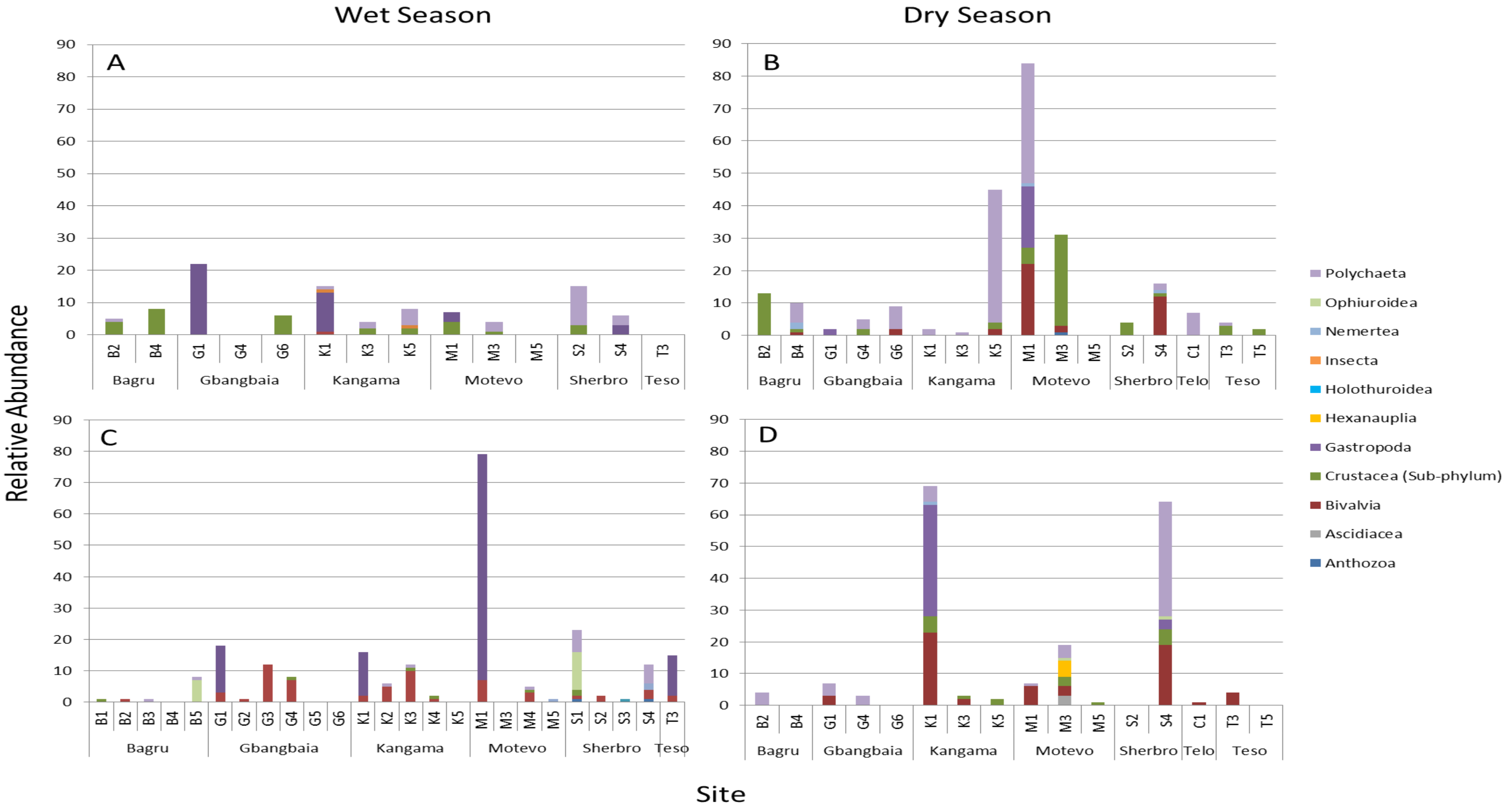


Figure 32. **Invertebrate abundance sampled at each site indicating relative contribution of taxonomic class in the sub-tidal benthic environment (top) and intertidal environment (bottom) during the August 2017 survey of estuarine creeks draining SR Area 1.**

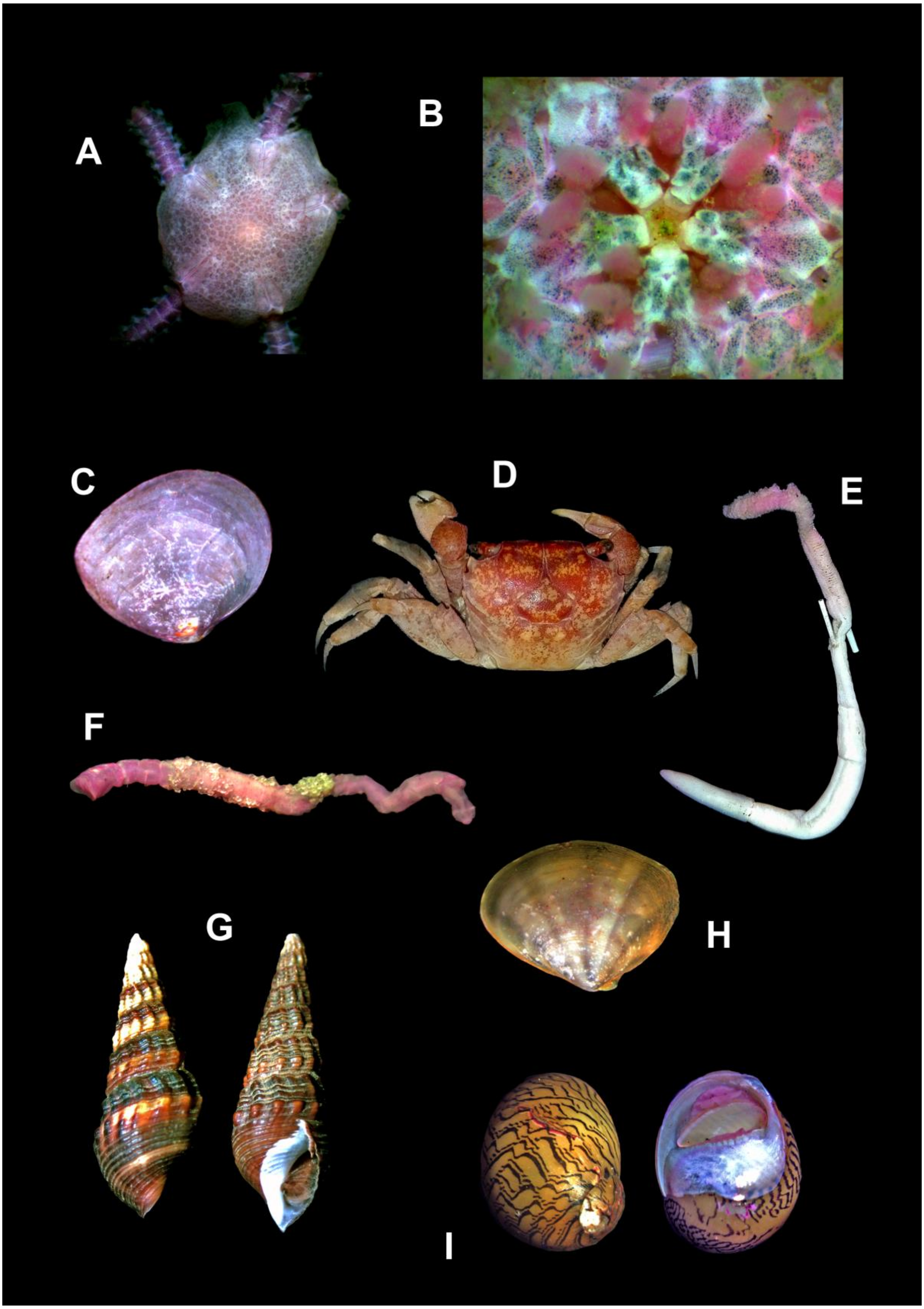


Figure 33. Examples of benthic invertebrate macrofauna found in sub-tidal grab and intertidal core samples: A – *Amphipholis squamata* (Brittle star); B – *A. squamata* mouth parts (integral for identification purposes); C – *Austromacoma nymphalis*; D – *Metagrapsus curvatus*; E – *Pteroeides* sp. (Sea pen); F – *Maldanidae* sp. (Bamboo worm); G – *Pachymelania fusca*; H – *Gari* sp.; I – *Natica fulminea.*

4.6 Fish

A total of 1 273 fish representing 55 species from 28 families were collected during the two field surveys (Table 19, Figure 34). The diversity of fish sampled during these surveys is lower than that reported in other fish surveys in the region, for example 67 species in the Gambia estuary (Gambia), 73 species in the Sine Saloum estuary (Senegal), and 64 species in the Ebrié Lagoon (Ivory Coast) (Simier *et al*. 2004, 2006, Ecoutin *et al.* 2005). Whitfield (2005) provides a list of some 173 fish species occurring in western and central African estuaries based on data contained within ten different studies undertaken in at least five different West African countries (Nigeria, Guinea, Senegal, Ivory Coast, Benin).

The fish diversity recorded in this study is slightly lower than that reported is some other studies elsewhere in the region, but the two surveys were undertaken over just nine days each and the total sampling effort was considerably less than in most of the studies cited above. The wet season survey was undertaken during peak river flows associated with the highest rainfall period of the year. The high flow rates meant that salinity was low (close to freshwater) at the majority of sampling sites (see Section 4.1.1.). This would have excluded a large number of fish species that form the marine component of the estuarine fish community that typically dominates diversity and abundance in African estuaries at many sites (Whitfield 2005, Simier *et al*. 2006). These marine estuarine species appear to have adjusted their distributions downstream, and indeed diversity and abundance during the wet season survey increased at sites closest to the sea, being greatest at the Motevo Creek and Sherbro Island (Table 20). The dry season survey did record an additional 10 species, mostly marine taxa (nine out of the 10) that were not found during the wet season survey; however the catch diversity for both surveys was similar with 44 and 45 species recorded during the wet and dry season surveys respectively (Table 20). Fish abundance during the dry season was however greater with more than double the number of fish caught (1 273) compared to during the wet season (544).

Table 19. Species list and life history information of fish sampled during the wet and dry season field surveys conducted during August 2017 and January 2018 in estuarine creeks draining Area 1.

Family	Species	Common Name	Bio-ecological category (Simier *et al.* 2006)	Adapted category[1]	Trophic level (fish base)[2]	Max length (TL cm)
Alestidae	*Alestes macrophthalmus*	Torpedo robber	Co	F	2	60
Batrachoididae	*Batrachoides liberiensis*	Hairy toadfish	Ma	M	3.7	46
Belonidae	*Strongylura senegalensis*	Senegal needlefish	Em	M	4.5	150
Carangidae	*Caranx crysos*	Blue runner	Ma	M	4.1	70
Carangidae	*Caranx fischeri*	Longfinned crevalle jack	Me	M	4	100
Carangidae	*Caranx hippos*	Crevalle jack	Me	M	3.6	124
Carangidae	*Chloroscombrus chrysurus*	Atlantic bumper	Me	M	3.5	42.5
Carangidae	*Hemicaranx bicolour*	Two-colour jack	Mo	M	3.9	70
Carangidae	*Trachinotus ovatus*	Pompano	Me	M	3.7	70
Cichlidae	*Tylochromis intermedius*	Tilapia sp.	Ce	F	2.6	23
Cichlidae	*Hemichromis fasciatus*	Tilapia sp.	Co	F	3.2	24

Family	Species	Common Name	Bio-ecological category (Simier *et al.* 2006)	Adapted category [1]	Trophic level (fish base) [2]	Max length (TL cm)
Cichlidae	*Sarothereron melanotheron*	Tilapia sp.	Es	E	2.5	28
Cichlidae	*Coptodon guineensis*	Guinean tilapia	Es	E	2.8	30
Clupeidae	*Ethmalosa fimbriata*	Bonga shad	Em	M	2.5	45
Clupeidae	*Pellonula leonensis*	Guinean sprat	Ec	F	3.3	9.3
Clupeidae	*Sardinella aurita*	Round sardinella	Mo	M	3.4	30
Clupeidae	*Sardinella maderensis*	Madeiran sardinella	Me	M	3.2	30
Clupeidae	*Sardinella rouxi*	Yellowtail sardinella	Me	M	2.9	16
Clarotidae	*Chrysichthys maurus*	Longfin catfish	Ec	F	2.7	51
Clarotidae	*Chrysichthys nigrodigitatus*	Bagrid catfish	Ec	F	3.2	65
Cynoglossidae	*Cynoglossus senegalensis*	Senegalese tounguesole	Em	M	3.6	66
Cytharichthys	*Citharichthys stampflii*	Smooth flounder	Em	M	3.9	16
Dasyatidae	*Fontitrygon margaritella*	Daisy stingray	Em	M	3.9	30
Dasyatidae	*Fontitrygon margarita*	Stingray	Em	M	3.4	100
Drepanidae	*Drepane africana*	African sicklefish	Me	M	3.1	45
Eleotridae	*Kribia leonensis*	Sleeper sp.	Co	F	3.2	3.7
Eleotridae	*Eleotris senegalensis*	Sleeper sp.	Co	F	3.7	22.4
Gerreidae	*Eucinostomus melanopterus*	Flagfin mojarra	Me	M	3.4	30
Gerreidae	*Gerres nigri*	Guinean striped mojara	ES	E	3.2	20
Gobiidae	*Periophthalmus barbarus*	Atlantic mudskipper	Es	E	3.2	25
Gobiidae	*Porogobius schlegelii*	Goby sp.	Es	E	2.9	15
Haemulidae	*Plectorhinchus macrolepis*	Biglip grunt	Em	M	3.7	45
Haemulidae	*Pomadasys incisus*	Bastard grunt	Em	M	3.8	50
Haemulidae	*Pomadasys jubelini*	Sompat grunt	Em	M	3.3	60
Haemulidae	*Pomadasys perotaei*	Parrot grunt	Em	M	3.3	36
Hemiramphidae	*Hemiramphus balao*	Balao halfbeak	Mo	M	3.9	40
Lutjanidae	*Lutjanus dentatus*	African brown snapper	Me	M	4	150
Monodactilidae	*Monodactylus sebae*	African moony	Es	E	3.9	25
Mugilidae	*Chelon dumerili*	Groovy mullet	Em	M	2.7	40
Mugilidae	*Parachelon grandisquamis*	Large-scaled mullet	Em	M	2	40
Myliobatidae	*Myliobatis aquila*	Common eagle-ray	Mo	M	3.6	183
Poeciliidae	*Aplocheilichthys spilauchen*	Banded lampeye	Ce	F	3	7
Polynemidae	*Galeoides decadactylus*	Lesser African threadfin	Me	M	3.6	50
Polynemidae	*Polydactylus quadrifilis*	Giant African threadfin	Me	M	4	200
Pristigasteridae	*Ilisha africana*	West African Ilisha	Em	M	3.6	30
Scianidae	*Argyrosomus regius*	Meagre	Me	M	4.3	230
Scianidae	*Pseudotolithus elongatus*	Bobo croaker	Em	M	4.1	47
Scianidae	*Pseudotolithus senegalensis*	Cassava croaker	Ma	M	3.8	114
Scianidae	*Pseudotolithus typus*	longneck croaker	Me	M	3.7	140
Scombridae	*Scomberomorus tritor*	West African Spanish mackerel	Ma	M	4.3	100
Serranidae	*Epinephelus aenus*	White grouper	Mo	M	4	120
Sphyraenidae	*Sphyraena guachancho*	Guachanche barracuda	Me	M	4.4	200

Family	Species	Common Name	Bio-ecological category (Simier *et al.* 2006)	Adapted category [1]	Trophic level (fish base) [2]	Max length (TL cm)
Sphyraenidae	*Sphyraena afra*	Guinean barracuda	Me	M	4.1	205
Tetraodontidae	*Lagocephalus laevigatus*	Smooth puffer	Mo	M	4	100
Tetraodontidae	*Tetraodon pustulatus*	puffer sp.	Mo	F	3.5	36

1. Describes the degree of estuarine association (see Table 7). F = freshwater guild, E = estuarine, and M = marine
2. Sourced from Fishbase.org, and is calculated as 1+ the mean trophic level of prey items.

Table 20. Number of fish recorded during the wet and dry season field surveys conduct during August 2017 and January 2018 in estuarine creeks draining Area 1. Species recorded in fisher's catches are depicted by asterisks: *: present, **: common, *: abundant**

Species/Creek	Gbangbaia Creek		Kangama Creek		Bagru Creek		Teso Creek		Motevo Creek		Sherbro Island		Telo Creek	Total all sites
Survey season	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**	**dry**	
Alestes macrophthalmus			1											**1**
Batrachoides liberiensis									*					*****
Strongylura senegalensis				2			1	1		3				**7**
Caranx crysos											**	1		**1**
Caranx fischeri												5		**5**
Caranx hippos				3						1		2		**6**
Chloroscombrus chrysurus											1	1		**2**
Hemicaranx bicolour						1			2		3			**6**
Trachinotus ovatus												1		**1**
Tylochromis intermedius							*			14				**14**
Hemichromis fasciatus		*												*****
Sarothereron melanotheron		*												*****
Coptodon (Tilapia) guineensis		18	5	1					4	1				**29**
Ethmalosa fimbriata									*	1		4		**5**
Pellonula leonensis	23	*	24	2	3	4		30	14		36	4		**140**
Sardinella aurita											***			*******
Sardinella maderensis		**			2	***						***		**2**
Sardinella rouxi											16	94		**110**
Chrysichthys maurus	**	1		2					3	**				**6**
Chrysichthys nigrodigitatus		***				**			**					*******
Cynoglossus senegalensis				3	**						4	**		**7**
Citharichthys stampflii		1		2					*	2				**5**
Fontitrygon margaritella		*							*		2			**2**
Fontitrygon margarita										*				*****
Drepane africana											1			**1**
Kribia leonensis	**													******
Eleotris senegalensis	**													******
Eucinostomus melanopterus			4			*	1							**5**

Species/Creek	**Gbangbaia Creek**		**Kangama Creek**		**Bagru Creek**		**Teso Creek**		**Motevo Creek**		**Sherbro Island**		**Telo Creek**	**Total all sites**
Gerres nigri									1		1			**2**
Periophthalmus barbarus	2	4	1							7				**14**
Porogobius schlegelii									1	1				**2**
Plectorhinchus macrolepis		*				**			*	**				**
Pomadasys incisus											*			*
Pomadasys jubelini		*			*							**		**
Pomadasys perotaei				1		3			1	11				**16**
Hemiramphus balao											1			**1**
Lutjanus dentatus						1								**1**
Monodactylus sebae	1			3										**4**
Chelon dumerili							1				7	1		**9**
Parachelon grandisquamis	***	95	3	8	40	91		64	33	445	29	3	255	**1 069**
Myliobatis aquila												*		*
Aplocheilichthys spilauchen	10	3	23	7	3		3	13	6	4				**72**
Galeoides decadactylus		1				5					18	3		**27**
Polydactylus quadrifilis		**		4	1	3			**					**8**
Ilisha africana		1			4	1			4		162	6		**178**
Argyrosomus regius					*				1					**1**
Pseudotolithus elongatus		**	1	3		1			**		3	2		**10**
Pseudotolithus senegalensis						**					24	7		**31**
Pseudotolithus typus						1						1		**2**
Scomberomorus tritor		*			2							*		**2**
Epinephelus aenus											1			**1**
Sphyraena guachancho				2	1					1				**4**
Sphyraena afra						*								*
Lagocephalus laevigatus											1	2		**3**
Tetraodon pustulatus											1	2		**3**
Total	**39**	**124**	**62**	**43**	**56**	**111**	**6**	**108**	**70**	**493**	**311**	**139**	**255**	**1 817**
No. species	**8**	**19**	**8**	**14**	**11**	**16**	**5**	**4**	**19**	**15**	**21**	**22**	**1**	**55**

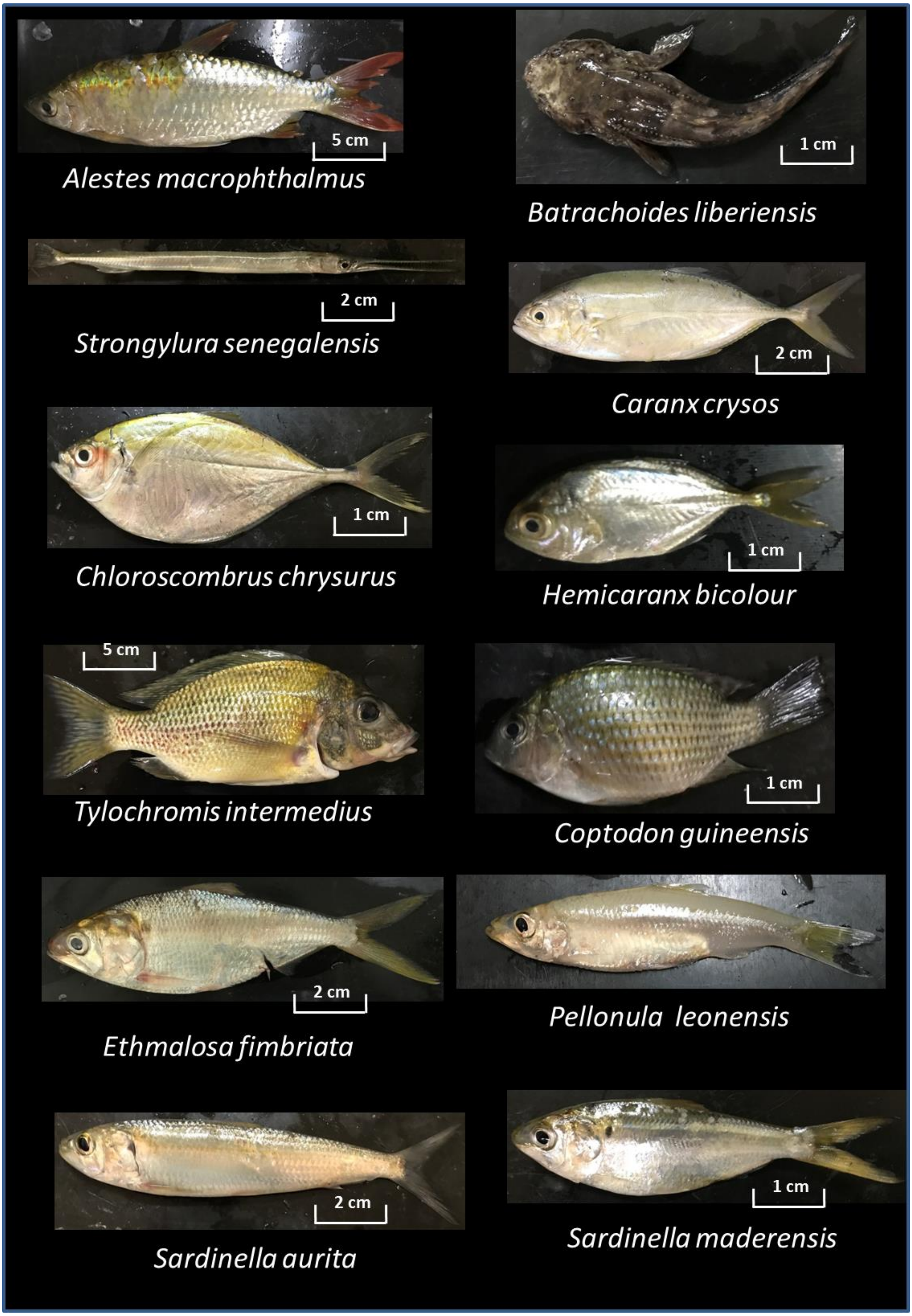


Figure 34. **Fish species recorded during the wet season field survey conducted during August 2017 in the estuarine creeks draining Area 1. (Plates still to be updated with dry season specimens).**

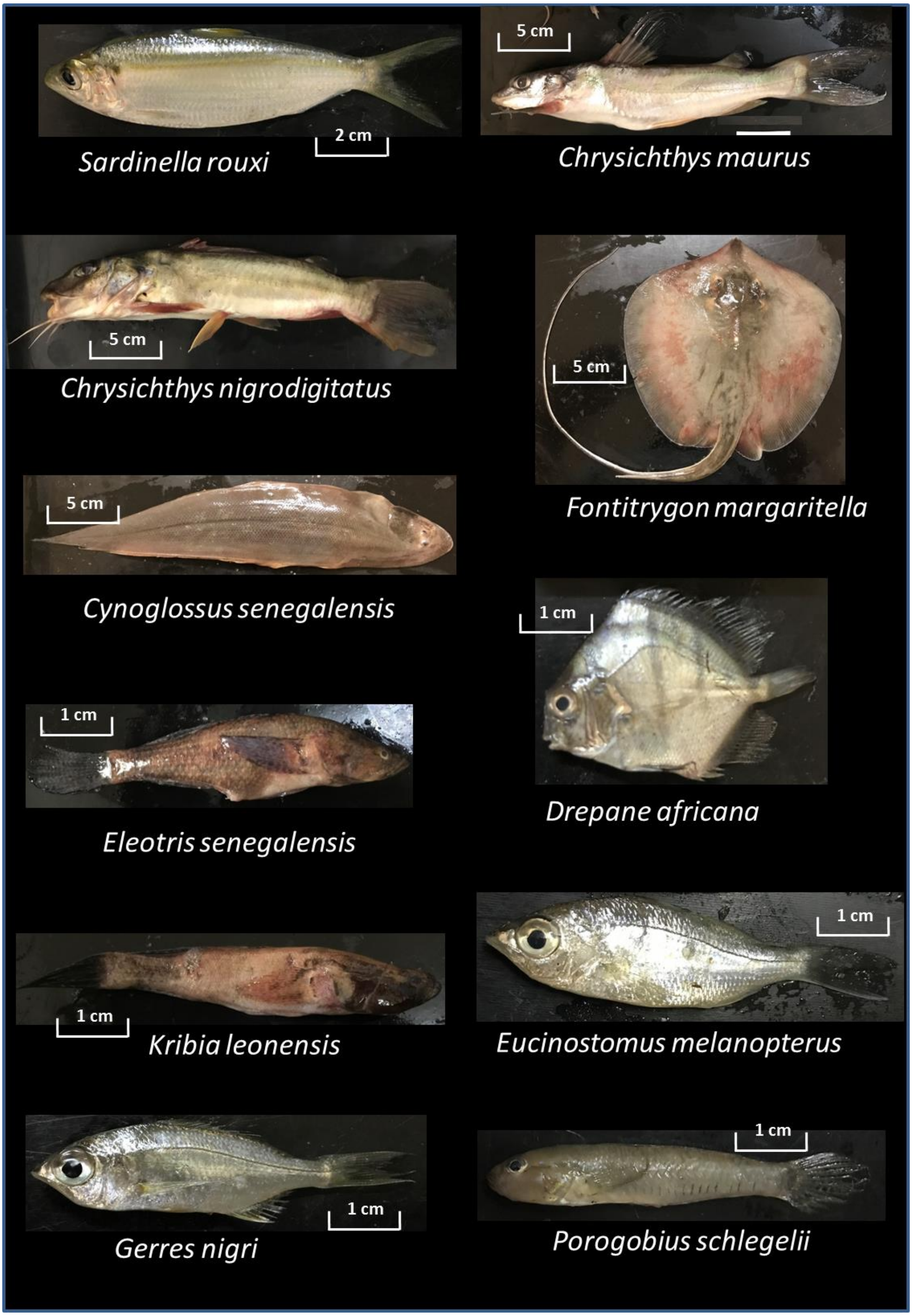


Figure 34 contd. Fish recorded during the wet season field survey conducted during August 2017 in the estuarine creeks draining Area 1.

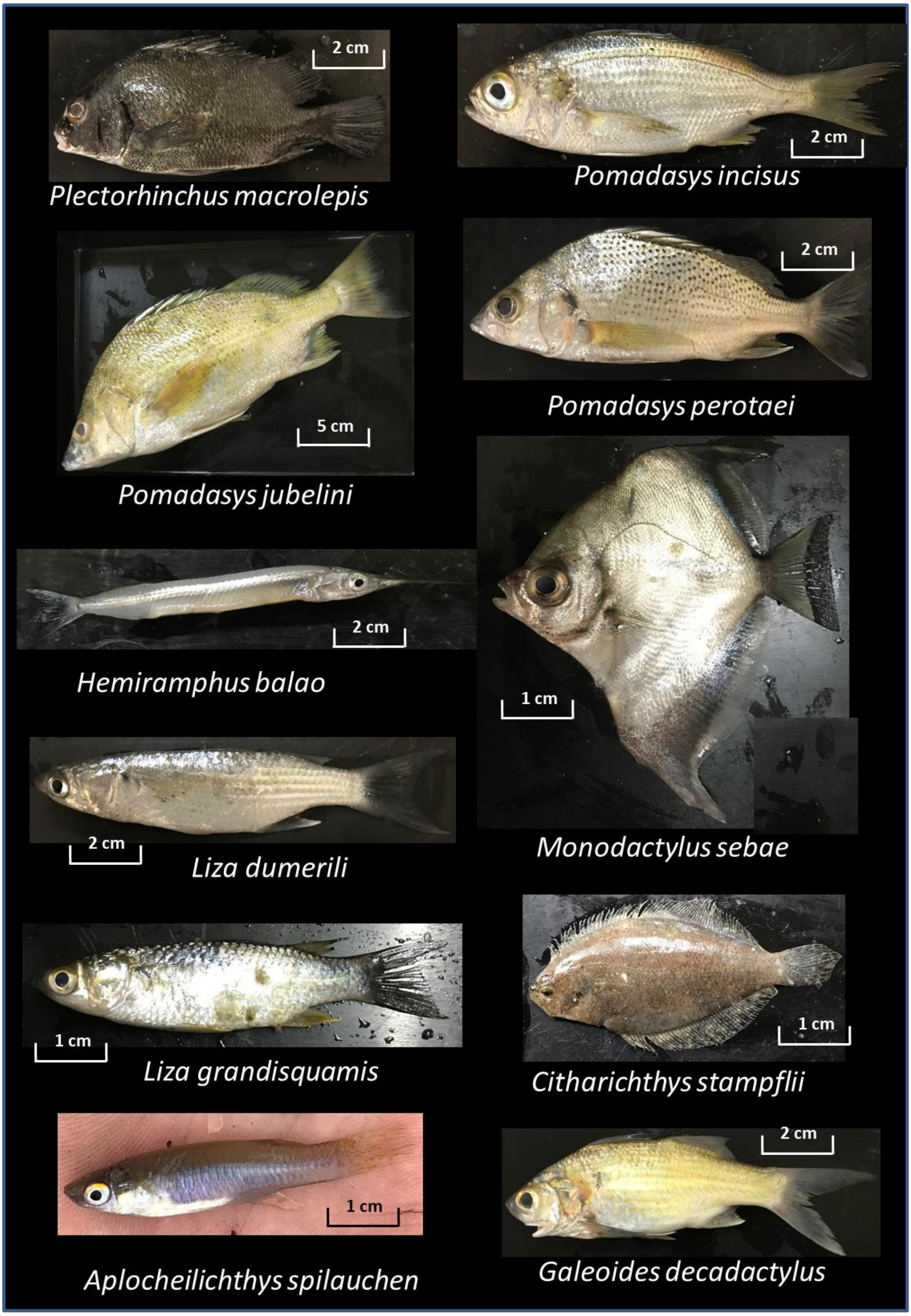


Figure 34 contd. Fish recorded during the wet season field survey conducted during August 2017 in the estuarine creeks draining Area 1.

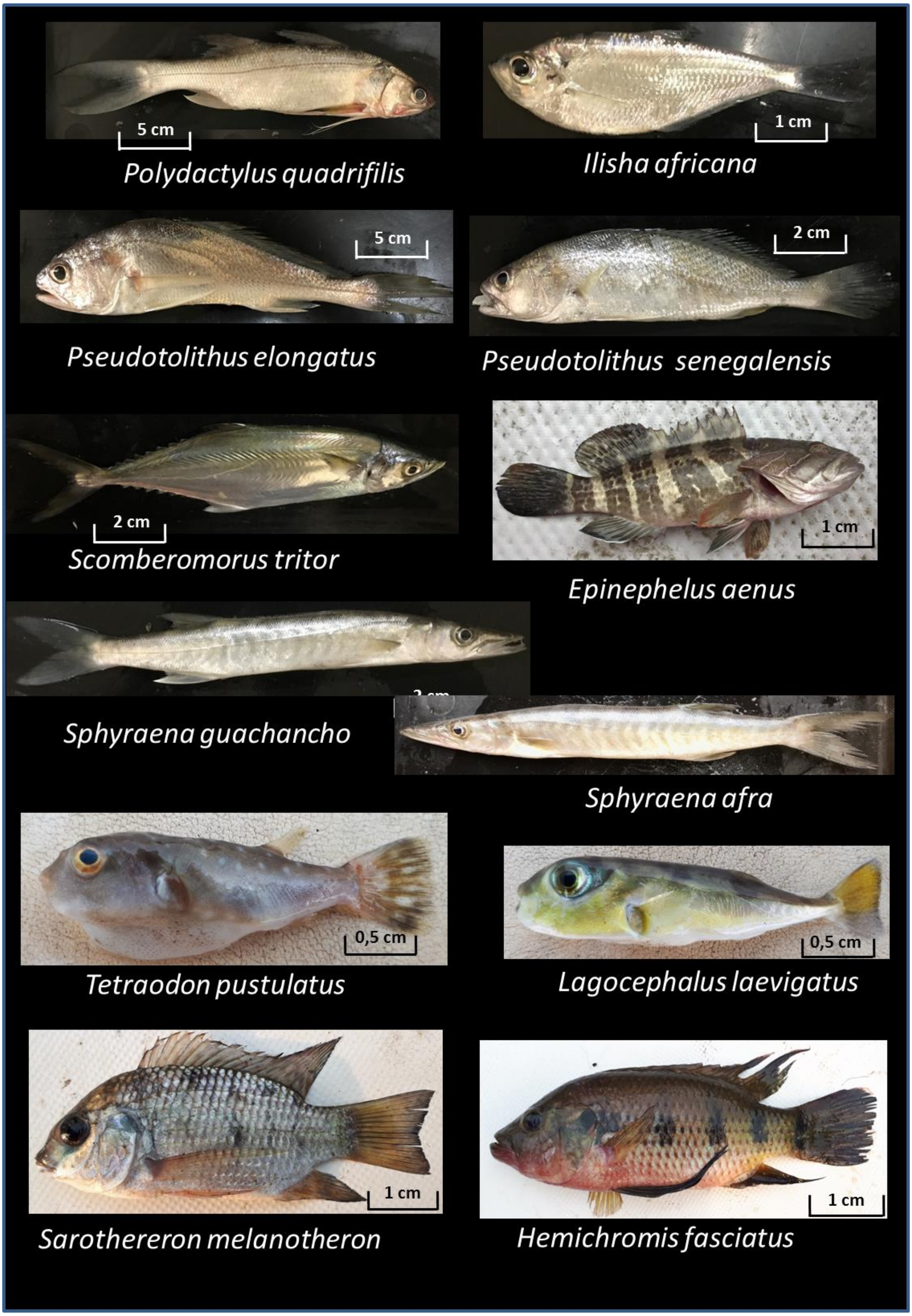
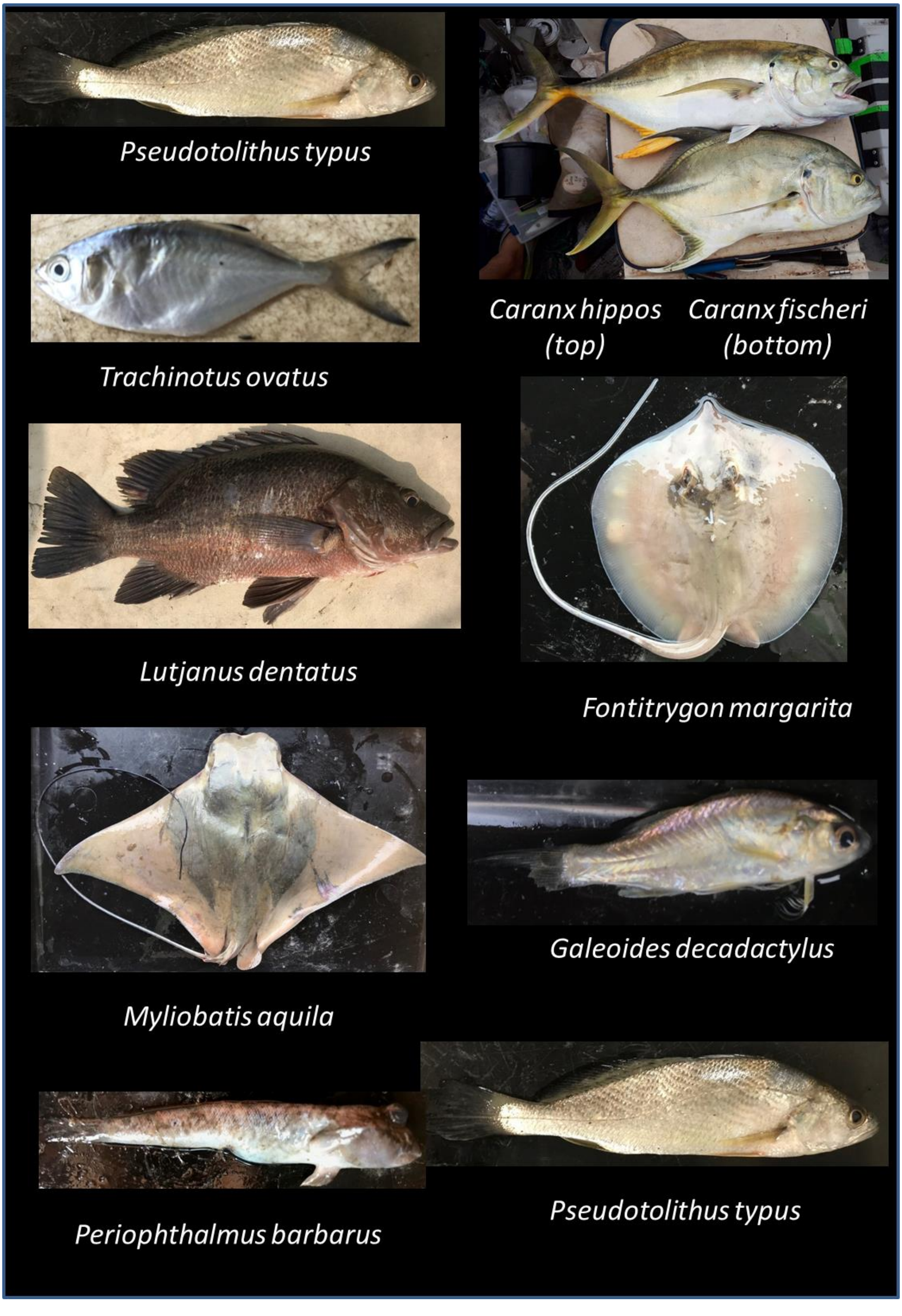


Figure 34 contd. Fish recorded during the wet season field survey conducted during August 2017 in the estuarine creeks draining Area 1.



Pseudotolithus typus

Caranx hippos (top) *Caranx fischeri* (bottom)

Trachinotus ovatus

Lutjanus dentatus

Fontitrygon margarita

Galeoides decadactylus

Myliobatis aquila

Pseudotolithus typus

Periophthalmus barbarus

Figure 34 contd. Fish recorded during the wet season field survey conducted during August 2017 in the estuarine creeks draining Area 1.

Combining the data for both surveys, the most diverse fish families in the samples were the Carangidae (jacks) represented by six species, Clupeidae (herring and sardines) represented by five species, the Haemulidae (grunts), Cichlidae (cichlids) and Sciaenidae (croakers and drums) with four species each (Figure 35). Nine other families were represented by two species each, and the remaining 14 families by one species each (Figure 35). Whitfield's (2005) assessment of fish diversity in sub-Saharan African estuaries identifies the following as the most diverse families in the Western Tropical region: Carangidae (13 species), gobies Gobiidae (11), cichlids Cichlidae (8), Sciaenidae (7) and mullets Mugilidae (6). All these families were represented in our samples during both surveys. In terms of abundance four families dominated numerically with Mugilidae (59%), Pristigasteridae (31%), Clupeidae (14%) and Poeciliidae (4%) contributing 87% of the total catch (Figure 36). There were noticeable seasonal changes in the fish community composition between surveys with the wet season survey catches having similar contributions by three families, Pristigasteridae (31%), Clupeidae (22%) and Mugilidae (21%), and a noticeable proportion of the catch comprising species of Poeciliidae (8%) and Sciaenidae (5%); dry season catches on the other hand were dominated by Mugilidae (76%) and Clupeidae (11%) (Figure 36).

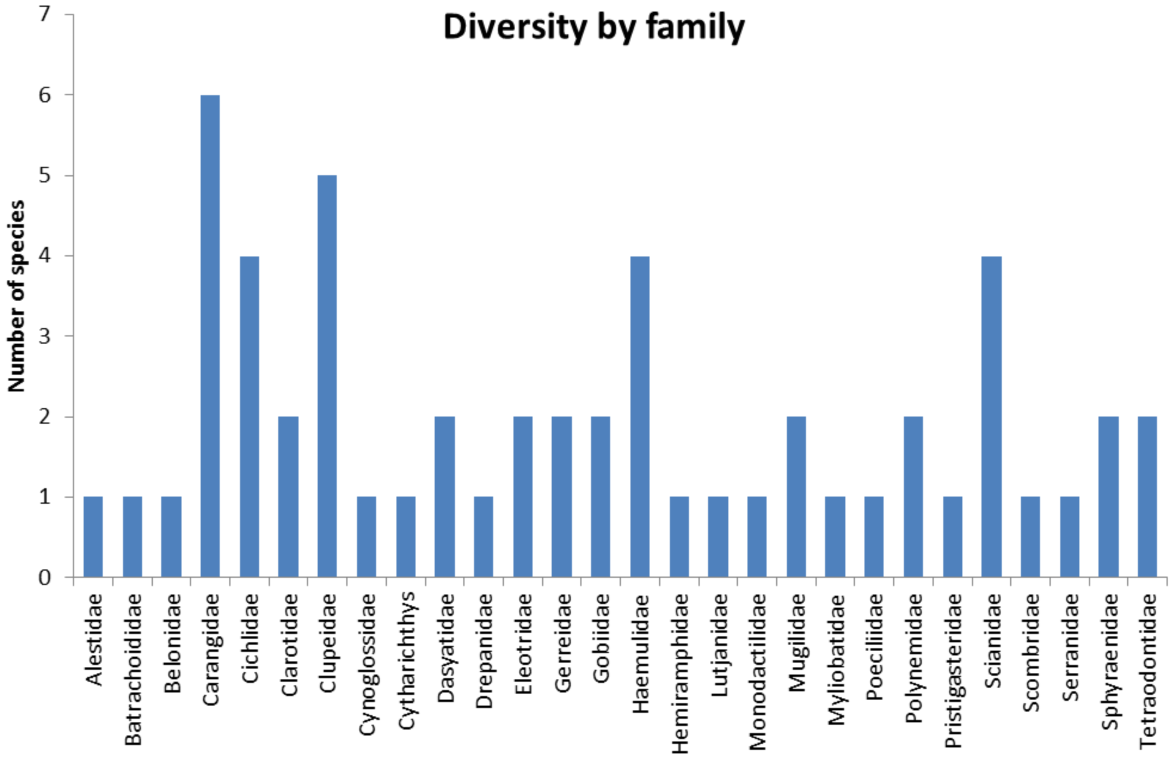


Figure 35. Number of species from each fish families recorded during the August 2017 and January 2018 surveys of estuarine creeks draining Area 1.

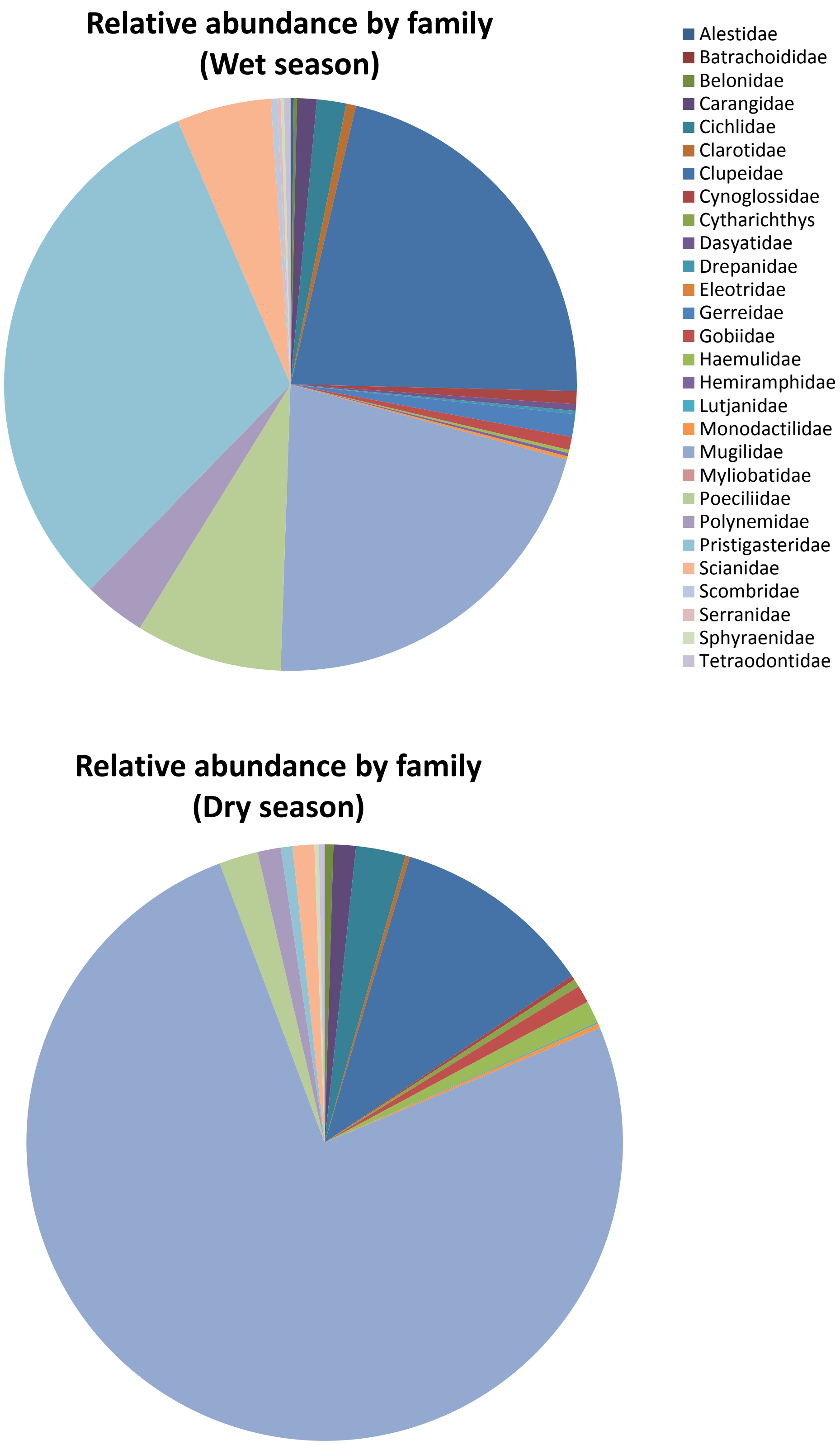


Figure 36. Relative fish abundance by family recorded during the August 2017 and January 2018 surveys in estuarine creeks draining Area 1.

Salinity is a major driver influencing fish communities including aspects such as composition, abundance and distribution in African estuaries (Whitfield 2005). Turbidity and temperature are also considered important factors structuring tropical estuarine fish communities (Simier *et al.* 2006, Ecoutin *et al.* 2010). However, these variables are nearly always correlated with the increased freshwater flows associated with the rainy season which typically results in decreased salinity and increased turbidity, whilst reduced river flow and increased marine influence via tidal flows during the dry season have the opposite effect, making it difficult to identify the most dominant drivers. These seasonal variations associated with wet and dry periods in tropical regions bring about substantial ecological changes in the estuarine biota. Many estuarine species seasonally shift their distributions up or downstream to suit their salinity tolerances, whilst increased flushing and light attenuation due to floods, results in decreased primary productivity and repercussions throughout the food web. Fish being highly mobile, and secondary or tertiary consumers, show a marked response to seasonal variations in estuaries. Most freshwater fish species can only colonise estuaries when low salinities (oligohaline) conditions exist, whilst conversely some marine fish species are stenohaline[18] and can only occupy the lower reaches of estuaries during low flow periods (Whitfield 2005). Some marine estuarine and all fully estuarine species, are euryhaline[19] and can occupy estuaries most of the time, thus forming the core of the estuarine fish community, but even these species may shift their distributions with seasonal events such as floods.

Studies of other West African estuaries have described a core component of marine estuarine species with a seasonal cycle ranging from freshwater to marine. The Ebrie Lagoon estuary in Ivory Coast has large water bodies far from the sea that are characterised by low salinities. Freshwater fish taxa are relatively abundant in these areas, whilst the marine group is generally limited to the lower reaches close to the communication with the sea (Ecoutin *et al*. 2005). The Sine Saloum in Senegal is a freshwater starved, inverse estuary which is hypersaline in the upper stretches with the result that the freshwater fish component is absent and the marine component is dominant throughout the system (Simier *et al*. 2004). The Gambia estuary experiences “normal” euryhaline conditions with seasonal variation, and the fish community in this system includes all seven bio-ecological categories (Simier *et al*. 2006). The marine component is generally dominant, contributing 49 out of 67 species and more than 92% of recorded abundance (Simier *et al*. 2006). The marine component of the estuarine fish fauna was dominant throughout most zones of the Gambia River Estuary, whatever the season, except the upper zone during floods (Simier *et al*. 2006).

In the Gambia study, the strictly estuarine category (Es) was represented by relatively few individuals in all seasons (0.05-1.41 % numerically), the estuarine marine category (Em) was abundant in most seasons and regions (60-89% numerically except for the upper region during the rainy season), whilst the freshwater groups (Co, Ce and Ec) were only abundant in the upper reaches during the wet season surveys (Simier *et al*. 2006).

The surveys of the estuaries downstream of SR Area 1 also indicated an estuarine fish community dominated by marine species that contributed 39 of the 55 species, whilst more freshwater species

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[18] able to tolerate only a narrow range of salinity

[19] Able to tolerate a wide range of salinity

(10) were recorded than strictly estuarine species (6) (Figure 37). During the wet season survey, the marine guild was also dominant in terms of fish abundance (69%) but the freshwater group contributed a significant 28% numerically to the total catch (Figure 38). Given the timing of the wet season survey at the peak of the rainy season, the contribution of freshwater species to the estuarine fish community is not unexpected. The dry season survey saw a shift in relative abundance, with the marine guild contributing 90% to the total catch and a substantial reduction in the numerical contribution of freshwater taxa to just 7 % of the total catch (Figure 38). As anticipated and demonstrated elsewhere (e.g. the Gambia River), the reduced freshwater flows and increased salinity in the upper estuarine creeks during the dry season (see Section 4.1.1) saw a reduction in abundance of freshwater fish taxa and an increase in marine species.

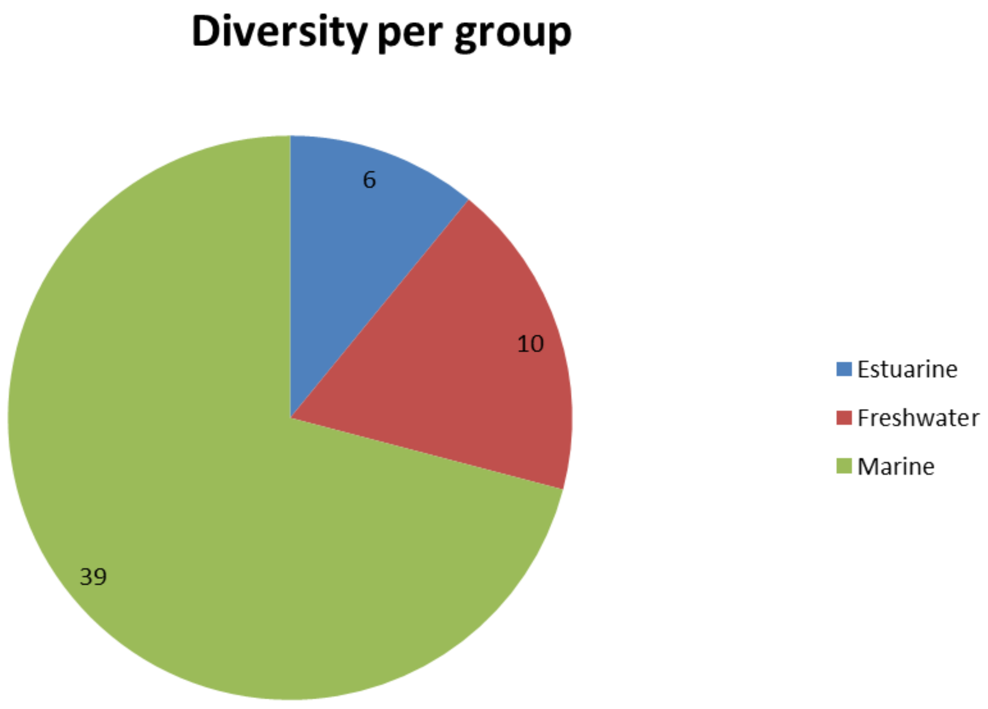
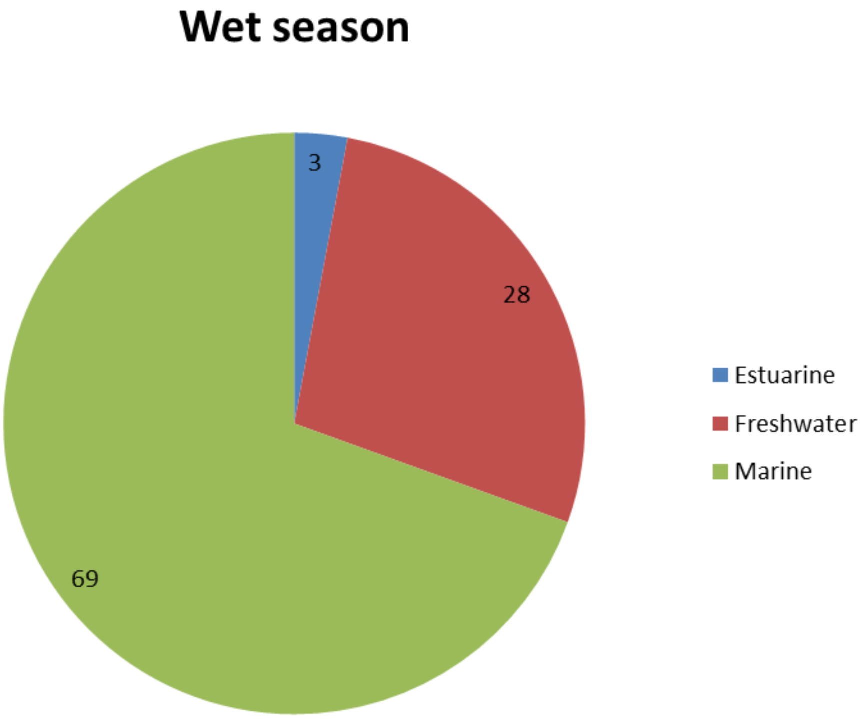


Figure 37. Diversity of fish species in each estuarine affinity group sampled during the ecological surveys of the estuarine creeks draining SR Area 1 for bothwet and dry surveys.



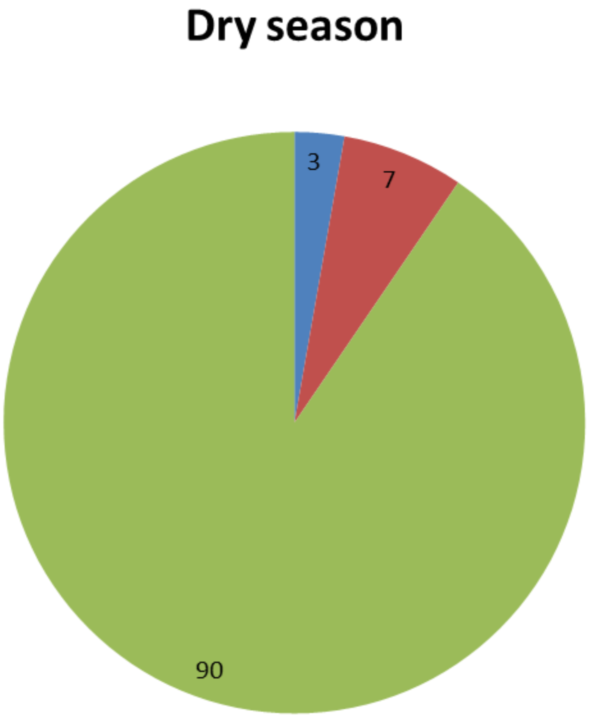


Figure 38. **Relative abundance of fish species (% total catch) in each estuarine affinity group sampled during the wet and dry season surveys of creeks downstream of SR Area 1.**

The estuarine fish community was dominated by carnivorous and omnivorous species with only one species classified as herbivorous (the phyto-planktivorous Bonga shad) (Figure 39). Most species present in the fish community were first level predators consuming mainly benthic invertebrates (p1-bt), zooplankton (p1-zo) and macrocrustaceans and insects (p1-mc), or second level generalist predators consuming mainly fish, shrimps and crabs (p2-ge) (Figure 40). In terms of abundance, the phytoplanktivorous mullets dominated, whilst the mainly zooplanktivorous predators that included the three *Sardinella* species and *Ilisha africana* were the next most common trophic group (Figure 40). A low number of second level predators, particularly piscivorous species is often an indication of high levels of fishing mortality, as these groups tend to include the larger and more sought after fish species. The overall average trophic level of our sample (trophic level of each species multiplied by its abundance in all samples and divided by the total catch) declined from 3.2 recorded during the wet season survey, to 2.6 after the dry season survey, a result due to the high abundance of mullet in the dry season samples. This is lower to the mean trophic level of 3.1 for the fish community in Bamboung Balong Bay, Sine Saloum estuary, Senegal, prior to the implementation of a fishing ban in 2000 (Ecoutin *et al*. 2014). The mean trophic level in the Sine Saloum estuary subsequently increased to around 3.4 in the four years following the fishing ban as did the proportion of second level predators, particularly piscivores, whilst a decrease in lower trophic level omnivores and herbivores was documented (Ecoutin *et al*. 2014). The low average trophic level for the fish community sampled in the estuaries below SR Area 1 does reflect the relatively high levels of fishing effort in the system.

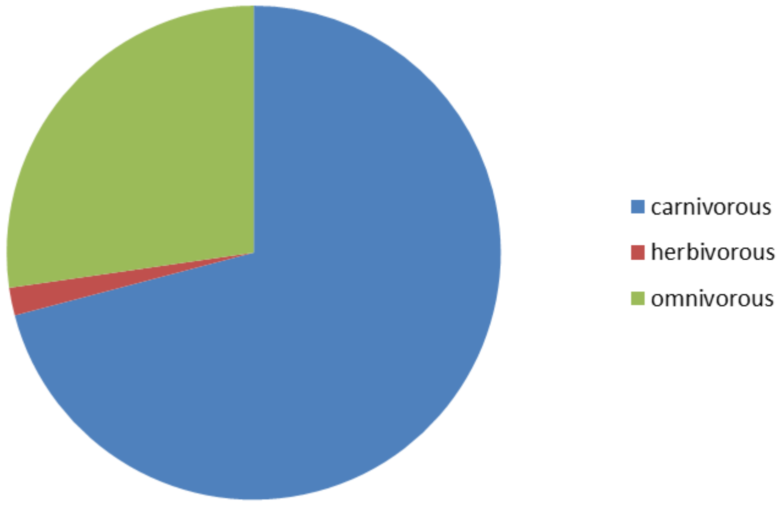
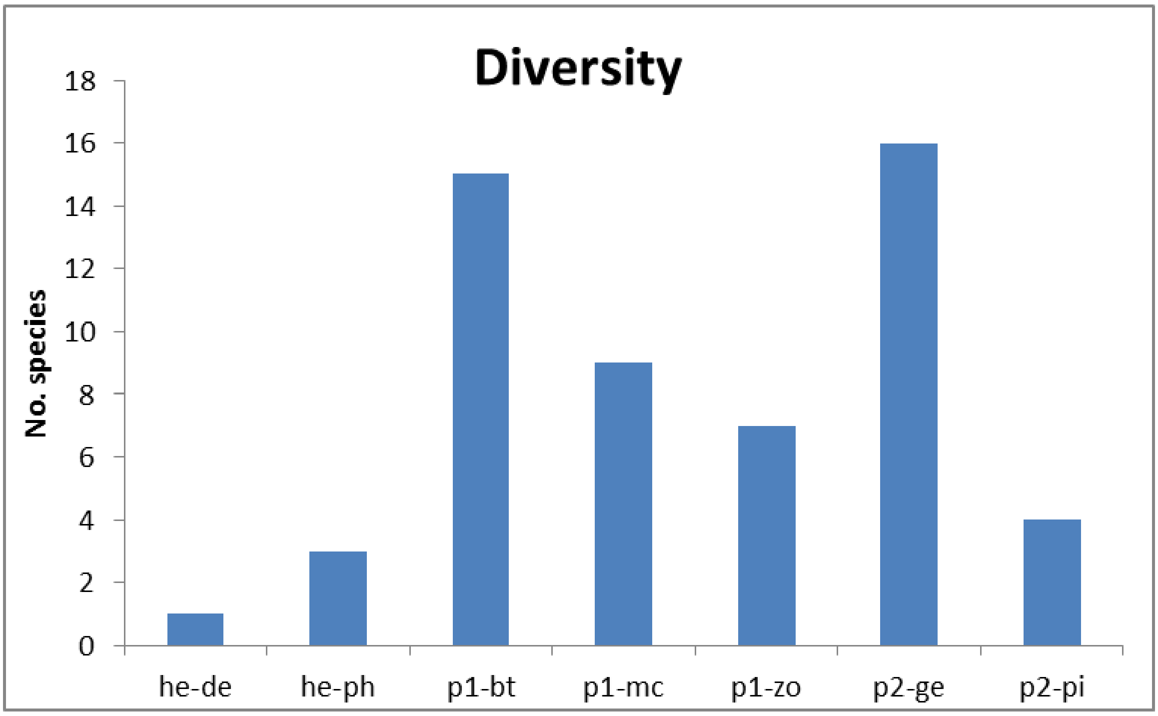


Figure 39. Estuarine fish community composition by feeding mode.



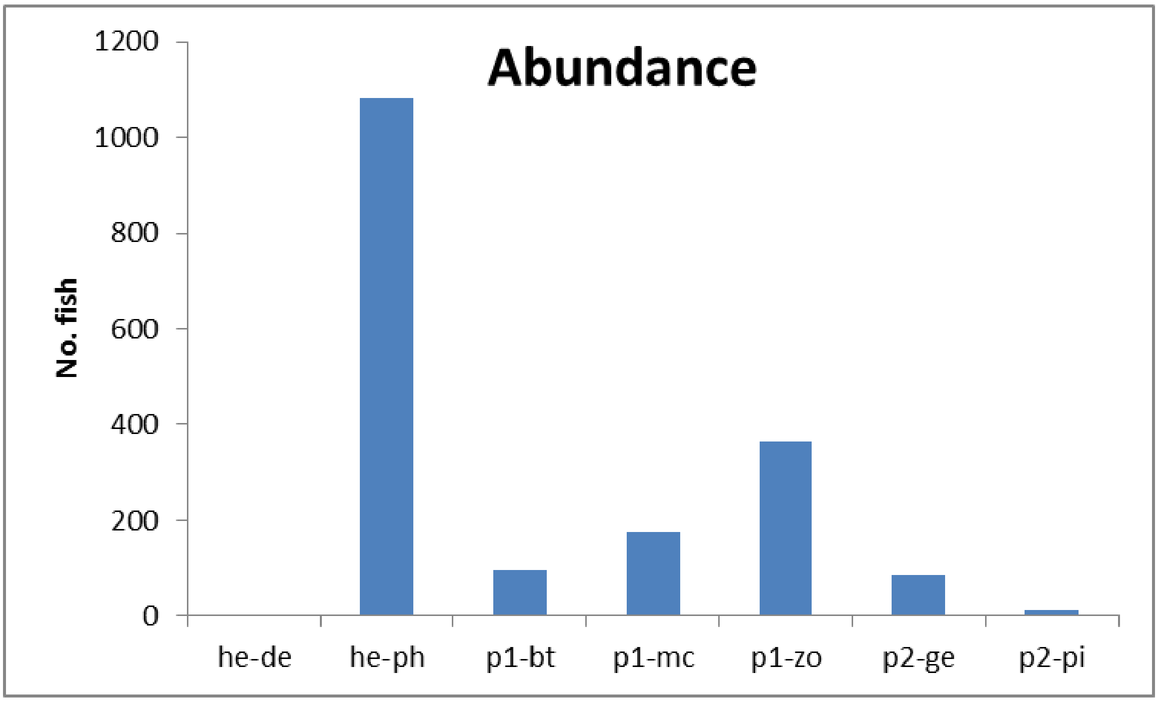
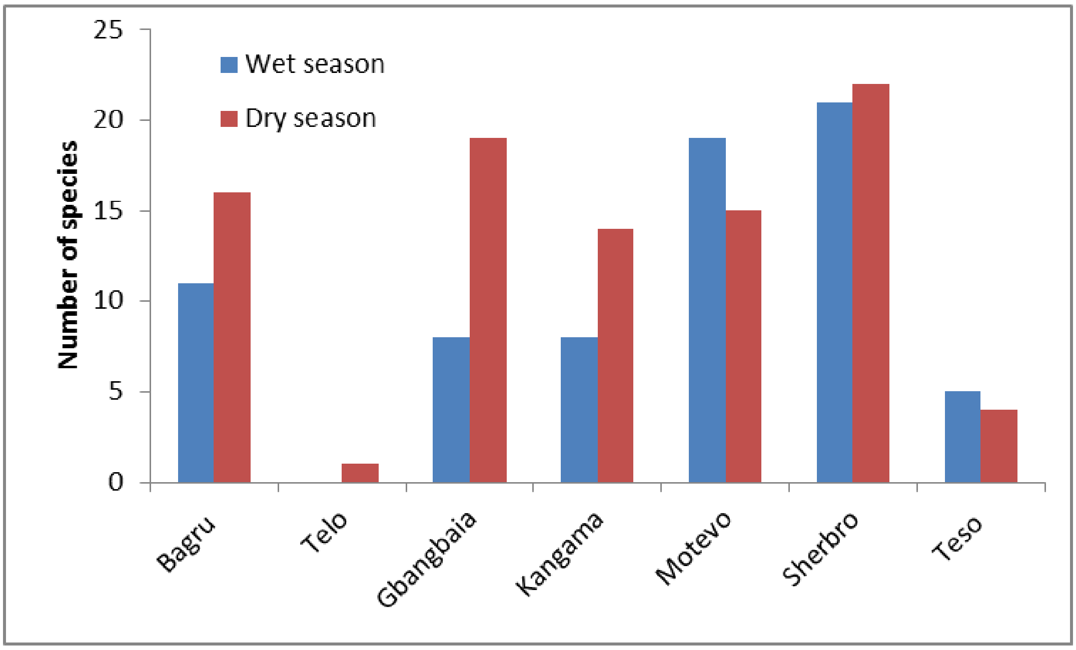


Figure 40. Estuarine fish community species composition and abundance by trophic group (see Table 8).

Fish diversity in samples collected from the Bagru, Gbangbaia and Kangama Creeks increased noticeably between the wet and dry season surveys, whilst small decreases in the number of species caught were observed in the Motevo and Teso Creek samples (Figure 41). Similarly fish abundance in all creeks, with the exception of Kangama Creek and the Sherbro Island sites, was higher during the dry season surveys (Figure 41). Wet season fish diversity was higher at the Motevo Creek and Sherbro Island sites compared to other sampled creeks, whilst dry season diversity was similar across all sites except for Telo creek where only one species of mullet was caught (Figure 41). Total catches (fish abundance) was similar across most creeks, with the exception of high catches at Sherbro Island during the wet season and in Motevo Creek during the dry season (Figure 41). Fish samples collected from creeks potentially adversely impacted by mining activities in SR Area 1 (Gbangbaia, Kangama and Teso Creeks) did not have markedly different diversity or abundance from samples collected in the Bagru, Telo and Motevo Creeks and Sherbro Island that are unlikely to be impacted by mining (with the exception of the higher abundance recorded at Sherbro Island during the wet season and Motevo Creek during the dry season, which is likely due to the proximity to the open coast and seasonal shifts in fish species utilising the estuaries).



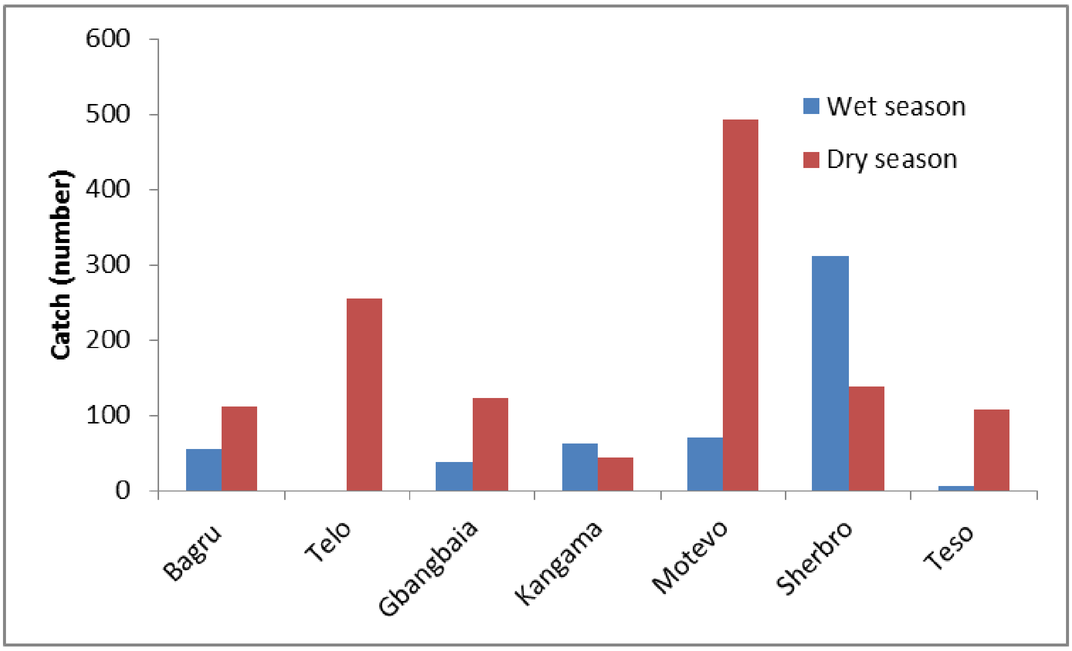


Figure 41. Fish diversity and overall abundance in the different estuarine creeks and Sherbro Island sampled during the wet and dry season field surveys.

Multivariate analysis that takes account of the fish community composition (i.e. the relative abundance of each individual species in each sample) confirmed the similarity of samples from the different creeks as one significant cluster and identified the marine dominated Sherbro Island sites and the one wet season Motevo Creek sample (M3W) as a separate significant grouping (Figure 42).

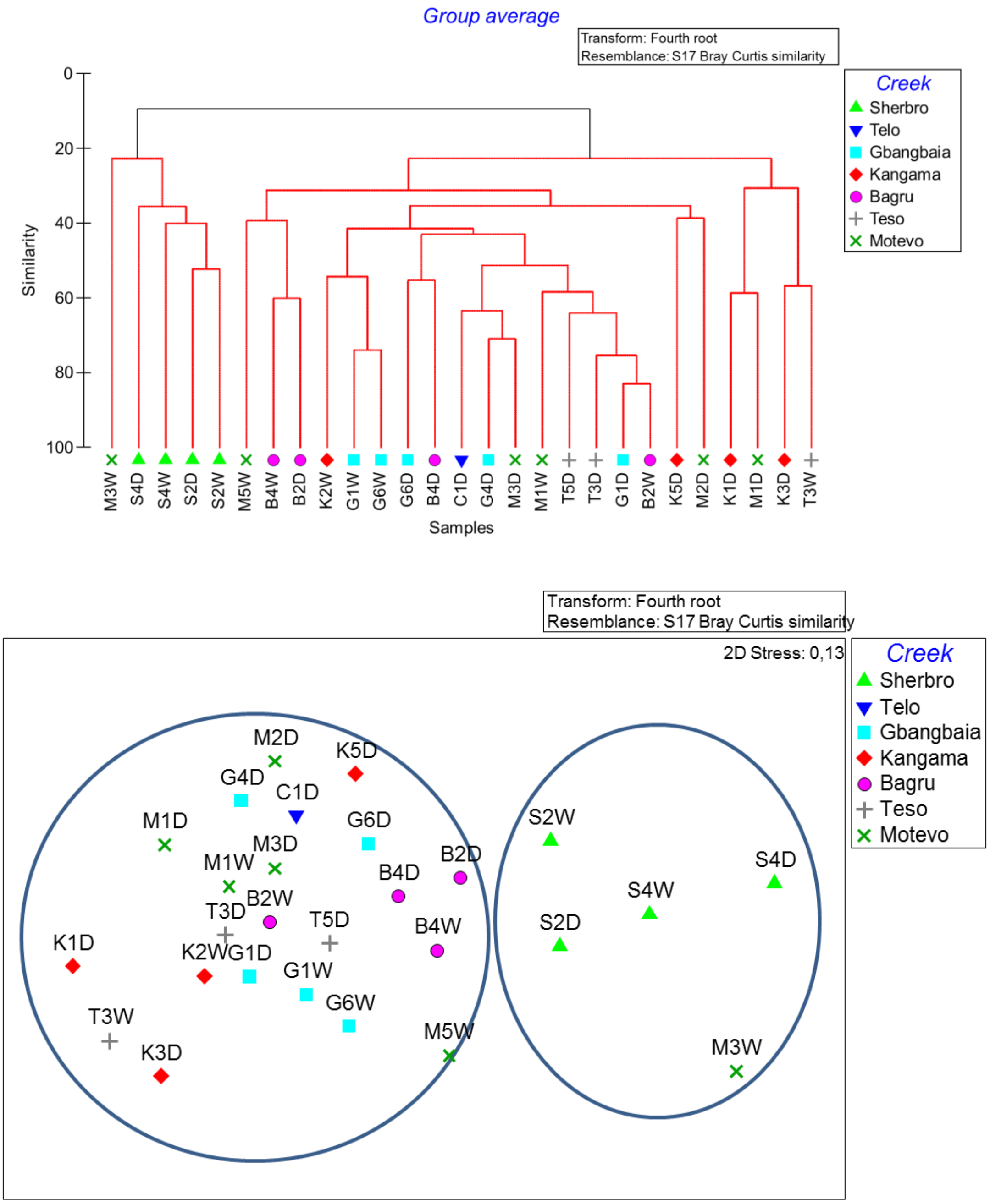


Figure 42. **Dendrogram and multi-dimensional scaling plot (MDS) showing Bay Curtis similarity between seine net fish samples from different sites during the wet (W) and dry (D) season surveys of estuarine habitats downstream of SR Area 1. Significant clusters identified at the P<0.05 level by the SIMPROF analysis in the dendrogram are identified by a change in colour of the branches from black to red and are circled in the MDS plot where the most similar samples are depicted as closest together in 2 dimensional space**

A loss of the freshwater component (including catadromous species) of the fish community is a potential impact of dams created by the current and historical SRL operations. This impact would have been most evident during the dry season survey when freshwater flows are at their lowest. However both surveys indicated seasonal diversity and abundance of freshwater species that is comparable to other studies in the region. Increased water turbidity during the wet season due to erosion of cleared areas may also negatively impact the abundance of sensitive species. These would most likely be species in the marine group, particularly the marine species accessory in estuaries (Ma) and the marine species occasional in estuaries (Mo) (Ecoutin *et al*. 2010). However, given the very low salinities observed at most sites, and the known importance of this physical driver, as well as the dominance of the marine group in the samples (particularly at lower stations), this does not appear to be the case. It is also important to note that the salinity in the upper creeks during the dry season never exceeded 16 PSU, and fish species with freshwater affinities were still present in the dry season samples collected in creeks potentially impacted by mining operations in Area 1 (Gbangbaia, Kangama and Teso Creeks). This indicates that a significant reduction in freshwater flows, or isolation of freshwater and catadromous taxa from freshwater habitats due to mining was probably not taking place at the time of the surveys (this does not mean that historical impacts did not occur when dams were first constructed, but rather that any impacts that may have occurred are no longer detectable). Based on these two fish surveys it appears that the estuarine fish community in terms of diversity and composition is typical of a “normal” West Africa estuary, however, the relatively low number of fish caught, the small size of individuals (relative to the reported maximum sizes) and the relatively low mean trophic level of the fish community, does indicate anthropogenic impacts. It is suspected that the constant high levels of fishing effort by artisanal and commercial fishers using both long lines and gill nets (see Section 4.8) is having a significant impact on the estuarine fish stocks.

4.7 Birds, reptiles and mammals

All birds, reptiles and mammals encountered on the estuarine creeks draining from Area 1 during the wet and dry season field surveys were identified, counted and photographed where possible, in the field using binoculars and guides. This was done opportunistically whilst travelling from Nitti Port to the various sampling sites, between sites, and on the return journey to the port. Sampling effort was not equitably distributed across the study area, therefore, with maximum effort being expended on the area close to Nitti Port (Gbangbaia Creek and Bagru Creeks). Data for these groups (birds, reptiles and mammals) are thus presented as a list of species recorded in each of seven counting areas (Gbangbaia, Kangama, Telo, Bagru, Moteva, Teso Creeks and Sherbro Island, Figure 43) rather than actual counts. In the case of birds, focus was placed on water birds only – i.e. those that have a close association with water for feeding, roosting or nesting purposes. Small passerines (birds of the order Passeriformes), most of which display little or no dependence with water, were not counted as part of the survey.

In all, 20 species of water birds recorded during the wet season survey and more than double (50) during the dry season (Table 21). Numbers of birds recorded was highest in Bagru Creek and Sherbro Island in both seasons. This was in spite of comparatively low sampling effort being expended in these two areas and is believed to be linked to the much greater sand and mudflat habitat available as preferred feeding areas for many water birds in these two counting areas. Species that were encountered most frequently included Little stint, Royal tern, Little tern, Great white egret, and Western reef egret.

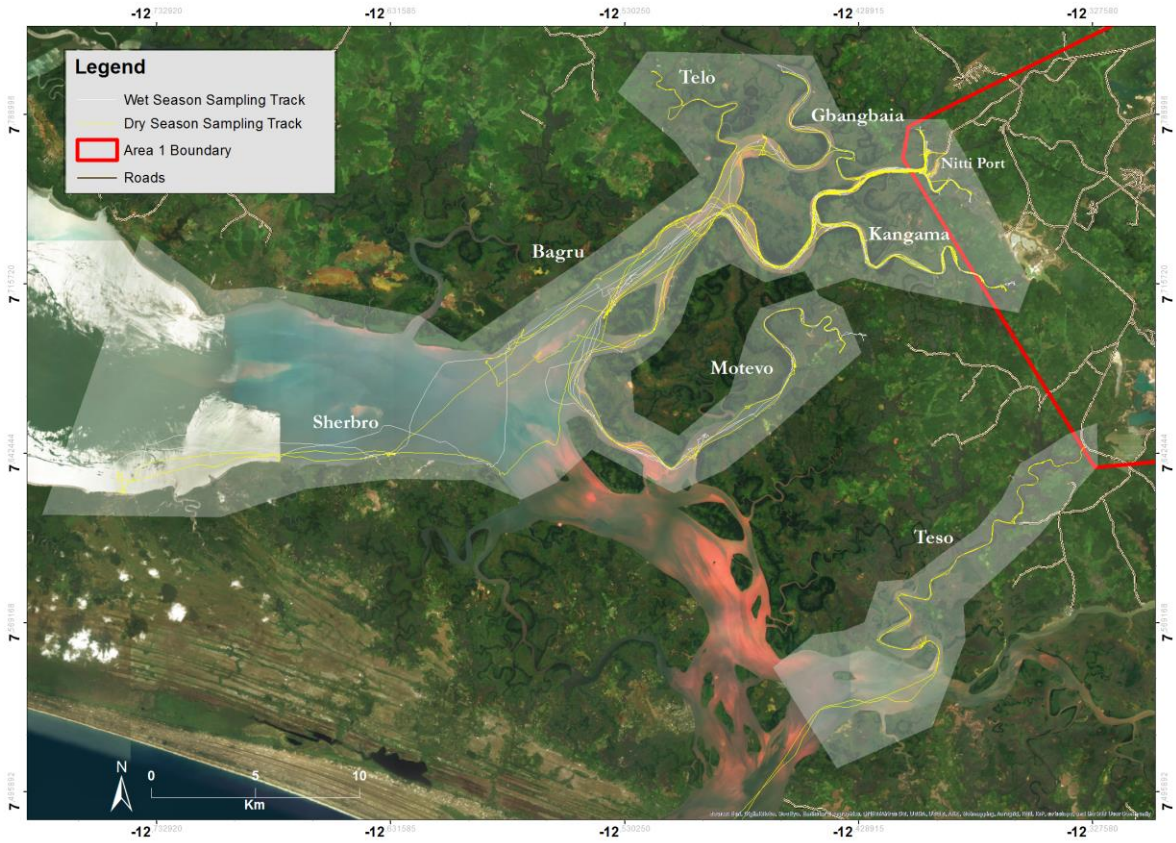


Figure 43. Bird counting areas (shading) and vessel tracks during the wet season (white lines) and dry season (yellow lines).

Three earlier accounts of water birds populations in the study area were identified in the literature. Tye & Tye (1987) list the Sherbro River Estuary, along with the Sierra Leone River estuary and Yawri Bay, as being the three major sites for waders in Sierra Leone, but did not provide any actual data on numbers or species of birds present at this site. They list the Scaries River estuary as being a fourth major site, but of lower importance than the other three sites. Dodman & Diagana (2003) provide some useful data on water birds recorded on coastal and inland wetlands in Sierra Leone from 1998 and 2000 but unfortunately did not include the Sherbro River Estuary in their surveys due to security concerns. Van der Winden *et al.* (2007, 2009) counted numbers of birds on the sand and mudflats and small creeks surrounding Sherbro Island in the summer (February) of 2005. Bird counts were restricted to the area around Sherbro Island (Figure 45) and did not extend up into the creeks draining SR Area 1 with the count data (species composition and numbers) presented in Table 22. Van der Winden *et al.* (2007) recorded a total of 14 515 birds from 56 species which is substantially many more than recorded during this wet season survey. The reasons for the greater diversity and numbers recorded in this survey are threefold-fold. Firstly, the Van der Winden *et al.* (2007) survey was conducted in the dry season (northern summer) when many more of the summer migrants are likely to be present; secondly, because their surveys were focussed around Sherbro Island and covered much more of the available habitat in this area where sand and mudflats are much more common than in the rest of the study area; and finally, because their surveys were devoted to bird counts only, as opposed to being undertaken opportunistically. Observations by Van der Winden *et al.* (2007) that water bird diversity and abundance declined rapidly with distance upstream in the creeks, certainly supports these assertions and tallies with the observations from our study.

Table 21. List of bird species recorded on the estuary during the wet (2017) and dry (2018) season surveys.

Common name	***Species***	**Gbangbaia Creek**		**Kangama Creek**		**Bagru Creek**		**Telo Creek**	**Motevo Creek**		**Teso Creek**		**Sherbro Island**	
Pink-backed pelican	*Pelecanus rufescens*						W				D		D	W
Long-tailed cormorant	*Microcarbo africanus*	D				D	W		D					W
White-breated cormorant	*Phalacrocorax capensis*													
Cattle egret	*Bubulcus ibis*	D												
Little egret	*Egretta garzetta*	D									D		D	
Great egret	*Ardea alba*	D		D				D	D		D		D	
Western reef egret	*Egretta gularis*	D		D		D			D		D		D	
Purple heron	*Ardea purpurea*					D								
Grey heron	*Ardea cinerea*	D				D			D		D		D	W
Greenback heron	*Ardea melanocephala*	D				D	W		D					W
Goliath heron	*Ardea goliathi*								D					
Hammerkop	*Scopus umbretta*	D	W		W	D	W			W		W	D	W
Wooly necked stork	*Ciconia episcopus*	D				D			D					W
Yellow-billed stork	*Mycteria ibis*								D					
Osprey	*Pandion haliaetus*				W	D	W						D	
Palm-nut vulture	*Palmiste africain*	D	W	D	W	D	W	D	D	W	D	W	D	W
Yellow-billed kite	*Milvus migrans parasitus*	D		D		D		D	D		D		D	
Water thicknees	*Burhinus vermiculatus*						W							W
Common ringed plover	*Charadrius hiaticula*	D				D							D	
Kentish plover	*Charadrius alexandrinus*	D											D	
Grey plover	*Pluvialissquatarola*	D		D		D							D	
Bar-tailed godwit	*limos lapponica*					D							D	
Whimbril	*Numenius phaeopus*	D		D							D		D	
Eurasian curlew	*Numenius aquata*						W						D	W
Little stint	*Calidris minute*	D				D	W		D	W			D	W
Sanderling	*Calidris alba*	D									D		D	
Curlew sandpiper	*Calidris ferruginea*	D				D			D				D	
Ruff	*Combattant punax*	D											D	

Common name	Species	Gbangbaia Creek		Kangama Creek		Bagru Creek		Telo Creek	Motevo Creek		Teso Creek		Sherbro Island	
Common redshank	*Tringa totanus*	D				D			D				D	
Common greenshank	*Tringa nebularia*	D				D							D	
Marsh sandpiper	*Tringa stagnatilis*					D							D	
Wood sandpiper	*Tringa ochropus*	D				D								
Common sandpiper	*Actitis hypoleucos*	D	W	D	W	D	W		D	W	D		D	W
Ruddy turnstone	*Arenaria interpres*						W							W
Royal tern	*Thalasseus maximus*	D		D		D	W				D		D	W
Gull-billed tern													D	
Sandwich tern	*Thalasseus sandvicensis*	D				D			D		D		D	
Common tern	*Sterna hirudo*												D	
Arctic tern	*Sterna paradisaea*												D	
Little tern	*Sternula albifrons*	D				D	W		D				D	W
Little swift	*Apus affinis*		W											
Malachite kingfisher	*Corythornis cristatus*	D	W	D	W			D		W				
Pied kingfisher	*Ceryle rudis*	D	W	D	W	D	W	D		W		W		W
Giant kingfisher	*Megaceryle maxima*							D						
Rock martin	*Ptyonoprogne fuligula*	D												
White-throated blue swallow	*Hirundo nigrita*										D			
Preuss's cliff swallow	*Petrochelidonpreussi*	D	W											
Africa pied wagtail	*Motacilla aguimp*									W				
Brown sunbird	*Anthreptes gabonicus*	D		D										
Total number of species		**31**	**7**	**11**	**7**	**27**	**16**	**6**	**18**	**9**	**14**	**4**	**29**	**16**

Van der Winden *et al.* (2007, 2009) also highlighted the same four areas as Tye & Tye (1987) as being the most important areas for water birds in Sierra Leone. In terms of national importance, they rated Sherbro River Estuary to be on a par with the Scaries River estuary but less important than Yawrie Bay, and more important than the Sierra Leone River estuary (Figure 45). Species highlighted as being particularly important in the Sherbro River estuary (in terms of the numbers recorded) included *Tringa totanus* (Common redshank), *Gelochelidon nilotica* (Gull-billed tern), *Thalasseus bengalensis* (Lesser crested tern), *Sternula albifrons* (Little tern) and *Rynchops flavirostris* (African skimmer). Van der Winden *et al.* (2007, 2009) recommended that based on their findings (total numbers of water birds and the species highlighted above), that Sherbro Island should be designated as a Wetland of International Importance in terms of the Ramsar Convention, and that this area should be designated as an Important Bird Area.

Table 22. Species composition and numbers of water birds recorded by Van der Winden *et al*. (2007) at Sherbro Island in February 2005. Those highlighted in bold were recorded during this study.

Species	No.
Long tailed cormorant	45
Pink backed pelican	**43**
Cattle egret	4
Green-backed heron	**70**
Black egret	28
Western reef egret	**378**
Little egret	158
Great white egret	101
Purple heron	1
Grey heron	**87**
Goliath heron	4
Hamerkop	**2**
Yellow-billed stork	3
African open billed stork	1
Woolly-necked stork	**39**
Sacred ibis	7
African spoonbill	11
White-faced whistling duck	156
Osprey	**6**
Yellow billed kite	53
African fish eagle	3
Palm-nut vulture	**93**
Black crake	1
Purple swamphen	2
African jacana	6
Eurasian oystercatcher	32
Common ring plover	751
Kentish plover	14
Grey plover	685
Sanderling	226
Little stint	**4**
Curlew sandpiper	2 090
Black-tailed godwit	8
Bar-tailed godwit	617
Whimbrel	**738**
Eurasian curlew	**20**
Common redshank	2 282
Common greenshank	201
Common sandpiper	**585**
Ruddy turnstone	**32**
Grey-headed gull	1
Gull-billed tern	130
Caspian tern	8
Royal tern	**815**
Lesser crested tern	43
Sandwich tern	579
Common tern	994
Little tern	**282**
Black tern	1 769
African skimmer	240
Grey-headed kingfisher	1
Blue-breasted kingfisher	**2**
Malachite kingfisher	7
Shining-blue kingfisher	1
Giant kingfisher	2
Pied kingfisher	**54**
Total	**14 515**

Figure 44. Sandwich (black bills) and Royal (yellow bills) terns at Sherbro Island.

No aquatic reptiles or mammals were recorded during this survey, but corresponds with the findings of Van der Winden *et al.* (2007) who also recorded low numbers of aquatic mammals and reptiles in their surveys. They recorded Nile crocodile, *Crocodylus niloticus,* in low numbers at the three other major coastal wetland sites in the country (Scarcies River, Sierra Leone River estuary and Yawri Bay) but not in the Sherbro River Estuary. They also recorded West African Manatee at the Great Scarcies River estuary but not at any of the other estuary sites. They reported that local fishermen had mentioned that manatee were still present in the Sherbro River Estuary at the time that their surveys were conducted (2005), but that these animals were killed whenever they were encountered. It is not clear whether they still exist in this area, but it is likely that this is not the case. Van der Winden *et al.* (2007) also recorded Clawless otter (*Aonyx capensis*) from the Sierra Leone River estuary but not in any of the other systems that they surveyed.

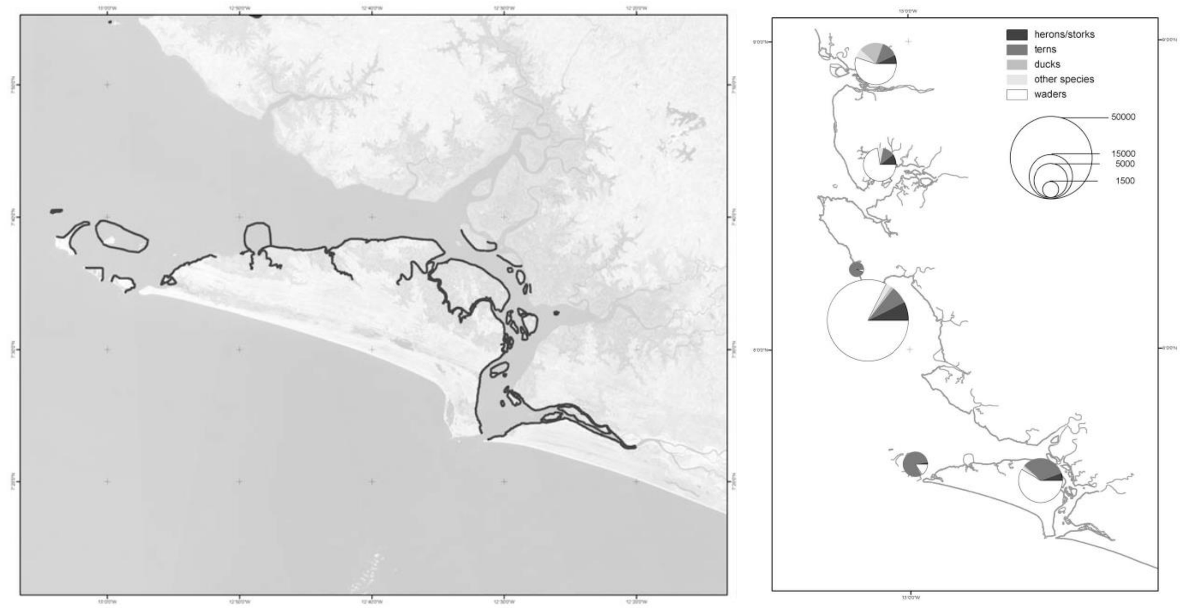


Figure 45. Portions of the Sherbro River Estuary counted by Van der Winden *et al*. (2007, 2009) (left) and their estimation of the national importance of the Sherbro River Estuary relative to other estuaries in the country (right).

Although no mammals were encountered in the mangroves during the 2018 dry season survey, several mammal tracks were evident in some of mangrove transects. Otter and monkey tracks were abundant in the Motevo Creek and Bagru Creek transects and a single feline track was further noted in the Motevo Creek transect (Figure 46). The otter track is likely to be that of the Clawless otter as this species as it has previously been recorded in Sierra Leone estuaries (Van der Winden *et al*. 2007). The monkey tracks could be from several different species which utilise mangroves for refuge and food resources. The monkey species typically associated with mangroves include Campbell's monkey (*Cercopithecus campbelli*) which has been noted to readily adapt to mangrove forest where it forages on mangrove leaves, *Rhizophora* spp. propagules, crabs, shrimps and mud skippers (Grubb *et al.* 1998, Kingdon *et al.* 2013). The Green monkey (*Chlorocebus sabaeus*) it a noted good swimmer and readily feeds on fiddler crabs associated with mangrove habitats (Galat & Galat-Luong 1976, Kingdon *et al.* 2013). The Western red colobus (*Procolobus badius*) utilises mangrove forest as refuge and a food source as a means to increase survivorship (Galat-Luong & Galat 2005, Kingdon *et al.* 2013).

Figure 46. Monkey tracks through the mangrove *Rhizophora racemosa* band adjacent to the channel in Motevo Creek (left). Otter tracks in the *Rhizophora racemosa* band adjacent to the channel in Motevo Creek (middle) and a feline track in the *Rhizophora mangle* band along the Motevo Creek transect.

4.8 Human use

Extensive fishing activity or evidence of fishing was observed in all the creeks surveyed during 2017 wet season survey. Three main types of fishing gear were observed: gill nets, long lines and purse-seine netting (shrimp traps were also seen at villages but not in use). Most commonly, monofilament or multifilament gill nets ranging from tens to several hundred meters long, with mesh sizes ranging from ~20 mm up to 200 mm were deployed by 2-4 fishers from non-motorised, wooden canoes (Figure 48). This type of fishing was practised throughout the study area, but the highest densities of fishers were encountered near the mouth of the Bagru Creek in the lee of Sherbro Island and in the lower stretches of Motevo Creek. The gill nets were deployed perpendicular to the estuary banks, i.e. across the channel, and fishers drifted with the nets mostly during ebb tide. Time was not spent sufficiently in one area long enough to determine the “usual” soak time of these gill nets during this survey, but it is suspected to be a tidal cycle (~6 hours). These gill nets mostly target pelagic species such as clupeids (sardinellas) and mullets, although bentho-pelagic sciaenids (croakers) and Polynemidae (threadfins) were also present in the gill net catches.

Weighted long lines made from a braided multifilament line of varying lengths (30->100m) with hooks approximately 1 m apart were also deployed by many fishers using non-motorised canoes (some deployed both gear types simultaneously). The long lines were anchored and buoyed, and it is not clear what bait was used (if any), although it was observed that fishers using hand nets scoop small shrimps in shallow creeks that they said was for bait (Figure 47). Longlines predominantly target and catch demersal fish such as catfish, tonguesole and grunts. Observed catches by both gill net fishers and long liners were modest, ranging from nothing to a few kilograms per boat. This suggests that most of this fishing is of a subsistence nature although it was observed that fishers were selling their catch for cash when the opportunity arose.

Purse-seine fishing was the only observed near the open sea adjacent to Sherbro Island during the wet season but in the dry season, two purse-seines were observed operating in the lower Bagru Creek, inland of Sherbro Island. This type of fishing involved the use of a large planked canoe around 10 m in length and powered by an outboard motor. The fishing gear was a very long net (~200 m, 8-10 m deep) deployed as a purse-seine but lacking the features required to properly purse the net. The net was hauled manually by approximately 15 fishers and the catch was dominated by sardinellas (clupeids), although some large croakers (sciaenids) were also caught in the haul we observed (Figure 49). This fishing method is apparently referred to as a “Ghana boat” after Ghanaian fishers who introduced it to Sierra Leone in the 1950s (Vakily 1992). The number of crew involved and size of the catch made by these purse-seine boats suggest that this fishing method is a commercial operation.

Observed fishing effort during the dry season survey was substantially less than that seen during the wet season survey and individual vessel catches were greater. The Sierra Leonean government is reportedly implementing management measures aimed at reducing the use of monofilament gill nets throughout the country, but it is not known if this was the reason for the reduced fishing effort, or if other factors were influencing fishing activity.

Large oyster shell middens were observed at many small villages along the mangrove creeks and provided evidence of extensive oyster harvesting for subsistence purposes (Figure 50). These oysters are abundant, growing on mangrove roots throughout most of the estuary, except the very upper reaches of the creeks where salinity of tidal influence was insufficient to permit their growth. Whilst collecting oyster samples the survey team was questioned whether the chief had given permission, which suggests some customary control of oyster harvesting and this resource certainly did not appear overexploited (although there is no data on historical oyster density or sizes).

Mangrove trees (mostly *Rhiszophora* spp.) are harvested for wood poles used to provide moorings for boats at villages and to create barriers across the upper reaches of the creeks (probably also in house construction although this practice was not further investigated). These barriers were found to take the form of a line of mangrove poles embedded in the creek floor and extending approximately 1 m above the high water surface. The purposes of these barriers is not known but may be associated with fishing activities such as to secure nets or traps, or even to prevent drifting gill nets from washing into shallow areas and becoming entangled in mangrove roots. The estuaries themselves serve as an important access route for the transport of people, goods and produce (Figure 51).

Figure 47. Long line fishing gear used in the estuaries (top) and fishers using scoop nets to catch shrimp (possibly for bait).

Figure 48. Gill net fishing and catch from the Sherbro River Estuary.

Figure 49. Purse-seine fishing.

Figure 50. Oyster shell midden showing extensive and long-term harvesting of oysters from the estuaries of the study area

Figure 51. Transport vessel carrying people and goods between villages.

5 IMPACT ASSESSMENT

5.1 Assessment methodology

The impact assessment methodology follows that prescribed in the Final Scoping Report (SRK 2017) and for brevity is not repeated here. This assessment of impacts is largely based on an understanding of estuarine ecology and functioning derived from the two field surveys and available literature.

5.2 Identification of impacts

The scoping study (SRK 2017) identified High Level Potential Impacts that may arise due to current and proposed mining activities. Those that are relevant to the estuarine and marine environment are listed in Table 23 below.

Table 23. High-level potential impacts of current and proposed mining activities in SR Area 1 (SRK 2017).

Baseline feature	Potential impacts from mining operations (pre-mitigation)
Water and drainage	• Change in condition of marshes, mangroves, watercourses and riverbanks • Change in ecological flows • Contamination of surface and groundwater • Sedimentation of surface water
Geology and soils	• Loss of, or constraints to, soil resource and future land use
Flora and Fauna	• Loss or degradation of habitats • Loss of species of special concern • Loss of ecological processes • Fragmentation of habitats and ecological processes • Modification or degradation of aquatic and terrestrial ecosystems • Loss or alteration to the provision of ecosystem services
Land use (estuarine fish and other resource use)	•Loss of land used for subsistence agriculture (artisanal fishing and other estuarine resource use)

Most of these impacts are correlated and there is considerable overlap within this list. Thus, in this specialist report identified impacts were consolidated into broader groups, with the following potential impacts of mining operations on the marine and estuarine environment downstream of Area 1 having been identified and assessed:

1. Impact 1: Direct loss of estuarine habitat and biota within the mining footprint;
2. Impact 2: Modification of remaining estuarine habitat;
3. Impact 3: Fragmentation of habitats and alteration of ecosystem functioning;
4. Impact 4: Changes in the community composition and distribution of estuarine biota; and
5. Impact 5: Impacts on livelihoods, and/or loss or alteration of ecosystem services.

Our perceptions of the nature (magnitude, duration, scale, consequence, probability of occurrence) and significance of each of these identified impacts are discussed in detail below.

5.3 Impact 1: Direct loss of estuarine habitat and biota within mining footprint

Estuarine habitat falling within the proposed future mining footprint is largely restricted to the Gangama dry mining and Nitti Port areas. It is assumed that the whole of the Gangama deposit (Figure 1) will be mined in future, resulting in the removal of approximately 3 km^2 of estuarine habitat, including the estuarine channel and fringing mangrove vegetation (Figure 52). This will result in the mortality of all estuarine vegetation (predominately mangroves) and the less mobile estuarine biota in this area. Active backfilling and rehabilitation of the estuary and mangrove habitat will be difficult during the active mining period when it is assumed that saline (marine) waters will be prevented from intruding into the area as a result of normal tidal action (this will presumably be compatible with dry mining operations). It is anticipated that the sensitivity of the sediments found in mangrove stands will further complicate rehabilitation of the area, as highlighted in the Soils and Land Capability Specialist Study (Earth Science Solutions 2017) that states:

"*The sensitive soils and wet based materials (Gleysols) should not be impacted if possible. However, as part of the mine plan this is not possible (mining of the mangrove swamp areas), and these areas will need to be managed with care. The loss of soil nutrients, organic matter and the drying out of the utilisable soil during storage will result in de-nutrification and formation of hard clods, something that is difficult to mitigate without substantial mechanical inputs and energy*."

This impact assessment takes cognisance of the spatial extent of the impacted habitat type, namely the mangrove lined estuary channel, and the relative scarcity or conservation importance of this habitat type. All vegetation within these two resource areas are considered to be of least concern on the ICUN red list or have not yet be assessed and incorporated in the ICUN red list ratings. Compared to the total of 682 km^2 of this habitat type downstream of the Area 1, including Sherbro Island and the adjacent Bagru Creek mangrove delta, the direct loss of estuarine habitat and biota within the mining footprint is only 0.44% (Figure 52). The estuarine areas falling within the mining footprint will definitely be subjected to moderate impacts (loss of habitat and biota) at the local or site specific scale that will be of long-term duration and the significance of the impact prior to management is therefore MEDIUM (Table 24). This Impact is revised to be LOW significance with effective implementation of management measures (Table 24). The mine closure phase involves the rehabilitation of impacted areas and the impacts are as assessed after management.

Table 24. Assessment of loss of estuarine habitat within the mining footprint

Impact 1: Significance of impact of loss of estuarine habitat	
Activity	Loss of estuarine habitat and biota due to mining activities (land clearance, draining, excavating)
Project Phase	Current and Planned operations

Potential impact rating	Magnitude	Duration	Scale	Consequence	Probability	SIGNIFICANCE	+/-	Confidence
Before Management	Moderate -	Long Term	Site or Local	Medium	Definite	Medium	-	High
Management Measures: • As far as possible limit footprint of mining operations in estuarine habitat (channel and mangrove). If possible do not mine the channel and maintain a buffer of mangrove vegetation. • Where possible (unfortunately not the case for existing operations) undertake mining and phased rehabilitation starting at the downstream edge (closest to the sea) and move upstream. • Rehabilitate mined areas once the operational phase has been completed, this will require infilling of mined out areas with tailings (sand and clay) where possible and in accordance with the mine closure plan, restoration of estuary channel profiles, removal of barriers to tidal flows and replanting of mangrove species in the affected areas. • Rehabilitation will be a fairly intensive and complex process with mangrove propagules having to be germinated and cared for in advance of the rehabilitation measures. Efforts should be made to plant the propagules in the same zonation bands commonly found in the surrounding mangrove regions. *Rhizophora* spp. should be planted along the creek channels at the water edge in band approximately 5-10 m wide. Behind this band of *Rhizophora* spp., a mix of *Avicennia germinans and Laguncularia racemosa* should be planted, with specimens of *Conocarpus erectus* and *Dodonaena viscosa* being planted along the landward margin of the rehabilitated areas.								
After Management	Minor	Medium-term	Site or Local	Low	Possible	Low	-	Medium

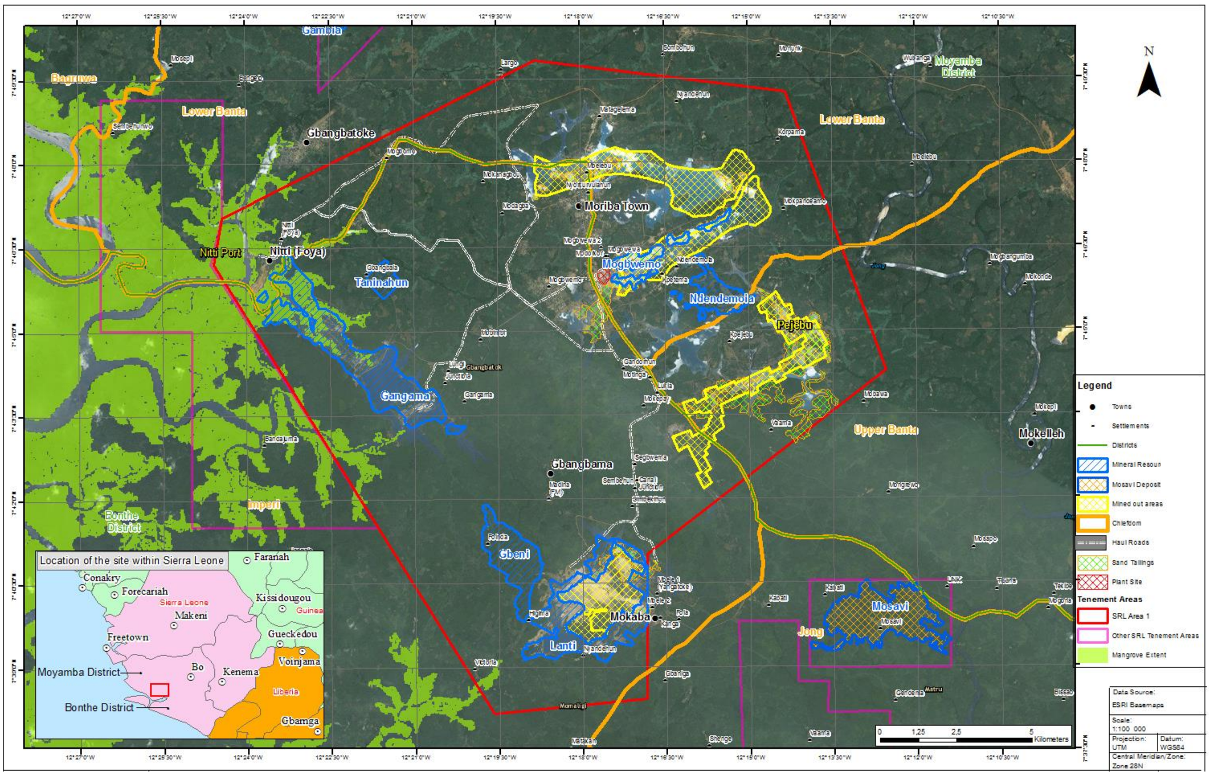


Figure 52. Estimated extent of original estuarine habitat (as depicted by mangrove extent) within Area 1. Note that only the Gangama deposit overlaps with the estuarine (mangrove) area.

5.4 Impact 2: Modification of remaining estuarine habitat

Modification of the remaining estuarine habitat downstream of Area 1 could potentially be mediated through the following three mechanisms: (1) reduction in freshwater flow, (2) increase in suspended sediments and/or turbidity, and (3) contamination with other pollutants. Each of these aspects are discussed in the respective sections below.

5.4.1 Reduction in freshwater flows

Mining activities in estuary catchments can impact estuaries by altering the quantity and quality of freshwater flows reaches these habitats. Historically, when wet mining was the predominant mining method, severe reductions in freshwater flows to the estuarine creeks downstream of Area 1 would have occurred during the period between dam construction and the flooding of the artificial impoundments. Once impoundments were filled, however, run-off probably reverted to a level that was very similar to natural conditions bar some minor losses due to increased evaporation and use of water in the processing plants. This certainly appears to be the case with the hydrological modelling showing very little change in monthly and annual flows in the Gangama and Gbeni catchments that feed the Kangama and Gbangbaia and Teso Creeks (SRK 2018; Table 25). The future planned operations involve dry mining only with a phasing out of wet mining in the near future. Dry mining should not result in reductions in freshwater flows to downstream estuaries, although water courses will be temporarily obstructed and diverted with storm water emanating from the mining pits discharged via a managed system of artificial channels and outfalls (Figure 39). It is, however, essential that freshwater flows that are similar to natural conditions (60% of average dry season flows) are maintained to all downstream estuary channels and they should not be diverted to other channels, particularly during the dry season. More substantial reductions in freshwater inputs to estuary channels (>40%) will have significant negative impacts on the ecology and could lead to substantial shifts in community composition and ecological functioning. Salinity will increase, estuarine and freshwater components of the invertebrate and fish fauna would be reduced or may even disappear from affected channels (potentially replaced by marine taxa), and changes in vegetation will occur. Mangrove vegetation zonation is heavily dependent on salinity gradients within the intertidal zone (Ball 1998a, b, 1996). Altering natural fresh water flows into the mangrove creeks is likely to alter mangrove vegetation dynamics. *Rhizophora* spp. are adapted to survival in lower salinities up to those found in seawater (35 ppt) (Beentje & Bandeira 2007), while *Avicennia germinans* is tolerant of salinities above 35 ppt and utilises an increase in salinity tolerance at the expense of growth and competitive ability to inhabit the more saline intertidal areas (Ball 1998a, b, 1996). Current and planned operations may decrease freshwater input in mangrove creeks below the mining areas, causing the intertidal areas to become hypersaline, decreasing the *Rhizophora* spp. zonation band and increasing the *A. germinans* band.

Table 25. Modelled average monthly flow rates for the Gangama and Gbeni catchments under natural and modified mining conditions (Source: SRK 2018 Surface Water Specialist study).

Month/Catchment	Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Natural conditions														
Gangama	Average	0.58	0.23	0.10	0.08	0.28	2.12	12.39	23.73	20.76	8.72	3.3	1.4	73.69
	Wet Period	0.78	0.35	0.15	0.21	0.73	6.29	22.64	35.58	28.12	14.58	5.28	1.92	116.63
	DryPeriod	0.35	0.15	0.07	0.02	0.06	0.36	1.4	16.08	8.73	1.08	1.53	0.89	30.72
Gbeni	Average	0.06	0.03	0.01	0.02	0.09	0.61	2.72	4.8	3.86	1.68	0.51	0.16	14.55
	Wet Period	0.08	0.04	0.02	0.06	0.22	1.51	4.88	6.92	5.08	3	0.87	0.21	22.89
	Dry Period	0.04	0.02	0.01	0	0.02	0.14	0.58	3.56	1.8	0.25	0.22	0.1	6.74
Modified Mining Conditions														
Gangama	Average	0.57	0.23	0.10	0.08	0.28	2.08	12.18	23.33	20.41	8.57	3.24	1.38	72.45
	Wet Period	0.77	0.34	0.15	0.21	0.72	6.18	22.26	34.98	27.65	14.3.4	5.19	1.89	114.67
	DryPeriod	0.34	0.15	0.07	0.02	0.06	0.35	1.38	15.81	8.58	1.06	1.50	0.88	30.20
Gbeni	Average	0.06	0.03	0.01	0.02	0.08	0.56	2.51	4.43	3.57	1.55	0.47	0.15	13.44
	Wet Period	0.07	0.04	0.02	0.06	0.20	1.40	4.51	6.39	4.69	2.77	0.80	0.19	21.15
	Dry Period	0.04	0.02	0.01	0.00	0.02	0.13	0.54	3.29	1.66	0.23	0.20	0.09	6.23

5.4.2 Increased turbidity

Run-off from cleared mining areas, access roads and sediment stockpiles, where vegetation has been cleared, will flow at a greater velocity than under natural conditions, and increased erosion will result in an increase in the sediment load carried by the water. This will, in turn, result in increased turbidity in downstream estuaries. Elevated turbidity due to run-off from mining areas would be most obvious during the wet season and the August 2017 survey did record lower Sechii depths and higher total suspended solids (TSS) in the Gbangbaia and Kangama Creeks that drain the Gangama dry mining area than in the upper Bagru, Moteva and Teso Creeks (Figure 9, Figure 10). TSS at the upper Bagru Creek B1 and B2 sites was noticeably lower than that recorded in the Gbangbaia and Kangama Creek stations, which would more than likely not be the case under natural conditions given the relative size of the rivers and catchments, but increased sharply after the confluence at site B3, indicating that the source of much of the suspended sediments were the creeks that drain Area 1. Tidal action and proximity to the sea (with marine waters generally being less turbid than the river water) and phytoplankton complicate the interpretation of turbidity data. For example, the high TSS values at Sherbro Island stations are correlated with high Chl-a values indicating phytoplankton rather than inorganic sediment as the source of elevated turbidity. In general, though, available data indicate elevated turbidity in the creeks draining the Gangama dry mining area. Elevated turbidity downstream of Nitti Port (G4-G6) also suggests that the source of some of the suspended sediment may be erosion from roads, cleared areas and bauxite stockpiles not neccersarily associated with SRL's activities.

Increased turbidity and sediment can negatively impact estuarine ecosystem functioning in several ways. Some fish species, typically pelagic species that are visual predators, are intolerant of high turbidity, whilst very high concentrations of suspended fine sediments may clog fish gills and interfere with respiration. Affected species will typically leave the impacted area changing the composition and abundance of the ichthyofauna. Benthic invertebrates, particularly those that filter-feed, are susceptible to the effects of turbidity as many lack the mobility inherent to fishes. They will ingest higher levels of inorganic material filtered from the water, which in turn can result in lower growth rates, starvation and, in the worst cases, mortality. The higher the turbidity, the less light is able to penetrate through the water column. This is likely to cause a temporary decrease in the productivity of autotrophic microphytobenthos and phytoplankton. Changes in the primary production and benthic invertebrates, will have knock on effects throughout the food web and will also effect higher predators, such as fish and birds. The removal of vegetation for mining of the mineral deposits is likely to result in increased sediment loads flowing into the mangrove creeks which in turn will affect mangrove vegetation downstream. If mangrove clearing is not strategically done (i.e. during the dry season), operations could result in large sediment loads being carried downstream and being deposited in the intertidal mangrove habitat, possibly smothering germinating propagules and affecting future mangrove regeneration.

5.4.3 Other pollutants

Mining activities may also release trace metals and other minerals into estuarine environment via surface water flows, whilst the use of heavy and light machinery, port activities and shipping carries a risk of hydrocarbon pollution of estuary habitats. Trace metal concentrations measured in sediment and biota during the field surveys did reveal some enrichment of arsenic, chromium, zinc, copper and lead, but these are not obviously attributable to mining activities within Area 1 (or any clear anthropogenic source). Testing of sediments samples for hydrocarbon pollution indicated only limited contamination below guideline levels at Niti Port and hydrocarbons were not detected at any other stations. These preliminary results suggest that pollution of estuary waters due to mining activities is not taking place but this should be confirmed by more regular monitoring.

5.4.4 Impact assessment

The modification of downstream estuarine habitat impacts due to mining activity is assessed as moderate intensity but will take place over the long term on a regional scale (extensive estuarine area outside of the site activity will be impacted) and is thus rated as HIGH negative significance without effective management. Successful implementation of management measures is assessed to reduce this impact to MEDIUM negative significance (Table 26). Mine closure phase will entail various activities (e.g. mixing of dredge mining sand and clay tailings, relocation and disposal of stock piles, reshaping and reprofiling of pit high walls and pond retaining dam walls, etc.) that will create temporary negative impacts on the downstream estuarine environment that are the same as those expected under current and future mining operations. In the long-term, once rehabilitation activities are complete, the impacts of the closure phase are expected to be the same as assessed after management below.

Table 26. Impact Assessment of modification of downstream estuarine habitat

Impact 2: Modification of downstream estuarine habitat								
Activity	Modification of estuarine water quantity and quality due to mining activities (land clearance, draining, excavating, storm water management, ore transport)							
Project Phase	Current and Planned operations							
Potential impact rating	**Magnitude**	**Duration**	**Scale**	**Consequence**	**Probability**	**SIGNIFICANCE**	**+ /-**	**Confidence**
Before Management	Moderate	Long Term	Regional	High	Possible	High	-	Medium
Management Measures: • Ensure that freshwater flow into each of the mangrove creeks is at least 60% of the natural base flow especially during the dry season. • Ensure vegetation clearing and soil disturbance is conducted during the dry season to limit erosion sediment loads flowing into the lower reaches of the mangrove ecosystem. • Follow recommended management measures in the Soils and Land Capability Specialist Study (ESS 2017) to minimise erosion of stockpiled soils specifically during the wet season. • Ensure there is adequate storm water management to prevent erosion from the newly exposed mining areas and transport of sediment into the lower reaches of the mangrove channels. Adhere to recommendations of the storm water management system (Figure 53). • Maintain and regularly service all equipment so as to minimise the risks of hydrocarbon spills. • Develop and implement a comprehensive water quality monitoring programme that includes sites where it enters the estuarine system and at stations in the vicinity of Nitti Port and along the ore transport route. • Develop and implement spill management and clean-up plans to prevent and or remediate pollution incidents								
After Management	Minor	Long-term	Local	Medium	Possible	Medium	-	Medium

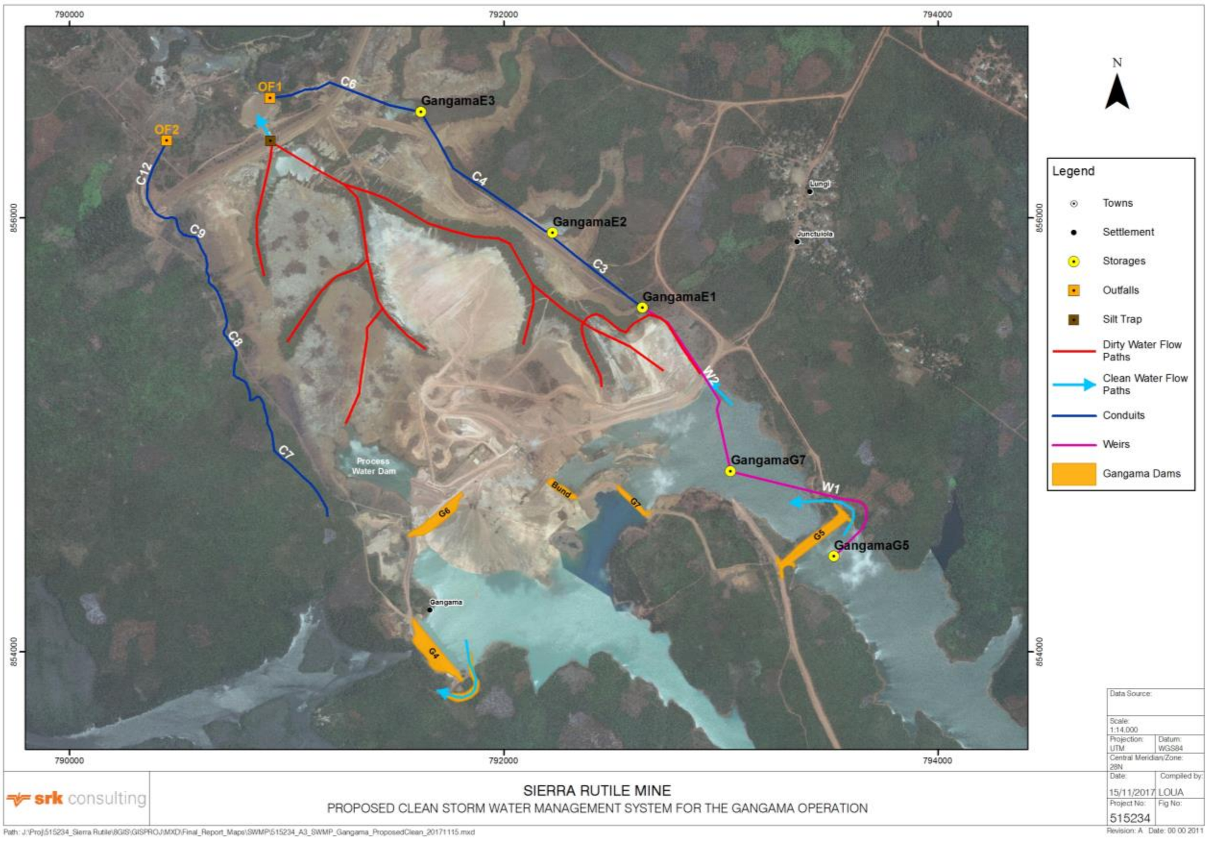


Figure 53. Proposed storm water management system for Gangama dry mine (source SRK 2018 Surface Water Specialist study)

5.5 Impact 3: Fragmentation of habitats and alteration of ecosystem functioning

Mining operations have the potential to act as a barrier to the migration of marine, freshwater and estuarine biota between the estuary and upstream freshwater habitats. Freshwater habitats upstream of the mining sites are not insignificant. For example, rivers upstream of the Gangama dry mining activities drain a catchment of 175.1 km^2 (Figure 54). There is insufficient life history information available on the biota of the study area to conclusively categorise fish or invertebrate species as anadromous or catadromous (i.e. species that require a freshwater or marine phase in order to complete their life cycles). It is, however, evident from this baseline survey that the biota of the estuaries include diverse freshwater, estuarine (brackish) and marine groups that will seasonally shift their distributions to suit their environmental requirements. The wet season survey indicated that the freshwater group makes a significant contribution to the estuarine fish fauna; however, it was not possible to establish the extent to which this may have been reduced by barriers created during historical mining operations. It is likely though that during the wet season, barriers to downstream migration are not significant as existing artificial impoundments have spill overs and the high flow rates would facilitate the movement of biota downstream. However, during the dry season, these freshwater species would need to shift their distribution upstream, whist estuarine and marine species would expand their distributions inland. Existing and proposed dams, outfalls, silt traps and spill overs of the storm water management systems required for dry mining activities may well constitute a significant barrier to upstream migration of biota during the dry season (Figure 53). The partial separation of estuarine habitats from inland freshwater habitats either through the creation of physical barriers, or unsuitable habitat in mined areas, could have negative impacts on estuarine biota potentially leading to changes in species composition, reduced diversity and abundance. Due to the regional nature of this impact (potentially throughout the catchment) and the long-term duration, this Impact is rated as HIGH negative significance without and MEDIUM negative significance with effective management (Table 27). Closure phase activities include lowering pond dam retention walls but this will not completely remove the barriers to migration of estuarine and freshwater biota. The impacts associated with mine closure phase on the estuarine environment therefore remain as assessed with effective implementation of management measures.

Table 27. Impact Assessment of fragmentation of habitats and alteration of ecosystem functioning

Impact 3: Fragmentation of estuarine habitat and alteration of ecosystem functioning								
Activity	Creation of barriers to migration and fragmentation of habitat due to mining activities (land clearance, draining, excavating, storm water management)							
Project Phase	Current and Planned operations							
Potential impact rating	**Magnitude**	**Duration**	**Scale**	**Consequence**	**Probability**	**SIGNIFICANCE**	**+ /-**	**Confidence**
Before Management	Moderate	Long Term	Regional	High	Possible	High	-	Medium
Management Measures: • Ensure that freshwater flow into each of the mangrove creeks does not drop below 60% of the natural base flow, especially during the dry season. • Design and manage diversion channels and outlets so as to allow migration of biota both upstream and downstream. • Create diversion channels that by-pass active mining pits and maintain the connection between estuarine and freshwater habitats. • Lower pond retaining walls during the closure phase at end of mine life.								
After Management	Minor	Long-term	Regional	Medium	Possible	Medium	-	Medium

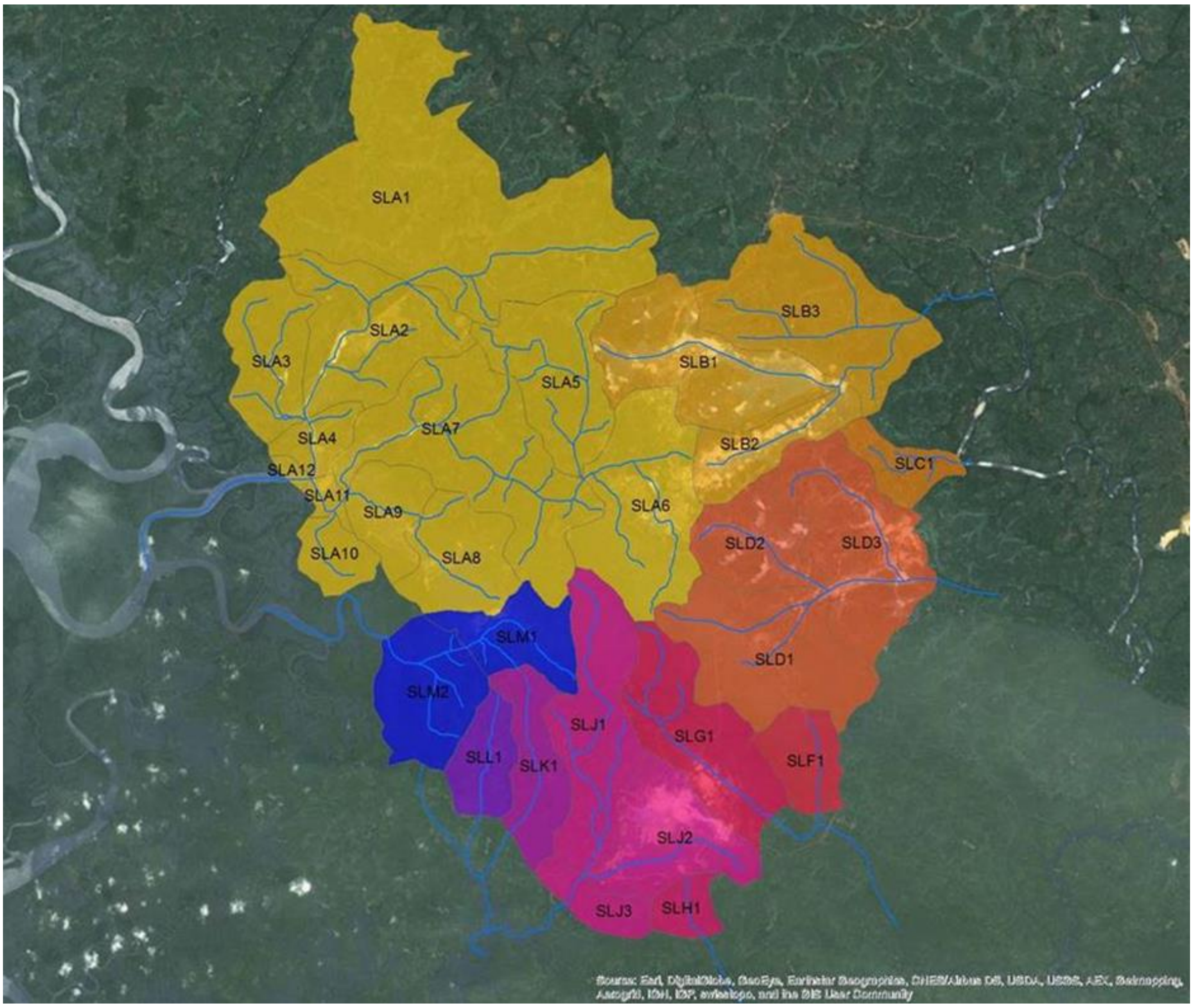


Figure 54. Catchments within the Area 1 (source SRK 2018 Surface Water Specialist study).

5.6 Impact 4: Changes in the community composition and distribution of estuarine biota

The loss of estuarine habitat within the mining footprint (Impact 1), potential deterioration in estuary water quality (Impact 2) and fragmentation of habitat (Impact 3) will potentially result in significant changes to the community composition abundance (relative abundance and biomass of different taxa) and distribution of estuarine biota. Loss of estuarine habitat will result in a nett overall loss of estuarine biota simply due to reduction in available space and resources.

Any estuarine creeks that are starved of freshwater will experience increased salinity particularly during the dry season. This will result in a decrease in the diversity and abundance of freshwater species as well as estuarine species with freshwater affinities. Depending on the magnitude of salinity increases in freshwater starved creeks, significant changes in mangrove vegetation could occur and the biota could become dominated by marine taxa with a complete loss of estuarine (brackish) and freshwater taxa.

Increased turbidity of estuary water downstream of mining activities could also cause a shift in community composition to taxa tolerant of altered conditions and a loss, or downstream shift, in the distribution of sensitive species. Pollution with trace metals and/or hydrocarbons could cause acute (mortalities) or chronic (e.g. reductions in longevity, reproductive output, growth rates) toxicity impacts on estuarine biota that would cause alterations in the abundance of affected species.

The creation of barriers to migration and the separation of estuarine and freshwater habitats would likely see a decline in diversity and abundance of estuarine species with freshwater affinities, and any catadromous or anadromous species. These species would decline in abundance both in estuarine areas downstream, and in freshwater habitats upstream of mining areas. It should also be noted that a large component of the estuarine biota (particularly fish) comprises the juveniles of marine fish species that use these warm, sheltered and productive environments as nursery areas (Wallace *et al*. 1984, Whitfield 1998). Most estuary-dependent marine species enter the estuary as larvae or post larvae (Whitfield & Marais 1999; Harris *et al.* 1999) and once the estuarine dependent phase is complete, they leave the estuary for the marine environment where they become available to marine fisheries, and upon maturity, contribute to the spawning stock (Wallace 1975a, b). These species are particularly important to the estuary as they dominate both numbers and biomass of the fish fauna in the estuary. Potential reduction in the suitability of the estuaries as nursery habitat due to the identified potential impacts of mining would therefore also extend beyond the estuarine environment into the marine realm with potential negative impacts on regional fisheries (Lamberth & Turpie 2003).

Due to the regional nature of this impact (potential changes in the community composition and distributions of biota in marine, estuarine and freshwater habitats) and the long-term duration, this impact is rated as HIGH negative significance without, and MEDIUM negative significance with effective management measure that are the same as for Impacts 1-3 above (Table 28).

Table 28. Impact Assessment of change in composition and distribution of marine biota

Impact 4: Change in composition and distribution of estuarine biota								
Activity	Secondary impact resulting from loss of estuarine habitat within the mining footprint (Impact 1), potential deterioration in estuary water quality (Impact 2) and fragmentation of habitat (Impact 3)							
Project Phase	Current and Planned operations							
Potential impact rating	**Magnitude**	**Duration**	**Scale**	**Consequence**	**Probability**	**SIGNIFICANCE**	**+ /-**	**Confidence**
Before Management	Moderate	Long Term	Regional	High	Possible	High	-	Medium
Management Measures: • As above for Impacts 1-3.								
After Management	Minor	Long-term	Regional	Medium	Possible	Medium	-	Medium

5.7 Impact 5 – Impacts on livelihoods, and/or loss or alteration of ecosystem services

The baseline estuary survey suggested a strong reliance by local communities on estuarine resources to meet basic food requirements and for sustaining livelihoods. Artisanal fishers target numerous estuarine species including oysters, crustaceans (prawns and crabs) and many species of bony and cartilaginous fish. Evidence of the use of mangrove wood poles was also documented both for fishing related equipment and homestead construction. Indeed, most of the materials used in homestead construction in settlements adjacent to the estuarine creeks appear to have been sourced locally from the estuarine habitat. The changes in community composition and distribution of estuarine species identified above will affect the value and accessibility of these resources for the local communities that are reliant on them. The important nursery function that estuaries fulfil for marine fish species also means that this ecosystem service could be compromised by mining related impacts on the estuarine environments, with potential negative repercussions for regional marine fisheries (Lamberth & Turpie 2003). The potential impacts on estuarine biotic community composition and distribution can negatively impact ecosystem functioning and lead to significant declines in the productivity of the estuarine, freshwater and marine systems. These potential declines in productivity would have a direct negative impact on the livelihoods of local communities that are clearly reliant on these estuarine resources. The potential impacts of mining activities on livelihoods and ecosystem functioning is assessed as HIGH negative significance without, and MEDIUM negative significance with effective management measures that are the same as those provided for Impacts 1-3 above (Table 29).

Table 29. Impact Assessment of potential impacts on livelihoods, loss or alteration of ecosystem services

<table>
<tr><th colspan="9">Impact 5: Impacts on livelihoods, and loss or alteration of ecosystem services</th></tr>
<tr><td>Activity</td><td colspan="8">Secondary impact resulting from loss of estuarine habitat within the mining footprint (Impact 1), potential deterioration in estuary water quality (Impact 2), fragmentation of habitat (Impact 3) and resultant changes in the community composition and distribution of biota.</td></tr>
<tr><td>Project Phase</td><td colspan="8">Current and Planned operations</td></tr>
<tr><td>Potential impact rating</td><td>Magnitude</td><td>Duration</td><td>Scale</td><td>Consequence</td><td>Probability</td><td>SIGNIFICANCE</td><td>+ /-</td><td>Confidence</td></tr>
<tr><td>Before Management</td><td>Moderate</td><td>Long Term</td><td>Regional</td><td>High</td><td>Possible</td><td>High</td><td>-</td><td>Medium</td></tr>
<tr><td colspan="9">Management Measures:
• As above for Impacts 1-3.</td></tr>
<tr><td>After Management</td><td>Minor</td><td>Long-term</td><td>Regional</td><td>Medium</td><td>Possible</td><td>Medium</td><td>-</td><td>Medium</td></tr>
</table>

5.8 Cumulative Impacts

SRL's mining and ore export activities are not the only potential contributors to impacts on the estuaries downstream of Area 1. Bauxite is also exported from Nitti Port and the haul roads, stockpiles and open areas used or created by the bauxite mining operations are also likely to contribute to impacts on estuarine water quality, whilst the potential impacts of hydrocarbon and other pollution are also cumulative, encompassing both port facilities. It was also evident that mangroves lining the creeks around Nitti Port were damaged due to mineral transport barges being pushed into creek banks and damaging the mangrove vegetation. Damage caused to the mangroves in this way leads to dieback of mangrove species and opens up the sides of the creeks to erosion and loss of mangrove habitat. This practice should cease and is easily addressed from a management point of view. Estuarine fish are also heavily exploited, primarily using gill nets which are known to have high catch and by-catch rates compared to traditional line or trap fishing methods. The apparent high fishing effort in combination with possible deterioration in estuarine habitat quality due to mining impacts can be considered a cumulative impact on the estuaries fish stocks.

6 RECOMMENDED ESTUARINE MONITORING PROGRAMME

Long-term monitoring of components of the estuarine environment downstream of the Area 1 is strongly recommended. Ongoing monitoring will serve to confirm effective implementation of the mitigation measures recommended in this report and serve to detect any impacts from future mining operations (expansion and closure). Utilizing the same methodology and a subset of the stations monitored during the ecological surveys described in this report, will provide comparable data against which any future changes can be benchmarked. A reduced set of nine sampling stations for annual wet (August) and dry (January) season sampling downstream of current and future planned mining operations within Area 1 have been identified (

Figure 55).

At each station the following should be monitored:

1. **Water quality**. Surface and bottom water temperature, salinity, dissolved oxygen and pH should be measured using a portable, electronic water quality instrument. Sechii depth as an indicator of turbidity should be recorded. Surface water samples must be collected and filtered using glass fibre filters for determination of Chlorophyll-a (an index of phytoplankton biomass) and total suspended solids.
2. **Sediment quality**. Subtidal samples (250 ml) of sediment should be collected from the creek channel at each station using a van Veen grab. Sediment samples should be analysed for granulometry (grain size distribution), total organic content and poly-aromatic hydrocarbons (PAHs).
3. **Macrobenthos**. Collection of macrobenthos at each station should be conducted using a Van Veen grab and sieving the samples through a 1 mm mesh. Preserved macrofauna should be identified to species level where possible and enumerated. Invertebrate community structure should be compared to control and baseline samples using multivariate statistical software.
4. **Biomonitoring**. Oysters should be collected at all stations during the wet and dry season (where possible) and the flesh analysed for trace metal content.

In addition to the above, mangrove vegetation should be monitored once per year during the dry season survey, repeating the baseline transects undertaken in Gbangbaia, Kangama and Motevo Creeks. Sampling should be conducted using the Point-Centred Quarter Method (PCQM+ protocol) as described by Dahdouh-Guebas & Koedam (2006). Mapping of mangrove extent throughout the study area using remote sensing data (Landsat) should be undertaken every 3-5 years to quantify any changes in the spatial area of mangrove vegetation.

The implementation of an ongoing artisanal fishery monitoring programme should be investigated in collaboration with the Sierra Leonean government. This monitoring programme should record representative catch and effort by the local fishers in all areas between Sherbro Island and Area 1. Survey clerks should be recruited, trained and deployed at known fish landing sites (access point survey). If possible, the following minimum information should be recorded for each vessel monitored:

- Date
- Vessel type and size
- Number of fishers
- Gear details- type and dimensions
- Area fished (the creeks should be divided into zones)
- Hours fished
- Catch (number of fish of each species)
- Size composition of catch (measure up to 30 fish of each species from each vessel inspected).

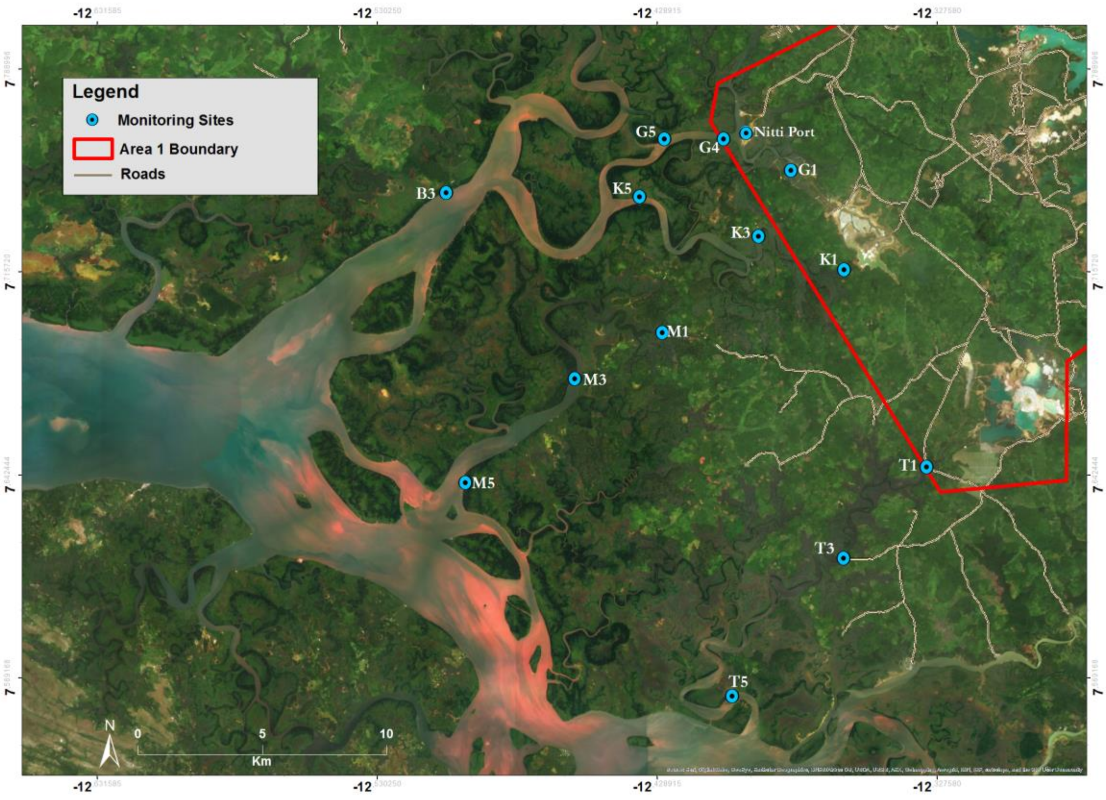


Figure 55. Stations Identified for annual monitoring of water quality, sediment and oyster tissue (biomonitoring).

Table 30. Coordinates of recommended monitoring sites.

Site	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
B3	7.744367	-12.5055
G1	7.752437	-12.3807
G4	7.763833	-12.405
G5	7.7638	-12.4265
K1	7.716411	-12.3614
K3	7.728632	-12.3924
K5	7.7429	-12.4355
M1	7.693767	-12.4273

M3	7.677083	-12.4589
M5	7.6394	-12.4985
T3	7.612221	-12.3615
T1	7.6451	-12.3315
Niti Port	7.7728	-12.3991

7 CONCLUSION

The estuarine impact assessment was informed by two estuary field surveys that that were undertaken during August 2017 (wet season) and January 2018 (dry season) as well as available scientific literature on comparable West African estuaries. These baseline surveys provided the first comprehensive picture of ecological functioning, and of the status and human use of estuarine habitats in this region. The data analysed indicated that the Sherbro River Estuary is comparable to similar systems in the West African region, and although relatively undeveloped, the estuary is not without anthropogenic impacts (particularly consumptive use). The surveys provided information on the estuarine functioning during the peak of the wet season when high river flow velocities and resultant low salinity and high turbidity were the dominant physical drivers; as well as during the dry season when marine influences and tidal action were the dominant drivers.

The assessment identified five potential impacts on the estuarine socio-environmental system:

1. Direct loss of estuarine habitat and biota within mining footprint.
2. Modification of remaining estuarine habitat.
3. Fragmentation of habitats and alteration of ecosystem functioning.
4. Changes in the community composition and distribution of estuarine biota.
5. Impacts on livelihoods, and/or loss or alteration of ecosystem services.

The assessment of these five impacts, all of which can be managed to achieve at least a medium overall significance, is summarised in Table 31. Identified cumulative impacts on the estuarine ecosystems include those associated with export of bauxite from Nitti Port and the consumptive use of living estuarine resources by local communities.

Table 31. Summary of assessment of estuarine environmental impacts potentially resulting from current and future mining impacts within Area 1.

Impact identified	Consequence	Probability	Significance	Confidence
Impact 1: Loss of estuarine habitat within the mining footprint	Medium	Definite	**MEDIUM**	High
With management	Low	Possible	**LOW**	Medium
Impact 2: Modification of downstream estuarine habitat	High	Possible	**HIGH**	Medium
With management	Minor	Possible	**MEDIUM**	Medium
Impact 3: Fragmentation of habitats and alteration of ecosystem functioning	High	Possible	**HIGH**	Medium
With management	Medium	Possible	**MEDIUM**	Medium
Impact 4: Changes in the community composition and distribution of estuarine biota	High	Possible	**HIGH**	Medium
With management	Medium	Possible	**MEDIUM**	Medium
Impact 5: Llivelihoods, loss or alteration of ecosystem services	High	Possible	**HIGH**	Medium
With management	Medium	Possible	**MEDIUM**	Medium

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