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Aquaculture and geochemistry: Considerations for food security and safety in Africa

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Aquaculture and geochemistry: Considerations for food security and safety in Africa

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Foreword

This report was compiled from discussions and co-design of activities with Odipo Osano (UoE), Christopher Aura (KMFRI), Martin Nyakinye (MoM), Samwel Otieno (MoA) and Tracey Coffey (UoN).

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Summary

This report explores the potential for BGS geochemistry and health work in Kenya underpinning Aquaculture, through linking existing partners in a multidisciplinary research partnership in exploring micronutrients and pollution pathways.

1 Introduction

This report explores the value of aquaculture to target food security in Africa, specifically Lake Victoria. This report will highlight the intricate relationship between pollution, nutrient uptake by fish and implications for consumers i.e. Food Security / safety. This will be of interest to aquaculture farmers, regulatory bodies, fish ecologists, nutritionists and Public Health Workers (PHW) in Kenya. Research on aquaculture and related inputs could inform regulatory bodies of the need to monitor fish for nutritional quality, food safety and anthropogenic pollution for Kenya and other countries in Africa rapidly increasing aquaculture production.

2 Background

Fisheries and aquaculture are currently one of the most important sources of food and indeed in some cases the only valuable source of nutrition and protein for hundreds of millions of people around the world. Further to this, both aquaculture and fisheries are an invaluable source of income and livelihoods for numerous artisanal and commercial fisheries. The increase in human consumption is attributed to the dynamic growth in aquaculture fish, which now provides almost half of all fish consumed (Figure 1).

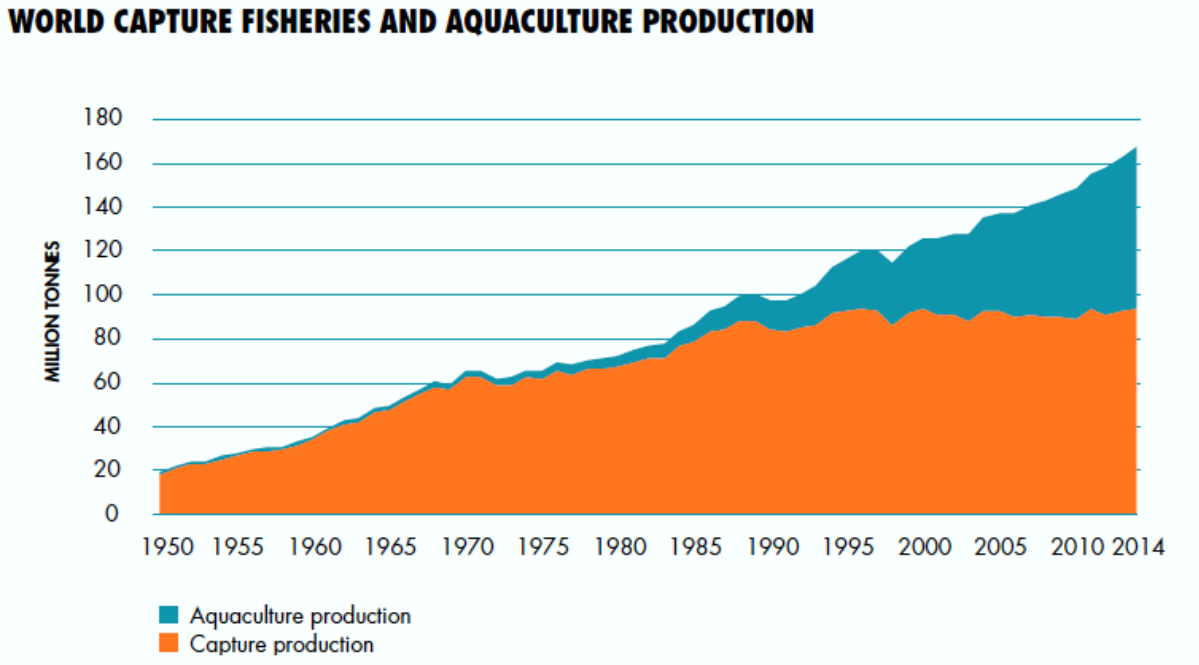

Figure 1. World capture fisheries & aquaculture production (taken from the FAO 2016 SOFIA report).

The global supply of total fish production for human consumption increased at an average rate of 3% for the years 1961-2013 (9.9kg to 19.7kg). This is set to increase further with estimates for 2014-2015 beyond 20kg (Figure 2). This substantial growth of enhanced global dietary intake of fish accounted for 17% of all animal protein consumed by 3.1 billion people worldwide (FAO, 2016). The impact of fish is an essential food source for vital amino-acids, vitamins A, B and D, minerals e.g. calcium, selenium, iron, zinc, iodine and long-chain omega-3 fatty acids. Furthermore, the nutritional benefits for early foetal growth and development, including the brain and nervous system, indicates the vital role of fish in the diet of those in many developing countries (FAO, 2016).

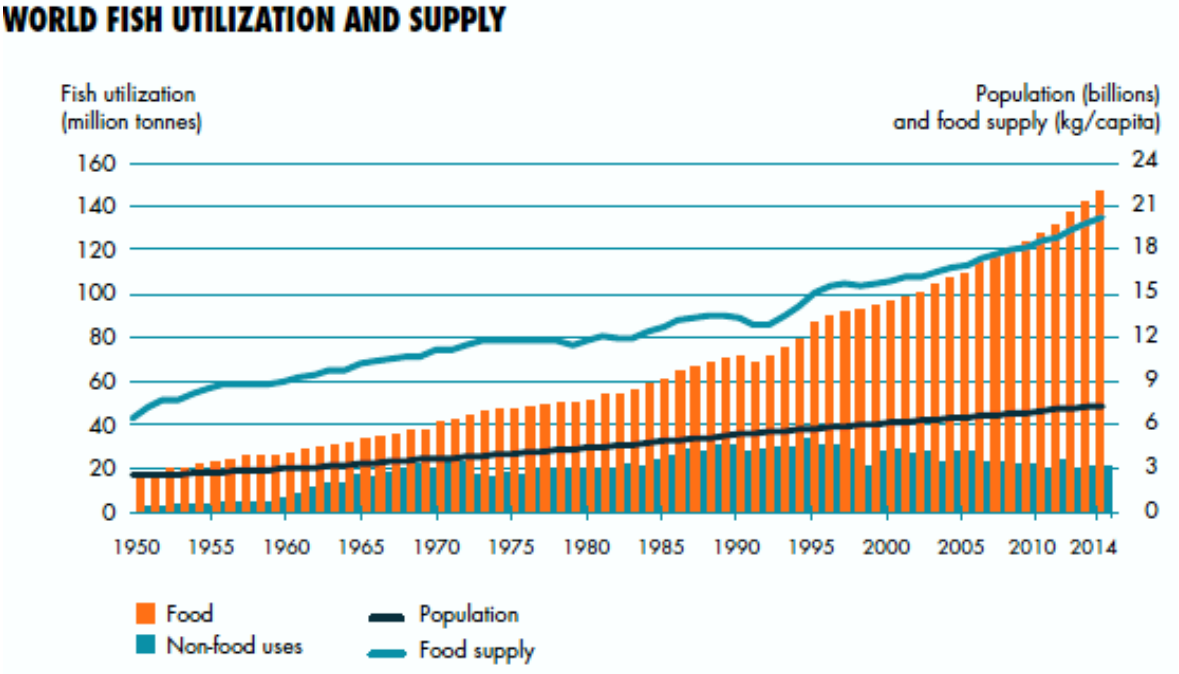

Figure 2. FAO fisheries and aquaculture utilization and supply for food consumption and per capita supply (taken from the FAO 2016 SOFIA report).

2.1 ECONOMIC CASE FOR AQUACULTURE PRODUCTION.

Production in 2014 of aquaculture fish increased to 73.8 million tonnes (c. $160 billion US), with nearly 50 million tonnes comprising fish alone ($99.2 billion US) and nearly all destined for human consumption (FAO, 2016). Global production of aquaculture fish accounted for 44% in 2014, an increase from 31% in 2004, and 2% increase from 2012 (42%). Africa represents a growing uptake of aquaculture to target food security, with Africa aquaculture comprising of 10% of all global fisheries and aquaculture production (Figure 3. FAO, 2016).

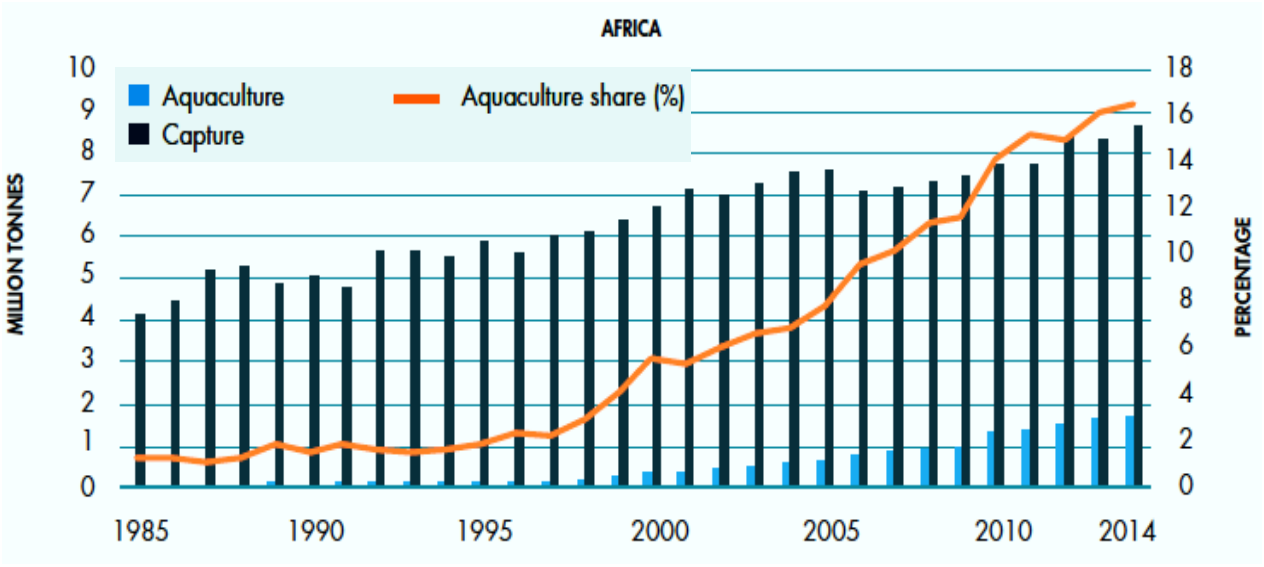

Figure 3. Share of aquaculture production and capture (excluding aquatic plants) for Africa (taken from the FAO 2016 SOFIA report).

In 2014, only one African country Nigeria, was in the top 25 of inland aquaculture fish producers (excluding Egypt) (FAO, 2016), producing over 313,000 tonnes (Figure 4). Combined aquaculture production for the main top 25 producer's equated to over 42 000,000 tonnes with 96% of the total farmed fish in the world (FAO, 2016).

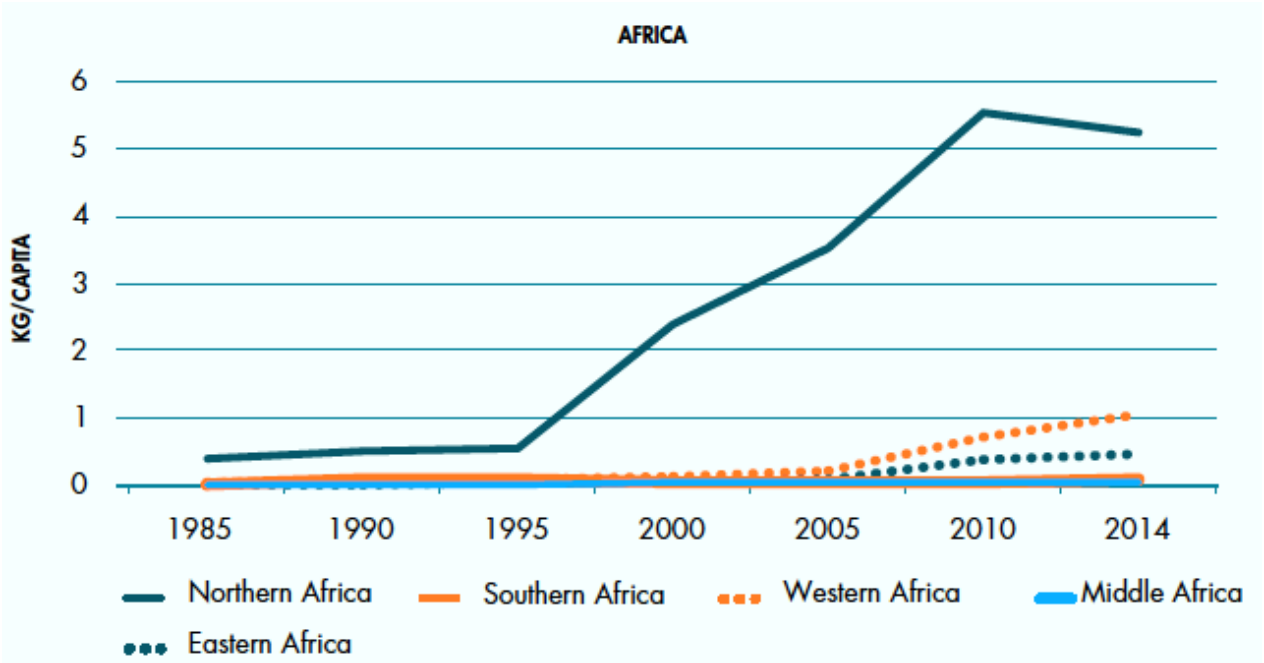

Figure 4. Per capita of aquaculture production (excluding aquatic plants) for Africa (taken from the FAO 2016 FAO report).

2.2 CASE STUDY KENYA.

With 30% of Kenya's children classified as undernourished and 10 million people overall suffering from chronic food insecurity and poor nutrition, food security, defined as improved health through food sufficiency, quality and safety, is clearly key to Kenya's economic and social development (Aura et al., 2013). Food security is influenced by availability, access to, supply, and quality or nutritional state (Abila, 2003). Climate change, droughts, environmental degradation, loss of biodiversity, livestock diseases and declining fisheries due to over-exploitation and habitat change, have increased food insecurity and malnutrition in the Lake Victoria basin. Lake Victoria is classed as a unique natural food resource (Te Lintelo, 2008; Aura et al., 2018) and plays a vital role, dominating Kenya's fish production inland and providing a major nutritional source for communities around the lake (FAO, 2015). Lake Victoria shares its shores with Kenya (6%), Uganda (43%) and Tanzania (51%) with 35% of the total fish production landed on the Kenyan portion of the lake. However, demand is outstripping production through overfishing and is threatened by anthropogenic pollution e.g. waste / sewage and mining in the region. Kenya's huge aquaculture potential, particularly the quick growing tilapia, is being exploited to boost food security (Njiru et al., 2012).

Kenya's fish industry is centred on Lake Victoria, which sustains over 40 million people and supports an industry worth £500 million/year in fish production (Njiru et al., 2012). However, multiple stressors such as overfishing, habitat change, pollution and eutrophication have depleted these stocks (Aura et al., 2018). The World Bank identified aquaculture as a route to eradicating poverty and hunger by increasing production utilising fast growing non-native tilapia (*Oreochromis niloticus*) farmed in cages on the lake and freshwater ponds (Aura et al., 2018). Whilst aquaculture is currently thought to cause no consistent environmental change, inevitably discharge of particulates such as uneaten feed, faecal and excretory products (including antibiotics) will negatively affect the ecosystem of the lake (Kundu et al., 2017; Aura et al., 2018).

Anthropogenic pollutants adversely effect physiological systems and through bioaccumulation in fish, present a potential hazard to human health unless monitored and researched. While some metals are essential trace elements (e.g. iron/copper/zinc) they are potentially toxic if ingested above recommended tolerable limits. Heavy metals such as arsenic, lead and mercury can originate from increased activities in the growth of commercial and artisanal mining, urban centre development and through increased agriculture farming. These in turn have an adverse effect through run-off into the lake basin and waterways via discharge of raw sewage, domestic and industrial waste, and fertiliser / chemicals from farms and contamination from both commercial and artisanal mining. This can be further compounded in areas where the reliance on a source of fresh fish protein is high (Campbell et al., 2003).

Sewage and agricultural/industry runoff coupled with urban encroachment results in the co-existence of metals and antibiotics within the environment, resulting in heavy metal driven co-selection of antimicrobial resistance (AMR). Enhancement of resistant bacteria at metal contaminated locations, and higher waterborne diseases in areas coupled with AMR, there are implications for ecosystem, livestock and consumer health. Our understanding of how pollution at the animal-human-ecosystem interface, and the potential risks / implications for animal / human health and food security needs to be increased if these issues are to be addressed particular with reference to Sustainable Development Goals (SDG: 1, 2, 3, 8, 11, 12, 14 and 17).

The recent increase in aquaculture in Kenya has highlighted our knowledge gaps on the impact of pollution on farmed and wild caught fish, and more importantly the understanding of farmed fish nutritional quality and food safety. In addition, exposure to particularly harmful metals can act as hidden drivers of AMR, which can cause severe infections and increased mortality in fish, combined with the dire impact of anthropogenic pollutants on the health of farmed fish. Their nutritional quality must also be understood (Okechi et al., 2016 a, b) in terms of addressing food sufficiency and micronutrient deficiency termed as “hidden hunger”.

3 Collaboration

Building on pre-existing British Geological Survey (BGS) collaborations in geochemistry and health, with the University of Eldoret (UoE), Moi University, International Agency for Research on Cancer a unit of the World Health Organisation (IARC-WHO) and the University of Nottingham, School of Veterinary Medicine and Science (UoN). For Aquaculture-geochemistry research BGS will co-ordinate activities spanning geochemistry, life sciences and health as follows with funding from a Newton grant, but will need in-kind contribution from BGS to exploit the scientific outcomes.

- UoE are the principal local partners with in-country connections to with regulatory bodies and expertise in geochemistry-human-animal health studies. UoE will contribute technical and academic personnel for gaining permissions, sample design and strategy and undertaking sample collection and preliminary sample preservation. They will provide the auxiliary sampling apparatus for management of field study logistics and organise proposed workshops with stakeholders. The UoE is key to the design, data collection and data analyses (with BGS and UoN), culminating in a report of the research outcomes.

- Veterinary School UoN will contribute expertise in microbiology and molecular biology through the analysis of bacterial load of both fish and their ecosystem. Technology transfer

will be provided to researchers in Kenya (UoE) and fisheries management on Lake Victoria by UoN who will provide access to bioinformaticians through ADAC. This expands on the UoN global research themes of **Health and Wellbeing** and **Sustainable Societies** and **Life in Changing Environments** researching AMR: a global issue.

New collaborations will involve the Kenya Marine and Fisheries Institute (KMFRI), who will facilitate interaction with the fisheries industry, whilst utilising BGS links at the Ministry of Mines (Nyakinye, geology and GIS) and the Ministry of Agriculture (Otieno, studying selenium concentrations in fish tissue) will enable a multi-disciplinary approach to investigating pollution pathways impact on fish health and implications for food safety / security and human health. Based on their experience and mandate, KMFRI fully support the sampling excursions on the lake as the partner who have experience with research on pollution in Lake Victoria. They will also facilitate discussions with policy makers for the implementation of research findings to inform methods to improve food security, animal / human health. KMFR communicate regularly with their Tanzanian and Ugandan counterparts, to which KMFR will disseminate findings from collaborative research to inform better management of Lake Victoria fisheries.

4 Objectives

Objectives will initially be achieved through funding from a recently awarded Newton International Links grant in 2018 and co-funding from the BGS ODA programme.

4.1 PROPOSED ACTIVITIES

The logistics in identifying sampling locations around Lake Victoria (Kenyan side) i.e. information on anthropogenic activities and sewage / waste run off, will be discussed by the project team prior to the main fieldwork. Preliminary surveys on the lake will be conducted by technical and academic personnel from the Kenyan partners with auxiliary sampling apparatus for field studies e.g. boats.

Priority sampling will include water samples collected from areas around the aquaculture cage i.e. near surface and at depth (where possible) and filtered at each of the sampling locations. Secondary sampling (if sufficient time remains) will include water samples collected from near shore and from areas near local tributaries flowing into the lake.

Samples from both wild and caged (aquaculture) fish will be collected by the projects local fisheries team. Priority sampling will focus on caged fish from various locations of low to high stocking density and from areas identified by the project team (Kenya) as subject to possible

anthropogenic activities e.g. municipal waste discharge, contaminated land, natural hazards and mineral exploration.

Fish will be taken, kept on ice for transport back to the laboratory, and frozen on arrival prior to processing for biological analysis e.g. helminthic infestations. Fish muscle tissue samples will be collected and freeze dried for mercury (Hg) and elemental analysis by inductively-coupled plasma-mass spectrometry (ICP-MS) analyses to undertake biomarker measurements and monitor outcomes of predicted environmental exposure. Similarly, muscle tissue will be collected and where necessary preserved for microbial and anti-microbial resistance (AMR) and genome sequence analysis to investigate connections between the environment and both economic (food security) and human health concerns.

Findings from the project will be disseminated through discussions with stakeholders e.g. policy makers in fish production, fish farmers, non-government organisations (NGOs), public health bodies and consumers. Outcomes from the project will be utilised to develop policy brief publications with KMFRI. The interpretation of the project and associated geochemical surveys, water resources, contaminated land, natural hazards and impacts of mineral exploration will be discussed as future projects.

4.2 DELIVERABLES

The project team will engage with KMFRI to undertake geochemical and biological surveys of fish samples. Estimate the extent of micronutrient and protein deficiencies for the fish, and how bacteria and helminthic infestations effect fish quality in relation to chronic food nutrient insecurity and exposure to harmful elements (food safety) in humans by utilising links to the district Public health Offices in Kenya.

4.2.1 Potential for Capacity Building

- Development of new partnerships through the understanding of pollution run–off from mining on an artisanal level through knowledge capacity building with the Ministry of Mines.
- Continued communication and synergies with the Ministry of Agriculture and collaborations with research partners by combining efforts with a MoA survey on selenium in fish tissue to enable a better understanding of the nutrient quality in fish.
- Potential for training / exchanges, multi-disciplinary working and data management through dissemination of information sharing.
- Pursue new funding opportunities for future and sustainable research.

4.3 IMPACT

- To determine the nutritional quality and health status of farmed and wild fish in the Winam Gulf of Lake Victoria, mineral levels will be compared in feral and farmed fish to determine possible confounding effects of potentially harmful metal exposure on micronutrients uptake and overall food safety. Identifying potential for improved fish yield and delivery of dietary mineral supply, by involving stakeholders and fisheries management e.g. KMFRI using a pathway to economic development and social welfare.
- Via the UoN, the study will inform and educate on possible linkages between the current escalation in AMR and intractable water borne bacterial infections in the region, and contamination of the lake and ponds with metal pollutants. Through education and land / water use policy reform, it is hoped that future disease outbreaks will be subverted.

Future work will support the development of policy tools to advise local authorities, farmers and industry on best practice for the management and monitoring of the fishing / aquaculture industries within the lake region, and on optimal locations for the freshwater ponds. It will provide infrastructure, equipment and training programs to the Kenyan scientific community to assess the role of pollution in human and livestock health, which can be applied to other aquaculture systems e.g. other cultured fish species / culture systems, and other livestock sectors (e.g. poultry).

KMFRI and UoE will benefit from BGS-UoN partnership by improving longstanding collaborative research on the status of Lake Victoria and its resources. Future work will also build on an ongoing BGS-UoE research association of wider geochemistry-health research.

District Ministry of Health officials (MH) and Public Health Workers (PHW) in Kenya will be provided with information to demonstrate the nutritive value of fish, which will enable improved estimates of the extent and causes of nutritional deficiencies and food safety (pollution exposure) clarified to allow for appropriate intervention measures. Fish from the inner gulf are contaminated with pathogenic coliforms and toxic metals (Musa et al., 2011) with potential to confer AMR hitherto not studied. Information on drivers of AMR in the region will be useful for MH / PHW and the state's environmental management authority. In addition, micronutrients are essential for fish growth and information on levels in fish tissues will benefit feed manufacturers, aquaculture farmers and government fisheries workers.

The outcomes of proposed work will inform regulatory bodies to begin to identify the effects of pollution and subsequently consult wider on mitigation strategies. With improvement in the fish farm stock health, consumers will benefit from increased availability (and lower cost) due to increased production and ultimately reduced health and welfare problems. Increased efficiency

and sustainability of fish production will improve food and job security in the region (SDG: 1, 2, 3, 8, 11, 12, 14 and 17).

5 Future vision to build on the Newton funded Aquaculture project

- Improve the awareness of the input from artisanal mining and agricultural influences into local water sources and subsequently Lake Victoria utilising information from the Ministry of Mines / Agriculture. This will provide a starting point for further consultation on devising mitigation and environmental management and further improve how to implement strategies for environmental protection.
- Further work to incorporate water quality and sediment loading in the lake into the management of effective controls e.g. information on historical inputs, particle loading of sediments for secondary pollution and identify hot-spots for pollution.
- Explore the environmental influence of high concentration aquaculture cages along coastal areas of the Lake, with particular regard to particles of uneaten fish feed and waste matter from fish e.g. faecal and excretory products.
- Explore further research activities to understand the ecological impact assessment of artisanal mines discharging waste into tributaries feeding into Lake Victoria, to include sampling of sediment, micro / macro-fauna and sampling of lakes and tributaries feeding Lake Victoria which may impact on aquaculture fisheries. Allocation of time and equipment could be handled in collaboration following a recent discussion instigated with Keely Mills of the ODA team.
- Explore the relevance of aquaculture in food security for the rest of Africa, and the possibility of expanding fisheries and aquaculture to sustainable levels (avoid environmental degradation) to supply the increasing demand for fresh fish.

Glossary

ADAC Advanced Data Analysis Centre
AMR Antimicrobial Resistance
BGS British Geological Survey
FAO Food and Agriculture Organization of the United Nations
GIS Geographical Information System
HMR Heavy Metal Resistance

IARC International Agency for Research on Cancer

ICP-MS Inductively-coupled plasma mass spectrometry

KMFRI Kenya Marine and Fisheries Institute

MH The Ministry of Health

MoA Ministry of Agriculture

MoM Ministry of Mines

NGO Non-Government Organisations

ODA Official Development Assistance

PHW Public Health Workers

SDG Sustainable Development Goals

SOFIA The State of World Fisheries and Aquaculture

UoE University of Eldoret

UoN University of Nottingham, School of Veterinary Medicine and Science

WHO World Health Organisation

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