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Risk of Incursion of *Aphanomyces invadans* into Lake Victoria from Zambezi River Basin

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Abstract: **The objective of the study was to determine the risk of incursion of Aphanomyces invadans in Lake Victoria as a result of importation of live fish from the countries in the Zambezi River Basin. The study utilized the quantitative and qualitative risk analysis procedure prescribed under international standards of the World Organization for Animal Health. Data and information was extracted from published literature through systematic review. A protocol for systematic review was developed and used to discipline the identification of relevant literature, methods of review and involvement of stakeholders. A narrative synthesis was done for qualitative data while quantitative data was synthesized by stochastic modelling using @Risk software.**

The study found that risk of entry would be 8.6% when risk management measures that are recommended under international standards are applied and would only be 0 if a perfect test is used in the selection of traded fish stock. Exposure assessment indicated that, given entry and release of A. invadans, the agent would likely be disseminated to susceptible fish species in Lake Victoria. There would both direct and indirect consequences of exposure to A. invadans which will be non-negligible. Risk estimation was also non-negligible.

The study demonstrated that risk avoidance and risk reduction are management options available to the aquatic animal health authorities in East African Community Partner States. It concluded that the findings of the study are useful in influencing policy and regulatory decisions of EAC Partner States and in capacity building of aquatic animal health authorities towards targeted surveillance for Aphanomyces invadans in Lake Victoria.

Keywords: **import risk analysis Epizootic Ulcerative Syndrome Lake Victoria.**

1. INTRODUCTION

Epizootic Ulcerative Syndrome (EUS) was reported in the Zambezi River Basin in 2006 [1]. This was the first time the disease was recorded in the African continent. It is caused by the water mould, *Aphanomyces invadans* [2]. The disease first emerged in 1971 in Japan and has since been reported in four continents: Asia, Australia, Africa and North America [2].

EUS is thought to be spread through movement of infected fish or contaminated water during international trade [2]. It has little species-specificity in infection and about a hundred fish species are susceptible [3]. A few fish species such as Nile tilapia (*Oreochromis niloticus*), common carp (*Cyprinus capio*) and milk fish (*Chanos chanos*) are thought to be resistant to natural infection [2], [4]. Affected fish manifest with skin ulceration and tissue granulomatous lesions, with high morbidity and mortality, the latter more so in newly introduced fish ponds.

EUS causes heavy economic losses through deaths and debility of fish, condemnations of carcasses in trade and trade bans [5]. The disease is not zoonotic though there is usually secondary infections of the wounds by such zoonotic bacteria like *Aeromonas* species [6].

Lake Victoria is a large fresh-water mass shared between three East African Community Partner States: Kenya, Uganda and Tanzania. The lake supports a vibrant fisheries enterprise for communities in the three countries. The three countries are also net importers of live fish for ornamental fish and other aquacultures for food production [7].

The objective of the study was to determine quantitatively the risk of incursion of the agent for EUS, *Aphanomyces invadans*, in Lake Victoria in East African Community as a result of importation of live fish from the countries in the Zambezi River Basin.

2. METHODS

The study utilized the quantitative risk analysis procedure prescribed under international standards [8]. The risk question was: **what is the risk of importing at least one consignment of live fish infected with *Aphanomyces invadans* from Zambezi River Basin into Lake Victoria in one year?** Data and information was extracted from published literature through systematic review.

A protocol for systematic review was developed and used to discipline the identification of relevant literature, the methods of review, the involvement of stakeholders and the timelines of the study [9]. The study took 26 weeks. The questions that were answered using systematic review concerned the likely pathways of spread of EUS from the Zambezi River Basin to Lake Victoria in the East African Community (EAC), the status of knowledge about risk of EUS to Lake Victoria fisheries from live fish imports by EAC Partner States from River Zambezi basin countries, the status of *Aphanomyces invadans* in fish in both Lake Victoria and Zambezi River Basin and its prevalence, the susceptible species of fish in these two regions, the sensitivity and specificity of tests used in surveillance for EUS in Zambezi River Basin, the capacities and capabilities of the fish health authorities in the two regions in detecting the disease, the quarantine and border control procedures applied for managing spread of the disease and their effectiveness, and the live fish trade volumes and projections between the two regions of interest.

The protocol set out the inclusion and exclusion criteria for data sourcing, specifying that inclusion would comprise publications from year 2000 to year 2018 and these would be in peer-reviewed journals in electronic databases, grey literature limited to official government websites, done in English language and which captured studies post-positivist and quantitative studies of fish, veterinary, fisheries, aquaculture, public health and agricultural nature in Kenya, EAC, Africa, the tropics and Asia in descending order of prioritization. Additionally, included literature should have specified the methodology and results in clear detail. Publications that did not fit the inclusion criteria were excluded.

The protocol specified the databases for journals that was to be accessed which were the *Google Scholar, African Journal OnLine, GoPubMed, PubMed, Hinari* and *WorldWideScience* and official government websites. Key words were used to search the databases. The two researchers reviewed titles and abstracts of identified publications based on the inclusion criteria and the questions under consideration; for those that met the inclusion criteria, the full text was extracted and further studied for relevance for inclusion. The protocol provided room for a third reviewer in case of disagreement by the two reviewers. The number of words used in the search would be narrow or broad enough to extract an average of 30 – 40 results for consideration, if available, of which at least 2/3 would be included for each category of the subject matters. If the results were less than 30, all of them were studied.

The protocol included a form to be used for data extraction and another for quality appraisal of the results. The data extraction form captured the details of the publication, the nature of the study as well as the outcomes and results of the study. For quality appraisal, the form captured a rating of 1 to 5, the latter being highest, for the quality of methodology used in the studies, appropriateness to the study question, the weight of evidence and the confidence in the findings would be used for extracted data, with randomized controlled studies earning the most and non-peer reviewed government website documents or with clear biases earning the least. Data from government documents would be synthesized and reported separately from peer-reviewed published studies. An average rating for all papers on a study question was calculated.

Quality assurance for the protocol was provided through two independent reviews, one by Professor Paul Kanyari of Kenyatta University and another by Professor Paul Mbuthia of University of Nairobi. Their feedback was used to enrich the protocol.

According to the protocol, a narrative synthesis was done for qualitative data. Quantitative data extracted through the protocol was synthesized by way of stochastic modelling using @Risk [10]. It provided evidence for the identification of the hazard, the assessment of risk of entry of *Aphanomyces invadans* into Lake Victoria, exposure to susceptible fish and consequence of such an incursion as described in international standards [8]. Estimation of the risk of entry was carried out quantitatively using @Risk through which 3 scenarios were assessed, i.e. risk following importation of live fish without application of risk management measures, risk with pre-export testing and border control risk management measures and also risk after combination of these pre-export and border measures and also quarantine measures at the destination points in the importing EAC Partner State. The risk of exposure and of consequence was assessed through a mixture of quantitative and qualitative methods, which was the same for overall risk estimation. The estimates were "negligible" when not likely to occur, "very low" when the likelihood of occurrence was not negligible but had very low chance of occurrence; it was "high" when the non-negligible and have above-average chances of occurrence and "very high" when it would most likely occur.

Stakeholders were invited to review the findings as part of risk communication. These stakeholders were the Kenyan Director of Veterinary Services who participated as the aquatic animal health regulator, Lucy Obungu who is a policy-maker in the State Department of Fisheries in Kenya, and Professor Paul Mbuthia who is the Kenyan national focal point for aquatic animals.

3. RESULTS AND DISCUSSION

The study was the first formal assessment of the risk of incursion of EUS into Lake Victoria in the EAC from live fish imports from Zambezi River Basin. Zambezi River Basin comprises countries that are served by that river which are Namibia, Botswana, Angola, Zambia, Zimbabwe, Malawi, Mozambique and southern Tanzania [11]. The Basin borders Democratic Republic of Congo and is also contiguous to South Africa.

3.1 Hazard identification

The agent for Epizootic Ulcerative Syndrome (EUS), *Aphanomyces invadans,* was present in the Zambezi River Basin; EUS was in 2017 officially reported to the OIE by South Africa, Namibia, Zambia and Democratic Republic of Congo [12]. Botswana last reported the disease to OIE in 2007 and also in wild fish in 2010. These countries were able to detect EUS agent using OIE-recognized tests; they also make use of the OIE Reference Laboratory called Aquatic Animal Health Research and Development Division in Thailand to validate their diagnostic results [13].

EUS has never been reported to the OIE by any of the EAC Partner States on Lake Victoria, i.e. Kenya, Uganda and Tanzania; these countries have been using "general surveillance", assumed to be "passive surveillance" [12]. They also have Aquatic Animal Health Services with moderate capabilities, based on their numbers of veterinarians and their laboratory capacity notified to OIE as compared to other OIE Members [14]. EUS agent was therefore assumed to be absent in Lake Victoria fish population but there was uncertainty on the true status; a risk based surveillance for the EUS agent in Lake Victoria by any of the EAC Partner States would reduce the uncertainty on the true status of the agent.

3.2 Entry assessment

3.2.1 Entry scenario 1: Importation of live fish without risk management measures

The probability of an imported consignment of susceptible live fish introducing *Aphanomyces invadans* into susceptible fish in Lake Victoria under Scenario 1 would be the prevalence of the agent at the exportation point in Zambezi River Basin, if the agent would be able to survive the period of transportation.

Systematic review identified fifteen papers that addressed the question of prevalence of the agent for EUS and met the inclusion criteria. Thirteen of the papers were accessed in peer-reviewed scientific journals; these were [1], [3], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25]. Two of the papers, i.e. [13] and [26] were intergovernmental reports. The papers were adjudged of good quality with a ranking of 3 and above out of 5 on the quality assurance assessment. Sixty six per cent (66%) of the findings from studies on prevalence recorded it as between 0.036% and 20% while a few papers documented above 20%. The prevalence of EUS agent in fishes in Zambezi River basin was therefore assumed to be Uniform (0.036%, 20%); the findings of prevalence above 20% were considered outliers and this assumption may slightly underestimate risk.

Aphanomyces invadans is able to survive in infected fish and contaminated transportation water for 19 days [2]. Transportation by air and by road from Zambezi River basin to Lake Victoria would take less than 19 days. Therefore, the probability of *Aphanomyces invadans* surviving the period of transportation is 100%.

The EAC Partner States on Lake Victoria have no recent record of any live fish imports from countries in the Zambezi River basin; they did not formally import live fish, Harmonization Code 0301, from the region in 2017, 2016 and 2015

[7]. Nevertheless, Kenya, Uganda and Tanzania do import live fish from other regions of the world and between 2012 and 2017 imported consignments ranging from 3 to 17 tonnes per year; these imports comprised live ornamental fish (HS Code 030111), live fish excluding ornamental fish, trout, eels, carp and tuna (HS Code 030199) live ornamental fish excluding fresh water (HS Code 030119) and live trout (HS Code 030191) [7].

Live fish is most likely imported for commercial fish farms and for ornamental aquaria [26]. Live fish is traded in consignments comprising individual fish or lots of fish caught from aquaria or from the wild. Consignments are packaged depending on sizes, water temperature, species, length of journey, and whether open or closed boxes are used [27].

There is clear demand for live fish imports of the EAC Partner States on Lake Victoria presently ranging from 3 to 17 tonnes which is being met by supplies from regions of the world other than Zambezi River basin countries. It is therefore assumed that formal imports of live fish from Zambezi River basin countries to the EAC Partner States are likely to take place in the future to meet the demand of 3 to 17 tonnes or more. This demand is equivalent to 3 to 17 consignments of live fish where one consignment is assumed to comprise one box weighing one tonne carrying 200 kg of live fish [28].

Based on the assumptions made of prevalence of EUS agent in Zambezi of Uniform (0.00036, 0.2), the number of consignments of live fish imported by EAC for Lake Victoria of Uniform (3, 17), and that surveillance of EUS was done under a perfect test, @Risk model returned Risk of Entry for Scenario 1 as mean 55.67% (90% Confidence Interval (8%, 93.5%)) with prevalence having the greatest effect on the estimate of Risk.

Nevertheless, surveillance for EUS agent would not be carried out using perfect tests. Systematic review identified eleven (11) papers, six scientific and five governmental, that addressed the question of sensitivity and specificity of diagnostic tests used in EUS surveillance. The scientific papers were [2], [20], [29], [30], [31] and [32] while governmental and intergovernmental literature were [33], [34], [35], [36] and [37]. Out of these papers, two quantitatively described the sensitivity of diagnostic for EUS agent: [33] indicated the sensitivity of as 70, 74%, 75% and 80% in different sites and [32] reported the sensitivity of PCR and of Flow-Through Immunoassay as 100%, respectively.

It was therefore assumed that diagnostic sensitivity of histopathology was 70-80%; histopathology is a test recommended for confirmation of infection with the EUS agent in susceptible species of fish within known geographical range of infection with *A. invadans* [2]. The diagnostic sensitivity for PCR was assumed to be 100%. Histopathology together with PCR is recommended for *A. invadans* confirmation in other host species or on outside the known range of the agent [2].

Systematic review did not identify any paper that quantified the specificity of the common diagnostic tests for diagnostic of *Aphanomyces invadans* in live fish: histopathology and PCR; however, it was reported as “good” and “high” but not as 100% [2], [38]. It was therefore assumed that the specificity of histopathology was 80-90%, with uncertainty on the true performance; where true specificity is higher than 80-90%, the assumption made would over-estimate risk and vice versa for a lower test specificity.

The surveillance system for EUS in Zambezi River Basin, a known infected region, should be based on the histopathology test which is assumed to have a sensitivity of Uniform (0.7, 0.8). Such testing during surveillance would underestimate prevalence and conversely the Risk of Entry; true prevalence is higher and the Risk of Entry under Scenario one is therefore higher than mean 55.67% (90% Confidence Interval (8%, 93.5%)).

3.2.2 Entry scenario 2: Importation of live fish with pre-export and border risk management measures

The importation process of live fish may make use several risk management procedures such as pre-export testing at source and border inspection at the point of exportation and at the point of entry into East African Community. Live fish would be harvested from the river and moved into a quarantine facility where testing would be done. Positively-testing consignment would be withdrawn from exportation which negatively testing consignment would be packaged into a consignment for export which would be moved in the exporting border post accompanied by a veterinary certificate. At the border post, the veterinary inspector would physically examine the fish through the container; a process which would be reported at the entry border post in the EAC Partner States on Lake Victoria. Any consignment testing positive would be rejected from further movement at the exportation border post and at the importation border post which negatively-testing consignment would be allowed to proceed in the movement for trade.

The test used at the source of fish in Zambezi River Basin would likely be histopathology, with the assumed sensitivity of Uniform (0.7, 0.8) and the assumed specificity of unity. Border tests at exporting and importing points are likely to be physical examination of a sample of the fish in a consignment, which was assumed to have a moderate sensitivity of 50-60%.

For entry of *Aphanomyces invadans* into Lake Victoria fishery to take place under Scenario 2, an infected consignment of fish would have to be selected from Zambezi River, fail to be detected during testing in quarantine at source and also fail to be detected during border inspection. Scenario 2 was modelled using @Risk with prevalence of Uniform (0.00036, 0.2), sensitivity of quarantine test of Uniform (0.7, 0.8), sensitivity and specificity of border test of Uniform (0.5, 0.6) and specificity of histopathology for quarantine test of Uniform (0.8, 0.9); the Risk of Entry for Scenario 2 was 22% (90% Confidence Interval 2%, 51%) with prevalence having the greatest effect on the estimate of risk followed by the number of consignments imported and the sensitivity of the pre-export test. When modelled using PCR as the pre-export test, and which have a sensitivity of 100%, Risk of Entry was zero.

3.2.3 Entry scenario 3: Importation of live fish with pre-export, border and post-importation risk management measures

Scenario 3 was application of an additional risk management measure to Scenario 2. The imported consignment would be placed under quarantine for a period where testing would be carried out. If the tests are negative, the consignment would be released into the destination aquarium but if positive, it would be impounded and euthanized. Under this scenario, *Aphanomyces invadans* would be released into Lake Victoria fishes if the test gives a false-negative result.

Scenario 3 was modelled using @Risk with prevalence of Uniform (0.00036, 0.2), sensitivity of pre-export and post-import quarantine test of Uniform (0.7, 0.8), sensitivity and specificity of border test of Uniform (0.5, 0.6) and specificity of histopathology for pre-export and post-import quarantine test of Uniform (0.8, 0.9); the Risk of Entry for Scenario 3 was 8.6% (90% Confidence Interval 0.6%, 22.06%) with prevalence having the greatest effect on the estimate of risk followed by the number of consignments imported and the sensitivity of the pre-export test. With a lower prevalence such as the 3% in [15], Risk for Scenario 3 would be 2% and if PCR, which has sensitivity of 100%, is used for pre-export testing, Risk would be 0.

3.3 Exposure assessment

Assessment was made on exposure of *Aphanomyces invadans*, given entry and release. The infected consignment, which is the primary source of exposure, will mostly comprise more than one fish conveyed in water which also would be contaminated. *Aphanomyces invadans* is contracted in susceptible fish percutaneously through contact, especially when the skin is mechanically damaged [20]. Conveyance water serves as a fomite for the mould where it encysts when outside a fish-host and survive for an undetermined period of time under natural conditions; the agent may survive for 19 days as determined through *in-vitro* studies [2]. Morbidity varies in different fish species but is higher than 50% in newly introduced fish culture ponds during cold periods when water temperature is 18° to 22° C; for lung fish species morbidity is as high as 100%. The incubation period under natural conditions is undetermined but experimentally it may range from 4 days to 55 days depending on species and presence of stressors [34]. The minimum infective dose at natural conditions is yet to be determined but experimentally, 1 spore infected the Atlantic menhaden, 5 spores the stripped mullets, and 1,000 spores the rainbow trout. Assuming the fish species in the consignment are susceptible to *Aphanomyces invadans*, the probability of exposure is indicated by the morbidity and, given that infection follows exposure, it is higher than 50%.

Several dissemination pathways are possible with live fish imports into East Africa. The infected consignment may be destined to upcountry aquariums with no relationship with Lake Victoria. The consignment may also end up in aquariums with waterways that drain into Lake Victoria. The more direct pathway, which was assessed in the study, was importation into cage-aquariums right inside Lake Victoria; the number of cage fish farms in the lake is thought to be over 25,000 (personal communication, unpublished).

Systematic review identified 17 papers that discussed the susceptible fish species in the Zambezi River Basin and in Lake Victoria. The peer-reviewed scientific papers were 15, being [1], [2], [3], [4], [16], [17], [19], [22], [39], [40], [41], [42], [43], [44] and [45], while [13] and [57] were the two intergovernmental papers. Zambezi River Basin is home to 156 fish species among which those susceptible to EUS agent include *Clarias gariepinus, Hepsetus odoe, Clarias ngamensis, Labeo lunatus*, *Lepomis macrochirus*, *Oncorhynchus mykiss*, *Hydrocynus vittatus*, *Glossogobius giuris*, *Carassius auratus, Barbus unitaeniatus, Barbus thamalakanensis, Barbus poechii, Barbus paludinosus, Arius* species and *Acanthopagrus berda.* On its part, Lake Victoria is home to about 37 fish species and those susceptible to the EUS agent

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includes *Clarias gariepinus* (African sharptooth catfish), *Barbus paludinosus* (Straightfin Barb), *Tilapia rendalli* (Redbreast tilapia), *Marcusenius macrolepidotus (Bulldog), Schilbe intermedius (Silver catfish), Schilbe mystus* (African butter catfish) and *Petrocephalus catostoma (Churchill)* [1], [2], [4], [16], [13], [40].

There are no reported application of the quarantine and other biosecurity measures in the Lake Victoria fisheries and the fish in the released imported consignments would be expected to mingle with other fish in the cage fish farms. Where the cage farm is propagating *Clarias gariepinus*, *Barbus paludinosus* or *Tilapia rendalli,* exposure with *Aphanomyces invadans* will occur, with a probability of more than 50%.

The water temperature of the lake ranges from about 15.6 °C and 26.7°C and rarely goes outside this range [46]. Exposure and dissemination of *Aphanomyces invadans* usually occurs in cooler temperatures than that of the lake though dissemination and spread has been reported at 31.6 ± 0.65°C [22].

The Lake Victoria water is slightly alkaline with the pH ranging from 7.1 ± 0.4 to 8.3 ± 0.4 in offshore waters and 8.1 ± 0.4 to 9.2 ± 0.5 in inshore waters [47]. The stressor that is a risk factor for EUS is pH lower than that of Lake Victoria water such as 6.0 ± 0.18 to 6.6 ± 0.18 [16]. However, exposure and dissemination of *Aphanomyces invadans* has been reported at the water pH of 8.5 ± 0.46 [22].

Lake Victoria has dissolved oxygen levels ranging from *6.1* ± 0.4 mg per litre to 7.8 ± 0.3 mg per litre inshore to 3.8 ± 0.9 mg per litre to 6.6 ± 0.5 mg per litre offshore [47]. Low dissolved oxygen levels are a risk factor for EUS but outbreaks of the disease have been reported at levels of 8.3 ± 1.42 mg per litre and continued even at 9.7 ± 0.4 mg per litre.

Unfavourable water quality reduces immunity in fish susceptible to *Aphanomyces invadans* leading to skin damages that allows attachment and infection by the agent [20]. The parameters of water temperature and pH of Lake Victoria appear not very favourable for exposure dissemination of the agent. However, it is not the absolute parameters that are stressors for fish but the rapidity of changes for example following massive rainfall or cold seasons [1], [3], [20], [21]. Further, exposure and dissemination have been reported in temperatures, dissolved oxygen and pH levels like that of Lake Victoria [22]. Therefore, exposure and dissemination of *Aphanomyces invadans to Clarias gariepinus*, *Barbus paludinosus* or *Tilapia rendalli*, exposure with *Aphanomyces invadans* in the rest Lake Victoria will occur, given release from the primary cage-farm.

Other than the translocational movement of live fish, *Aphanomyces invadans* may also be carried from the cage-farm of release and transmitted through fish-eating birds and terrestrial mammals, contaminated fishing boats and equipment [3], [13]. Lake Victoria water will be a fomite for dissemination of the agent in which it may survive outside hosts for undermined period of time but experimentally about 19 days.

Sun-drying and liming of fish-ponds and other general disinfectants may be applied as measures for controlling the spread of *Aphanomyces invadans* [13], [20]. These disposal and disinfection are not possible with cage-farming in the lake as the cages are suspended in the water.

From the foregoing, exposure of *Aphanomyces invadans* to fish in the consignment of release will occur, and the agent will be disseminated to *Clarias gariepinus*, *Barbus paludinosus* and *Tilapia rendalli* in the primary cage-farm and also in the rest of the Lake Victoria; the risk of such exposure will be non-negligible, and will increase with increase in quantities imported and released. Exposure will lead to infection in these fish species with a morbidity of over 50%.

3.4 Consequence assessment

Searched under the words: "cost impact economic trade loss epizootic ulcerative syndrome" and "economics Lake Victoria fisheries", systematic review identified 11 papers, 5 scientific and 6 governmental, which had discussed the consequences attributable to Epizootic Ulcerative Syndrome and to the socioeconomic performance of Lake Victoria fisheries. The scientific papers were [48], [49], [50], [51], [52]. Governmental and intergovernmental papers were [53], [54], [55], [56], [57], [58].

Given exposure to Aphanomyces invadans, there will be direct and indirect consequences to Lake Victoria fisheries.

3.4.1 Direct consequences

At least seven fish species, i.e. *Clarias gariepinus* (African sharptooth catfish), *Barbus paludinosus* (Straightfin Barb), *Marcusenius macrolepidotus* (Bulldog), *Schilbe intermedius* (Silver catfish), *Schilbe mystus* (African butter catfish) and

Petrocephalus catostoma (Churchill) and *Tilapia rendalli* (redbreast tilapia), will be infected and develop Epizootic Ulcerative Syndrome and the probability of that consequence is very high; morbidities and mortalities will be very high, likely 50-100%. Cage aquariums in Lake Victoria which culture these fish species will encounter such consequences; the disease has been recorded as causing economic losses equivalent to 15% - 38.7% of production in fish farms [49], [52].

Fish production by quantities and value in Lake Victoria *per se*, estimated as 500,000 metric tonnes worth US$ 600 billion, is dominated by *Lates niloticus* (Nile Perch) and *Oreochromis niloticus* (Nile Tilapia), contributing 41-60% and 10-49% respectively [50], [53], [55], [56]; these two species are not naturally susceptible to the disease. The three species susceptible to EUS, Clarias *gariepinus*, *Barbus paludinosus* and *Tilapia rendalli*, account for about 1% to 5% of fish production from the lake. However, in the lakes and dams that are satellite to Lake Victoria, *Clarias gariepinus*, *Oreochromis niloticus* and *Barbus* a*pleurogramm* are the most widely distributed of the 25-28 species present [56]. These satellite lakes serve as breeding sites for these species and also as source of fish for local consumption by the local communities. *Clarias gariepinus* is also harvested for use as baits for catching Nile Perch [53]. A likely consequence of Epizootic Ulcerative Syndrome will therefore be a small loss of commercial fish production from the lake of about 1% to 5%, with commensurate low economic consequence. However, the loss of fish production in the satellite lakes and dams is likely to be high. The survival of the susceptible species will also be threatened due to high mortality rates which would be a loss of biological diversity that would likely be irreversible [59].

Epizootic ulcerative syndrome is not zoonotic. However, fish with lesions will be condemned on inspection for aesthetic reasons. Further, lesions brought about by the disease are susceptible to infections with such zoonotic bacteria as *Aeromonas hydrophila*, thereby likely to cause illness in humans such as gastroenteritis and would infections [60]. Consumers will also most likely have fear that the infected fish may be harmful to humans, precipitating a drop in overall fish consumption, a fall in prices and closure of a few fisheries facilities; [51] documented a 25-40% drop in fish prices owing to such a fear by consumers and traders. Reduction in production of fish from lakes and dams that are satellite to Lake Victoria will very likely harm nutrition and food security for the communities dependent on these fish for subsistence [61].

3.4.2 Indirect consequences

East African Community Partner States on Lake Victoria will incur costs of surveillance and control of Epizootic Ulcerative Syndrome. [48] found that EAC Partner States had limited coverage for overall fish health management. They have limited use of quarantine facilities and rarely carry out risk analysis. There was no specialized fish diagnostic laboratory that was recognized by the World Organization for Animal Health and diagnosis was being done by universities and research organizations, more so for academic reasons. Though national legislation in Kenya and Tanzania provide for fish health, no specific pathogen or disease is listed while in Uganda, the fisheries policy has no strategy for fish health management and the animal health legislation does not include aquatic animals. Incursion of Epizootic Ulcerative Syndrome will necessitate the setting up of an active surveillance system largely from scratch which will include providing for the specific disease in public policy and legislation, establishment of a detection and reporting system with supporting laboratories and an organization, training and equipping aquatic health authorities and staff and running a public education programme. Madagascar established a laboratory for epidemiological surveillance for Shrimp White Spot Syndrome at a cost of €1.4 million [62]. The costs of surveillance are therefore likely to be very high and the probability of their incurring is also very high.

Epizootic ulcerative syndrome may be controlled in a fish tank or pond through treatment of fish, depopulation with compensation and also liming of the facility once harvesting has been done [13], [52]. But in cage fish farms in Lake Victoria, treatment and control would not be possible. The disease will therefore establish endemicity and become a constant threat to production of susceptible fish species and to biodiversity.

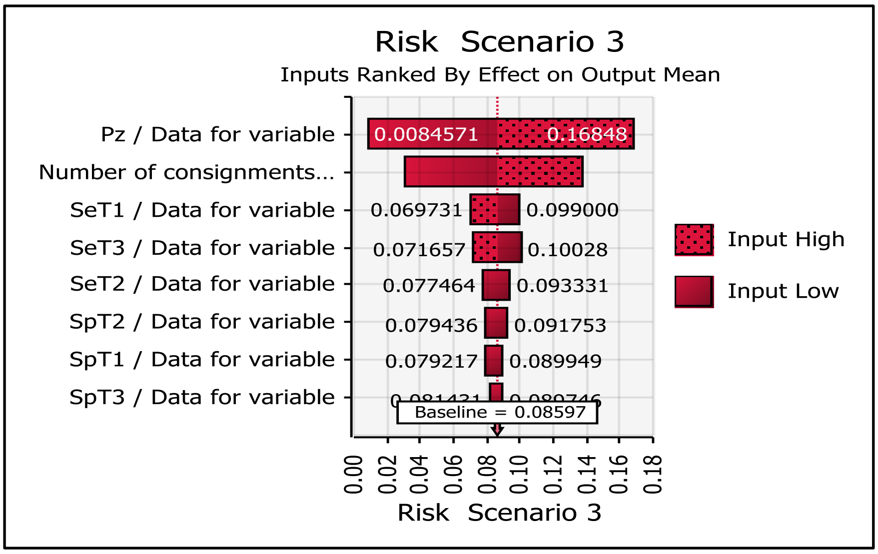
Within EAC Partner States and in the region, movement of fish and consigning water for trade purposes would be restricted to prevent the spread of the disease from Lake Victoria. This will likely lead to domestic trade losses amounting to US$ 264 million [50]. Loss of trade will also affect negatively the livelihoods supported by the industry; 3 million livelihoods are supported by the fishing industry in Lake Victoria [54]. Exports will also be affected. Epizootic Ulcerative Syndrome is a listed disease by the World Organization for Animal Health thereby requiring international surveillance. Countries free of the disease and those applying official control programmes would legitimately restrict importation of fish from East Africa owing to the disease or impose risk management measures. Such measures will include testing live fish consignments at source or importation of live fish only into quarantine stations where they will be tested or bred as well as treatment of all transport water, equipment, effluent and waste materials in order to render it free from *Aphanomyces invadans* [63]. For fish imports destined for human consumption or for processing for human consumption, such measures will include heat treatment at source in accordance with OIE standards or holding in a quarantine or containment facility while awaiting such heat treatment. Whereas exports of Nile Perch and Nile Tilapia and their products should not be restricted as these species are not susceptible to the disease, and subject to the results of a risk analysis, there may be imposition of additional requirements to prevent contamination of consignments with *Aphanomyces invadans* and their transmission of the disease as fomites.

3.5 Risk estimation

The risk of entry or release of *Aphanomyces invadans* would be high (0.556 (90% Confidence Interval (0.08, 0.935))) when no risk management measures are applied in the importation of susceptible live fish from Zambezi River Basin to Lake Victoria basin. The risk of entry would reduce to low (0.22 (90% Confidence Interval (0.02, 0.51))) when pre-export testing and border testing is applied; it would reduce to very low (0.086 (90% Confidence Interval (0.06, 0.22))) when post-entry quarantine is applied at the importing aquarium. It would become negligible (0) only when PCR or a test with equivalent 100% sensitivity is used for pre-export testing at the source. The prevalence of Epizootic Ulcerative Syndrome at the exportation area had the greatest contribution to the estimate of the risk of entry, followed by the number of fish consignments imported and the sensitivity of the pre-exportation test, as illustrated in ***Figure 1***.

Given entry, the risk of exposure to *Aphanomyces invadans* would be moderate to high where susceptible species are cultured at the importing aquarium. *Clarias gariepinus*, *Barbus paludinosus*, *Tilapia rendalli*, *Marcusenius macrolepidotus*, *Schilbe intermedius*, *Schilbe mystus* and *Petrocephalus catostoma* species would be exposed. The mode of transmission of *Aphanomyces invadans* would be through contact between fish and between fish and transporting water.

Figure 1: Results of sensitivity analysis for Scenario 3



Key

Pz - Prevalence in Zambezi

SeT1 - sensitivity of pre-export test

SeT2 - sensitivity of border test

SeT3 - sensitivity of post-import quarantine test

SpT1 - specificity of pre-export test

SpT2 - specificity of border test

SpT3 - specificity of post-import quarantine test

The risk of dissemination of the agent to the rest of Lake Victoria would be non-negligible and would increase with the number of consignments released. The modes of the wider dissemination in the lake will be through contact between fish, contact between fish and contaminated water, as well as dissemination by fish-eating birds and mammals. Exposure to *Aphanomyces invadans* by susceptible fishes will lead to infection with a high morbidity rate of over 0.51.

Given exposure to *Aphanomyces invadans*, there will be biological, economic and environmental consequences. Mortality for the *Clarias gariepinus*, *Barbus paludinosus*, *Tilapia rendalli*, *Marcusenius macrolepidotus*, *Schilbe intermedius*, *Schilbe mystus* and *Petrocephalus catostoma* would be high, likely 50-100% and all the aquaria culturing these species would suffer heavy production and economic losses. The overall fish production losses from the Lake Victoria would be low, likely 1%-5%, since the main commercially-harvested species (Nile Perch and Nile Tilapia) are not naturally susceptible to the agent. However, there will be access problems in domestic, regional and export trade due to Epizootic

Ulcerative Syndrome which will necessitate the institutionalization of very costly surveillance, control and certification measures. Moreover, susceptible species dominate in the lakes and dams satellite to Lake Victoria and which provide domestic subsistence to local communities; these species will suffer high mortality, hence high production losses, and this would likely have high impacts on human nutrition and local commerce. Eradication of the agent from Lake Victoria would not be possible due to vastness of the water-mass and endemicity would most likely ensue and pose continuous threats to susceptible species of fish; endemicity coupled with high mortality for affected fishes would have high negative impacts on biodiversity which would be irreversible.

3.6 Risk management

Aquatic animal health authorities in the EAC are responsible for protecting the health of fish in the shared Lake Victoria. The hazard may enter through any of the three Partner States, Kenya, Uganda and Tanzania and thereafter spread to all the three and precipitate consequences. The three authorities should therefore work in harmony in managing risk of Epizootic Ulcerative Syndrome. This may be achieved by enacting a regional risk management regulation at the EAC, for example under the Lake Victoria Transport Act.

None of the three EAC Partner States have determined their appropriate level of protection from Epizootic Ulcerative Syndrome. Nevertheless, being Members of WTO and OIE, they have undertaken to improve the animal health status of their countries where free status is a desired goal. It is therefore fitting to assume that their appropriate level of protection is zero or negligible risk. The risk of posed by Epizootic Ulcerative Syndrome as a result of potential live fish trade with Zambezi River Basin is therefore not acceptable.

Two management options are available to the aquatic animal health authorities for the risk under consideration, i.e. risk avoidance and risk reduction. For Tanzania which is contiguous to the Zambezi River Basin a third option of contingency planning is applicable.

In risk avoidance, aquatic animal health authorities should only allow imports of live fish from countries with the same health status as the EAC which is assumed to be “free status”. They may legitimately decline importation requests from infected countries in the Zambezi River Basin. It is noteworthy that Mozambique has been applying targeted surveillance for Epizootic Ulcerative Syndrome for several years with negative results [64]. Imports of live fish from Mozambique and from other countries deemed free of Epizootic Ulcerative Syndrome may therefore be considered.

In risk reduction, the Scenario 3 of Entry Assessment would be applicable if the aquatic animal health authorities consider that the benefits of importation are more than the costs of mitigation. In the scenario, importation would be considered from infected countries but with very low prevalence; the consignment of live fish proposed for exportation would undergo testing at source, at the border of entry and at a quarantine station at the importing aquarium in Lake Victoria. The pre-export test in this scenario should be PCR; this would be a higher standard that OIE standard for such pre-export testing but it is justified under the WTO rules of trade by the assumed free status of EAC Partner States. If this risk reduction option is taken up, it has to be monitored and evaluated during the period of actual importations to find out if it is performing as expected and adjust accordingly.

As a contiguous country to a region infected with the agent for Epizootic Ulcerative Syndrome, Tanzania may face additional threats that may be posed by informal cross-border trade in live fish. Tanzanian aquatic animal health authorities should therefore have in place a contingency plan for Epizootic Ulcerative Syndrome with the components of early detection, rapid response and, preferably, a stamping out capacity.

3.7 Risk communication

The findings of the study were subjected to review by Dr Obadiah Njagi, the Kenyan Director of Veterinary Services who was an aquatic animal health regulator.

4. CONCLUSION

The study has established that in the consideration of importation trade in live fish from the Zambezi River Basin to Lake Victoria in East Africa, *Aphanomyces invadans* would be a hazard and that there would be non-negligible risk of its entry and exposure, with marked negative biological, economic and environmental consequences. Endemicity in susceptible fish species in Lake Victoria would ensue, posing continuous threat to the fishing industry as the full range of susceptible species is still unknown. The risk elucidated by the study would be unacceptable to the aquatic animal health authorities of Kenya, Uganda and Tanzania which share Lake Victoria and these authorities may adopt the risk avoidance or risk reduction options that have been suggested.

The study predicted the future and was not based on an ongoing consideration of a request for importation. Therefore, it did not cover the full range of risk communication activities or the status of Epizootic Ulcerative Syndrome at the specific country of exportation of live fish. Future research at the time of processing live fish imports may build on the findings of this study, implement a full risk communication strategy and refine the risk assessment model developed through this study. Additionally, the assumptions made in the study can be tested through further research which may also generate more data to build on the quantitative entry assessment already done by carrying out full quantitative assessment of exposure and consequence and quantitative risk estimation. Future research may also address the risk question with pathways other than that considered in the study such as entry of *Aphanomyces invadans* to Non-Lake Victoria destinations.

The East Africa Community Partner States may use the findings of the study to build on the evidence at their disposal in making policy and regulatory decisions such as enacting or enhancing their legislation in the area of fish health in general and Epizootic Ulcerative Syndrome in particular. The findings should also trigger urgency in building the capacity of aquatic animal health authorities towards targeted surveillance for Epizootic Ulcerative Syndrome in Lake Victoria and for their official controls for managing the risk.

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