E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2019; 7(5): 224-230

www.fisheriesjournal.com
Received: 21-07-2019
Accepted: 25-08-2019

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A test of the applicability of the Lake Habitat Survey for hydromorphological monitoring of a tropical alkaline lake (Simbi) with a fisheries potential

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Abstract
The Lake Habitat Survey (LHS) is an ecological integrity monitoring tool developed for temperate lakes by an independent team of researchers to support the implementation of the EU Water Framework Directive (WFD). It has been widely applied but more testing is needed in different settings, therefore this study investigated the applicability of the LHS protocol in assessing the habitat quality of a tropical alkaline lake in the face of increasing impacts of anthropogenic pressure and climate change. The LHS metrics of Lake Habitat Quality Assessment (LHQA) and Lake Habitat Modification Score (LHMS) estimated for Lake Simbi collectively suggested that the physical habitat quality of the lake is moderate since its hydromorphology is moderately modified. In conclusion, LHS is effective for monitoring ecological condition of water bodies to inform decision making for conservation and management hence it is suitable for adoption in Kenya and the tropics as one of the standard tools for lake environmental assessments.

Keywords: anthropogenic pressures, ecological integrity, conservation value, lake Habitat modification, lake habitat quality

1. Introduction
An ecosystem is a self-governing system involving the interplay of both abiotic and biotic elements. The integrity of an ecosystem is achieved when the natural composition, structure and functioning of the ecosystem is not impaired in any way. The integrity of an ecosystem can be compromised by the natural processes of the environment and anthropogenic interventions. Lakes are lentic ecosystems that provide essential resources and ecological services. The quantity and quality of these benefits are currently facing constant threat from climate change and unprecedented pressures from anthropogenic exploitation. This therefore presents the need for constant ecological monitoring of the quality of the habitats of these systems as well as the degree of anthropogenic perturbations in them. For this reason, lakes' ecosystem integrity assessments have become prevalent all around the world. Several regions around the globe have come up with various tools for assessing the lake habitat quality. One such tool is Lake Habitat Survey, developed to assess hydromorphological alteration in support of the EU Water Framework Directive (WFD) [1], a framework established by the European Directive 2000/60/EC as guiding outline for water policy [2]. In introducing the concept of ecological status, WFD recognized that hydro-morphological alterations have potential impacts on the composition and abundance of biotic communities in surface waters. The LHS tool is highly recommended for use in assessing physical habitat of lakes in the European Union and elsewhere [3].
This tool has been widely used in countries found in European Union [4] and Australia [5], but limited use in Africa with recent trials conducted in few reservoirs in Zimbabwe [6]. The LHS method was designed to describe the shoreline of the lake habitat in terms of the vegetation cover, macrophytes assemblages, littoral substrate and the human pressures occurring along it. These elements are important drivers responsible for regulating the ecological characteristics of an aquatic ecosystem [7]. The methodology of LHS was formulated based on the Environmental Monitoring Assessment Program (EMAP) scheme developed by [8, 9] and the River Habitat Survey (RHS) which had been earlier developed in the UK. The detailed description of the LHS as outlined in [8, 9] states that the geomorphology is investigated by

having ten predetermined Hab-plots set up around the entire length of the lake and using them to examine the littoral, shore and riparian zones of the lake. In addition, the information is collected on the human pressures and development modifications happening throughout the lake. Data is mainly collected through observation of the different characteristics occurring in the Hab-plots. Since LHS provides such robust and integrative protocols for scanning the habitat quality and scale of human alterations in water bodies of conservation value, it can be valuable tool for watershed management [10].

Lake Simbi is an important national bird sanctuary in Kenya which supports massive bird populations including the nearly-threatened migratory lesser flamingos (*Phoeniconaias minor*). The lake is located in a semi-arid area characterized by heavy anthropogenic activities, making it vulnerable for degraded habitat quality. This study therefore employed LHS in the hydromorphological monitoring of Lake Simbi to establish its ecological condition with the aim of informing an evidence-based decision-making for appropriate and effective conservation and management of the lake biodiversity including the potential development of fisheries by relevant stakeholders.

2. Materials and Methods

2.1 Study Area

Lake Simbi Nyaima presented in Figure 1 is deep soda lake in Kenya that hosts colossal populations of birds, a feature that earned it the status of a national bird sanctuary with international ecotourism recognition. The lake is positioned at an altitude of 1142 m above sea level and lies at 0°22'5"N and 34°37'47"E coordinates on the Nyanzan Gulf approximately 1km from the L. Victoria. The morphometry of Lake Simbi is characterized by a maximum depth of 27.7 m, an average depth of 17 m, a surface area of 0.301 km^2 and a shoreline perimeter of 2.097 km. The lake is situated adjacent to Kendu Bay Town of Homabay County of Kenya, in a semi-arid area receiving an average precipitation of between 500 mm and 1700 mm annually with temperature range between 18 and 31 °C. Being a tecto-volcanic endorheic lake, it doesn't have any recognizable inlet or outlet. However, the water level in the lake is solely maintained by direct precipitation and the inflows from its underground hydrological framework. The lake lacks the capacity to support any fishery activities because of the extreme conditions of salt-tress and hypoxia which are not favorable for the existence of fish populations. Nonetheless, this lake is important for ecotourism, and provides scientific, cultural, religious and educational benefits.

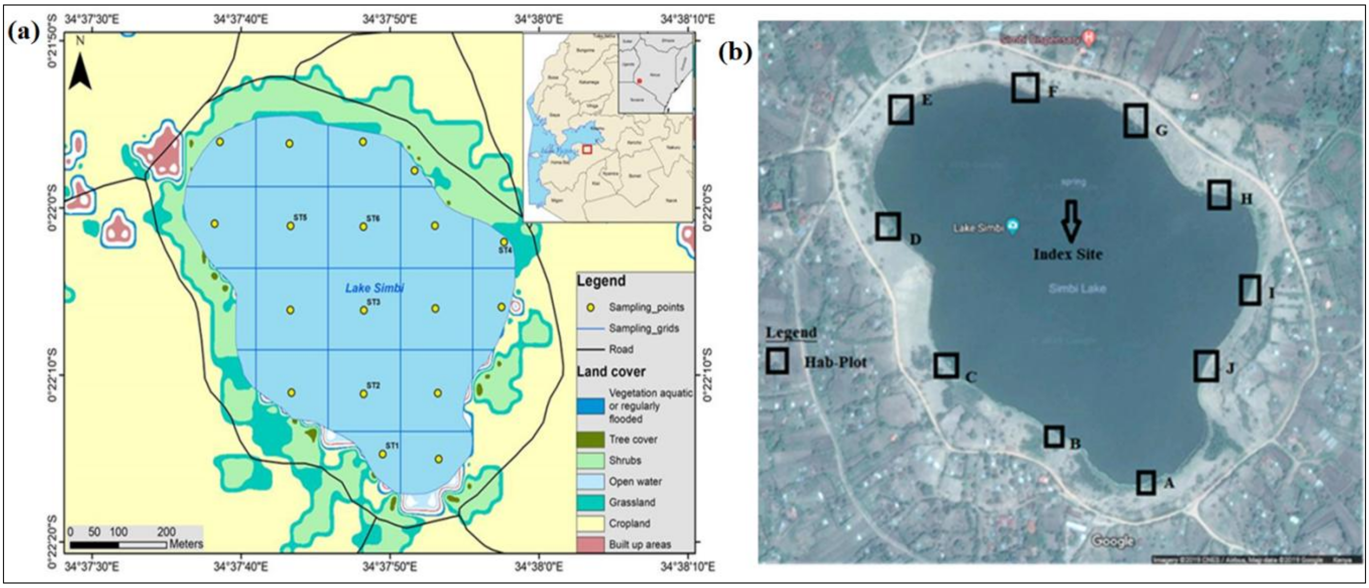

Fig 1: Map of Lake Simbi showing the land cover types (image a) and the locations of Hab-plots A-J around the lake (image b)

2.2 Lake Habitat Survey Protocol

Following the stipulated procedure for Lake Habitat Survey [11] which has been severally validated [5], LHS was done by a combination of both site surveys and desk-based data collection. Since Lake Simbi is a small lake it was sufficient for 10 habitat observation plots (Hab-plots A-J) around the perimeter of the lake (Figure 1b) to be done over two days, in February of 2019. The position of the first Hab-plot was selected randomly, with the rest distributed evenly around the lake. Each Hab-plot consists of three zones; the riparian zone, exposed shore zone and the littoral zone. For each plot, a detailed intensive data collection process was carried out by filling a standard LHS questionnaire as provided in the LHS procedure [11]. In these zones, a more detailed visual examination of the vegetation cover, the substrate properties, morphology and the human pressures were recorded and analyzed together with the more generalized visual examination of the entire perimeter of the lake. Based on this information, the two LHS metrics of Lake Habitat Quality Assessment (LHQA) and Lake Habitat Modification Score (LHMS) were estimated and scored for Lake Simbi based on the well-established LHS criteria [12, 11]. The rated scores were summed up to find the total values for LHQA and LHMS indices for the entire lake. The LHS rating system [5] (Table 1) was then adopted in characterizing the ecological condition of the lake measured by each metric as; very poor, poor, moderate, and or good depending on the indices values. LHMS is an LHS index that is designed to classify the habitat quality in terms of the degree of hydro-morphological alterations in the lake habitat resulting from the various anthropogenic activities [12]. It has a scale running from 0-42, with 0 representing least modified habitat (high ecological status) and 42 representing highly modified habitat (low ecological status). LHQA is an LHS index that is designed to quantify the degree of diversity and naturalness of the lake physical habitat [12, 6, 13]. It has a scale running from 0-112, with 0 representing a habitat that is highly degraded and low diversity, while a 112 representing a habitat that is not degraded at all and has high diversity.

Table 1: LHS Ratings of Habitat Quality and Potential Threats (EPA Victoria, 2010)

Rating	Lake Habitat Quality Assessment (LHQA)	Lake Habitat Modification Score (LHMS)
Good	>45	0 - 15
Moderate	30 - 45	15 - 30
Poor	15 - 30	30 - 45
Very poor	0 - 15	> 45

3. Results

3.1 Lake Habitat Survey

Each Hab-plot consists of three zones i.e. the littoral zone (an area which covers about 10m into the lake from the waterline), exposed shore zone (an area of variable width bound between the edge of the bank and the waterline, may be present or absent) and the riparian zone (covers an area of about 15m outwards from the banks of the shore). Hab-plot B was recorded as containing the highest number of various pressures (10) occurring within its entire length (0-50m), followed by Hab-plot C (9), then Hab-plots A, D, I and J (7), then Hab-plots E, F and G (5) and finally Hab-plot H which recorded the least number of pressures (4). In all the Hab-plots, the pressures observed stretched landwards from 15m to 50m. All Hab-plots used in Lake Simbi LHS study had more than 3 pressures occurring within both the 0-15m band and >15 – 50m band (Table 4). This is an indication that when pressures occur, they often most probably stretch landwards into the riparian zones. From these observations, the study concluded that the shoreline of Lake Simbi is experiencing an intense pressure from various competing anthropogenic activities as well as non-natural land uses as illustrated by GIS remote sensed imagery in Figure 1. Some of the most widespread pressures include farming, development of residential homes, deforestation and erosion in riparian areas.

The Lake Simbi shoreline land cover types were recorded for both perimeter bands of each Hab-plots (i.e. 0m-15m & >15m – 50m). The greatest diversity in terms of the land cover types was recorded in Hab-plots A, C and E (each had 4 various types), followed by D (had 3 types), then B and F (each had 2 various types) and the rest (Hab-plots G, H, I and J) recorded only 1 type of land cover (Table 5). The natural land cover along the shoreline habitat for Lake Simbi was established to be predominantly consisting of scrub and shrubs (with coverage ranging between 10% and 40% of almost every Hab-plot) interspersed by few tall trees with the rest of the shoreline under bare exposed ground.

The substrate characteristics for each Hab-plot (A-J) were also recorded in Lake Simbi (Table 6). The shoreline substrate material was predominantly silt and clay which was observed in all the Hab-plots with coverage of above 40%. Sand was the second most dominant substrate material in the shoreline of Lake Simbi. Sand was recorded in almost all Hab-plots, with coverage of less than 10 % observed in Hab-plots A, B, E and G, and coverage of between 10 - 40% in Hab-plots F, H and J. Only 4 Hab-plots (F, G, H and I) recorded bedrock as part of their substrate characteristics with areal coverage of less than 10%.

The habitat of Lake Simbi comprised of mainly scrubs and shrub vegetation as seen in the remote sensed image in Figure 1. The predominant species included *Acacia tortilis, Balanites aegyptiaca*, *Combretum molle,* Senna siamea and *Striga hermonthica* (Striga weed). The Lake's habitat is also having small coverage of sisal, Aloe vera and cactus plants in some hill slopes along the shores. Even though there are currently no fish in Lake Simbi, it is known to have dense phytoplankton and zooplanktons community which makes it a potential for fishery development.

3.2 Habitat Quality Indicators

Based on the information collected in the entire survey, the aggregate scores for habitat quality indices of LHQA and LHMS were generated in Tables 2 and 3 respectively, and then used to describe the condition of the lake habitat based on the stipulated rating guidelines [5] (Table 1). Lake Simbi recorded a much higher LHQA score of 70/112 (which is indicative that the habitat quality is "good") and a relatively lower LHMS score of 18/42 (which is indicative that the habitat modification is "moderate"). These indices collectively suggested that the Lake Simbi habitat can be still be regarded as a pristine ecosystem despite the numerous pressures it experiences since these human-induced pressures are still operating on relatively smaller scales.

Table 2: Features and scores for Lake Habitat Modification Score (LHMS) for Lake Simbi

Pressure	Score
Shore zone modification	2
Shore zone intensive use	4
In-lake use	4
Hydrology	2
Sediment regime	6
Nuisance Species	0
LHMS total score (out of 42)	18

Table 3: Features and Scores for Lake Habitat Quality Assessment (LHQA) for Lake Simbi

Zone	Measurable LHS feature	Counts of features across lake, or number of Hab-Plots with a feature	Score allocated
Riparian	Complex or simple veg.	7	3
	> 10% large trees	4	2
	Natural/semi natural veg.	8	3
	No. natural types	3	3
	No. bank top features	2	2
Shore	Earth/sand bank	4	1
	Trash line	4	2
	Natural bank material	5	2
	No. natural types	4	4
	Natural beach material	7	3
	No. natural types	2	2
Littoral	Coefficient variation	0	0
	Natural littoral substrate	9	4
	No. natural types	3	3
	Total macrophyte cover	1	1
	Extend lake wards?	5	2
	No. macrophyte types	3	3
	Total fish cover	0	0
	No. littoral features	4	4
Whole lake	No. wetland habitats	4	20
	No. islands	0	0
	No. deltaic deposits	2	4
Vegetation structure	Introduced species	1	2
LHQA total	score (out of 112)		70

Table 4: Summarized data for shoreline anthropogenic pressures recorded within the 15m and between 15m to 50m for each Hab-Plot in Lake Simbi LHS study (February, 2019) expressed as extent of the entire perimeter of the lake.

Anthropogenic pressures and non-natural land-use										Hab-Plots										
		A		B		C		D		E		F		G		H		I		J
	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50
Commercial activities	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residential areas	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2
Roads or railways	1	1	0	1	1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Parks and gardens	0	2	0	1	0	2	0	2	0	1	0	2	0	1	0	0	0	1	0	2
Recreational beaches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Educational activities	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Litter, dump, landfill	1	1	1	1	1	1	1	0	1	0	1	0	1	0	1	0	1	1	1	1
Quarrying or mining	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0
Coniferous plantation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Evidence recent logging	2	0	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Observed grazing	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tilled land	0	2	0	2	0	2	0	2	0	0	0	2	0	2	0	2	0	2	0	2
Orchard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erosion	2	1	2	1	2	1	2	0	1	0	1	0	2	0	1	0	1	1	0	1
Number of pressures	6	7	5	10	5	9	5	7	4	5	3	5	3	5	3	4	4	7	3	7

Note: (i) 15 represent an area of between 0m to 15 m while 50 represent an area of between 15m to 50 m of the Hab-Plot.
(ii) 0, 1, 2, 3 and 4 represents areal coverage of between (0 – 1 %), (>1 – 10 %), (> 10 – 40 %), (> 40 – 75 %) and (> 75 %) respectively.

Table 5: Summarized data for shoreline habitat land cover types recorded within the 15m and between 15m to 50m for each Hab-Plot in Lake Simbi LHS study (February, 2019) expressed as extent of the entire perimeter of the lake. The general diversity of the land cove

Lake Habitat Land Cover Types										Hab-Plots										
		A		B		C		D		E		F		G		H		I		J
	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50
Broadleaf/Mixed woodland	1	2	0	1	2	2	2	1	0	1	0	0	0	0	0	0	0	0	0	0
Broadleaf/Mixed plantation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferous woodland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scrub and shrubs	1	3	0	0	1	3	0	2	0	3	2	1	0	0	0	0	3	0	0	2
Moorland/heath	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Open water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rough grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tall herb/rank vegetation	1	1	0	1	1	1	1	1	0	1	0	1	0	1	0	0	0	0	0	0
Rock, scree or dunes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fringing reed banks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wet woodlands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking banks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other (e.g. fen, marsh)	2	1	0	0	2	1	0	0	2	1	0	0	0	0	2	1	0	0	0	0
Extent of the predominant cover	4	4	0	2	4	4	2	3	1	4	1	2	0	1	1	1	1	0	0	1
Diversity of land cover types	4		2		4		3		4		2		1		1		1		1	

Table 6: Summarized data for predominant shoreline substrate characteristics found in the different Hab-Plots (A-J) for the littoral zones in Lake Simbi during the LHS study (February, 2019).

Predominant shore-forming material in Lake Simbi										
Littoral substrate texture	**Hab-Plot**									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Bedrock	0	0	0	0	0	1	1	1	1	0
Boulders (>256 mm)	0	0	0	0	0	1	1	1	0	0
Cobbles (>64–256 mm)	0	0	0	0	0	2	0	0	0	0
Pebbles (>2–64 mm)	0	0	0	0	1	0	0	1	0	1
Sand (>0.063–2 mm)	1	1	0	0	1	2	1	2	0	2
Silt/clay (<0.063 mm)	4	4	4	4	4	3	3	3	4	3

Note: 0, 1, 2, 3 and 4 represents areal coverage of between (0 – 1 %), (>1 – 10 %), (> 10 – 40 %), (> 40 – 75 %) and (> 75 %) respectively.

4. Discussion

LHQA is an LHS index that is designed to quantify the degree of diversity and naturalness of the lake habitat. Lake Simbi recorded a much higher LHQA score of 70/112, indicative that the habitat quality is “good”. This implies that the lake’s habitat quality can be regarded as a moderately modified which is by so far less affected by anthropogenic interferences. Drawn comparison from similar studies in the tropics across the continent shows that Lake Simbi scored lower than both Cleveland (78) and Malilangwe (76) but slightly higher than higher than Lake Chivero (62), all of which are water bodies similarly surveyed in Zimbabwe [6, 13]. However, it scored higher than all the Victorian lakes similarly surveyed in Australia [14] and most lakes similarly studied in the UK [15]. These findings suggest that the lakes in the tropics might be having better habitat quality as compared to their counterparts in the temperate regions that are probably losing their naturalness and level of diversity due to the influence of anthropogenic activities. The “good” habitat quality recorded in Lake Simbi shows that the recent conservation efforts by various concerned stakeholders in Lake Simbi are paying off. Lake Simbi fared better on the LHQA index despite an established fact by [16] that small alkaline lakes (such as Lake Simbi) always score lower on LHQA index notwithstanding their naturalness, compared to large highly alkaline lakes because they normally possess relatively small number of emergent macrophytes and little habitat diversity. Alkaline-saline lakes such as Lake Simbi are saline environments possessing “salt stress” which limits the growth and development aquatic plants [17]. It is well established that only few macrophytes which have developed strong adaptation mechanisms in their structure, physiology and biochemistry can withstand the extreme conditions of saline lakes [18].

LHMS is an LHS index that is designed to classify the habitat quality in terms of the degree of hydro-morphological alterations in the lake habitat resulting from the various anthropogenic activities. It essentially measures the pressures occurring in the lake habitat that might have impacts on its “ecological status”. Lake Simbi scored a relatively lower LHMS score of 18/42, indicative that the habitat modification is “moderate”. This suggests that the lake’s hydro-morphology is moderately impacted by the pressures from anthropogenic and non-natural land uses. By comparison, this score ranks lower than Lake Chivero (32) but higher than Malilangwe (16) and Cleveland (10), all of which are tropical water bodies in Zimbabwe surveyed by [6, 13]. The LHMS score for Lake Simbi ranked higher than most Victorian lakes in Australia [14], (such as Hattah and Locke which both scored 0 – no modification) and lower than some Victorian lakes (Reedy Lake and Longmore Lagoon which both scored 36-greater modification). Lake Simbi is impacted by numerous pressures including widespread erosion, extensive agricultural activities, grazing, logging, indiscriminate dumping of wastes, and quarry/mining of salt locally known as *bala* and encroachment by residential developments. Despite harboring these numerous pressures, the habitat of Lake Simbi was found to be moderately modified because these pressures are still operating at marginal scales. The lake suffers from constant pollution from the dumping of wastes both medical and domestic from the nearby health dispensary, schools and surrounding homes, sedimentation resulting from widespread erosion along its banks occasioned by salt (*bala*) mining and grazing, encroachment of the riparian zones through construction of residential homes by the local community, and deforestation from clearing of bushes to create space for agricultural activities.

The LHS survey of Lake Simbi generally established that the physical habitat quality of the lake is moderately pristine since its hydromorphology is moderately modified by the numerous pressures which are operating at marginal scales. The continuous activity of these anthropogenic invasions coupled with climate change impacts will in the future assessments, make Lake Simbi score low on LHQA scale and high on LHMS scale, generally indicating an impaired and degraded ecological integrity unless appropriate and effective measures are put in place to eliminate the identified pressures and combat their associated impacts on the lake’s ecological condition.

The scrubs and shrub vegetation is typical of semi-arid conditions around the lake characterized by high temperatures, low rainfall and clay soil type. No aquatic plants were identified in the Lake’s habitat since their growth is restricted by both elevated salinity and limited concentration of dissolved oxygen in the water.

The sediments are regarded as a crucial "physical habitat indicator of biological stress" [19]. Sediments make up an important part of the lake habitat since they provide substrates for macrophytes growth which in turn provides shelters for fish avoiding predation as well as food for some macro-invertebrates. The size and properties of a substrate are significant contributing factors to the habitat behavior for fish and other aquatic organisms such as macro-invertebrates because they influence hydrologic alterations [20]. The shoreline substrate material observed in Lake Simbi was predominantly fine sediments of silt and clay observed in all the Hab-plots with coverage of above 40%. These fine sediments indicate a response to the latest alterations in the flow and sediment supply resulting from increased land use practices such as intense agricultural activities, grazing, deforestation, quarry/mining of salt locally known as *bala* and construction of residential developments occurring within the catchment including in the riparian areas all around Lake Simbi. This sedimentation coupled with high evaporation rates threatens the existence of this lake since being an endorheic, it lacks the mechanisms for getting rid of some of this sediments which end up building up overtime on the it's floor. Such excess buildup of fine sediments can block the habitat spaces between the much larger substrates in the water such as rocks thereby impairing those habitats by suffocating the aquatic organisms that live in them together with their breeding grounds [19].

The lands cover and land uses in Lake Simbi catchment area were accurately categorized through remote sensing images. The extent of some of the pressures such as crop lands and built areas on the lake's habitat could also be clearly identified from the GIS remote sensed images. Even though the remote sensed information couldn't provide finer details on the structure of the vegetation cover, it proved to be an important tool that should be used to complement the field assessment in carrying out the Lake Habitat Survey (LHS). It's important to note that the remote sensing by GIS can't be used alone as the only method for carrying out LHS assessments. This is the third study in the tropics that has tested the applicability of LHS in evaluating the ecological status of a water body. The two earlier studies had tested it in the ecological monitoring of small reservoirs in Zimbabwe [6, 13]. This study therefore recommends that since Kenya (and generally Africa) lacks any environmental monitoring tool for the lakes' habitats [15], the LHS should be adopted as a standard tool for assessing ecological health of water bodies of conservation value in Kenya (such as Ramsar sites) because it possesses crucial indices useful for easier and rapid tracking of the scale of anthropogenic interventions on lake's physical habitat, hence informing decision making by the management.

In conclusion, LHS is effective for monitoring ecological condition of tropical water bodies for management and conservation purposes since it can help the relevant government agencies identify the water bodies at *risk* of habitat quality degradation so that they prioritize them for conservation programs. However, the LHS falls short in some aspects as an environmental monitoring tool for aquatic ecosystems. It fails to integrate the measurements for the basic physico-chemical variables into the scoring system of any of the two indices (LHQA and LHMS) despite having it as a requisite part of LHS. These measurements ought to be compared with the relevant international standards as a baseline and integrated into the scoring criteria for rating the most appropriate index. In agreement with previous similar study [6], since LHS was initially developed for temperate regions, it requires further improvements so as to strengthen its effectiveness in environmental monitoring and management for aquatic ecosystems in the tropics.

5. Acknowledgement

We wish to express our sincere gratitude to God Almighty for his providence and the African Development Bank (AfDB) for the financial support that made this research possible.

6. References

1. Rowan J. Development of a technique for Lake Habitat Survey, 2005. Retrieved from http://epa.gov/nheerl/arm/indicators/lhs_report.html.
2. European Commission. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities. 2002; L327:66-106.
3. CEN. (Comité Européen de Normalisation – European Standards Agency). Water quality: guidance standard on assessing the hydromorphological features of lakes. Ref. No. EN 16039:2011. Brussels: European Standards Agency.
4. Radulović S, Laketić D, Popović Ž, Teodorović I. Towards candidature of the Crno jezero (Black Lake) (Durmitor, Montenegro) as a high ecological status (HES) site of the dinaric western Balkan Ecoregion. Archives of Biological Sciences, Belgrade. 2010; 62(4):1101-1117.
5. EPA Victoria. Environmental quality guidelines for Victorian lakes (EPA publication 1303), Melbourne, 2010. Retrieved from http://www.epa.vic.gov.au/~/media/Publications/1303.pdf
6. Dalu T, Clegg B, Nhiwatiwa T. Application of the Lake Habitat Survey method on the tropical Malilangwe reservoir, south-eastern lowveld, Zimbabwe. African Journal of Aquatic Science. 2013; 38(1):21-34.
7. Stella JC, Rodríguez-González PM, Dufour S, Bendix J. Riparian vegetation research in Mediterranean-climate regions: common patterns, ecological processes, and considerations for management. *Hydrobiologia*. 2013; 719(1):291-315.
8. Kaufmann PR, Peck DV, Paulsen SG, Seeliger CW, Hughes RM, Whittier TR *et al*. Lakeshore and littoral physical habitat structure in a national lakes assessment. Lake and Reservoir Management. 2014a; 30:192-215.
9. Kaufmann PR, Hughes RM, Van Sickle J, Whittier TR, Seeliger CW, Paulsen SG. Lakeshore and littoral physical habitat structure: a field survey method and its precision. Lake and Reservoir Management. 2014c; 30:157-176.
10. Latinopoulos D, Ntislidou C, Kagalou I. A multi-approach Lake Habitat Survey method for impact assessment in two heavily modified lakes: A case of two Northern Greek lakes. Environmental Monitoring and Assessment. 2018; 190(11):658.
11. Rowan JS, Soutar I, Bragg OM, Carwadine J, Cutler MEJ. Lake Habitat Survey in the United Kingdom field survey guidance manual version 3.1. Final Report Project WFD 42. Scotland and Northern Ireland Forum for Environmental Research (SNIFFER), Edinburgh, 2008, 4-36.
12. Rowan JS, Carwardine J, Duck RW, Bragg OM, Black AR, Cutler MEJ *et al*. Development of a technique for

lake habitat survey (LHS) with applications for the European Union Water Framework Directive. Aquatic Conservation: Marine and Freshwater Ecosystems. 2006; 16(6):637-657.

13. Dalu T, Tambara E, Chari LD, Moyo S, Nhiwatiwa T. A test of the Lake Habitat Survey method in Cleveland Reservoir and Lake Chivero (Manyame River Basin, Zimbabwe). Water SA. 2016; 42(1):102-111.
14. Victoria EPA. A Snapshot of the environmental condition of Victorian lakes. EPA Victoria (EPA publication 1303). Melbourne, 2009. Retrieved from https://www.epa.vic.gov.au/~/media/Publications/1303.pdf
15. Rowan JS, Duck RW, Carwardine J, Bragg OM, Black AR, Cutler MEJ. Development of a technique for Lake Habitat Survey (LHS): Phase 1. SNIFFER/Environmental Systems Research Group, University of Dundee. Final Report, Project WFD 40. Edinburgh: SNIFFER, 2004.
16. McGoff E, Irvine K. A test of the association between Lake Habitat Quality Assessment and macroinvertebrate community structure. Aquatic Conservation: Marine Freshwater Ecosystems. 2009; 19:520-533.
17. Sim LL, Davis JA, Chambers JM, Strehlow K. What evidence exists for alternative ecological regimes in salinizing wetlands?. Freshwater Biology. 2006; 51(7):1229-1248.
18. Haller WT. Effects of salinity on growth of several aquatic macrophytes. Ecology. 1974; 55:891-894.
19. USEPA. Aquatic resource surveys. 2006. Retrieved from http://www.epa.gov/national-aquatic-resource-surveys/indicators-streambed-sediments_
20. Kaufmann PR, Whittier TR. Habitat characterization. Section 5. In: Baker, J.R., Peck, D.V., Sutton, D.W., (eds). Environmental Monitoring and Assessment Program Surface Waters: Field Operations Manual for Lakes. U.S. Environmental Protection Agency, Washington, D.C. EPA/620/R-97/001, 1997.