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Exploring the demarcation requirements of fish breeding and nursery sites to balance the exploitation, management and conservation needs of Lake Victoria ecosystem

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Running head: Lake demarcation requirements; M.C. AURA *ET AL*.

Exploring the demarcation requirements of fish breeding and nursery sites to balance the exploitation, management and conservation needs of Lake Victoria ecosystem

Abstract

Fisheries resources in vital freshwater ecosystems have been reported to be under immense threat, resulting in conflicts between conservation, management and exploitation. This study established requirements for identifying and mapping fish breeding and nursery grounds in such ecosystems in the Kenyan part of Lake Victoria. The criteria were characterised by the use of indigenous knowledge, field data, literature on breeding sites, macroinvertebrates distribution, larval and relative fish abundances, digitization, participatory mapping and periodic sampling. Data were collected from trawl and seine net surveys. Digitization and mapping of the proposed conservation sites were carried out using Quantum GIS software. Participatory physical demarcation of sites was done using buoys and markers. Larval and juvenile fish were diverse and abundant in all seven river mouths and six bays surveyed with little variance; an important aspect of breeding areas. Additionally, a preponderance of macroinvertebrates and high fish diversity compared with offshore sites in the lake strengthened the hypothesis that these are critical habitats for spawning and preferred habitats for nurseries for fish. The approach can be adopted globally to guarantee the long-term integrity of critical fish habitats for sustainable fisheries management and blue growth.

Key words: Criteria, critical habitats, lake-fishery, blue economy, conflicts, integrity.

Introduction

Lake Victoria is the largest of all African lakes and the second largest by area in the world (length of 337 km and a width of 240 km), which makes it an important focus for ecosystem conservation and the growth of a blue economy. It supports numerous business and resource security opportunities for the more than 40 million people that live in the basin and the greater East Africa region (Aura et al., 2018). These include water-based transport; industrial, domestic and agricultural water uses, and hydroelectric power generation. The lake basin has been designated an economic growth zone by the East African Community (EAC) (Abila, 2000), and Lake Victoria supports one of the largest freshwater fisheries in the world.

Historically, the lake supported more than 500 species of fish, most of which were endemic. However, following the introduction of the large sized predatory and highly competitive Nile perch *Lates niloticus* (L.) and four Tilapiine species, now known as *Coptodon* (Dunz & Schliewen, 2013) (*Oreochromis niloticus* (L.), *Oreochromis leucostictus* (Treewavas), *Coptodon zillii* (Gervais) and *Coptodon rendalli* (Boulenger)) in the late 1950s to early 1960s, coupled with overexploitation of resources and excessive environmental degradation, a large proportion of native fish species have disappeared from the lake. It is estimated that more than 200 endemic species of fish have been lost (Njiru et al., 2012; Downing et al., 2014; Arinaitwe et al., 2016). Ostensibly, the introductions were made to boost fisheries in Lake Victoria (Aura et al., 2013) through predatory conversion of the biomass of small-sized bony cichlids, and efficient niche occupation and utilisation by the larger-sized species. At the same time, wetlands were cleared for other uses such as agriculture. This reduced the natural capital and ecosystem service delivery of the ecosystem, including the provision of refugia for indigenous fish species.

As a result, Lake Victoria, which originally supported at least 12 major commercial fish species, now supports only three (Hecky et al., 2010). These are two introduced species, Nile perch and Nile tilapia, and one native fish species, the pelagic cyprinid *Rastrineobola argentea* (Pellegrin), locally known as omena (Njiru et al., 2007). The catch and biomass of fish in the lake are currently dominated by omena and haplochromines, indicating that numbers of Nile perch and Nile tilapia, which are preferred by the export market and for domestic consumption, have declined (Hecky et al., 2010).

Natural fish stocks in Lake Victoria have declined due to the interaction of multiple stressors such as species introductions, eutrophication, pollution, and habitat change from over-exploitation, overfishing, and illegal and unregulated fishing in critical habitats (Njiru et al., 2012). The most important critical habitats in the lake are fish breeding sites (Njiru et al., 2007), which require wide-ranging changes in management practices to ensure the future sustainability of the fishery and the lake ecosystem. Realizing the full potential of the lake now requires a paradigm shift in management to embrace a new, responsible and sustainable approach that is more environmentally, socially and economically effective. This has come at a crucial time when population growth rapidly increasing the demand for food and resources from the lake. It is widely believed that the development of a sustainable blue economy in this area needs to be supported by the better conservation and management of fish breeding sites.

Previous studies that have addressed conservation and management issues in relation to designing reserves and critical habitats include those of Ezenwa and Ayinla (1994), Salmi et al. (2000), Harding *et al*. (2001), Crooks (2002) and Gumm et al. (2011). Few studies have also been carried out to establish the spawning periods and spawning sites for the three-commercial species. Surveys showed that both Nile perch and *Coptodon* bred during the rainy season (Hughes, 1992;

Goudswaard et al., 2011; Cornelissen et al., 2015). This was characterized by reduced movement of fish and their abiding in particular sites for longer periods of time. It was established that during rainy seasons food is more abundant and water temperatures are low, reducing the need to seek out more favorable, distant foraging sites. *Rastrineobola argentea* on the other hand bred throughout the year with peaks between March and June; December. The species were found to move into shallower waters (offshore) to spawn (Ojwang et al., 2014). However, these studies provide little information on the methodological frameworks required to identify and map lacustrine fish breeding and nursery grounds for conservation purposes and to protect the fishery and the ecosystem on which it depends. This is because the sustainable utilisation of fisheries in a lake calls for a balance to be struck between the protection of critical habitats, such as fish breeding areas, and exploitation by the fishing community, which is generally poor and with low individual incomes. This study aimed to identify the prerequisites for mapping and demarcation of critical fish breeding, nursery and fishing grounds to support the more sustainable use of resources and to reduce user conflicts, using Lake Victoria, Kenya, as a case study.

Activities of the study were to establish criteria for identifying and mapping fish breeding sites and nursery grounds in lacustrine ecosystems with a particular focus on offshore areas, river mouths and sheltered bays. Such critical areas are known to be associated with increased diversity and abundance of biota (e.g. Dejen et al., 2017). This is because one conceptual driver of inland fisheries, such as Lake Victoria, is the widely held vision of an inevitable demise of inland fisheries in the face of escalating human impacts, which is reflected in studies from all continents (Friend et al., 2009). In Lake Victoria, catches are on the decline with the main driver being increased demand for fish, leading to illegal fishing in critical sites (Aura et al., 2018).

Materials and methods

Study area

Lake Victoria delivers important ecosystem services to more than 40 million people in the three riparian countries. These include fisheries, transport, and water for domestic, agricultural and industrial uses (LVFO, 2015). With a surface area of over 68,500 km^2, Lake Victoria is the world's second largest freshwater lake and is shared by the three East African countries: Tanzania, Uganda and Kenya. It lies at an altitude of 1134 m above sea level, and is relatively shallow, with a maximum depth of about 84 m and an average depth of about 40 m (Aura et al., 2013). The highly indented shoreline of the lake is estimated at about 3,440 km in length. Kenya has the smallest part of the lake by area (approximately 4,128 km^2) and a shoreline of about 550 km. The Kenyan part of the lake includes the Winam Gulf (Kavirondo Gulf or Nyanza Gulf), which is joined to the main lake by the Rusinga channel. The Winam Gulf is purported to have been the area where the rapid increase in the Nile perch population began. The Kenyan waters, especially the Winam Gulf, were also the first part of Lake Victoria to exhibit shallow-water hypoxia and associated fish kills, and the first area to experience overfishing of the Nile perch population (Okely et al., 2010; Kundu et al., 2017; Aura et al., 2018).

The Kenyan part of Lake Victoria was used as a case study to demonstrate the criteria that are useful for identifying and demarcating lacustrine critical habitats The investigated areas included river mouths and associated wetlands, fringe wetlands, rocky habitats, bays and areas with extensive/dense macrophyte cover.

Demarcation criteria for fish breeding sites

Figure 1 shows a schematic representation of the criteria used in the demarcation of fish breeding sites within this study. This involved:

i. raising community awareness of the importance of demarcating and protecting the breeding areas;
ii. interviewing fishers and other stakeholders on potential fish breeding grounds using indigenous knowledge;
iii. identifying key breeding areas and nursery grounds;
iv. reviewing secondary literature on fish species, breeding period and distribution (Table 1 and Table 2);
v. collecting field data on fisheries and relevant limnological information such as relative abundance of fish eggs and larvae, maturity status of fish, diversity indices, and macroinvertebrate occurrence inside and outside of the potential fish breeding sites for demarcation;
vi. digitizing and mapping of fish breeding sites using a Geographical Information System (GIS); and
vii. physically delineating the sites with markers and buoys, in collaboration with stakeholders, and periodically monitoring the sites inside and outside of the demarcated fish breeding grounds to assess the effects of demarcation.

To identify fish breeding, nursery and fishing grounds, data and literature on larval and relative fish abundance was obtained from trawling, seine netting and net trawl surveys. Several authors (Table 1) recorded that fish breeding occurs in sheltered bays and river mouths (Manyala et al., 2005). For example, they noted that cichlids usually establish their nests in sandy beaches; carps and catfishes migrate to denuded floodplains for breeding; and lungfish breed in marginal swamps. Sampling periods and areas of the current study were established based on the secondary literature (Table 1) and indigenous knowledge sourced from stakeholder interviews and structured questionnaires, (Table 2). Spawning periods were mainly mentioned (75% of respondents) as occuring in the rainy season i.e. March - May and October – December. Sampling was undertaken during such periods to capture a wider and robust pattern. Field sampling entailed geo-referencing using hand held GPS (Garmin), biophysical characterisation and description of each of the areas considered critical, and verification using indigenous knowledge from resource users and experienced fishers. Relative abundance and maturity status of fishes (including species of economic importance, namely Nile perch, Nile tilapia and Dagaa - *R. argentea*), and habitat uniqueness in terms of sheltered, and open; were used as factors to determine habitat suitability as a breeding ground for mouth brooders and broadcasters, such as Nile perch (*L. niloticus*) and Dagaa or omena (*R. argentea*).

The Shannon diversity index (H') was used to characterize species diversity in a different habitats (i.e. river mouths, sheltered bays and offshore areas). The index was defined as:

$$H' = -\sum_{i-1}^{s} P_i - Ln(P_i)$$

where P_i is the relative abundance, i.e. the number of individuals for each species divided by the total number of individuals for all species (S) in each sample (Begon et al. 1990). Differences in median H' in the different sites was tested using Kruskal–Wallis test. Dunn's Test (1964) was used to pinpoint which specific median H' were significantly different from the others. Additionally, the Simpson index, inverse Simpson index, Species richness, rarefaction were employed following Oksanen et al. (2018).

The GIS software Quantum GIS Desktop Version 2.18.11 was used to calculate the area of each demarcated fish breeding site, after applying a WGS84 projection to the data layer and the underlying map data. The field calculator function in QGIS was then used to provide the area (in km^2) of each region of interest (QGIS Development Team, 2009).

Results

Analysis of benthic macroinvertebates revealed differences in diversity and abundance across different habitat types in Lake Victoria (Fig. 2). Sheltered bays and river mouths were found to have the highest diversity score in relation to the Shannon Weiner index, with differences in the index being significant (χ^2 = 7.159; p = 0.028) across the three habitats. Dunn's (1964) test of mulitiple comparisons revealed no significant difference (p = 0.72) in benthic invertebrate diversity between sheltered bays and river mouths. However, diversity in river mouths was significantly different (i.e. p = 0.05) from offshore sites.

On the other hand, sheltered bays and river mouths had higher median fish diversity scores than offshore sites in the lake (Fig. 3), indicating that river mouths and sheltered bays are preferred by fish, and hence critical habitats for their survival. Given the relatively high abundance of fish eggs and larvae in these areas, it can be deduced that river mouths and sheltered bays are also important fish breeding areas (Fig. 4a).

Furthermore, offshore sites had almost negligible proportions (< 2%) of juvenile and mature fish that mainly consisted of Nile perch and Dagaa which are known to breed in such zones (Fig. 4b, c). Among the juveniles, *Synodontis victoriae* (33%) and *O. niloticus* (6%) were the most and the least dominant, respectively, in the sheltered bays. Mature *Clarias gariepinus* (24%) and *S. victoriae* (10%) dominated the sheltered bays and river mounths, respectively (Fig. 4c).

Both sheltered bays (0.45) and river mounths (0.50) had relatively high proportions of juvenile and mature fish, indicating that they are also nursery grounds for these fish. Based on the findings above, together with local indigenous knowledge and secondary literature, a set of criteria was established for defining and mapping fish critical habitats, and fish breeding and nursery grounds (Table 2 & Fig. 5).

Of the 13 sites identified, the breeding areas comprised seven river mouths and six bays. The Kuja River mouth (89.15 km^2), Nyakach Bay (68.73 km^2) and Nzoia River mouth (64.82 km^2) were the largest habitats, providing extensive fish breeding and nursery grounds. The least extensive habitats (< 10 km^2) were found in Oluch River Mouth, Kendu Bay and Kisumu Bay.

Discussion

In the current study, a preponderance of macroinvertebrates and high fish diversity were observed in sheltered bays and river mouths compared to offshore sites in the lake. High diversity of macroinvsertebrates in sheltered bays and river mouths could be linked to availability of suitable food for larval fish (Aura et al., 2010). This could be because fish larvae tend to aggregate in areas with sufficient food to increase their chances of survival and their distribution occurs in areas that are near or at the breeding grounds due to difficulties in swimming (Aura et al., 2013).

Previous studies (e.g., Hughes 1992; Ojwang et al., 2014) have found negligible proportions of juveniles in offshore sites and mature fish that mainly consisted of Nile perch and Dagaa. Furthermore, in consistent with the current study, *Synodontis victoriae* and *O. niloticus* juveniles were found to be the most and the least dominant, respectively, in the sheltered bays, whereas, mature *Clarias gariepinus* and *S. victoriae* dominated the sheltered bays and river mounths, respectively (Fig. 4c; Ojwang et al., 2014).

The higher species diversity scores in the river mouths and sheltered bays indicated that these are critical habitats for fish. Similarly, relatively high proportions of juvenile and mature fish indicated that they are also nursery grounds for fish. Additionally, the relatively high abundance of fish eggs and larvae in the same habitats strengthens the observations that river mouths and sheltered bays are fish breeding areas. These could be because sheltered bays are characteristically calm with relatively warmer waters than elsewhere which confers upon them great importance as nursery grounds for fish, while the high nutrient content of river water provides food for larval, juvenile and adult fish. Apart from the abundant food, river mouths and bays are often fringed with macrophytes, giving them a structural complexity that provides excellent shelter against predators (Nagelkerken et al., 2000).

In addition, river mouths and shallow bays have relatively turbid waters, which decreases the foraging efficiency of visual predators (Robertson & Blaber, 1992). In combination, these attributes define areas that are important refugia for all stages of fish and, therefore, important and critical habitats. As such, fishing needs to be restricted in these areas to allow for the breeding and maturation of fish, and to sustain sufficient stocks of fish to support a growing blue economy.

In summary, these attributes, combined with local indigenous knowledge and secondary literature, were used to identify and map fish breeding and nursery grounds. Of the 13 sites identified, breeding areas comprised seven river mouths and six sheltered bays. Larger river mouths and bays provided more expansive fish breeding grounds than less extensive areas. It is hypothesised that limiting access to the demarcated sites by humans (e.g. fishers) will lead to increased fish recruitment and fish abundance in such areas, and eventually in the entire lake. However, conservation of the targeted sites using this approach can only be efficient with sufficient time, financial and scientific resources. Furthermore, local indigenous knowledge and commitment from Kenyan Beach Management Units (BMUs) members, may be too limited to contribute to effective management actions (Gumm et al., 2011).

There is a need to explore other biota (such as flora) that were not covered in this study to ascertain their abundance and diversity in relation to fish breeding and nursery grounds for the conservation and management of these sites. The demarcation approach outlined above could be adopted globally to aid the conservation and protection of the integrity of critical fish habitats to achieve the ultimate aim of achieving sustainable fisheries management, and hence a healthy, growing blue economy.

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References

Abila, R.O. (2000). *The development of the Lake Victoria fishery: A boon or bane for food security? Socio-economics of the Lake Victoria Fisheries*. *Report 8*. IUCN Eastern Africa Programme. 15pp.

Arinaitwe, K., Kiremire, B. T., Muir, D. C. G., Fellin, P., Li, H., Teixeira, C., & Mubiru, D. N. (2016). Legacy and currently used pesticides in the atmospheric environment of Lake Victoria, East Africa. *Science of the Total Environment*, 543, 9–18.

Aura, M.C., Raburu, P.O., Herrmann, J. (2010). A Preliminary Macroinvertebrate Index of Biotic Integrity for Bioassessment of the Kipkaren and Sosiani Rivers, Nzoia River Basin, Kenya. *Journal of Lakes and Reserviors: Research and Management,* 15, 119-128.

Aura, C.M., Musa, S., Njiru, J., Ogello, E.O. & Kundu, R. (2013). Fish-Restocking of Lakes in Kenya: Should solemnly be an Environmental Issue, 39-60pp. In: W.A. Adoyo & C.I. Wangai

(Eds.) *African Political, Social and Economic Issues: Kenya Political, Social and Environmental Issues*. New York: NOVA Science Publishers, Inc. ISBN: 978-1-62081-085-9.

Aura, C.M., Musa, S., Yongo, E., Okechi, J., Njiru, J.M., Ogari, Z., Wanyama, R., Charo-Harrison, H., Mbugua, H., Kidera, S., Ombwa, V. & Abwao, J. (2018). Towards balancing lake use and culture fisheries off Lake Victoria beaches, Kenya: mapping and socio-economic assessment of cage culture. *Aquaculture Research,* 49, 532–545.

Begon, M., Harper, J.L. and Townsend, C.R. (1990). Ecology: Individuals, Populations and Communities. 2nd. ed. Blackwell Scient. Publ., 945 pp.

Cornelissen, I. J. M., van Zwieten, P. A. M., Peter, H. K., & Nagelkerke, L. A. J. (2015). Nile perch distribution in south-east Lake Victoria is more strongly driven by abiotic factors, than by prey densities. *Hydrobiologia*, 755(1), 239–255.

Crooks, K.R. (2002). Relative sensitivities of mammalian carnivores to habitat fragmentation. *Conserv. Biol*., 16, 488–502.

Dejen, E., Anteneh, W. & Vijverberg, J. (2017). The decline of the Lake Tana (Ethiopia) fisheries: causes and possible solutions. *Land Degrad. Develop*., 28, 1842–1851.

Downing, A. S., Van Nes, E. H., Balirwa, J. S., Beuving, J., Bwathondi, P., Chapman, L. J., Van Zwieten, P.A.M. Wanink, J., Witte, F. Mooij, W. M. (2014). Coupled human and Victoria's Ecosystem services. *Ecologiy and Society*, 19(4), 31.

Dunn, O. J. (1964). Multiple Comparisons Using Rank Sums. *Technometrics*, 6(3), 241-252, DOI: 10.1080/00401706.1964.10490181.

Dunz, A. R., & Schliewen, U. K. (2013). Molecular phylogeny and revised classification of the haplotilapiine cichlid fishes formerly referred to as "Tilapia." *Molecular Phylogenetics and*

Evolution, 68(1), 64–80.

Ezenwa, B.I. & Ayinla, O.A. (1994). Conservation strategies for endangered fish breeding and nursery grounds within the coastal wetlands of Nigeria. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 4, 125-133.

Friend, R., Arthur, R. & Keskinen, M. (2009). Songs of the doomed: the continuing neglect of capture fisheries in hydropower development in the Mekong. In: F. Molle, T. Tira Foran & M. Käkönen (Eds.) *Contested waterscapes in the Mekong Region.* London, UK: Earthscan.

Goudswaard, P. C., Katunzi, E. F. B., Wanink, J. H., & Witte, F. (2011). Distribution of Nile perch Lates niloticus in southern Lake Victoria is determined by depth and dissolved oxygen concentrations. *African Journal of Aquatic Science*, 36(2), 147–153.

Gumm, J.M., Snekser, J.L., Leese, J.M., Little, K.P., Leiser, J.K., Imhoff, V.E., Westrick, B. & Itzkowitz, M. (2011). Management of interactions between endangered species using habitat restoration. *Biological Conservation,* 144, 2171-2176.

Harding, E.K., Crone, E.E., Elderd, B.D., Hoekstra, J.M., McKerrow, A.J., Perrine, J.D., Regetz, J., Rissler, L.J., Stanley, A.G., Walters, E.L. & Nceas Habitat Conservation Plan Working Group (2001). The scientific foundations of habitat conservation plans: a quantitative assessment. *Conserv. Biol*., 15, 488–500.

Hecky, R.E., Mugidde, R., Ramlal, P.S., Talbot, M.R. & Kling, G.W. (2010). Multiple stressors cause rapid ecosystem change in Lake Victoria. *Freshwater Biology,* 55, 19–42.

Hughes, N. F. (1992). Growth and reproduction of the Nile perch, Lates niloticus, an introduced predator, in the Nyanza Gulf, Lake Victoria, East Africa. *Environmental Biology of Fishes*, 33(3), 299–305.

Kundu, R., Aura, C.M., Nyamweya, C., Agembe, S., Sitoki, L., Lung'ayia, H.B.O., Ongore, C., Ogari Z. & Werimo K. (2017). Changes in pollution indicators in Lake Victoria, Kenya and their implications for lake and catchment management. *Lakes Reserv. Res. Manage*., 22, 199–214.

Nagelkerken, I., van der Velde, G., Gorissen, M.W., Meijer, G.J., Van't Hof, T. & den Hartog, C. (2000). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Estuar. Coast. Shelf Sci*., 51, 31–44.

LVFO (2015). Lake Victoria (Kenya) Biennial Fisheries Frame Survey 2014 National Report. Ministry of Agriculture, Livestock and Fisheries, Kenya. 52pp.

Manyala, J. O., Bolo, J.Z. Onyango, S. & Rambiri, P.O. (2005). Indigenous Knowledge and Baseline data survey on fish breeding areas and seasons in Lake Victoria, Kenya. In: Knowledge and Experiences gained from managing Lake Victoria Ecosystem. Lake Victoria Environmental Management Programme (LVEMP), Kisumu. pp. 529-551.

Njiru, M., Nzungi, P., Getabu, A., Wakwabi, E., Othina, A., Jembe, T. & Wekesa, S. (2007). Are fisheries management, measures in Lake Victoria successful? The case of Nile perch and Nile tilapia fishery. *African Journal of Ecology*, 45, 315–323.

Njiru, M., Sitoki, L., Nyamweya, C.S., Jembe, T., Aura, M.C., Waithaka, E. & Masese, F. (2012). Habitat degradation and changes in Lake Victoria fisheries. Nova Publishers, Environmental Degradation: Causes, Issues and Management. pp. 1–34.

Ojwang, W. O., Ojuok, J. E., Nyamweya, C., Agembe, S., Owili, M., Yongo, E., & Wakwabi, E. O. (2014). The intriguing dynamics of Rastrineobola argentea fishery in the Kenyan waters of Lake Victoria. *Aquatic Ecosystem Health and Management*, *17*, 80–89.

Okely, P., Imberger, J. & Antenucci, J.P. (2010). Processes affecting horizontal mixing and dispersion in Winam Gulf, Lake Victoria. *Limnology and Oceanography*, 55, 1865–1880.

Oksanen, J, Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D.,. Minchin, P. R 'Hara, R. B. O., Simpson, G. L. Solymos, P., Henry, M., Stevens, H., Szoecs, E., Wagner, H. (2018). vegan: Community Ecology Package. R package version 2.5-2.

QGIS Development Team (2009). QGIS Geographic Information System. Open Source Geospatial Foundation. URL http://qgis.osgeo.org.

Robertson, A.I. & Blaber, S.J.M. (1992). Plankton, epibenthos and fish communities. In: A.I. Robertson & D.M. Alongi (Eds.), Tropical Mangrove Ecosystems. *Coastal and Estuarine Studies*, 41, 173–224.

Salmi, P., Auvinen, H. & Jurvelius, J. (2000). Finnish lake fisheries and conservation of biodiversity: coexistence or conflict? *Fisheries Management and Ecology*, 7, 127-138.

Table 1. Breeding characteristics of common fish species of Lake Victoria (after Manyala et al., 2005). Blanks indicate missing information.

Species	Breeding Season	Breeding area	Source
Bagrus docmak	Protracted/Peaks in Jan/August	Lake Victoria	Lowe-McConnell, 1987
Barbus altianalis	Mar-Apr/Aug-Sep/Oct-Nov	Rivers/floodplains	Ochumba & Manyala, 1992
Clarias gariepinus	April-June/Sept-Oct		Lung'ayia, 1994a
Clarias gariepinus	Feb-Aug	Rivers/floodplains	Ochumba & Manyala, 1992
Clarias gariepinus	Protracted/Peaks in Jan/August	Lake Victoria	Lowe-McConnell, 1987
Clarias gariepinus	Sep-Oct	Rivers	Lung'ayia, 1994a
Haplochromis spp.	End of rainy seasons	Littoral/Sub-littoral	Witte, 1981
Labeo victorianus	Jan-Apr/Sep-Nov	Rivers	Ochumba & Manyala, 1992
Lates niloticus		Pelagic zone	Lung'ayia, 1994a
Oreochromis esculentus	April-May/Sept-Dec		Lowe-McConnell, 1987
Oreochromis esculentus	Sep-May		Greenwood, 1966
Oreochromis leucostictus	Throughout the year	Inshore	Lowe-McConnell, 1987
Oreochromis niloticus	Apr-Jun/Sep-Dec	Rivers	Ochumba & Manyala, 1992
Oreochromis niloticus		Nyanza Gulf	Lung'ayia, 1994a
Oreochromis niloticus		Offshore	Lowe-McConnell, 1987
Oreochromis variabilis	Jun-Aug	Rivers	Ochumba & Manyala, 1992
Oreochromis variabilis		15 m from shoreline	Lung'ayia, 1994a
Protopterus aethiopicus	Apr-May/Sep-Nov	Marginal swamp	Greenwood, 1966
Protopterus aethiopicus	July-Aug/Feb	floodplains	Lowe-McConnell, 1987
Protopterus aethiopicus		Marginal swamps	Greenwood, 1966
Protopterus aethiopicus		Marginal swamps	Lowe-McConnell, 1987
Protopterus aethiopicus		Papyrus swamp	Greenwood, 1966
Protopterus aethiopicus		Papyrus swamps	Greenwood, 1966
Protopterus aethiopicus		Semi-aquatic grass	Greenwood, 1966
Rastrineobola argentea	Feb-Mar	Pelagic	Lung'ayia, 1994a
Rastrineobola argentea	Oct-Nov	Pelagic	Lung'ayia, 1994a
Schilbe intermedius	Protracted/Peaks in Jan/August	Rivers/floodplains	Lowe-McConnell, 1987
Schilbe intermedius	Rainy season	Rivers/floodplains	Ochumba & Manyala, 1992
Schilbe intermedius	Sep-Apr	Rivers	Ochumba & Manyala, 1992
Schilbe intermedius		Rivers	Lowe-McConnell, 1987.
Synodontis victoriae	Apr-Jun/Oct-Dec	Rivers/floodplains	Ochumba & Manyala, 1992
Synodontis afrofischeri	Jan-Apr/Jul-Sep	Rivers/floodplains	Ochumba & Manyala, 1992
Synodontis victoriae	Protracted/Peaks in Jan/August	Rivers/floodplains	Lowe-McConnell, 1987
Tilapia zillii	Throughout the year		Lowe-McConnell, 1987

Table 2. Critical habitats for fish breeding and nursery grounds in Lake Victoria, Kenya.

Critical breeding habitat		GPS coordinates		Species
Number	**Name**	**Longitude**	**Latitude**	
1	Sio River Mouth	33.958 E	0.171 N	*Lates niloticus, Haplochromines, Rastrineobola argentea*
		33.985 E	0.161 N	
2	Nzoia River Mouth	33.954 E	0.082 N	*Lates niloticus, Haplochromines, Rastrineobola argentea,*
		33.946 E	0.070 N	
		33.956 E	0.059 N	
3	Kadimo Bay	34.074 E	0.104 S	*Lates niloticus, Haplochromines, Rastrineobola argentea, Oreochromis niloticus*
		34.081 E	0.107 S	
		34.093 E	0.082 S	
		34.099 E	0.076 S	
		34.111 E	0.074 S	
		34.121 E	0.079 S	
		34.123 E	0.089 S	
		34.111 E	0.102 S	
		34.111 E	0.110 S	
		34.114 E	0.118 S	
		34.118 E	0.121 S	
4	Asembo Bay	34.381 E	0.229 S	*Lates niloticus, Oreochromis nilotucus, Synodontis victoriae, Clarias gariepinus*
		34.382 E	0.208 S	
		34.389 E	0.197 S	
		34.422 E	0.192 S	
		34.463 E	0.176 S	
		34.485 E	0.174 S	
5	Kisat River Mouth	34.727 E	0.100 S	*Synodontis victoriae, Clarias gariepinus, Barbus sp., Lates niloticus*
		34.744 E	0.108 S	
6	Nyakach Bay	34.757 E	0.345 S	*Synodontis victoriae, Clarias gariepinus, Barbus sp., Lates niloticus*
		34.744 E	0.329 S	
		34.739 E	0.293 S	
		34.773 E	0.276 S	
7	Awach River Mouth	34.644 E	0.344 S	*Synodontis victoriae, Clarias gariepinus, Barbus sp., Lates niloticus*
		34.652 E	0.347 S	
8	Oluch River Mouth	34.492 E	0.452 S	*Oreochromis niloticus, Lates niloticus, synodontis victoria*
		34.498 E	0.459 S	
9	Samunyi River Mouth	34.432 E	0.500 S	*Oreochromis niloticus, Lates niloticus, synodontis victoria*
		34.444 E	0.520 S	
10	Mirunda Bay	34.275 E	0.450 S	*Lates niloticus, Oreochromis nilotucus, Bagras docmak*
		34.328 E	0.443 S	
		34.368 E	0.443 S	
11	Ngothe Bay	34.164 E	0.363 S	*Lates niloticus, Oreochromis nilotucus, Bagras docmak*
		34.188 E	0.358 S	

12	Nyango Bay	34.066 E	0.629 S	*Haplochromines, Lates niloticus*
		34.066 E	0.571 S	
13	Kuja River Mouth	34.108 E	0.988 S	*Lates niloticus*
		34.111 E	0.915 S	
		34.127 E	0.885 S	
		34.161 E	0.885 S	

Table 3. Area of fish breeding sites in Lake Victoria, Kenya.

Site	Area (km^2)
Kuja River Mouth	89.15
Nyakach Bay	68.73
Nzoia River Mouth	64.82
Asembo Bay	40.65
Usigu Bay	34.91
Miruda Bay	30.18
Sio River Mouth	29.49
Kadimo Bay	26.58
Maboko Bay	17.35
Nyongo Bay	13.44
Samunyi River Mouth	10.38
Oluch River Mouth	6.33
Kendu Bay	5.79
Kisumu Bay	4.64

Figure Legends

Figure 1. Schematic representation of the demarcation process for fish breeding sites within Lake Victoria, Kenya.

Figure 2. Macroinvertebrate Shannon Weiner diversity score in different habitats in Lake Victoria, Kenya.

Figure 3. Fish diversity scores in different types of habitat in Lake Victoria, Kenya; a = Shannon Weiner's, b = Rarefaction, c = Simpson's, d = Inverse Simpson's, e = Alpha and f = Species richness.

Figure 4. Relative abundances in different types of habitats in Lake Victoria, Kenya consisting of (a) fish eggs and larvae abundance, (b) juveniles, and (c) mature fish by species.

Figure 5. Demarcated fish breeding sites in Lake Victoria, Kenya.

Figures

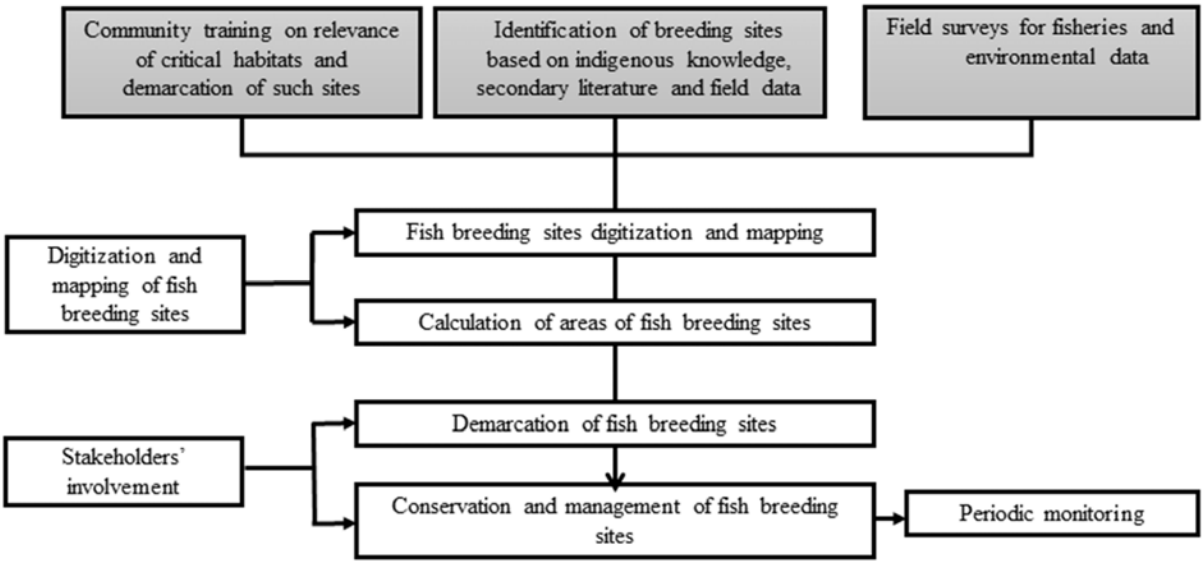
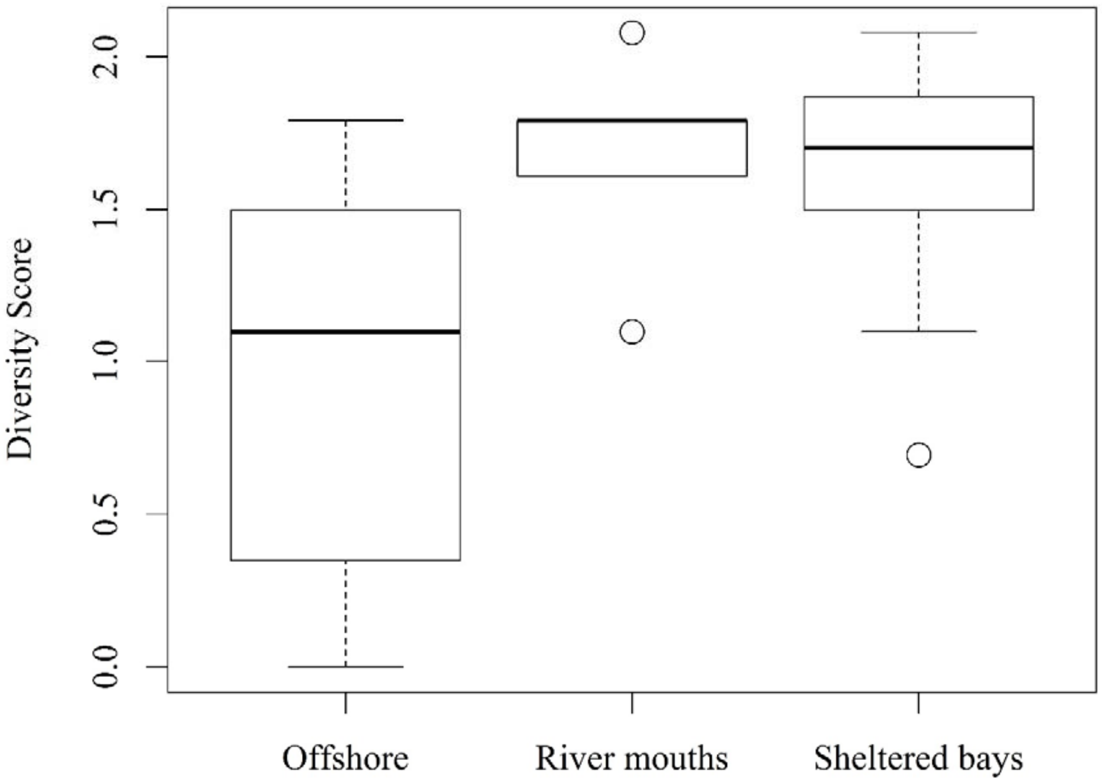


Figure 1.



2.0
1.5
1.0
0.5
0.0
Diversity Score
Offshore
River mouths
Sheltered bays

Figure 2.

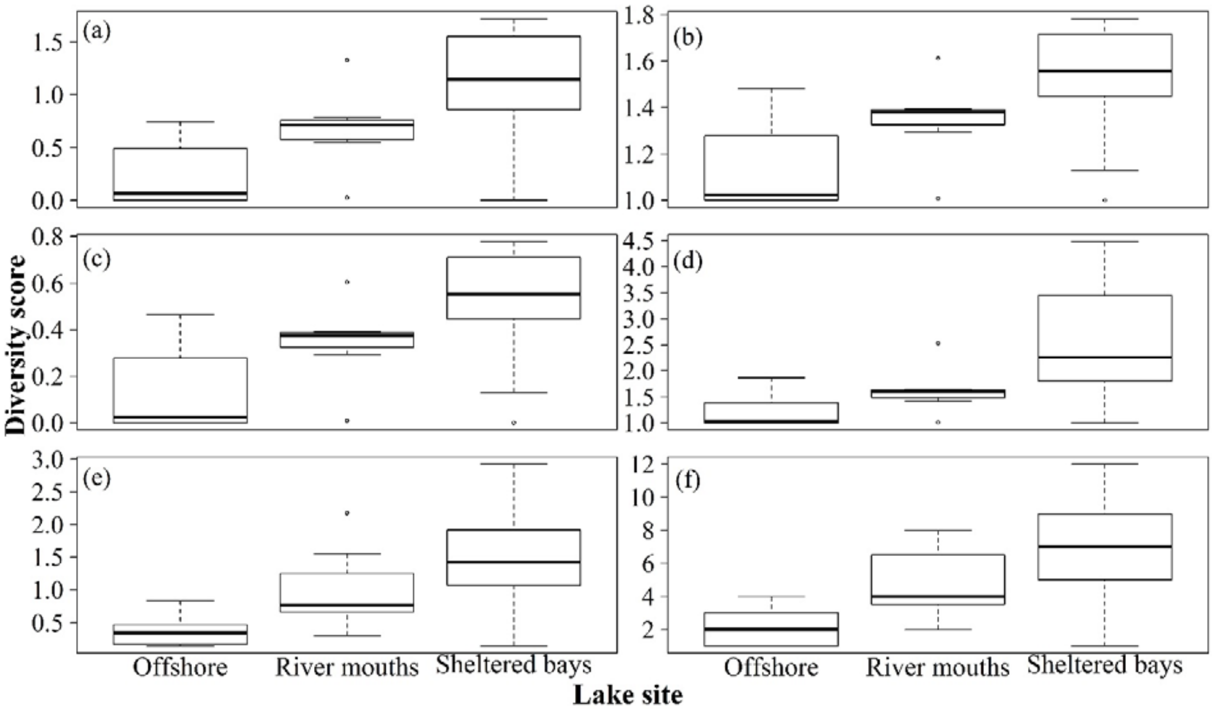

(a)
(b)
(c)
(d)
(e)
(f)
Diversity score
Offshore
River mouths
Sheltered bays
Lake site

Figure 3.

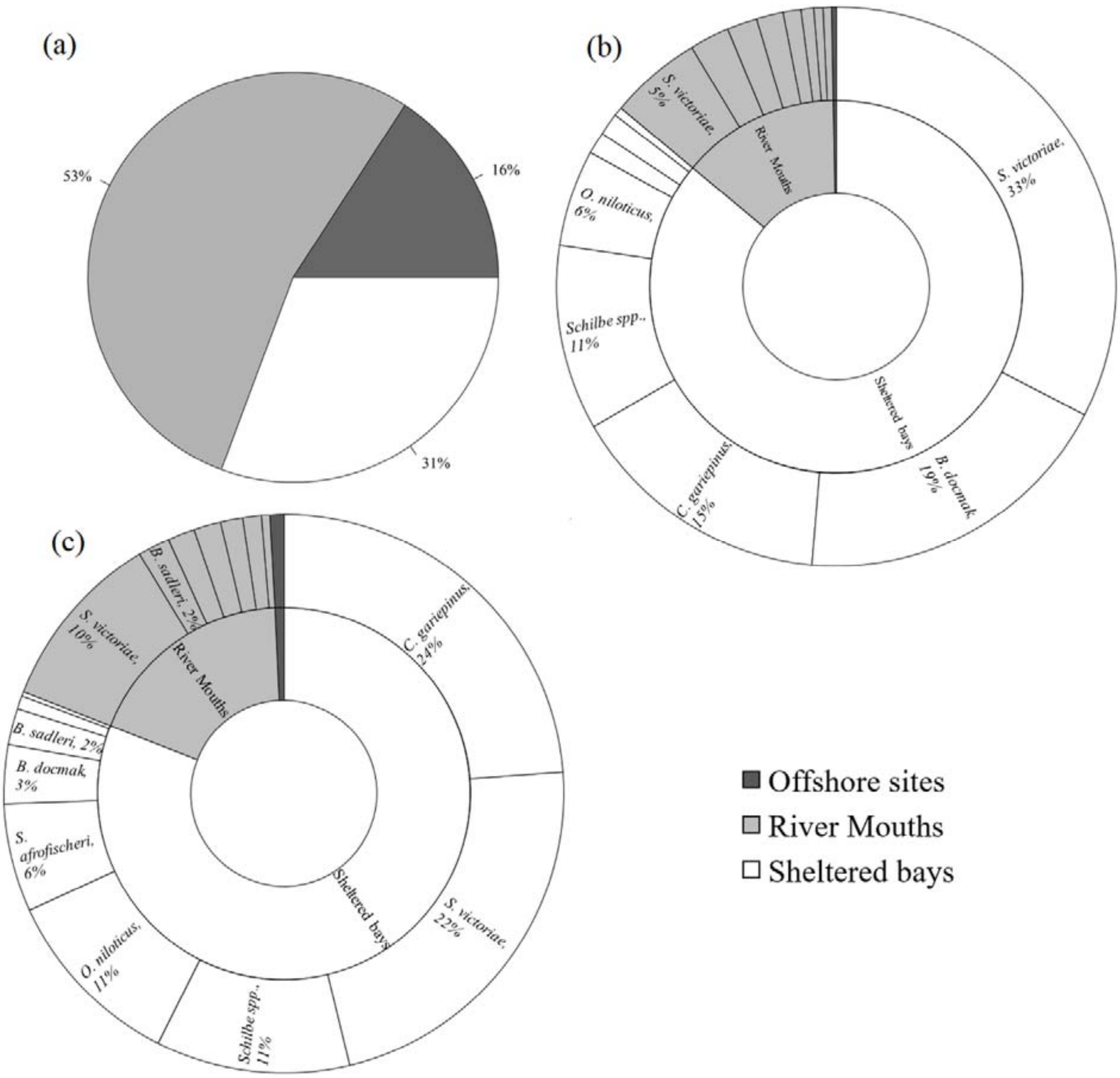

(a)
53%
16%
31%
(b)
S. victoriae, 5%
River Mouths
O. niloticus, 6%
Schilbe spp., 11%
C. gariepinus, 15%
Sheltered bays
B. docmak 19%
S. victoriae, 33%
(c)
B. sadleri, 2%
S. victoriae, 10%
River Mouths
B. sadleri, 2%
B. docmak 3%
S. afrofischeri, 6%
O. niloticus, 11%
Schilbe spp., 11%
Sheltered bays
S. victoriae, 22%
C. gariepinus, 24%
Offshore sites
River Mouths
Sheltered bays

Figure 4.

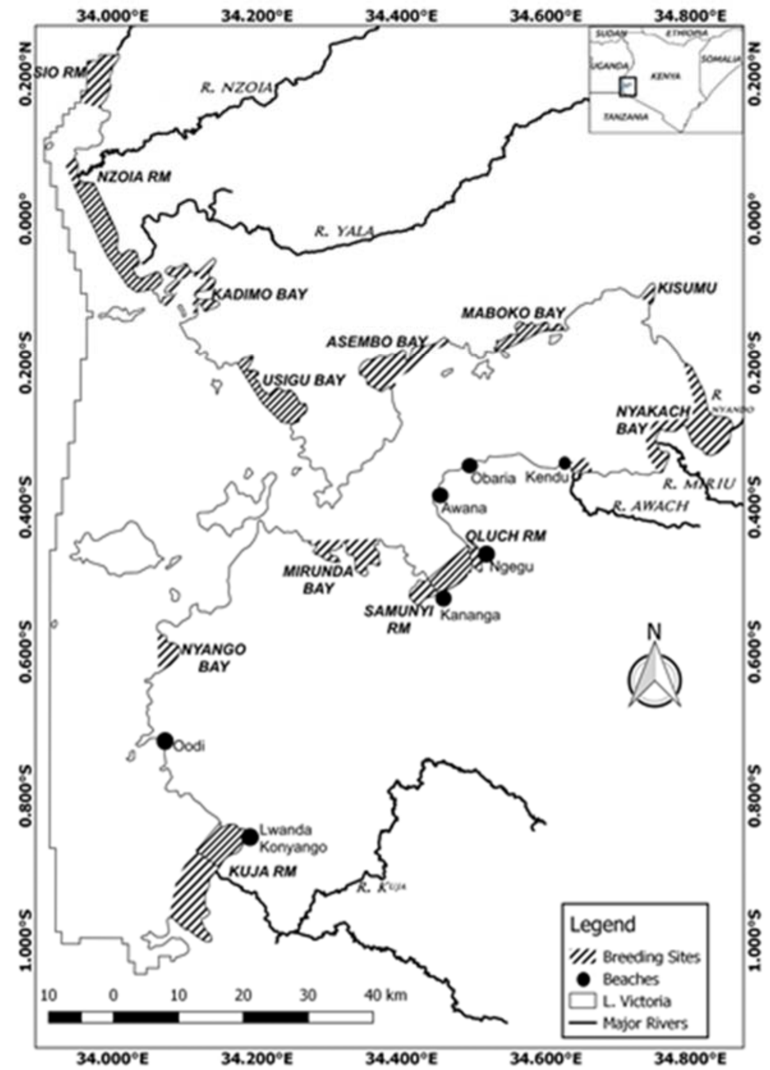

34.000°E
34.200°E
34.400°E
34.600°E
34.800°E
0.200°N
0.000°
0.200°S
0.400°S
0.600°S
0.800°S
1.000°S
SIO RM
R. NZOIA
NZOIA RM
R. YALA
KADIMO BAY
ASEMBO BAY
MABOKO BAY
KISUMU
USIGU BAY
NYAKACH BAY
Obaria
Kendu
R. MIRIU
R. AWACH
Awana
OLUCH RM
Ngegu
MIRUNDA BAY
SAMUNYI RM
Kananga
N
NYANGO BAY
Oodi
Lwanda Konyango
KUJA RM
R. Kuja
Legend
Breeding Sites
Beaches
L. Victoria
Major Rivers
10 0 10 20 30 40 km
SUDAN
ETHIOPIA
UGANDA
KENYA
SOMALIA
TANZANIA

Figure 5.