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INTEGRATING REMOTE SENSING APPROACH WITH POLLUTION MONITORING TOOLS FOR AQUATIC ECOSYSTEM RISK ASSESSMENT AND MANAGMENT: A CASE STUDY OF LAKE VICTORIA(UGANDA)

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Abstract. Aquatic ecosystems around the world, lake, estuaries and coastal areas are increasingly impacted by anthropogenic pollutants through different sources such as agricultural, industrial and urban discharges, atmospheric deposition and terrestrial drainage. Lake Victoria is the second largest lake in the world and the largest tropical lake. Bordered by Tanzania, Uganda, and Kenya, it provides a livelihood for millions of persons in the region. However, the lake is under threat from eutrophication, a huge decline in the number of native fish species caused by several factors including loss of biodiversity, over fishing and pollution has been recently documented. Increasing usage of pesticides and insecticides in the adjacent agricultural areas as well as mercury contamination from processing of gold ore on the southern shores are currently considered among the most emergent phenomena of chemical contamination in the lake. By the application of globally consistent and comprehensive geospatial data-sets based on remote sensing integrated with information on heavy metals accumulation and insecticides exposure in native and alien fish populations, the present study aims at assessing the environmental risk associated to the contamination of the Lake Victoria water body on fish health, biodiversity from agricultural activities which occur in the cachment surrounding the lake. By the elaboration of Landsat 7 TM data of November 2002 and Landsat 7 TM 1986 we have calculated the agriculture area which borders the Lake Victoria bay, which is an upland plain.

The resulting enhanced nutrient loading to the soil is subsequently transported to the lake by rain or as dry fall. The data has been inserted in a Geographical information System (ARCGIS) to be upgraded and consulted. Heavy metals in fish fillets showed concentrations rather low except for mercury concentrations being higher than others as already described in previous investigations. In the same tissue, cholinesterases activity (ChE) as an indicator of insecticides exposure showed significant differences among fish species in both activity and sensitivity of selected inhibitor insecticides. This integrated approach aims at identifying and quantifying selected aquatic environmental issues which integrated with monitoring techniques such as contaminant concentrations and biological responses to insecticides exposure in fish populations provide a basis for aquatic management and assist in policy makers at the national and international levels.

Keywords: remote sensing, ARCGIS, Lake Victoria, heavy metals, insecticide exposure, fish

Introduction

Lake Victoria, the World's second largest fresh water lake is shared by East African Community Partner States of Kenya, Tanzania and Uganda and is of great socio-economic development to the East African people. The Lake basins endowed with a rich and unique terrestrial and aquatic biodiversity ranging from forests, wildlife and fisheries and abounds in minerals. The Lake catchment supports one third of East African Community population of approximately 30 million people. The riparian states rely highly on the Lake for fish, hydropower generation, transport and communication, water supply for domestic, agricultural and industrial use, recreation and biodiversity conservation. Lake wide fish production is estimated at 500,000 metric tons per annum valued at USD 400 million. The Lake is of great scientific interest globally as it harbours over 350 endemic fish species. The rate of population increase of the countries is about 3.4% per annum (Hecky and Bugenyi, 1992; Hecky 1993) and is increasing (Alabaster,1981). Due to increased multiple human activities in the last 40 years, the Lake basin has experienced patterns in unsustainable practices and exploitation of its resources. These trends have caused serious socio-economic and environmental problems including deterioration of water quality, loss of biodiversity, water hyacinth infestation, deforestation, severe soil erosion, wetlands destruction and poverty among the Lake basin communities. By the application of globally consistent and comprehensive geospatial data-sets based on remote sensing integrated with information on heavy metals accumulation and insecticides exposure in native fish populations, the present study aims at assessing the environmental risk associated to the contamination of the Lake Victoria water body on fish health, land cover distribution, biodiversity and the agricultural area surrounding the lake. By the elaboration of Landsat 7 TM data of November 2002 and the Landsat 7 TM 1986, we calculated the agricultural area which surrounding the bay, and the potential increase of nutrient loading to the soil, which is subsequently transported to the lake by rain or as dry fall.

Remote sensing is one of the emerging technologies that has the potential to extend measurements over a range of spatial scales ranging. Remote sensing offers tools to formulate and test ecological hypotheses at larger scales.

Present satellite systems provide information on the physical measurements of the absorptance, reflectance, and emittance properties of landscapes, obtained over a spectral interval that goes from ultraviolet to thermal infrared and microwave. Optical Remote sensing measurements convert photons received by a sensor from pixels (smallest resolvable surface areas) arrayed in a spatial context into voltages that are digitised. Information about the surface is derived from the spectral characteristics and their spatial patterns. These data can be used to explore ecological properties and processes after conversion of the raw data to radiances and then to reflectances, which can be considered a property of the surface observed. This data when confronted on a spatial or temporal basis can be used to predict states and processes.

A fundamental property of matter is that it absorbs and emits energy at specific wavelengths; the absorption spectrum is determined by the chemical composition and structure of the compounds present. Many plant compounds now are identified routinely using spectroscopic assays n the laboratory (Weyer, 1985; Marten *et al.*, 1989), suggesting that spectral characteristics could be used to measure biogeochemical properties at other scales. Vegetation spectra are most varied at the level of biochemical constituents and cell structure. As spatial scales increase, spectral variation decreases nonlinearly, with a trajectory that is not completely understood. The changing variance results largely from the averaging of some components, including the vegetation cover, vegetation structure and shape, soils, and other extraneous effects, for example, atmospheric conditions, as spatial scales increase.

Regarding biological effects related to the exposure to agricultural insecticides such as organophosphates (OPs) and carbamates (CBs) in native and alien fish populations of Lake Victoria, cholinesterases (ChEs) activity was investigated in muscle tissue of two alien species Nile tilapia (*Oreochronis niloticus)* and the redbelly tilapia (*Tilapia zilli)* and one native species the *ngege* (swahili) (*Orechronis variabilis*).

Cholinesterases (ChEs) are a class of serine hydrolases ubiquitous in the animal kingdom. They are widely classified in vertebrates in two homologous groups: acetylcholinesterase (AChE, EC 3.1.1.7) and butyrylcholinesterase (BChE, EC 3.1.1.8) also called pseudocholinesterase or non-specific cholinesterase. AChE, mainly present in brain, plays the physiological role of degradation of the transmitter acetylcholine (ACh) in the cholinergic synapses and neuromuscular junctions while BChE, mainly found in serum, contribute to ChE activity in muscle and nerve tissue (Massouliè *et al.*, 1993). ChEs are strongly inhibited by exposure to neurotoxic compounds including organophosphate (OP) and carbamate (CB) insecticides therefore they represent a well established and specific biomarker of insecticides exposure in non-target terrestrial and aquatic organisms (Weiss, 1964; Fulton*et al.*, 2001). More recently, its field application in biomonitoring programmes on fish species has been reported to be less specific, thus it is now emerges as a more general marker of exposure to neurotoxic contaminants including heavy metals and organochlorines (Gill *et al.*, 1990a,b; Sturm *et al.*, 1999). The sensitivities of ChEs to insecticides exposure concentrations may differ from species to species and may also display variations due to peculiar conditions such as place of origin. In addiction, since more than one ChE seems to be present in muscle tissue of marine fish, a biochemical characterization of ChEs and of their sensitivity to selective inhibitors and insecticides are needed in order to validate their use as a biomarker.

Materials and Methods

Study site

Lake Victoria is the world's most extensive tropical lake (ca. 69,000 km^2) but is relatively shallow (ca. 80 m max. depth; Crul, 1995). Fishes champion was collectedin Jinja Bay Uganda (Figure 1; 0°18′N, 33°20′E). The bay floor dips northward to a depth of 12 m and papyrus swamps fringe the shoreline. More than 90% of Lake

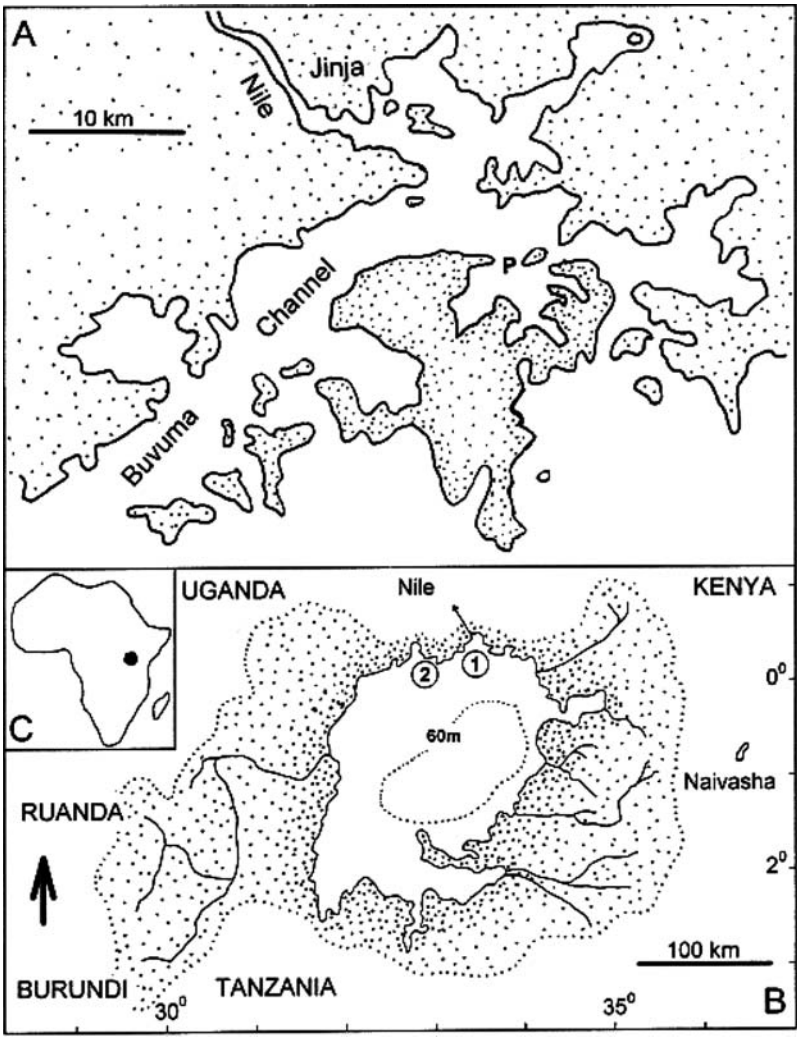

Figure 1. Site map (A) Jinja Bay. (B) Lake Victoria watershed. 1 = Pilkington Bay 2 = Damba Channel. (C) Africa with Lake Victoria watershed dotted.

Victoria's water enters and leaves via the atmosphere with most rain falling around March–May (long rains) and October–December (short rains) with the arrival of the Intertropical Convergence Zone (ITCZ). Between rainy seasons, dry winds associated with the Afro-Asian monsoon system contribute to the breakdown of thermal stratification (Talling, 1966). The past 50 years have brought major changes to Lake Victoria, including eutrophication and persistent thermal stratification (Hecky, 1993). Native fishes have declined and the phytoplankton, formerly dominated by green algae and diatoms (*Aulacoseira* spp.) that require strong mixing, are now dominated by cyanobacteria and diatoms (*Nitzschia* spp.) that are typical of stable water columns (Ochumba and Kibaara, 1989; Hecky, 1993).

Until the 1960s, Lake Victoria could boast a rich, well-balanced plant and animal species complex (Greenwood, 1956). Overfishing, pollution from industrial and agricultural sources, noxious water weeds and predatory introduced fish species have all threatened the sustainability of Lake Victoria's resources and, consequently, the economies and well-being of the surrounding governments and people. Many of the threats to Lake Victoria have been the result of increases in the surrounding human populations (Food and Agriculture Organisation (FAO), 1990, 1996; LVFO, 1996).

In the early 1960s, the Nile perch (*Lates niloticus*) was introduced into Lake Victoria in an effort to improve the declining fishery of the popular native species, partially for sport fishing purposes and partially to boost the fishing economy. At the time, there were heated disputes about the possible costs and benefits to such an introduction (Fryer, 1960; Anderson, 1961). Nile perch introduction resulted in the disappearance of many native species that were abundant in the lake. At present, the huge haplochromines cichlid flock has been driven to near extinction and only pockets of some species may be seen in protected bays, rocky shores and inlets acting as refugia (Ogari and Dadzie, 1988). Scientists estimate that 200 cichlid taxa have been lost (Barel *et al.*, 1991). The native tilapia (*Oreochromis esculentus*), previously a fish of great commercial importance, has fallen to insignificant numbers in Lake Victoria (Goldsmidt and Witte, 1992; Witte *et al.*, 1992). It is likely that many other biota such as aquatic insect, crustacean and plant species have been affected by the radically altered trophic structures in the lake. At present, two exotic species (Nile perch and Nile tilapia) and a native sardine dominate the commercial fishery. The lake fishery that was once multi-species is now dominated by three species.

The fishery resources of Lake Victoria had high historical value as a source of protein and employment opportunities, especially for the lakeside communities. Nile perch is a vital foreign exchange earner for the riparian states, cherished internationally, while the other fishery resources had ready regional markets. This demand for fish and the environmental degradation highlighted above placed considerable pressure on the fisheries resources of Lake Victoria.

The traditional fish fauna and fishery of Lake Victoria was dominated by Cichlids. Two Tilapia species *(O. esculentus* and *Oreochromis variabili*s) plus a few other fishes *(Bagrus docma*c, and *Labeo victorianu*s) were the main stay of the fishery, while, haplochromines, which evolved in the lake into about 300 species through explosive speciation, dominated the itchthiofauna. Many of the haplochromine species were endemic to Lake Victoria. There were only about 50 non-cichlid fish species in the lake, Lowe-McConnel but the traditional commercial fishery depended on relatively few taxa. Four alien tilapiines *(Oreochromis niloticus*, *Monochromes leucostictus*, *Oreochromis melanopleura* and *Tilapia zilli*) and alien Nile perch were introduced into Lake Victoria in the 1950s and early 1960s, respectively.

Some information has been collected by local and national authorities on the scale and location of polluting industries, and there are a number of basic industries that are common to most of the major urban areas, for example, breweries, tanning, fish processing, agroprocessing (sugar, coffee) and abattoirs. Some of these have implemented pollution management measures but in general the level of industrial pollution control is low. Small scale gold mining is increasing, in Tanzania in particular, and this is leading to some contamination of the local waterways by mercury which is used to amalgamate and recover the gold. Some traces of other heavy metals, such as chromium and lead, are also found in the lake, although the problem has not yet reached major proportions.

The fish were collected along the shoreline within the ecotone area between papyrus stand and open water using different methodologies: gill nets for the tilapia *sensu lato* (*Oreochromis* spp. and *Tilapia* spp.) and electrofishing equipment for the haplochromines species. Each specimens collected was then preserved in ethanol solution (70%).

Remote Sensing Analysis

In order to characterise the of Jinja bay ecosystem, satellite based measurements of reflected and emitted electromagnetic radiation in the visible (400–700 nm), near infrared (700–1100 nm) and thermal infrared (10000–13000 nm) wavebands were used to examine spatial and temporal trends in the environment. The availability of a historic series of data permits the analysis of environmental changes due to natural or induced factors. As satellite data is obtained nearly instantaneously over a wide area, the study of the spatial distribution of specific territorial characteristics is facilitated. The availability of information on the emission in several wavebands from the surface of a territory gives valuable information about the conditions and cover of these areas. The use of high or medium resolution data permits the creation of specific indices that can be used to make intra-territorial comparisons and decisions. Landsat Thematic Mapper (TM) images were used to map the cover of Jinja area. TM data have advantages over the other sensors that TM records an additional infrared channel at 1.55–1.75μm. This is important for discriminating different vegetation types (Fuller *et al.*, 1989; Townshend, 1992).

Image interpretation: Vegetation is the dominant and important component in most ecosystems and useful indicator environmental conditions. Many remote sensing mechanisms operate in the green, red and near infrared regions of the

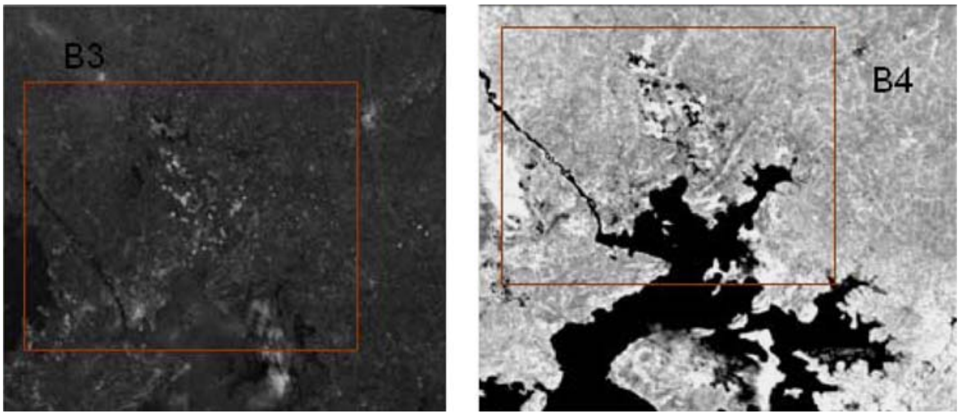

Figure 2. In this figure a comparison between the band 3 and the band 4 of the Landsat 7 ETM image of November 2002. Black - and - white images represent light intensity variations for a single band. Band 3 (red) is strongly absorbed by active vegetation, whereas band 4 (near infrared) is strongly reflected. Because of this vegetated areas are bright in the band 4 image, and dark in the band 3 image (Aber, 2000). On left side in the band 3 image the light area is the modified area and the wetland are light too. Permanent and temporary waterbodies are black. Light areas refersto population centers and roadways. The band 4 image shows waterbodies in black, wetlands in dark grey and agricultural areas in ligh and dark grey, depending upon irrigate regime.

electromagnetic spectrum. They can discriminate radiation absorption and reflectance of vegetation. Changes in vegetation are useful for recognizing changes in other environmental factors. Identifying vegetation in remote sensing images depends on plant characteristics: leaf shape and size, overall plant shape, water content, and associated background (e.g. soil types and spacing of the plants).For interpretation is used single band images (bands 3, and 4) and bands compositions are particulary useful (Figure 2).

The studied area is the Jinja Bay, in the northwest Ugandan part of the Lake (Figure 1). Around the bay there is extensive area with agricultural production.

From this area there is a series of streams which cross the crops and flow into the Lake.

We elaborated a technique of false color composition and unsupervised (Figure 2) classification the Landsat 7 TM image of November 2002 and November 1986. These techniques have shown that from 1986 to 2002 the land cover around the studied bay has changed.

Biological Effect of Insecticides Exposure: ChE In Vitro Test

ChEs were extracted from crude homogenates of portion of dorsal muscle according the colorimetric method of Ellman *et al.* (1961). Dried tissue was homogenized in 0.1 mg/ml of 20 mM Tris-HCl, 5 mM $MgCl_2$, 0,1 mg/ml Bacitracin, 8×10^{-3} TIU/ml Aprotinin, 1% Triton X$-$100 and centrifuged at 9,000 g for 20 min recovering the supernatant. ChE activity was assayed at 30 °C using

TABLE I

IC_{50} calculate to the inhibition curve of ChE activity (nmol min^{-1}mg $protein^{-1}$) versus ASCh (1 M) in *in vitro* exposure to insecticides at range of 10^{-9} to 10^{-3} M

OP insecticides	Nile tilapia (*O. niloticus*)	Redbelly tilapia (*Tilapia zilli*)	Ngege *(O. variabilis)*
DFP	1,E-05	1,E-05	1,E-06
Fenitrothion	1,E-03	1,E-03	1,E-05
Chlorpyriphos	1,E-04	1,E-04	1,E-04

1 mM acetylthiocholine iodide (ASCh) and butyrilthiocholine iodide (BSCh) as substrates. Selective ChE inhibitors [tetra(monoisopropyl)pyrophosphor-tetramide (iso-OMPA) for BChE and 1,5-bis (4-allyldimethylammoniumphenyl)-penthan-3-one dibromide (BW284c51) for AChE] were tested at a fixed concentration of 3 mM while three OP insecticides [diisopropyl fluorophosphate (DFP), fenitrothion and chlorpyriphos], were tested at 10^{-9} to 10^{-3} M and the resulting IC_{50} calculated. Both inhibitors and insecticides were tested by incubating 15 min crude muscle homogenates with them and then adding substrate ASCh (1 mM) and DTNB. Reaction was read in 5 min (linearity) at 30 °C in a 550 Model microplate reader and ChE versus ASCh activity expressed as nmol $minutes^{-1}$mg $proteins^{-1}$. Total protein content of crude homogenates was measured by the method of Bradford *et al.* (1976) in a Shimadzu UV-Visible recording spectrophotometer λ 595 nm, Biorad Protein and bovine serum albumin (BSA), as reference standard, were used. In the Table I are expressed the results of the CHe *in vitro* test.

Heavy Metals Analysis

Muscle and liver tissue of fishes were freeze dried (lyophilisator LIO 5 PASCAL 220 V with Vacuum Pump RV8) before analysis. Samples of about 0.15 g of both materials were digested with 2.5 ml nitric acid in PTFE digestion bombs at 120 °C for 9 h (Jackwerth and Wurfels, 1997). Before mineralization, known amounts of the elements analysed was added to 0.15 g of each specimen type to obtain an internal standard from which a standard calibration curve is derived. The digested material was analysed for Cd and Pb by electrothermal atomic absorption spectrometry with Zeeman background correction (Perkin Elmer ZETAAS), for Zn, Cu and P by inductively coupled plasma emission spectrometry (Perkin Elmer ICP-AES) and for Hg by flow injection mercury system (Perkin Elmer FIMS 400). In order to prevent contamination, during every digestion cycle more that one blank analysis was performed by introducing only the reagents in the Teflon vessels. The accuracy of the results was verified by analysing Standard Reference Material DORM-2 (dogfish muscle), obtained from the National Research Council Canada, Institute for Environmental Chemistry, Ottawa, Canada. Uncertainty related to sample homogeneity, digestion and analysis was assessed by replicate determination of samples and was

TABLE II
Trace element values are expressed as μg/g dw

Sample	Hg	Cd	Pb	Zn	P	Cu
O. variabilis Fillet	<0.005	<0.01	<0.05	24.648	8373	<1
O. variabilis Fillet	0.0126	<0.01	<0.05	31.637	4587	1.0619
Nile tilapia (*O. niloticus*) Fillet	0.0335	<0.01	<0.1846	48.173	86190	1.6244
Nile tilapia (*O. niloticus*) Fillet	0.0526	<0.01	0.0962	40.794	11958	1.4286
Redbelly tilapia (Tilapia zilli)	0.1204	<0.01	0.2031	78.603	17123	1.8436

found to be below 10%. Data are expressed as μg g^{-1} dry weight. In the Table II are expressed the concentration of the metals in the issiue of the fishes.

Results and Discussion

From the remote sensing analysis we can see that the land use around Lake Victoria has changed in the last 10–15 years. Many of the natural shrub areas presents in 1986 have been replaced by intensive agricultural area (Figure 3). Wetlands also appears to have decreased.

The agriculture area is located at higher elevation with respect to the Lake. Therefore channels crossing the bring sediments and nutrients into Jinja Bay carring along with pesticides and heavy metals.

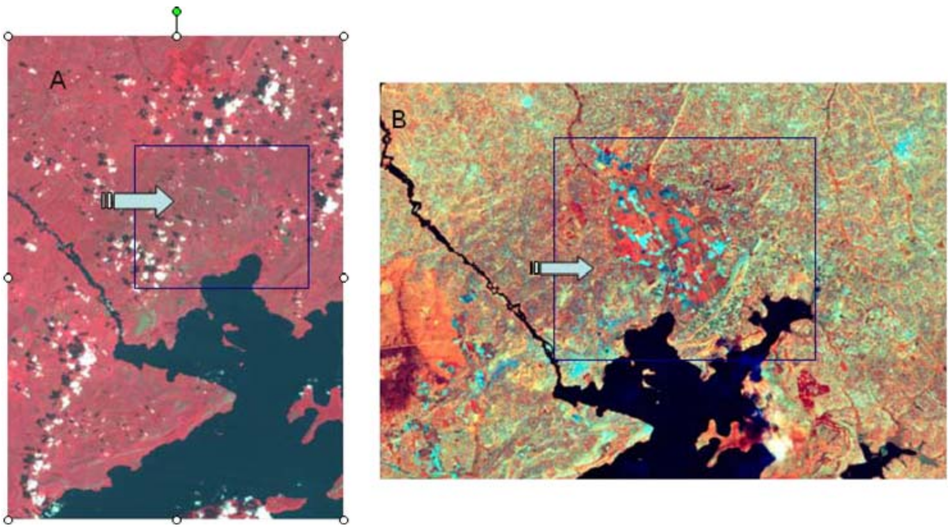

Figure 3. False colour composition. In this figure the two Landsat images respectively in the band 4,3,2 are shown. In the picture A, the around Jinja Bay in 1986 are shown where the uniform red color shows natural areas while the green colour shows agriculture crops. In the figure B, the same area is shown in 2002, showing an increase in agricultural areas.

Both satellite images were elaborated using a unsupervised classification procedure to extract the land cover information. The principals crops grown in the watershed include maize, cotton, sisal, tobacco, beans, sugarcane, and coffee. Most of these are intensive crops that require significant uses of herbicides and agricultural chemicals.As there is a significant pressure to increase export related products, the continue expansion of crops is likely.

Regarding the biological effects on insecticide exposure on fish populations, ChE activities were investigated and the following results were found. Crude muscle homogenates of the three species showed similar ChE activities versus ASCh as substrate and comparable higher selectivity to ASCh as substrate compared to BSCh. An apparent lower selectivity was observed for the native species *O. variabilis* compared to both alien Nile tilapia and redbelly tilapia. Both tilapia species showed comparable hydrolysis of ASCh and no substrate inhibition at concentration > of 1 mM.

Regarding sensitivity to specific ChE inhibitors, significant inhibition with both Iso-OMPA (against BChE) and BW248 c51 (against AChE) was observed in all three species (from 40 to 70%). These findings are consistent with the well established views that there are only two types of ChE in vertebrates including fish (AChE and BChE) in addition to which an atypical ChE cleaving BChE substrates and also sensitive to BW284c51 seems to be present in fish muscle tissue (Sturm *et al.*, 1999). Similar data resulted in agreement with previous observations reported by Rodriguez-Fuentes *et al.* (2004) in muscle tissue of the Nile tilapia (*O. niloticus*) from Mexico and with previous investigation in other fish species (Varò *et al.*, 2003). No substrate inhibition was in fact reported supporting the hypothesis that the ChE present in muscle tissue (as well as in liver) might have properties that resemble a butyrylcholinesterase (BChE, EC 3.1.1.8) due to the high affinity to BSCh.

The *in vitro* exposure to OP insecticides DFP, fenitrothion and chlorpyriphos showed a slight different sensitivity in the native species compared to tilapias (Table I). IC_{50} values suggest that ChE activities (versus ASCh) of both tilapia species (Nile tilapia and redbelly tilapia) might be more resistant to OPs than ChE activities of native *O. variabilis* which resulted more inhibited even at the lowest concentrations (10^{-7}–10^{-6}M) (Table I).

Conclusion

Environmental impacts to the lake Victoria ecosystem includes enhanced siltation, nutrient enrichment and pollution loading due to destruction of the buffering capacity of the wetlands; loss of biodiversity, and other lake resources; and degradation of fish habitats and fish stocks.

The studied areas of the rivers feeding the lake and the shoreline is particularly polluted by municipal and industrial discharges. Some information has been collected by local and national authorities on the scale and location of polluting industries, and there are a number of basic industries that are common to most of the major urban areas, for example, breweries, tanning, fish processing and agro-processing (sugar, coffee). Some of these have implemented pollution management measures but in general the level of industrial pollution control is low. Small scale gold mining is increasing, in Tanzania in particular, and this is leading to contamination of the local waterways by mercury which is used to amalgamate and recover the gold. Some traces of other heavy metals, such as chromium and lead, are also found in the lake, although the problem has not yet reached major proportions. The use of fertilizers and animal manure has increased tremendously, causing accelerated eutrophication of Lake Victoria waters.

Lake Victoria has undergone a dramatic change associated with excessive eutrophication causing its bottom waters, which were previously oxygenated by wind-inducing mixing, to remain stratified and anoxic year-round (Lowe-McConnell, 1997). The use of agrochemicals is gaining momentum in the lake basin even among the small-scale producers, particularly in Kenya and Tanzania where there are large-scale farms of coffee, tea, cotton, rice and maize.

ChE activities in term of sensitivity to substrate and inhibitors resulted in agreement with previous investigation on Nile tilapia and in general with other fish species of both Atlantic and Mediterranean ecosystems. Sensitivity to insecticides exposure reveal a similar response to that observed in other fish species even the high sensitivity of the native species ngege (O. variabialis) compared to the alien tilapia suggest the need for further investigation for conservation of the native species biodiversity in the lake.

Further studies on target insecticides tissue such as brain and *in vivo* exposure to pesticides readily used in the agricultural area are needed a toxicological risk for fish populations can be determined in relation to the increasing impact of agriculture in the area surrounding the lake. Moreover, the lack of accurate data on fertilizer and pesticide usage continues to hinder decision-making about appropriate measures of control. New environmental impact assessment measures being put in place by the national environment authorities of the three countries bordering the lake may help clarify many of the issues related to data and monitoring. In conclusion ,the integrated approach based on ecotoxicology analysis and remote sensing analysis applied in the present study clearly revealed that conversion and unsustainable management of catchment areas of Lake Victoria can have a negative impact on resource quality and in particular fish.

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