ISSN 2731-7890 (Online)

International Journal of UNESCO Biosphere Reserves

www.biospherejournal.org

Published by VIU Press

Volume 2 Issue 2 November 2018

VIU

Bull Kelp (*Nereocystis luetkeana*) enhancement plots in the Salish Sea

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Keywords: bull kelp, environment, enhancement, Strait of Georgia

Introduction

Data regarding the abundance of bull kelp (*Nereocystis luetkeana*) along the east coast of Vancouver Island in British Columbia is limited, but there is evidence that bull kelp populations have been in steady decline within the central Strait of Georgia within recent decades (Lamb et al., 2011). In addition, local residents that frequent the coast have reported that *N. luetkeana* has been significantly declining in the Salish Sea over the past 30 years, becoming nonexistent in regions where it was previously abundant (Lindop, 2017). Reasons for significant declines of *N. luetkeana* forests in the Salish Sea may include coastal development, rising ocean temperatures, local changes in oceanographic conditions (e.g. salinity, turbidity and sedimentation), intensified herbivore grazing or a combination of these factors (Steneck et al., 2002, Heath et al., 2017).

The Mount Arrowsmith Biosphere Region Research Institute (MABRRI) has undertaken a pilot project, attempting to re-establish bull kelp beds that have begun to diminish or have perished in the Salish Sea, specifically the Strait of Georgia. MABRRI's Bull Kelp Monitoring and Enhancement Plot project involved the installation of kelp enhancement plots at two different sites within the Strait of Georgia, including one located in the Winchelsea Islands, near the entrance of Nanoose Bay, and the other northwest of Dodd Narrows, in the Northumberland Channel (Figure No. 1). Located within the UNESCO designated Mount Arrowsmith Biosphere Region, the Winchelsea Islands site was noted by locals to have a flourishing bull kelp forest; however, no bull kelp is found near the site today. Additionally, the Northumberland Channel historically and presently has bull kelp just south of the enhancement plot site.

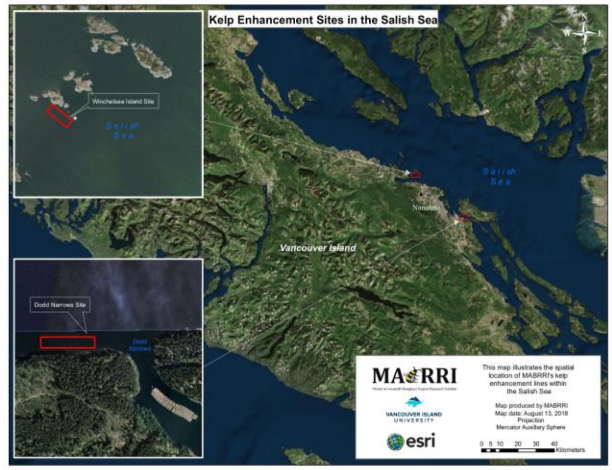

Figure No. 1. Site locations of MABRRI's *Nereocystis luetkeana* enhancement plots in the Strait of Georgia, British Columbia

Site selection for the *N. luetkeana* enhancement plots was based on local historical knowledge that was obtained by speaking with fishermen and divers that have frequented the area for the past 30 years. Through this knowledge sharing, it was noted that bull kelp has either declined, or is now completely absent in these regions. Additionally, prior to this project, initial surveys were conducted indicating small amounts of *N. luetkeana* near Dodd Narrows. Further, data loggers, measuring temperature and light intensity at the bottom and six metres from the bottom, were deployed at both sites, and initial results indicated favourable characteristics of bull kelp. Both sites were determined to have rocky substrate with suitable depths of approximately 9 meters, and suitable currents that support the growth of *N. luetkeana*.

Methods

Installation of enhancement plots followed Project Watershed's methods, used at their enhancement plots off Hornby Island. The set up included two concrete anchors with a 19mm diameter rope strung between them. Multiple spools of pre-seeded lines, which are strings with *N. luetkeana* growing on them, were wrapped onto the rope as it was lowered (Heath & Chambers, 2014). Additionally, mature *N. luetkeana* were collected and transplanted onto the rope. One of the transplant methods was adapted and modified from a project in Washington State; the other was developed by MABRRI and Heath (Carney, Waaland, Klinger, & Ewing, 2005).

Two methods were employed during the transplant. The first method ("Method A"), involved a piece of nylon cord looped around the stipe of the *N. luetkeana*, just above the holdfast, with the loop being secured by a cable tie. A second loop, on the open end of the nylon cord, was created with a second cable tie, through which the third cable tie was guided to attach to the nylon cord to the rope (Figure No. 2a) (Carney et al., 2005). The second method ("Method B"), involved fastening the holdfast directly onto the rope by wrapping veterinary tape around them. A single cable tie was then attached on either side of the stipe, over top of the veterinary tape, to secure the holdfast while minimizing abrasion (Figure No. 2b). A total of 12 individual kelp were evenly distributed along the rope, with an even number of each method used at each site. Each kelp was coded and tagged to easily monitor each kelp's individual progress.

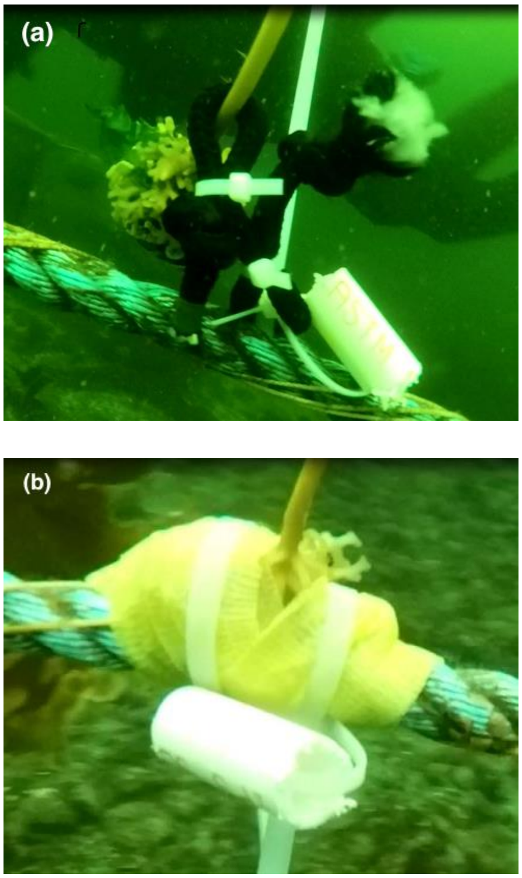

Figure No. 2. The two methods used to attach mature *Nereocystis luetkeana* sporophytes to the enhancement plot rope.

Preliminary Results

The transplant of all mature *N. luetkeana* sporophytes occurred on June 6, 2018. By August 16, 2018, seven individuals remained between both sites; four individuals that were attached via Method A, and three individuals that were attached via Method B. The individuals that did not survive either snapped along their stipe, were grazed, or were completely absent from the site. Five individuals were observed to have sori over the summer, and we will continue to monitor for new sporophyte production occurring at both sites.

Using a time-lapse camera and periodic observations from divers, species that were commonly observed using the *N. luetkeana* as habitat were schools of Pacific herring *(Clupea pallasii)*, schools of shiner perch *(Cymatogaster aggregate)*, and juvenile copper rockfish *(Sebastes caurinus)*. Our dive team is also surveying the benthic species present near the enhancement plots, recording whether changes are occurring to the composition of benthic flora and fauna over time. This surveying is accomplished by using one-meter by one-meter quadrats in pre-determined locations underneath the kelp lines, at both sites.

Next steps

The goal of the enhancement plots is for the *N. luetkeana* to reproduce and form self-sustaining kelp forests within our study sites, as well as provide habitat for species that would normally use these kelp beds as habitat. In addition to the efforts of restoring *N. luetkeana*, baseline data regarding water parameters and species composition at each site is being collected. This data may then be used to assist future projects in understanding how bull kelp is being impacted over time by changing environmental and climatic conditions.

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The analysis of mangrove forest changes period of 20 years in Can Gio Biosphere Reserve, Viet Nam using remote sensing and GIS technology

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Abstract

On January 21, 2000, the MAB/UNESCO Committee recognized the Can Gio mangrove forest as an International Biosphere Reserve. The MAB/UNESCO committee requires every potential biosphere reserve to be assessed for a period of 10 years. During this time, the ecology of the area is closely reviewed, including the vegetation cover. This study used 45 sample plots in the field and utilized Remote Sensing and Geographic Information Systems (RS & GIS) technology for mapping, allowing for the close observation of changes in the mangrove forest during a 20 year period (1996-2016). The results show that, from the SPOT, Landsat 8 OLI satellite imagery, we can categorize the land cover maps in Can Gio Mangrove Biosphere Reserve, including periods of 1996, 1999, 2004, 2009 and 2016, into six classes: dense mangrove forest, open mangrove forest, young mangrove forest and scrub, agriculture land, water body, and barren land. The accuracy of the land cover maps for 1996, 1999, 2004, 2009 and 2016 was high, with scores of 84.89 percent, 83.89 percent, 87.78 percent, 82.78 percent, and 84.44 percent, respectively.

Keywords: Mangrove forest, monitoring, remote sensing, GIS

Introduction

Vietnam is located on the Indochinese Peninsula, and has a 3,260 km long coastline. Of the eight International Biosphere Reserves (IBRs) in Vietnam, seven IBRs are positioned along the coast and including rich natural resources, such as mangroves (Hong et al., 1997). Vietnam is one of the countries most affected by climate change. In recent years, we have seen an increase in irregular weather and natural disasters, especially in the form of storms and floods. Droughts and floods have caused widespread damages to the country in 2006, 2007, 2009, and 2015. In areas of southern Vietnam, such as Ho Chi Minh city and Can Tho Ca Mau, provinces that had never suffered from floods in the past, are now regularly hit. In June 2009, the Ministry of Natural Resources and Environment conveyed concerns regarding climate change, and asked the departments to develop an action plan addressing the threat of rising of sea levels. According to the Ministry's calculations, the temperature in Vietnam will have increased by 2.3^{o}C, and most of the area in the southern provinces (agricultural land, residential land, mangrove forest, etc.) will be flooded by the end of the 21st century (Tran Thuc et al., 2016). The Can Gio Biosphere Reserve, lying entirely within the Can Gio district in southern Vietnam, is an important mangrove forest ecosystem, and is regarded as the "green lungs" of the region (Nguyen Hoang Tri et al., 2000). Due to its international significance, it was recognized as the first International Biosphere Reserve in Vietnam by the MAB/UNESCO committee in 2000 (UNESCO, 2000). After serious damage suffered during the Vietnamese war, the reserve is now under threat of global climate change and rising sea levels along the Mekong river. There are around 58,000 people living within the boundaries of this reserve, and approximately 54,000 people living in the transition area (Tuan et al., 2002). The local people are of various origins and ethnical groups; Consequently, a mixture of culture and social systems is inherent to this region. The main economic activities are agriculture, fisheries, aquaculture, and salt production. Most of the families in this region must earn their livings by catching crabs and mollusks, and by collecting firewood. The livelihood of the local people depends on mangrove forests, either directly or indirectly. The scientific management of the mangrove forests is extremely important, not only for the conservation of natural coastal environments, but also for safeguarding the livelihood of thousands of local people.

The purpose of this study is to monitor the mangrove forests of the Can Gio Biosphere using remote sensing data and geographical information system (GIS) technology, and help protect an important biosphere reserve of both Vietnam and the world.

STUDY AREA

Can Gio mangrove forest lies entirely within the district of Ho Chi Minh City, on the geographic co-ordinates of are 10^{o}22’14N to 10^{o}40’09’’N latitude and 106^{o}46’12’’E to 107^{o} 00’ 59’’ E longitude. The reserve is located south of Nha Be district, and north of Dong Nai and Ba Ria – Vung Tau and Long An sit to the east and west, respectively. The area measures 35 km from North to South and 30 km from East to West (Tuan et al., 2002; Hirose et al., 2004) (Figure No. 1).

Figure No. 1. Local map of study area (Can Gio Biosphere Reserve)

DATA AND METHODOLOGY

In this study, we used five optical satellite images: SPOT 4 of 1996, 1999, SPOT 5 of 2004 and 2009, and Landsat 8 OLI 2016. Data for 1999, 2004, and 2009 was acquired from the works of Luong and Singh (Luong., 2009, 2011; Singh and Luong 2013). The optical satellite used in the present study are shown in Figure No. 2.

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(a.)

(b.)

(c.)

(d.)

(e.)

Figure No. 2. False colour composite of (a.) SPOT HRV in 1996, (b.) 1999, (c.) 2004, (d.) 2009, (e.) Landsat 8 OLI in 2016.

FIELD WORK

In total, 45 sample plots were used in this study. The diameter of all the trees larger than 5 cm in diameter were measured at breast height (D) and full height (H). The tree diameter and height were measured by using laser instruments, and the central geo-location (latitude and longitude) of each sample plot was recorded with a GPS device. The average forest parameters (units per hectare) in each plot were calculated according to the guidelines provided by Hong et al., 2006. The summary of results from filed work are shown in Table No. 1.

Table No. 1. Summary of forest inventory parameters in Can Gio Mangrove Reserve

Parameter	**Forest inventory parameters**			
	Minimum	Maxmum	Mean	Standard Deviation
Diameter (m)	5.83	17.60	11.10	3.25
Height (m)	6.34	17.04	13.84	2.85

Paramete r	Forest inventory parameters			
	Minimum	Maxmum	Mean	Standard Deviation
Woody volume ($m^3.ha^{-1}$)	8.27	206.03	136.56	64.26

(a)

(d.)

(b.)

(e.)

(c.)

(f.)

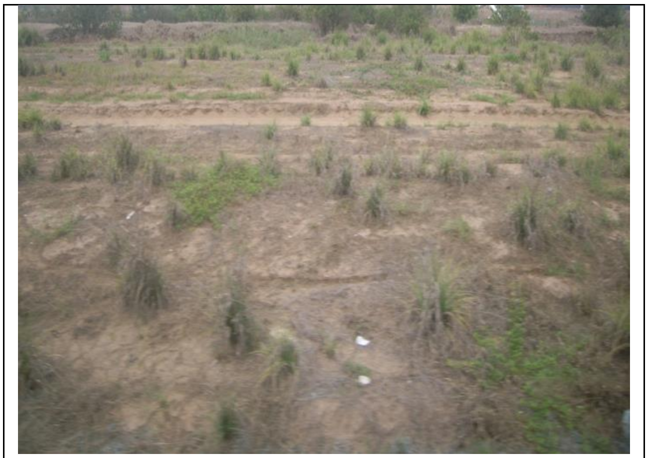


Figure No. 3. Photo from field work: (a.) Dense mangrove forest, (b.) Open mangrove forest, (c.) Young mangrove forest, (d.) Scrub, (e.) Agriculture land, (f.) Barren land

LAND COVER CLASSIFICATION

The classification scheme is based on the objectives or requirement of the user. In this study, we used five satellite images, four of the five from SPOT satellites including SPOT in 1996, 1999, 2004, 2009 and one of them from Landsat 8 satellite in 2016. The selected satellite images did not differ much about time observed per the years, it is an advantage to accurately detect changes in mangrove forest over time. The classification makes easily use to mangrove forest manager, and also conformity with criteria for the classification by Vietnam (MARD, 2009), and was adopted classification criteria of the UNESCO (1973) and Thai Van Trung (1998) systems. The classification scheme land covers in this study are described following:

- Level 1 (main classes) has two classes: Forest land and Other land (none forest).
- Level 2 (Sub-classes) has six classes: Dense mangrove forest (dense forest), Open mangrove forest (open forest), Young forest&scrub (young forest and scrub mixed), Agriculture land, Water body, and Barren land.

PROCESSING OF SATELLITE DATA

The processing of satellite data in this study included geometric correction, image to map rectification, image registration, image fusion, and change analysis (Laben et al., 2000; Luong et al., 2015). Supervised classification method was used. The supervised classification is the process of sampling a known identity, in order to classify pixels of unknown identity. Samples of known identities are pixels located within training areas. Pixels located within these areas are used to guide the classification algorithm, assigning specific spectral values to appropriate information classes. There are three basic steps to the supervised classification procedure: define signatures, evaluate signatures, and process a supervised classification.

RESULTS

Land cover mapping

Land cover map in 1996

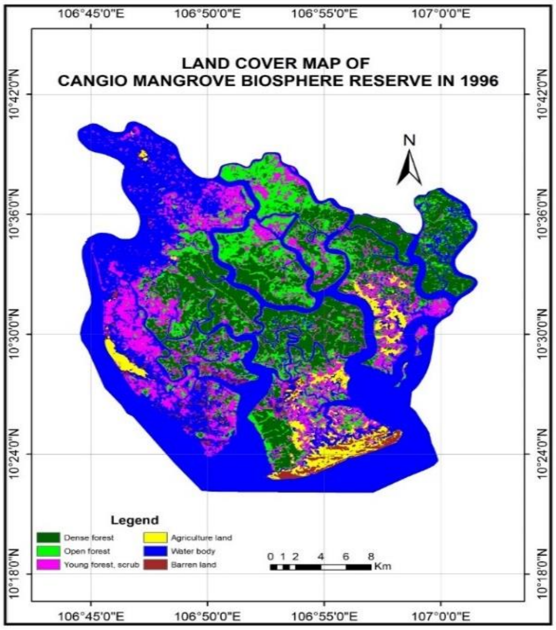


Figure No. 4. Land cover map in 1996

The statistical results from the land cover map in 1996 were comprised of 20.22 dense forest area, 12.12 percent open forest, and 15.82 percent young forest and scrub. Water accounted for 46.29 percent, while both agricultural and barren land made up 3.56 percent, see at Table No. 2 and Figure No. 4.

The overall accuracy of this data is 84.89

percent, with an average accuracy of 82.95 percent (Kappa statistics (K) is 0.7994).

Table No. 2. Area statistics of land cover in Can Gio Biosphere Reserve in 1996

Main classes	**Sub-classes**	**Pixel count**	**Area**	
			Hectare (ha)	Percent (%)
Forest land	Dense forest	1496933	14969.33	20.22
	Open forest	897561	8975.61	12.12
	Young&scrup	1171464	11714.64	15.82
	Sub-total		***35659.58***	***48.16***
Other land	Agriculture land	263693	2636.93	3.56
	Water body	3428002	34280.02	46.29
	Barren land	147222	1472.22	1.99
	Sub-total		***38389.17***	***51.84***
Total			**74048.75**	**100.00**

Land cover map in 1999

The land cover map based on the supervised classification of SPOT 1999 had given in Figure No. 5 and the statistical results of land cover had given in Table No. 3.

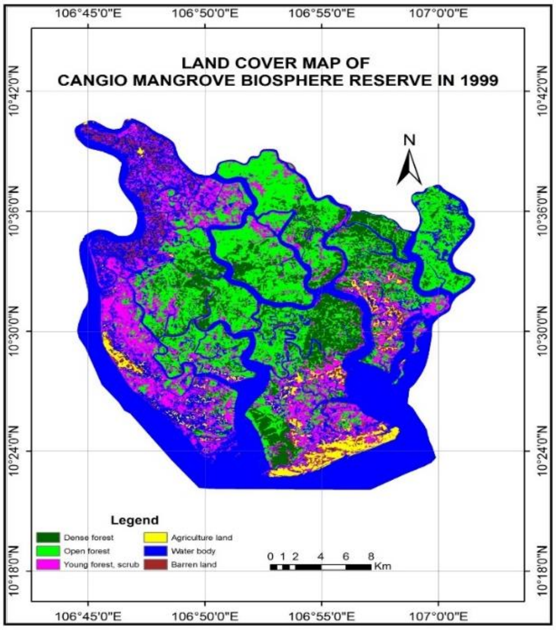


Figure No. 5. Land cover map in 1999

The dense forest area is 13.89%, open forest is 23.73%, young forest and scrub are 15.83%, agriculture land is 2.76%, water body is 41.67% and barren land is 3.11%.

Table No. 3. Area statistics of land cover in Can Gio Biosphere Reserve in 1999

Main classes	**Sub-classes**	**Pixel count**	**Area**	
			Hectare (ha)	**Percent (%)**
Forest land	Dense forest	954698	9546.98	12.89
	Open forest	1757084	17570.84	23.73
	Young&scrup	1172494	11724.94	15.83
	Sub-total		***38842.76***	***52.46***
Other land	Agriculture land	204564	2045.64	2.76

	Water body	3085532	30855.32	41.67
	Barren land	230503	2305.03	3.11
	Sub-total		***35205.99***	***47.54***
Total			**74048.75**	**100.00**

Classification accuracy assessment based on confusion matrix. The results of the overall accuracy is 83.89% and average accuracy of 81.95%. Kappa statistics (K^) is 0.7894.

Land cover map in 2004

The land cover map based on supervised classification of SPOT 2004 had given in Figure No. 6 and the area analysis of land cover had given in Table No. 4.

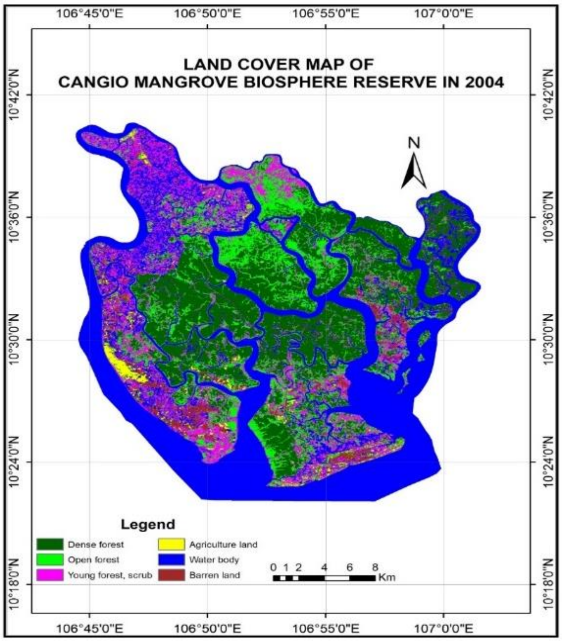


Figure No. 6. Land cover map in 2004

The dense forest area is 27.01%, open forest is 14.38%, young forest and scrub are 14.53%, agriculture land is 1.26%, water body is 39.65% and barren land is 3.16%.

Table No. 4. Area statistics of land cover in Can Gio Biosphere Reserve in 2004

Main classes	**Sub-classes**	**Pixel count**	**Area**	
			Hectare (ha)	**Percent (%)**
Forest land	Dense forest	2000306	20003.06	27.01
	Open forest	1064922	10649.23	14.38
	Young&scrup	1075806	10758.08	14.53
	Sub-total		***41410.37***	***55.92***

Main classes	Sub-classes	Pixel count	Area	
			Hectare (ha)	**Percent (%)**
Other land	Agriculture land	93606	936.06	1.26
	Water body	2936131	29361.03	39.65
	Barren land	234105	2341.29	3.16
	Sub-total		***32638.38***	44.08
Total			**74048.75**	**100.00**

The classification accuracy based on confusion matrix had estimated. The results of the overall accuracy of mapping is 87.78% and average accuracy of 82.90%. Kappa statistics (K^) is 0.82%.

Land cover map in 2009

The land cover map based on supervised classification of SPOT 2009 had given in Figure 7 and the area analysis of land cover had given in Table No. 5.

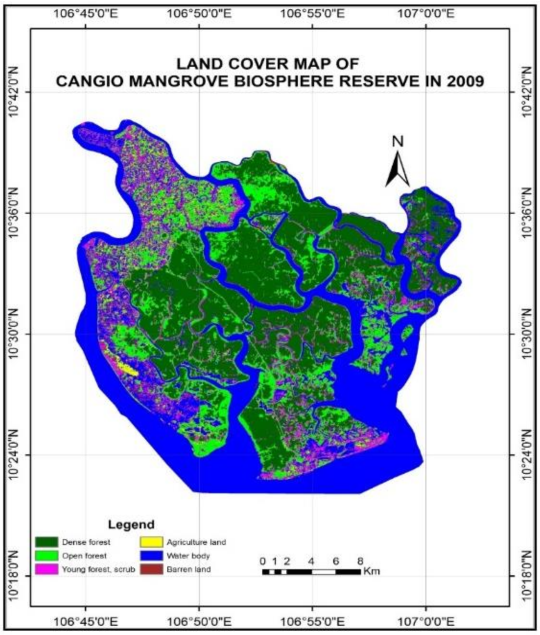


Figure No. 7. Land cover map in 2009

The dense forest area is 32.62%, open forest is 16.38%, young forest and scrub are 14.53%, agriculture land is 1.26%, water body is 39.65% and barren land is 3.16%.

Table No. 5. Area statistics of land cover in Can Gio Biosphere Reserve in 2009

Main classes	Sub-classes	Pixel count	Area	
			Hectare (ha)	**Percent (%)**
Forest land	Dense forest	2415361	24153.61	32.62
	Open forest	1251370	12513.70	16.90
	Young&scrup	802878	*8028.78*	10.84
	Sub-total		***44696.09***	***60.36***
Other land	Agriculture land	109498	1094.98	1.48

Main classes	Sub-classes	Pixel count	Area	
			Hectare (ha)	**Percent (%)**
	Water body	2699259	26992.59	36.45
	Barren land	126509	1265.09	1.71
	Sub-total		***29352.66***	***39.64***
Total			**74048.75**	**100.00**

The accuracy assessment based on confusion matrix. The results of the overall classification accuracy based on confusion matrix is 82.78% and average accuracy of 70.00%. Kappa statistics (K^) is 76.09%.

Land cover map in 2016

The land cover map based on supervised classification of Landsat OLI 2016 had given in Figure 8 and the area analysis of land cover had given in Table No. 6.

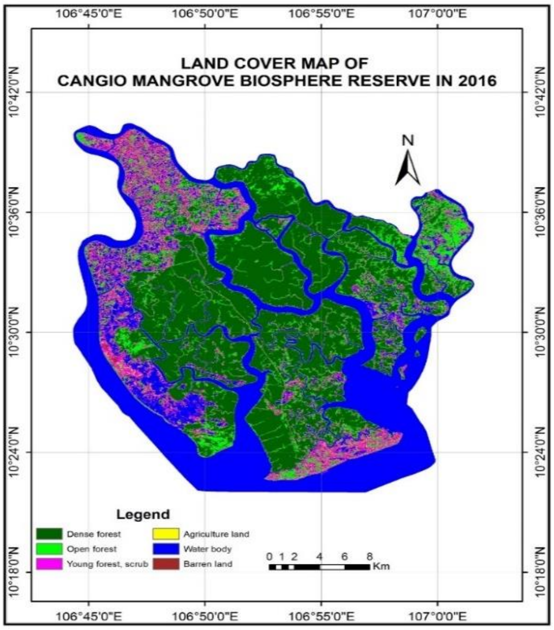


Figure No. 8. Land cover map in 2016

The dense forest area is 38.53%, open forest is 11.17%, young forest and scrub are 9.79%, agriculture land is 2.76%, water body is 34.07% and barren land is 3.69%.

Table No. 6. Area statistics of land cover in Can Gio Biosphere Reserve in 2016

Main classes	Sub-classes	Pixel count	Area	
			Hectare (ha)	Percent (%)
Forest land	Dense forest	1268111	28532.50	38.53
	Open forest	367447	8267.56	11.17
	Young&scrup	322096	*7247.15*	9.79
	Sub-total		***44047.21***	***59.48***

Other land	Agriculture land	90737	2041.58	2.76
	Water body	1165704	25228.34	34.07
	Barren land	76961	2731.62	3.69
	Sub-total		***30001.55***	***40.52***
Total			**74048.75**	**100.00**

The accuracy assessment based on confusion matrix. The overall classification accuracy based on confusion matrix is 84.44% and average accuracy of 70.00%. Kappa statistics (K^) is 76.09%.

Analyze the change of mangrove forests

The analysis of land cover changes of mangrove forest in Can Gio Biosphere Reserve over of 20 years (1996-2016), and divided into four periods are from 1996 to 1999, from 1999 to 2004, from 2004 to 2009 and from 2009 to 2016. In there are (+) Increase and (-) decrease. The detailed results of the analysis of land cover changes in study area in each period as follows;

Period from 1996 to 1999

The total area of forest land area has changed to 3,183.18 ha, there include rich forest (-5,422.35 ha), open forest (8,595.23 ha) and young forest and scrub (10.30 ha). Other land area has changed by 3,183.18 ha, there include agriculture land (-591.29ha), water body (-3,424.70 ha) and barren land (-3,183.18ha). The result are shown in Table No. 7.

Table No. 7. Land cover changed during 1996 to 1999; (+) Increase and (-) decrease

Sub-classes	**Area 1996**		**Area 1999**		**Changed area 1996-1999**	
	ha	%	ha	%	ha	%
Dense forest	14969.33	20.22	9546.98	12.89	-5422.35	-7.32
Open forest	8975.61	12.12	17570.84	23.73	+8595.23	+11.61
Young forest & scrub	11714.64	15.82	11724.94	15.83	+10.30	+0.01
Sub-total	***35659.58***	***48.16***	***38842.76***	***52.46***	***+3183.18***	***+4.30***
Agriculture land	2636.93	3.56	2045.64	2.76	-591.29	-0.80
Water body	34280.02	46.29	*30855.32*	*41.67*	-3424.70	-4.62

Sub-classes	Area 1996		Area 1999		Changed area 1996-1999	
	ha	%	ha	%	ha	%
Barren land	1472.22	1.99	2305.03	3.11	+832.81	+1.12
Sub-total	***38389.17***	***51.84***	***35205.99***	***47.54***	***-3183.18***	***-4.30***
Total	**74048.75**		**74048.75**	**100.00**		

Period from 1999 to 2004

The total area of forest land area has changed to 2,567.61 ha, there include rich forest (-1,0456.08 ha), open forest (-6,921.61 ha) and young forest and scrub (-966.86 ha). Other land area has changed by (-2,567.61 ha), there include agriculture land (-1,109.58 ha), water body (-1494.58 ha) and barren land 36.26 ha. The results are shown in Table No. 8.

Table No. 8. Land cover changed during 1999 to 2004; (+) Increase and (-) decrease

Sub-classes	Area 1999		Area 2004		Changed area 1999-2004	
	ha	%	ha	%	ha	%
Dense forest	9546.98	12.89	20003.06	27.01	+10456.08	+14.12
Open forest	17570.84	23.73	10649.23	14.38	-6921.61	-9.35
Young forest& scrub	11724.94	15.83	10758.08	14.53	-966.86	-1.31
Sub-total	***38842.76***	***52.46***	***41410.37***	***55.92***	***+2567.61***	***+3.47***
Agriculture land	2045.64	2.76	936.06	1.26	-1109.58	-1.50
Water body	30855.32	41.67	*29361.03*	*39.65*	-1494.29	-2.02
Barren land	2305.03	3.11	2341.29	3.16	+36.26	+0.05
Sub-total	***35205.99***	***47.54***	***32638.38***	***44.08***	***-2567.61***	***-3.47***
Total	**74048.75**	**100.00**	**74048.75**	**100.00**		

Period from 2004 to 2009

The total area of forest land area has changed to 3,285.72 ha, there include rich forest 4,150.55 ha, open forest 1,864.47 ha and young forest and scrub (-2,729.30 ha). Other land area has changed by (-3,285.72 ha), there include agriculture land 158.92 ha, water body (-2,368.44 ha) and barren land (-1,076.20 ha). The results are shown in Table No. 9.

Table No. 9. Land cover changed from 2004 to 2009; (+) Increase and (-) decrease

Sub-classes	**Area 2004**		**Area 2009**		**Changed area 2004-2009**	
	ha	%	ha	%	ha	%
Dense forest	20003.06	27.01	24153.61	32.62	+4150.55	+5.61
Open forest	10649.23	14.38	12513.70	16.90	+1864.47	+2.52
Young forest&scrub	10758.08	14.53	8028.78	10.84	-2729.30	-3.69
Sub-total	***41410.37***	***55.92***	***44696.09***	***60.36***	***+3285.72***	***+4.44***
Agriculture land	936.06	1.26	1094.98	1.48	+158.92	+0.21
Water body	29361.03	39.65	*26992.59*	*36.45*	-2368.44	-3.20
Barren land	2341.29	3.16	1265.09	1.71	-1076.20	-1.45
Sub-total	***32638.38***	***44.08***	***29352.66***	***39.64***	***-3285.72***	***-4.44***
Total	**74048.75**	**100.00**	**74048.75**	**100.00**		

Period from 2009 to 2016

The total area of forest land area has changed to 3,285.72 ha, there include rich forest (-648.88 ha), open forest (-4,246.14 ha) and young forest and scrub (-781.63 ha). Other land area has changed by 648.89 ha, there include agriculture land 946.60 ha, water body (-1,764.25 ha) and barren land 1,466.53 ha. The results are shown in Table No. 10.

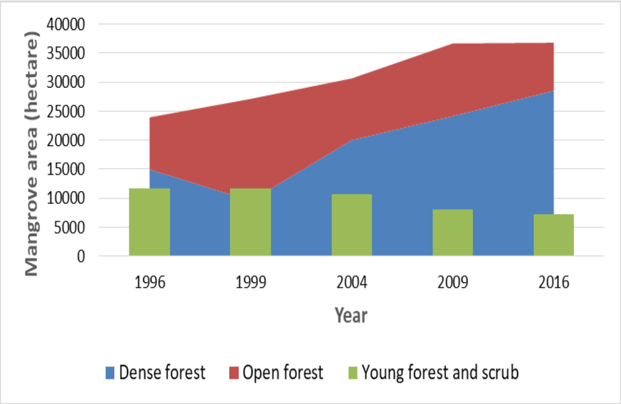
Table 10. Land cover changed from 2009 to 2016; (+) Increase and (-) decrease

Sub-classes	**Area 2009**		**Area 2016**		**Changed area 2009-2016**	
	ha	%	ha	%	ha	%
Dense forest	24153.61	32.62	28532.50	38.53	+4378.89	+5.91
Open forest	12513.70	16.90	8267.56	11.17	-4246.14	-5.73
Young forest & scrub	8028.78	10.84	7247.15	9.79	-781.63	-1.06
Sub-total	***44696.09***	***60.36***	***44047.21***	***59.48***	***-648.88***	***-0.88***
Agriculture land	1094.98	1.48	2041.58	2.76	+946.60	+1.28
Water body	26992.59	36.45	*25228.34*	*34.07*	-1764.25	-2.38
Barren land	1265.09	1.71	2731.62	3.69	+1466.53	+1.98
Sub-total	***29352.66***	***39.64***	***30001.55***	***40.52***	***+648.89***	***+0.88***
Total	**74048.75**	**100.00**	**74048.75**	**100.00**		

CONCLUSIONS AND DISCUSSIONS

In this study, we have used satellite imagery from SPOT, Landsat OLI for assessing mangrove forest dynamics at Can Gio Biosphere Reserve for 20 years (from 1996 to 2016). The results are summarized are shown in Diagram No. 1: The results show that; young and scrub mangrove forests area in Can Gio Biosphere have always been reduced over the periods from 1996 to 2016; there are in 1996 (11,714.64 ha); in 1999 (11,724.94 ha); in 2004 (10,758.08 ha); in 2009 (8,028.78 ha) and in 2016 (7,247.15 ha). Although according to the annual Can Gio Biosphere Reserve reports, the area of mangroves has been expanded by afforestation or regeneration of natural forests. However, some young forest areas have been converted into open mangrove forest and rich mangrove forest.

Statistical results from satellite images have also shown that; The open mangrove forest area has also increased over the period 1996 to 2009, there are in 1996 (8,975.61 ha); in 1999 (17,570.84 ha); in 2004 (10,649.23 ha) and 2009 (12,513.70 ha), and the area has not changed much in the periods from 2009 (12,513.70 ha) to 2016 (8,267.57 ha). The reasons are that the area of young mangrove forest converted to open mangrove forests, and some open mangrove forest area converted to the rich mangrove forest area are equivalent.



Histogram No. 1: Distribution of mangrove forests area over periods of 1996, 1999, 2004, 2009 and 2016

The study also showed that: The area of rich mangroves has always increased over the periods from 1996 to 2016, there area in 1996 (14,969.33 ha); in 1999 (9,546.98 ha); in 2004 (20,003.06 ha); in 2009 (24,153.61 ha) and in 2016 (28,532.50 ha). These are proven results for the conservation and development of mangroves that have been implemented well in Can Gio Mangrove Reserve, Vietnam.

Funding Sources

Nagao Natural Environment Foundation, Japan

ACKNOWLEDGMENT

The authors are grateful to Nagao Natural Environment Foundation, Japan for financial support to this research.

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The Status, Drivers, and Impacts of Poaching in Lake Chilwa Biosphere Reserve

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ABSTRACT: An assessment of the status, drivers, and impacts of poaching was conducted in the Lake Chilwa Biosphere Reserve (LCBR) in Malawi. One hundred households from which primary data was collected were sampled using systematic random sampling. Secondary data was collected from fisheries and agriculture departments, and the biosphere reserve manager. The results of the study indicate that poaching in the LCBR exists, and its level of frequency is high, as indicated by 61.3 percent of respondents, and the annual licensing of <5 percent of tools. The main drivers of poaching are poverty, food insecurity, population growth, low level of education, and unemployment. Poaching is causing a decline in fish catches, reduction in composition of both birds and fish species, and size of fish caught. There is also a reduction of income in the area, as well as an increase in malnutrition, due to lack of cheap protein sources. The Malawi government should put up policy framework that will create a good environment for small businesses to thrive, improve the livelihood of communities, and eliminate the exploitation of resources from the biosphere reserve. Deliberate policies must be enacted to provide sustainable alternative protein sources.

Keywords: Poaching, Fish, Birds, Impacts, Drivers, Lake Chilwa

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Introduction

Poaching is a term that carries a variety of definitions, dependent on the context and individual. In common terms, for convenience and consistency, Carter et al. (2017) adopted the definition of poaching as the illegal killing or taking of wildlife. In this context, it refers to hunting without license or permit in protected areas (National parks, game reserves), using illegal equipment or tools, and any other hunting practices that are against legal provision of any institution or country. Poaching is a problem where wildlife meat is valued as a source of both income and protein (Wilfred and Maccoll, 2015). Wildlife meat is any non-domesticated terrestrial mammals, birds, reptiles, and amphibians harvested for consumption (Nasi et al*.,* 2008). Brashares et al. (2004) reported that the intensity of hunting in Africa is usually inversely related to time spent on agricultural activities. The presence and importance of factors behind wildlife exploitation differ from place to place, and the strategies employed to address problems related to poaching cannot be universal.

Human pressure on wildlife in protected areas is increasing. This is partially due to wildlife being driven off from their habitats as land is converted for settlements and agricultural use. Illegal wildlife use is usually related to the distance between human settlements and protected areas. For example, in the Serengeti of Tanzania, both wildlife meat poaching and consumption rates are quite high among the villages near protected areas (Hofer et al., 1996).

Biosphere reserves are established in hopes of preserving both cultural and natural heritage, in accordance with sustainable development (Sonali, 2017). These reserves include unique areas of the world's biomes, whose selection has been greatly facilitated by a thorough knowledge of the important biotic communities. According to Ratika (2013), biosphere reserves conserve genetic resources, species, ecosystems, and landscapes, without uprooting inhabitants. Biosphere reserves are models for co-existence between nature and human, and provide significant information for scientific studies and research.

Lake Chilwa Biosphere Reserve in Malawi has a variety of birds, fish, and small animal species, that are used for food by a large proportion of the local community (Bhima, 2006). In the area, poaching is considered a key component of the socio-economic framework of people's livelihood. Population increase, poverty, and food insecurity are some of the factors that can influence poaching levels.

Hunting of birds and fishing in the Lake Chilwa wetland of Malawi has taken place for many years, ultimately developing into a significant socio-economic activity. The practice supports a variety of groups of people, both nutritionally and economically. In recent years, the pressure on the wildlife has been increasing due to higher populations, and illegal and unsustainable hunting practices. This has become a threat to the sustainability of fish, birds, and other wildlife species in this unique ecosystem. Though poaching is a common practice in the Lake Chilwa wetland, there has been no research on status of poaching within the biosphere, and its drivers and impacts caused are not known. Such information is crucial for decision making, considering the LCBR has no legal protection status, despite being a wetland of national importance.

This study sought to assess the status of poaching, driver forces, and its impact on birds and fisheries within the Lake Chilwa Biosphere Reserve. It is through the understanding of the status, drivers, and impacts that we generate information, and can incorporate these findings into existing and new legislations to help eradicate the vice in the management of resources by the relevant authorities.

Methodology

Lake Chilwa Biosphere Reserve and its wetland ecosystem lies in three districts: Machinga, Zomba, and Phalombe. It also lies between the two countries of Malawi and Mozambique.

Lake Chilwa Biosphere Reserve is located in the Southern region of the Republic of Malawi, on the country's eastern border with Mozambique, between latitude 15°00'S and 15°30'S, and longitudes 35°30′E and 35°55′E (EAD, 2001). The biosphere reserve comprises of the lake, typha swamps, marshes, and seasonally inundated grassland floodplain, in which the transition, buffer, and core zones are located. The hydrology of the wetland is an important control on the ecology of the biosphere reserve, determining not only the water chemistry and physical properties, but also the composition of the vegetation and soil characteristics (Howard and Walker, 1974). The area has a tropical climate, that is relatively dry and strongly seasonal (British Geological Survey, 2004).

The Lake Chilwa Biosphere Reserve has a high population, with a density of 164/ km^2 and 1 700 452 in the entire Lake Chilwa basin (EAD, 2001). In 2008, the estimated number of households in the area was 347 300 (NSO, 2008). In an economy dominated by agriculture, individual maize production is one of the key occupations in the area, while tobacco is cultivated as the leading cash crop. Small and medium-scale businesses dominate the area's non agro-based economy, with general retail accounting for the gross of sales (Ludaka, 1991).

Lake Chilwa continues to be the main source of fish in the area, with an annual catch of more than 5 000 tons (Njaya, 2001). Lake Chilwa Biosphere Reserve also hosts a variety of bird species, including some that are migratory (Bhima, 2006). It is estimated that 164 bird species are associated with the area, of which 41 are Palearctic and 14 intra-African.

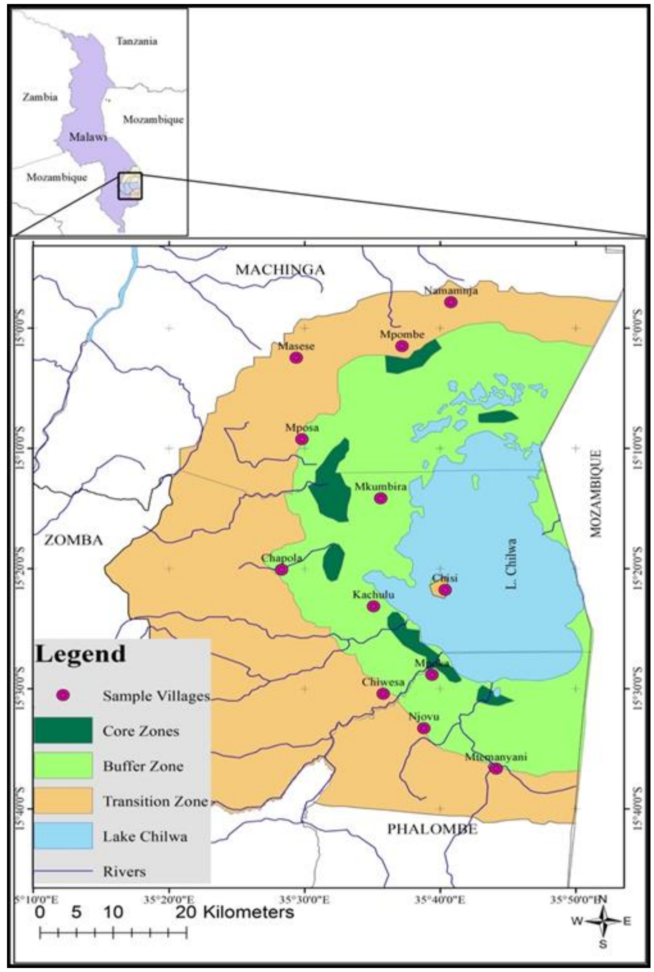

Figure No. 1: Map of the study area.

This study employed a social survey research design, in which semi-structured questionnaires were used to interview sampled households in communities around Lake Chilwa, and key informants in different government sectors. The target population for the study was the community members living within the transition zone of the LCBR. The targeted community comprised of 347 300 households.

The formula below, by Nassiuma (2000), was used to determine the appropriate number of households that were sampled from the Lake Chilwa Biosphere Reserve.

$n = \frac{NC^2}{C^2+(N-1)e^2}$........................ (Nassiuma, 2000)

In the formula above; n represents sample size; N represents the population size of 347 300 households; C represent coefficient of variation, ≤ 30 percent; and *e* represents margin of error, which is fixed between 2-5 percent. The sample was calculated at 30 percent coefficient of variation, and 3 percent margin of error.

$$n = \frac{347300 \times 30^2}{30^2 + (347300 - 1)3^2} = 99.97 \approx 100$$

Table No. 1. Number of households sampled

District	Target Households	Sampled Households
Machinga	113 683	34
Zomba	158 563	45
Phalombe	75 054	21
Total	347 300	100

Primary data was collected through administration of questionnaires and focused group discussions. Secondary data was collected from documented information in government departments and institutions, and included fisheries and agriculture, and the Biosphere Reserve Manager.

Results and Discussion

The status of poaching

The survey results indicate that poaching occurs in the LCBR, as reported by respondents. The existence of poaching in the LCBR was supported by 88 percent of those surveyed. Respondents who acknowledged the existence of poaching, classified its prevalence as follows (Figure No. 2): 61.3 percent high, 30.7 percent medium, 5.7 percent very high, and only 2.3 percent indicated low levels of poaching. The respondents also indicated that poaching occurs at higher levels on fish, rather than birds.

There are three key reasons for the popularity of poaching in the area. Firstly, it is due to easy access to the buffer and core zones of the LCBR. Secondly, the increase in number of people in the area, resulting in corresponding increase in number of people fishing and hunting. This could also result from fishing being one of the community's major sources of subsistence, second only to farming.

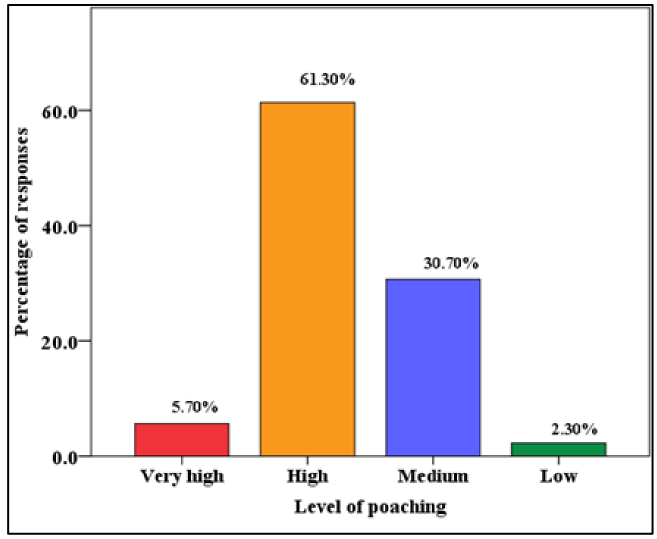

Figure No. 2: Level of poaching in LCBR

Fish is the main source of protein, as it is relatively cheap to obtain in comparison to other livestock, such as goats, poultry, and cattle. Bird hunting is mostly intensified when fish catches no longer meet demand but is otherwise only practiced by a few people in the community. An assessment on the status of biodiversity and threats in Malawi by Millington and Kaferawanthu (2005), revealed that hunting of wildfowl in LCBR has been practiced for some time, but its exploitation increased in 1996, following the drying up of the lake and the collapse of the fishery in 1995.

Poaching levels were also indicated by the trends in licensing of fishing tools. An assessment on the number of fishing tools licensed on annual basis between 2014 and 2017, as shown in Table No. 2 and Figure No. 3, indicate that less than 5 percent of the total recorded fishing tools are licensed annually. This implies high levels of poaching, as it is in contravention of the fisheries regulations.

Table No. 2: Percentage of licensed fishing tools from 2014 to 2017

Year	2014	2015	2016	2017
Estimated tools	74078	82393	37950	-
Licensed tools	48	192	742	23
Percentage licensed	0.06	0.23	1.95	-

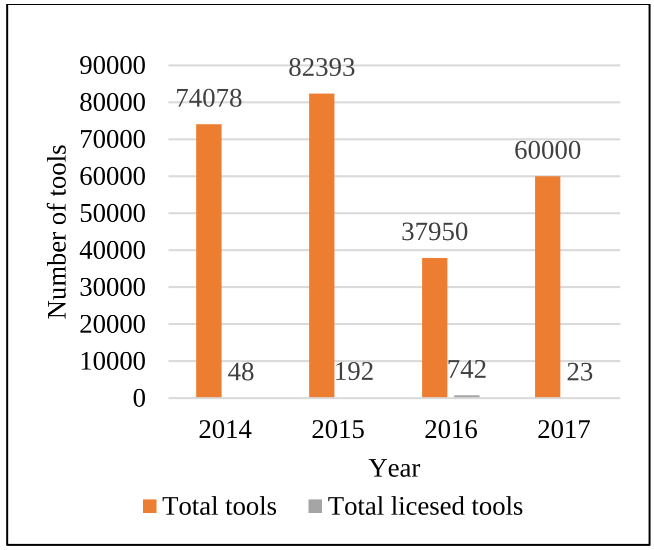

Figure No. 3: Total number fishing tool and total licensed tools

Other indicators of poaching

In the LCBR there was an overall increase in trend of the number of people engaged in fishing between 2008 and 2016 ($r^2 = 0.0711$; $y = 4357+140t$) (Figure No. 4). The reduction in numbers of fishermen between 2011 & 2012 coincides with the period in which Lake Chilwa dried up and the fishery collapsed. The general increase in the trend indicates the possibility of an increase in poaching on fisheries resources.

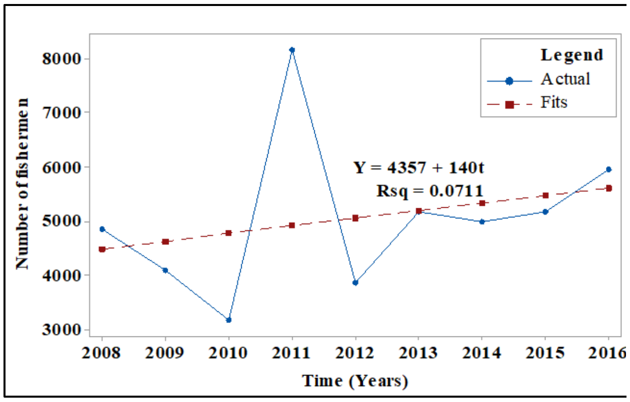

Figure No. 4: Numbers of fishermen from 2008 to 2016

A variety of tools are used for fishing in the LCBR, including gillnets, fish traps, seine nets and lines, and hooks. Many of these tools are modified in violation of the government's prescribed regulations (e.g. mesh size and net material). There has been a general increase in the number of different fishing tools over the years (Figure No. 5), which are rarely licensed, as per the government requirements (Table No. 2). This increase has been brought on by a growth in the number of local fishermen. This further indicates that most of the people involved in fishing activities do so illegally, as they do not have the permit to do so.

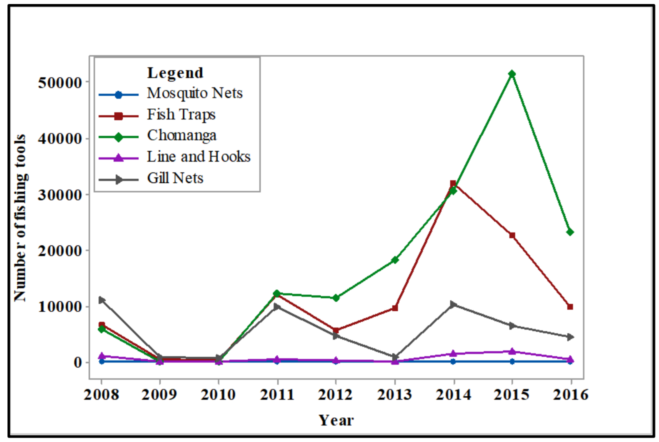

Figure No. 5: Trends of fishing tools in Lake Chilwa from 2008 to 2016

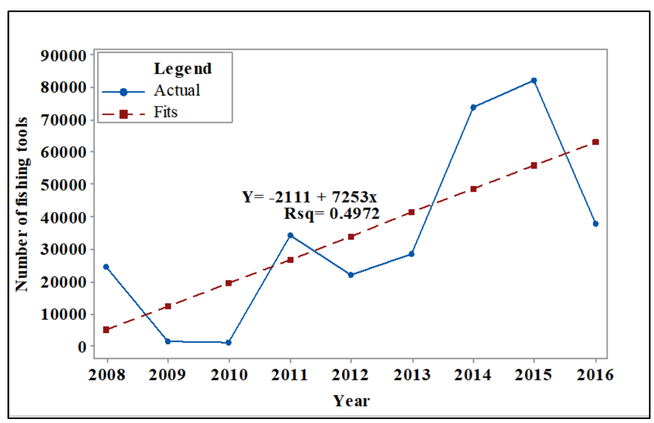

Figure No. 6: Trend of annual total number of fishing tools in the LCBR from 2008 to 2016

The trend of the total number of all fishing tools has been significantly rising ($r^2 = 0.4972$; $y = -2111+7253x$, $p< 0.05$) (figure 6). In addition, some fishermen clear vegetation in the lake, such as the *Typha dominguensis* (*mjedza*) and *Aeschynomene pfundii*, to make it easier to catch higher quantities of fish. Such practices result in the destruction of habitats for both fish and bird species. The vegetation provides a natural sanctuary—a secure breeding and hiding spot for fish—and also serves as sites for bird nests. The removal of such vegetation is an illegal practice, as per fisheries regulations.

Drivers of poaching

The driving forces of poaching in the LCBR are the need of food and income, and, to a smaller extent, employment and the protection of crops. Poaching as a means of food and income account for 48 percent and 48 percent, respectively. Employment and the protection of crop fields only accounts for a combined total of 4 percent. Community members are mostly engaged in poaching for sustenance, in both nutritional and economical senses of the word. However, it was indicated that poverty, lack of enough food, population growth, inadequate enforcement resources, low education levels, and unemployment drive poaching to higher levels (Figure No. 7).

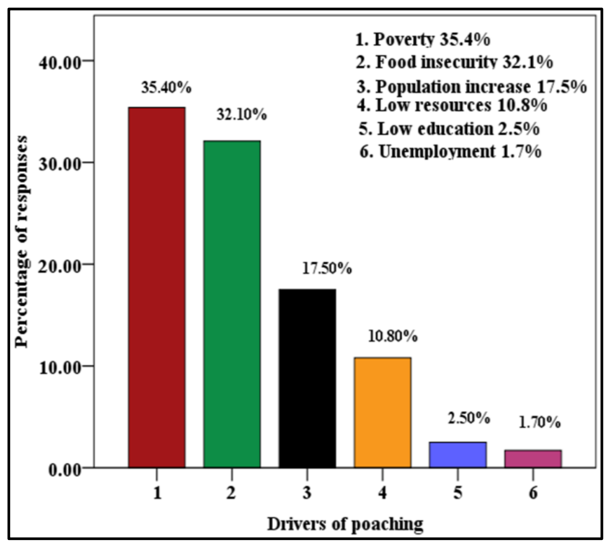

Figure No. 7: Drivers of poaching in the LCBR

Table No. 3: Level of income and involvement in fishing and bird hunting in the LCBR

Daily Income	Fishing and Bird Hunting		Overall (%)	χ^2
	Not involved **(%)**	Directly involved **(%)**		
Below $1.90 /day	66.7	67.3	67	0.005
Above $1.90 /day	33.3	32.7	33	
Total	100	100	100	

The results show that 67.3 percent of those directly involved in fishing and bird hunting were poor, as opposed to the 32.7 percent who were not poor (Table No. 3). Though the findings show that poverty drives illegal fishing and bird hunting, the results indicate that there is no association between income level and involvement in the activity (X^2 (1) >= 0.005, p = 0.946). This is because those with high income have the capacity to procure efficient fishing and hunting tools, as opposed to the poor who must resort to more traditional fishing and hunting methods.

Malawi is one of the poorest countries in the world, with 50.7 percent of the population living below the poverty line (IMF, 2017), receiving approximately $1.90 per day. The population of the Lake Chilwa wetland is no different, and people depend on fishing to earn an income. The report by CITES Secretariat et al., 2013, discloses that sites with communities experiencing higher levels of poverty, will also have higher levels of poaching. However, in their review, Duffy and St. Johns (2013) found that, though poverty may motivate people to poach, members of poor communities would not engage in the poaching of commercially valuable species, unless there was demand from wealthier communities. Individuals in the LCBR mostly practice subsistence type of poaching. The primary purpose for this kind of poaching, is food, and, in the process, supports local trade, as not all can be fishermen.

Table No. 4: Level of education and involvement in fishing and bird hunting in the LCBR

Education Level	Fishing and Bird Hunting		Overall (%)	χ^2
	Not involved (%)	Directly involved (%)		
Primary	41.02	65.6	56	6.099*
Secondary	53.85	32.8	41	
Tertiary	5.13	1.6	3	
Total	100	100	100	

The results (Table No. 4), show that 56 percent of the respondents only attained primary education, thus indicating that most individuals in the biosphere reserve are not highly educated, and lack the credentials required for employed in the formal sector. The results also show that 65.6 percent and 32.8 percent of those directly involved in fishing and bird hunting attained primary and secondary education, respectively, and only 1.6 percent attained tertiary level. There is a significant association between level of education and direct involvement in fishing and bird hunting in LCBR (X^2 (2) = 6.099, $p < 0.05$). In Malawi, unemployment rates are very high. Many people remain idle due to a lack of skills and experience required in the labor force. It is also a fact that many uneducated people are involved in illegal hunting, simply because they don't understand the importance and benefits of wildlife resources.

Table No. 5: Food security status and involvement in fishing and bird hunting

Food security status	Fishing and Bird Hunting		Overall (%)	χ^2
	Not involved (%)	Directly involved (%)		
Food Insecure HH	46.2	70.5	61	5.923*
Food Secure HH	53.8	29.5	39	
Total	100	100	100	

The results (Table No. 5) show that 70.5 percent of those involved in fishing and bird hunting are food insecure, whereas 29.5 percent are food secure. Food security level in the LCBR significantly influences the involvement of individuals in fishing and bird hunting activities (X^2 (1) = 5.923, $p < 0.05$). In addition, food insecurity has been indicated as one of the key drivers of poaching (figure 7). According to World Summit on Food Security 1996, food security exists when all people, at all times, have physical, social, and economical access to sufficient, safe, and nutritious food, adequately meeting their dietary needs and food preferences. In recent years, adverse effects of climate change, e.g. drought, have led to loss of yields, thereby forcing people to seek alternative sources of food. Natural resources, such as fish and birds, are prone to exploitation when they are open access. Such is the case in the LCBR. These findings coincide with the findings of Kafumbata et al. (2014). In their report, they noted that African inland lakes, such as Lake Chilwa, contribute significantly to food security and livelihoods through direct exploitation of fisheries resources. However, they stated that the ecosystem services provided are under significant stress, mainly owing to the high demands of an increasing population, negative anthropogenic impacts on lake catchments, and high levels of poverty, resulting in unsustainable use.

With the increase in population, farmable land is becoming smaller, resulting in low food production. GOM and World Bank (2006) found that the average landholding size per household in Malawi is 1.2 hectares, while the average land per capita is 0.33 hectares, leading to low agriculture production whilst the population grows. The report by CITES Secretariat et al. (2013), supports the reports that poaching levels decrease as food security increases.

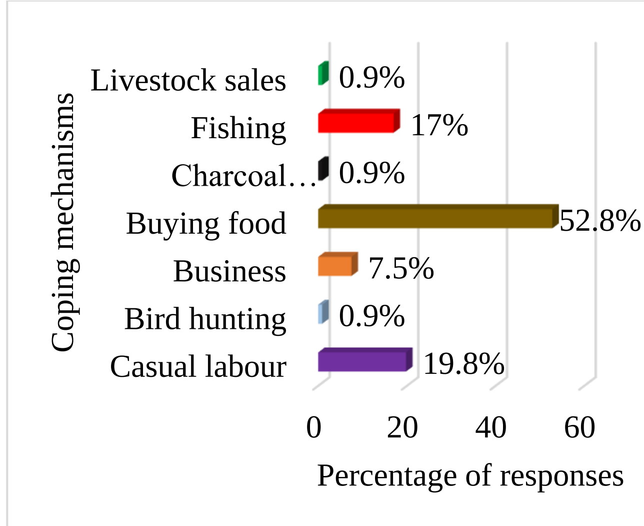

Figure No. 8: Coping mechanisms during food shortage

Fishing is one of the major coping mechanisms used by people in times of food shortage (Figure No. 8). This indicates that some people are driven into fishing activities due to a lack of food. It has also been shown that the fishing and hunting of birds are often ways for individuals to support their families.

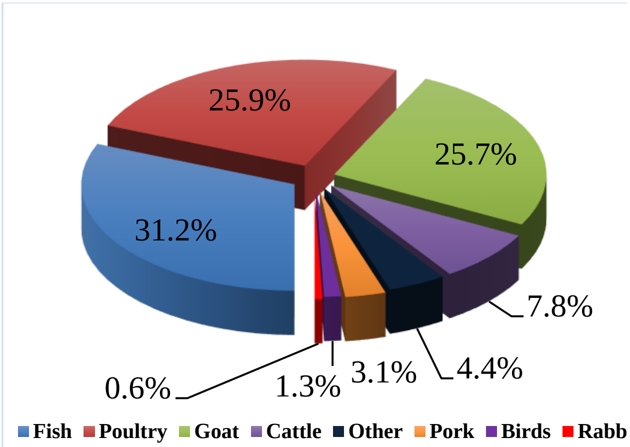

Figure No. 9: Identified protein Sources for communities

Fish is also one of the major animal proteins to the people in the LCBR, as indicated by 31.2 percent of respondents (Figure No. 9). This is because it is readily available and cheaper than other animal protein sources. Lake Chilwa is an open access resource and easily accessible by everyone, making illegal fishing and bird hunting an easy option for people during times of food shortage. Many people depend on natural resources for food during difficult times. In their study, Chiotha et al. (2017) reported that bird hunting intensifies from November to February in the LCBR, a period when most households experience seasonal food shortages. These indicators show the link between food security status and an increase in poaching levels in the LCBR. According to Fa (2000), intensive farming of livestock and other forms of domestic protein is the only way to provide a sustainable source of food. However, Brown and Williams (2003) argue that the capital for livestock rearing is too restrictive for smallholder farmers. Therefore, this condition makes it difficult for most individuals to stop relying on natural resources for food and other amenities, because most of them are openly accessible, and simple, inexpensive tools are used to kill them. This results in a high return for little investment.

The impacts of poaching

Poaching has been causing devastating impacts to both the biosphere resources (fish and birds) and people's livelihood in the Lake Chilwa Biosphere Reserve. In Figure No. 10, 28 percent of the respondents indicated that there was reduction in fish catches, followed by 27 percent reduction in sources of cheap protein, and 21, 11, 5, 4, 3, and 1 percent indicating reduction in income for the people and species, variability of bird species, reduction size of fish caught over time, increased malnutrition, and non-existence of some fish species respectively.

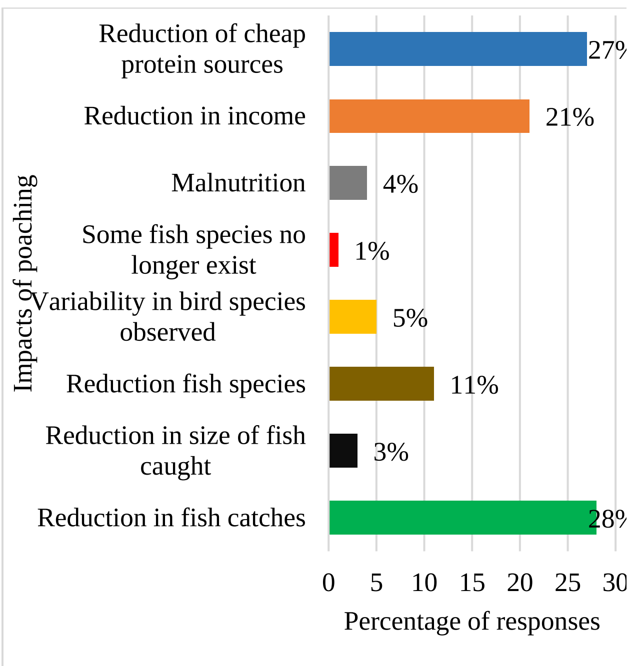

Figure No. 10: Results on observed impacts of poaching

The impact of poaching in the biosphere reserve on species is manifested through a reduction in fish catches. It is reported that in the past, the lake had a variety of fish species. In recent year, however, only a few species are found, and the fish population is currently dominated by catfish (*Clarias gariepinus*), tilapia (*Oreochromis shiranus chilwae)*, and barbus species (*Barbus paludinosus*). This shift indicates that the number of fish species has significantly diminished; a stark contrast to years before. Figure No. 11 shows the decline in species diversity between 2008 and 2017 The trend shows an actual reduction in catches of most of the species. The trend in Figure No. 12 shows that there has been a steady reduction of catches of all fish species over the course of ten years ($r^2 = 0.1576$, $y = -485t + 9173$).

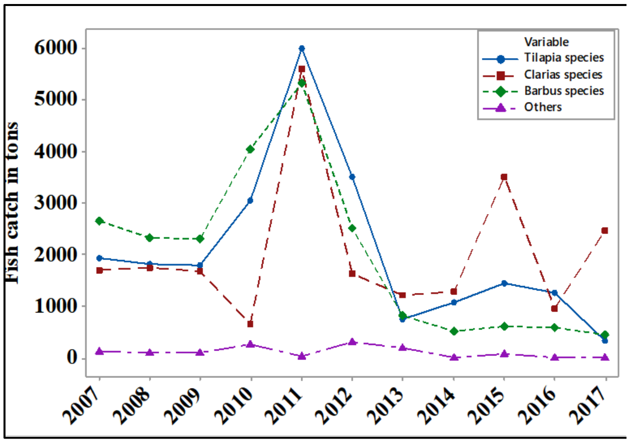

Figure No. 11: Trend of fish catches in the LCBR from 2007 to 2017

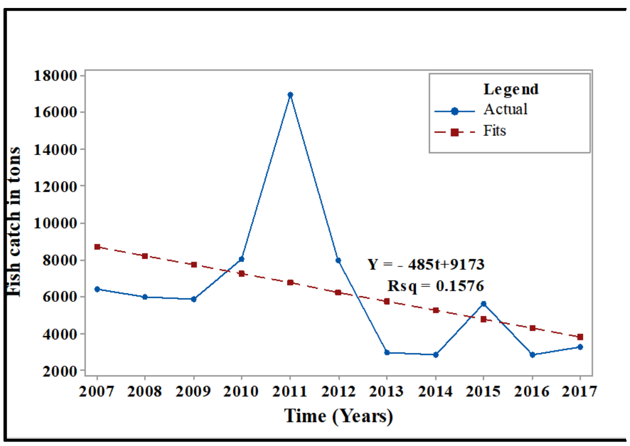

Figure No. 12: Trend of total annual fish caught between 2007 and 2017

In Figure No. 13, the total number of birds killed/trapped over the years shows a general increase between 2009 and 2012, and a decline between 2012 and 2013, indicating the trend is somehow dynamic. The trend's line shows a gentle increase in number of birds killed, though not significant (r^2=0.0088, y = 321+10.3).

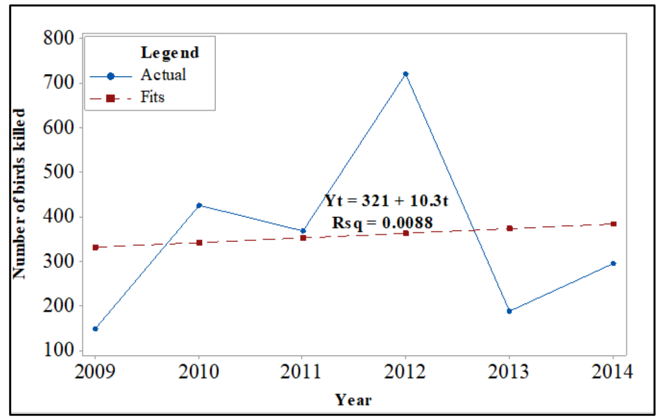

Figure No. 13: Trend of birds trapped between 2009 and 2014

The slight increase in number of birds trapped is attributed to high levels of poaching, confirming that people continue to exploit birds, thus threatening them with extinction. Birds are poached for both consumption and income. The collapse of the fishery due to overfishing and frequent lake recessions has resulted in the need for an alternative source of livelihood: the hunting of many bird species. The major bird species most targeted include Fulvous whistling ducks (*Dendrocygna bicol-*

or), white-faced whistling ducks (*Dendrocygna viduata)*, Lesser Moorhen (*Gallinula angulata),* Lesser Gallinula (*Gallinula alleni*), Crested francolin (*Dendroperdix sephaena*), Lesser masked weaver (*Ploceus intermedius*), and Spur-winged goose (*Plectropterus gambensis)*. However, there is paucity of data indicating the number of birds killed per species, as well as the amount of birds that have been caught in the past, due to a lack of documentation.

In this study, poaching has been implicated as the main cause of reduction in quantities and size of fish caught, reduction in variety of fish species caught, seasonal variability in bird species observed and trapped, and inexistence of some species. The respondents also indicated that these changes could not be entirely attributed to poaching alone, but also the effects of climate change, poor farming practices, and destruction of habitats. Climate change in the area has been evidenced by fluctuating water levels in the lake. This affects availability of water in the lake, thereby impacting breeding and habitat of fish and bird species. Climate change is also affecting crop production in the area, leading to poor harvests for the community, and ultimately driving people to rely on the natural resources within the biosphere reserve, for both food and income. It has been reported that some people depend solely on the resources of the LCBR for livelihood.

Funding Sources

This work was supported by the United States Agency for International Development as part of the Feed the Future initiative, under the CGIAR Fund, and the predecessor fund, the Food Security and Crisis Mitigation II. Part of this work was also supported by the German Federal Agency for Nature Conservation (BfN) through Biosphere Reserves as Models for Anti-Poaching in Africa (BRAPA) project, implemented by the African Wildlife Foundation.

ACKNOWLEDGMENT

I wish to sincerely thank Dr. Paul Makenzi and Dr. Marlene Chikuni for their input in this work. I wish to acknowledge the communities living around Lake Chilwa, the fishermen committees and the Malawi government agencies, especially the fisheries and agriculture departments for their invaluable support, and for providing all data needed during my research work.

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