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Review

Marine protected area: Prospective tool for ecosystem-based fisheries management in Nigeria

Yetunde E. Agbeja

Department of Aquaculture and Fisheries Management, University of Ibadan, Nigeria.

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Ecosystem based approach rather than species based approach to management and conservation of marine recourses has been recognized as the sustainable way to tackle ecological complexities that apply to maintaining biodiversity. In this light Marine Protected Areas (MPAs) has gained prominence worldwide as a laudable tool for ecosystem based marine conservation and fishery management. This paper examines MPAs and suggests guidance for establishing them in Nigeria, whilst highlighting its benefits to ecosystem-based approach to coastal and marine resource such as fisheries management in Nigeria.

Key words: Marine protected areas, fisheries conservation, ecosystem based management.

INTRODUCTION

Effective management of the impact of human activities on marine ecosystem and its surrounding environment has been identified as the main issue to be addressed towards achieving sustainable development of marine resource use and consequently it has been placed as priority in numerous global agreements such as the United Nations Conference on Environment and Development (UNCED) 1992. This conference produced some major agreements as regards the marine environment, which include the Rio Declaration on Environment and Development, the Framework on Climate Change; the Convention on Biological Diversity and the Agenda 21 (Cicin-Sain and Knecht, 1998).

Chapter 17 of the Agenda 21 of Noteworthy recognizes that the Oceans all kinds of seas, which includes enclosed and semi-enclosed seas, and coastal areas should be protected, while taking into consideration the rational use and development of their living resources (UNEP, 1992). Agenda 21 and other international instruments such as the Convention on Biological (CBD) also encourage the use of protected areas or area-based closures (FAO, 2014). The World Summit on Sustainable Development (WSSD) in Johannesburg, 2002 is the international conference that placed MPAs at the top of the international agenda. The plan of implementation of the WSSD (the Johannesburg Plan of Implementation), focused attention on MPAs by calling on nations to promote the conservation and management of important and vulnerable marine and coastal areas including "…the establishment of marine protected areas consistent with

*Corresponding author. E-mail: eniolagbeja@yahoo.com.

international law and based on scientific information, including representative networks by 2012".

Other international agreements in support for MPAs include; The Convention on Wetlands of International Importance Especially as Waterfowl Habitats (Ramsar Convention) makes provision that parties should designate at least one wetland in their territories for the Ramsar list of Wetlands of International Importance. Wetland as defined by the Convention includes "areas of marine waters, the depth of which at low tides does not exceed six metre" (RCS, 2013). Guidance on site selection for their uniqueness indicates considerations as regards MPAs under the Ramsar Convention.

The Agenda also reflects the aims of fisheries management, which concerns how to achieve optimal and sustainable utilization of fishery resources for the benefit of humanity. This necessitates safeguarding ecosystems and conserving biodiversity. Provided the aims of conventional fisheries management approaches are efficiently implemented they include, regulating fishers' behaviors and controlling fish mortality, to be able to achieve this sustainability objective. However, because of the failure of conventional measures in many cases, MPA have increasingly been promoted (FAO, 2011).

In the same vein, the desire to achieve ecosystem-based management (EBM) in the coastal region of countries of the world has been a common theme in coastal and ocean management policy discussions worldwide (Bianchi, 2008; Bianchi et al., 2008). Ecosystem based management is a form of natural resource management that has grown consistently over the last two decades. It has emerged from the common feeling that traditional types of natural resource management are not working or are ineffective and that a new, more holistic way of understanding how ecosystems work is needed (Curtin and Prellezo, 2010).

Ecosystem based management has been identified as an integrated approach that considers entire ecosystems, including humans (DeYoung, 2008). It addresses the cumulative impacts of multiple activities across space and time as it considers the connections within and among ecosystems. This all-embracing, ecological approach strives to ensure the continuance of services people want and need by maintaining healthy and productive ecosystems (ELI, 2013).

Instituting MPAs in the protection of marine biodiversity and local management of coastal and marine resources have been recognized as highly effective worldwide (Lubchenco et al., 2003; Lester et al., 2009; Cabral et al., 2014).

It is a strategy that shows commitment to ecosystem based management as it enhances conservation measures essential for the maintenance biological diversity and productivity of the marine environment.

Nigeria, a coastal state with a coastline of 853 km and a 200 nautical miles Exclusive Economic Zone (EEZ) adopted the United Nations Convention on the Law of the Sea (UNCLOS) in 1982. The coastline is faced with numerous challenges (such as climate change, flooding, overfishing, pollution from industrial, domestic and agricultural effluents) that have predisposed it to rapid and ill- managed degradation as a result of the diversified uses of the zone which includes fisheries (artisanal, industrial and aquaculture), gas exploration and exploitation, shipping, agriculture and tourism. These activities impact on the marine environment therefore, marine and coastal ecosystems will not deliver the full suite of ecosystem services upon which humans (especially the coastal communities) have come to rely.

The objectives of this paper are to give an overview of MPAs and highlight its benefits to ecosystem based approach to fisheries management in Nigeria and also suggest guidance for the establishment of MPA in Nigeria.

There have been several proposals on the promotion of MPAs notably that of the Caracas action plan that developed from the IV World Congress on National Parks and Protected Areas in 1992 (IUCN,1994). The action plan promoted the following objectives:

a) Protected areas being integrated into larger planning frameworks
b) Support for protected areas being expanded
c) The capacity to manage protected areas are strengthened
d) Expansion of international cooperation as regards financing, development and protected areas management (Gubbay, 1995).

As mentioned earlier, the need to protect or restore marine biodiversity has led to increasing calls for the establishment of MPAs. International commitments made provisions to protect 10% of the world's coastal and marine EEZ by 2010 (CBD, Simard et al., 2016).

This deadline is already behind and this target is not close to being met, but concerted efforts are being made worldwide to improve commitments. An example of such commitment is the, goal 14.5 of the sustainable development goals (U.N., 2015) states that "*By 2020, conserve at least 10% of coastal and marine areas, consistent with national and international law and based on the best available scientific information".*

Creating a MPA on the coastline of Nigeria may be a daunting task based on the fact that the marine and coastal environment has a very wide and diversified use and human population is on the increase in the country, which is causing an increase of human impacts on the marine environment and communities along the coast line have come to be highly dependent on the marine resources for their livelihood. However, with the placement of appropriate political and other institutional arrangement it can be achieved.

AN OVERVIEW OF MARINE PROTECTED AREAS

Marine protected areas are one of the tools suggested for use in Integrated Coastal Management (ICM) programs. Other tools include land-use control, permit systems and marine zoning, conflict resolution as regards resource use, planning, and fisheries management (Christie, 2005).

Protect Planet Ocean, an initiative by IUCN with the collaboration with UNEP-WCMC reports that “there are around 5000 MPAs designated around the world, that cover an area of approximately 2.85 million km^2, representing 0.8% of the world's 361 million km^2 of ocean, and 2.0% of the 147 million km^2 of ocean under national jurisdiction of the global marine area that is protected, only 300,000km^2 – that is, just under 10% of the global MPA area - is a marine reserve ('no-take' MPA)”.

The MPAs definition as developed at the 4th World Wilderness Congress and adopted by IUCN at its 17th General Assembly in 1988 is; ‘Any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective mans to protect part or all of the enclosed environment’.

Gubbay et al. (1995) reported that IUCN through its commission on National Parks and Protected Areas provided a list of categories of protected areas. These areas are managed primarily for the following:

i) Strict protection (that is, strict nature reserve/wilderness area)
ii) Ecosystem conservation and recreation (that is, national parks)
iii) Conservation of natural features (that is, natural monument)
iv) Conservation through active management (that is, habitat/species management area)
v) Landscape/seascape conservation and recreation (that is, protected land/seascape)
vi) Sustainable use of natural ecosystems (that is, managed resource protected area)’.

MPAs have multiple uses or in some cases restricted uses for example; ‘traditional fisheries and scuba diving, or combine a set of uses within a spatial zoning. Specific cases of MPAs where some form of extractive uses are prohibited include partially protected areas, fishery reserves, fishery closures, gear restriction zones and buffer zones’.

The aims of management that have led to the creation of MPAs are as follows (Claudet and Pelletier, 2004; Baker, 2004):

1) Protection and conservation of natural resources in areas that have been identified as most essential to the health of ecological diversity to safeguard their long-term viability and to preserve their genetic diversity or enable and support populations to recover to more pristine levels.
(2) Restoration of damaged or over-exploited areas identified as crucial to the survival of species, or of significant importance for the life cycles of economically important species;
(3) Improvement of the relationship between humans, environment and economic activities, by maintaining sustainable traditional uses and sustainable exploitation of resources, through the prevention of outside activities from detrimentally affecting the MPA, and by protecting and managing historical, cultural and aesthetic sites;
(4) Improvement of fishing yields, by safeguarding spawning stock biomass, through being a source of recruited and post-recruited stages for surrounding areas, by restoring the age structure of natural populations, and by acting as an insurance against mismanagement in fishing areas;
(5) Resolution of anticipated or present conflicts between coastal area users;
(6) Improvement of knowledge about marine environment by dealing with research and educational aspects; and
(7) Valuation of heritage for the local administration through tourism and economic profitability for the residents.

Marine reserves

Marine reserves are a special category of MPA. Biological resources within the reserve are usually protected through the use of restrictions and or prohibitions on fishing and the removal of disturbance of living and non-living marine resources, except as necessary for monitoring or research to evaluate the effectiveness of the reserve. Marine reserves will generally help to improve the ecosystem such as increases in stock abundance, age/size composition, spawning stock biomass, yield per recruit, and restoration of healthy trophic levels within its boundaries. Marine reserves are believed to be effective fisheries management tools based on the following:

Biomass export

It has been established by research that biomass of exploited species is generally higher within well protected MPAs (Jennings, 2001; Russ, 2002; Pelletier et al., 2008). In an ideal situation animals will prefer to move towards areas where density is low relative to available resources if this is beneficial to their fitness (Fretwell and Lucas, 1970). Therefore, it is expected that increases in density of exploited species within MPAs could enhance yields in

Figure 1. Map of Nigeria's Coastal Area (Google Earth, 2016).

neighboring fisheries through density dependent emigration. For example in the Tsitsikamma National Park in South Africa (established in 1964, one of the oldest reserves in the world) densities of a commercially important sparid fish, Chrysoblephus laticeps, were an estimated 42 times higher than in nearby fishing grounds (Buxton and Smale, 1989).

Egg and larvae export

Because reserves contain more and larger fish, populations protected will have the opportunity to produce more offspring than population exposed to exploitation. Increased egg output presupposes greater supply of juvenile fish to adjacent fisheries through export of offspring on ocean currents. Additionally, as protected stocks build up, the reserves are expected to supply local fisheries through density-dependent spillover of juveniles and adults into fishing grounds' (Roberts et al., 2001).

Zoning in MPAs

Zoning can be described as a management tool for spatial control of activities within a MPA. It aimed to define activities that will be permitted including their associated conditions or prohibitions from specified geographic areas. It usually used to separate activities that are potentially conflicting and in some cases, exclusive use of an area may be granted to a particular sector of special interest.

A zoning plan typically provides for four different zones in the reserve

i) sanctuary or "no take" areas which makes provision for complete or partial protection from fishing, but allow observation and boating activities such as, swimming and diving to continue.

ii) zones designated towards habitat protection which protect sensitive habitat by forbidding high impact activities like commercial trawling, but permits recreational fishing and low impact commercial fishing to continue

iii) zones designated for general which cater for a broad range of sustainable activities

iv) special purpose zones designated for sites that may require special management arrangements such as ports or jetties.

AN OVERVIEW OF THE NIGERIAN COASTAL ENVIRONMENT

The country lies within the Gulf of Guinea Large marine Ecosystem (GCLME). Figure 1 shows Nigeria's coastal area. Nigerian coastal zone has been classified into four geomorphic divisions, namely:

1) The Barrier-Lagoon Complex: The barrier-lagoon complex stretches eastward for about 200 km from the Nigeria-Benin Republic border to the western side of the Mahin transgressive mud coast. The morphology has generally been determined by coastal dynamics and drainage (Ibe, 1988). The beaches are erosive in nature due to lack of exoteric rivers which would have compensated for the sand displaced or lost due to longshore current action. The barrier-lagoon complex is supported by the Badagry Creek, the Lagos Lagoon, Lekki Lagoon and several other creeks that connect to the sea through the Commodore Channel in Lagos. The complex also consists of narrow beach ridges which are aligned parallel to the coast (Ibe, 1988).

2) Mahin Transgressive Mud Coast: This area is characterized by medium to coarse sandy beaches of Badagry, Lagos and Lekki. It is positioned eastward into mud beach off Lekki- Lagoon. The mud beach covers about 75 km and ends at the mouth of Benin River on the northwestern side of the Niger Delta. This mud coast is low lying and its almost totally devoid of sand. The absence of substantial quantities of sand on the beach and the seeming failure of longshore currents to continue the barrier island formation beyond the barrier-lagoon complex is attributed to the Avon and Mahin canyons which channel away sand to submarine fans on the slope (Burke, 1972).

3) The Strand Coast: This area covers about 85 km from Imo river estuary to the Cross-River estuary (east of the Niger Delta). The coast includes flat beaches which changes into a beach ridge plain with a few swamp systems (Burke, 1972). The swamp is linked directly with the sea at the Cross-River estuary and the Rio-del Rey estuary. The swamp systems are supported by older sediments. Two major breaks can be identified on the Strand coast, at the Kwa Iboe River and Cross-River entrances. At the entrance to the Kwa Ibo River there is a well-developed delta, while the Cross-River entrance exemplifies a typical estuarine complex.

4) The Niger Delta: The Niger Delta is a prominent geomorphic feature in the Nigerian coastal zone. It extends for about 450 km from the Benin River estuary eastward and ends at the mouth of the Imo River estuary. About 21 estuaries are said to discharge into the sea through the Delta. The Niger Delta comprises of many distinct ecological zones that includes fresh water swamp, creeks, mangroves, barrier islands and estuaries. The Niger Delta has further been classified into four major ecological zones namely; the barrier island complexes, the lower flood plain, the vegetated tidal flats and the upper flood plain (Burke, 1972; Allen, 1970).

RATIONAL FOR THE ESTABLISHMENT OF MPAS IN NIGERIA

Nigeria signed UNCLOS on the 10th of December 1982 and ratified it on the 14 August 1986; the country also ratified the agreement relating to the implementation of Part XI of the Convention on the 28 July, 1995.

As stated earlier, MPAs have been identified and proposed as flagships of marine conservation programs in many parts of the world (FAO, 2011). Establishing a MPA in Nigeria is essential due to the peculiar challenges and issues affecting coastal resource conservation (especially the fisheries) in Nigeria.

In Nigeria, approximately 25% of the country's 170 million people live in coastal areas and their livelihood is dependent on the lagoons, estuaries, creeks and inshore waters (Agbeja and Jenyo-Oni, 2013). Issues that pose as challenges to sustainable marine and coastal ecosystems in Nigeria are mostly that of environmental degradation and illegal, unreported and unregulated fishing (IUU). A study by UNEP on "Combating living resource depletion and coastal area degradation in the Guinea Current Large Marine Ecosystem (GCLME) through ecosystem-based regional actions" characterized the following issues as factors affecting conservation of coastal resources; human population growth, urbanization, habitat degradation, fisheries depletion, public health and sanitation, land use planning and coastal erosion (Ajayi, 1994). In addition to these issues, Nigeria has peculiar issues that range from civil unrest to poor political will and inconsistent policy (Afegbua, 2014).

In addition, many agricultural plantations, several harbors, airports, numerous industries as well as many other parts of the socio-economic infrastructure in Nigeria are located at or near the coast. This is ascribed to the fact that the coast is rich in natural resources and a history of early European contact in the coastal areas. (Ajetunmobi, 2012). Urbanization and development in the coastal area is also not adequately planned which promotes destruction of habitat and the poorly regularized industrialization contribute to stresses on the environment that includes pollution pressures on the coastal and international water body. These uncontrolled and poorly addressed urbanization of the coastal region leads to use conflicts that requires decisive actions to prevent civil unrest (WACAF, 1993).

There is also the issue of untreated sewage emptied into the coastal environment could invariably impact on the health of people and the environment in general. The sewage treatment facilities are inadequate in the country and especially in the coastal areas, raw sewage is discharged into the environment. The combination of these issues with the limited water exchange in the lagoons, results in pervasive eutrophication in the region (TDA, 2006).

The GCLME is rich in living marine resources especially commercially valuable fish species captured from deep sea and coastal. One million metric tons of fish are estimated to be caught annually, from the region of which a third is exported.

The extensive mangroves that occur along the Nigerian coast are the spawning grounds for numerous species of fish, including the many commercial varieties which have been degraded over the years. Mangroves of the GCLME are especially important for the coastal communities, where they are used as fuel wood for smoking fish, general household cooking, and building materials. Unfortunately, overuse and pollution (e.g. from oil spills) has severely damaged the mangroves (UNEP, 2011). Physical destruction of habitats in the coastal areas especially wetlands, result in the loss of spawning and breeding grounds for a lot of fauna, which has led to the loss of the rich biodiversity of the region including some rare and endangered species (UNEP, 2011).

In Nigeria, 33% in the Niger Delta, the mangroves and significant marshlands along the coastal area has been destroyed through pollution and overcutting (TDA, 2006; UNEP, 2011).

Urbanization and industrial growth has also led to a huge decline of mangrove to the extent that several species are said to extinct. In many instances mangrove areas, have been reduced to saline grasslands. The mangroves species that occurs in the Niger Delta of Nigeria extends from the Benin River in the West and the Calabar-Rio del Rey estuary in the East (UNDP, 2016).

Mangrove forest provide nutrients to adjacent shallow channel and bay systems- that serve as the primary habitat of numerous aquatic species of commercial importance. Besides the rich flora, there is a diverse array of associated fauna that need stringent measures towards their conservation, these include small mammals such as otters, *Atilax paludinosus*, *Dasymys* sp. and large mammals such as *Cephalophus* sp. Molluscs found in the GCLME include *Crassostrea gasar*, *Arca senilis*, *Cymbium pepo*, cones, cowries and conches (TDA, 2006). These molluscs constitute important component of fish and bird food and humans. Mangroves are home for some species of crocodiles, one is locally known as alligator, and there is also the endangered West African manatees, *Trichechus Senegalensis*. The mangrove forests are continually under pressure from over cutting for fuel wood and construction, and other anthropogenic activities which invariably threaten their roles in the regeneration and as reservoirs of biological diversity (UNDP, 2012).

Agriculture at subsistence and commercial levels are important to all countries in the region. The use of chemical fertilisers and pesticides in agricultural practices also impact the marine and coastal environment, and in recent years there has been noticeable increase development of commercial agriculture as there is the need to improve food production as population increases in the region (TDA, 2006).

Substantial amounts of nutrients that come from domestic and agricultural effluents, used in primary production are carried to the sea through river outflows. Approximately 30% of fertilizer applied are estimated to be actually utilised by the plants and the reminder either evaporates into the atmosphere or transported into surface waters. These excess nutrients in addition with sewage pollution, are a serious threat to lagoons (Portmann et al., 1989). These large amounts of sediments are also important sources of nutrients and suspended matter to the coastal and marine environment contributing to eutrophication and harmful algal blooms which have serious implications to ecosystem and human health.

These stresses on the environment lead to the destruction of coastal habitats and result in the loss of spawning and nursery grounds for living resources, loss of the rich and varied fauna and flora especially rare and endangered species.

Resulting impacts include decreases in the resident fish stocks near shore and the sustainability of the straddling and highly migratory fisheries of the region, both of which are of high significance towards food security and economic health to the people of the region.

Finally, there is also these risks associated with petroleum pipeline development, such as petroleum products being spilled accidental and operational discharges from shipping (e.g. ship wastes) and the accidental introduction of toxic chemicals and exotic species can seriously damage the receiving ecosystem, leading to food and habitat loss (UNEP, 2011). Harbor construction activities also alter long-shore current transport of sediments that lead to coastal erosion and siltation problems thereby placing fishing and other coastal communities in danger from loss of roadway and habitable lands.

CONSIDERATIONS FOR THE ESTABLISHMENT OF MPAS IN NIGERIA

There are no definitive models for MPAs because each nation has different social, political, economic and environmental parameters.

Protected areas; however, not new in Nigeria, are provisions regarding protection of forestry and wildlife but as at the time of this report no marine area has been designated officially for protection.

Looking at the national policy on the environment and forestry, wildlife and protected areas are part of the broad provisions of the policy, which was developed in 1989 (Federal Republic of Nigeria 1989) and later revised in 1999 (Federal Government of Nigeria 2001). The objectives of the policy are to achieve sustainable development in the country with particular emphasis on the following (Usman and Adefalu, 2010):

i) Promoting and sustaining environmental quality adequate for the health and wellbeing of all Nigerians
-Conservation of the environment and natural resources in order to benefit present and future generation of Nigerians.
ii) Restoring, maintaining and enhancing the ecosystems and ecological processes which are necessary for proper functioning of the environment.
iii) Raising public awareness and promoting public understanding of the important linkages between the environment and development.
iv) Cooperating with other countries and international organizations to preserve the environment (Usman and Adefalu, 2010)

Examples of specific strategies for achieving these goals as regards protection of the forestry, wildlife include:

i) Regulation of forestry activities to ensure conservation and environmentally sound management practices.
ii) Strengthening of forest protection activities in marginal areas to prevent harmful changes in such areas.
iii) Encouraging afforestation and reforestation programmes with the aim of reversing the effects of deforestation.
iv) Supporting Non-Governmental Organizations (NGOs) and tree planting programmes of local communities.
v) Supporting the development of other alternative sources of energy while encouraging the development of more efficient way of wood energy utiization (Federal Republic of Nigeria 1989).

These existing provisions targeted towards terrestrial protected areas in Nigeria can be extended toward coastal and marine protection.

Therefore, towards designing MPAs in Nigeria, it would be beneficial to establish the following four sequential steps (NAP, 2001):

(1) Evaluate conservation needs at both local and regional levels: The intensity and method of uses of resources, the physical and biological characteristics of the habitats in a marine or coastal region of a country influence local and regional conservation needs therefore, the importance of planning an MPA cannot be overemphasized. Adequate identification and mapping of habitat types and living marine resources should be primary. There are eight coastal states in Nigeria therefore, the federal and state governments have to select the region of the country the MPA would be most appropriate based on scientific evidence and wide consultations. Local participation is of great necessity if proposal are to be successful (Agbeja, 2012). The local communities residing in the target coastal area should be involved in the selection as their cooperation will be crucial to the survival of the MPA program.

(2) Define the objectives and goals for establishing MPAs: The step is the proposal of specific management goals for the projected MPA. MPAs usually have multiple objectives which include protection of representative habitats, conserving biodiversity such as conservation of rare species, improving fishery management, protecting ecosystem integrity, fish stock restoration or enhancement, or safeguarding of historical sites preserving cultural heritage, providing educational and recreational opportunities, and establishing sites for scientific research etc. These objectives should be categorized and ranked based on the local conservation need, giving due consideration to conflicting objectives by establishing tradeoffs and negotiations.

When siting a MPA, biodiversity conservation is of utmost concern therefore siting criteria should include '*habitat representation and heterogeneity, species diversity, biogeographic representation, presence of vulnerable habitats or threatened species, and ecosystem functioning. To improve fishery management, site choice may depend on the locale of stocks that are overfished to provide insurance against stock collapse or to protect spawning and nursery habitat. Site should be selected to reduce by-catch of non-target species or juveniles of exploited species'* (NAP, 2001).

(3) Describe the key biological and oceanic features of the region: Data should be generated by collecting information on the life histories of exploited or threatened species (e.g, spawning and nursery sites, dispersal patterns) and the oceanic features of the region. Information on the features of the region to be acquired should include water current and circulation patterns, identification of upwelling zones and other features associated with productivity enhancement, water quality (nutrient inputs, pollution, sedimentation, harmful algal blooms), and habitat maps. This will aid in the evaluation of the sites for its suitability and also serve as base line information that will guide future management decisions.

(4) Site Identification: Identify and choose site(s) that have the highest potential for implementation. Incorporating the desired properties of an MPA into a zoning plan that specifies size and location of reserves requires matching the biological and oceanic properties to meet the specified objectives. There is a necessity to have in place a marine spatial plan (MSP), as MSP is a process that guides where and when human activities can take place in marine spaces, so that the choice of sites for MPAs can be integrated into an overall plan for marine area management in order optimize the level of protection available to the marine ecosystem as a whole because the success of MPAs depends on the quality of management in the surrounding waters (NAP, 2011).

5) Institutional Arrangements: Federal and state/ regional agencies identified for the MPA siting will need to make available resources such as expertise and coordination so as to be able to effectively integrate MPAs into the frameworks for sustainable, ecosystem based coastal and marine resource management in order to achieve established goals at the state, regional, national, or international level. The lead agency will identify all stakeholders, both on- and off-site, and then utilize methods of communication appropriate for various user groups to optimize effort.

CONCLUSION

Designation of a MPA in Nigeria is very crucial, considering all the challenges so far discussed, so as be able to establish meaningful sustainable development of coastal and marine resource (especially fisheries) in the nation. As protected area designation is not new in Nigeria, institutional arrangements in existence can be used to support the establishment of MPAs. Establishing MPA in Nigeria may seem difficult but in my opinion, it is achievable as the usefulness of reserves MPAs as tools for environmental management cannot be over-emphasized.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Biodiversity conservation using the indigenous knowledge system: The priority agenda in the case of Zeyse, Zergula and Ganta communities in Gamo Gofa Zone (Southern Ethiopia).

Abayneh Unasho Gandile*, Solomon Mengistu Tessema and Fisha Mesfine Nake

College of Natural and computational Sciences, Department of Biology, Dilla University, Ethiopia.

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Biodiversity has fundamental values to humans, because we are dependent on it for our nutritional, cultural, economic, and environmental/ecological well-being and the mismanagement of biodiversity leads to resource decline and biodiversity crisis. Moreover, Indigenous Knowledge develops in local contexts to solve local problems, and it is just another form of knowledge which does not set itself in opposition to sciences. However, values of biodiversity and manifold roles of indigenous knowledge including biodiversity conservations are overlooked and are at a risk of getting extinct in general and in Ethiopia in particular. The objective of this study was to collect information on the values of biodiversity, its current status and conservation of biodiversity using indigenous knowledge of the Zeyse, Zergula and Ganta communities in Southern Ethiopia. Data were collected from six focus group discussions (Native Individuals with age range: 30 to120) to achieve the goals of the research and all of the discussants were indigenous members of each community. A qualitative research design was used and the data were organized and analyzed around the key themes of the research.The result showed value of the biodiversity including specific values of plant biodiversity- *Arundinaria alpinak* and *Moringa stenopetala* as human assets for the livelihood of the community. Moreover, the result indicated strong traditional beliefs, laws and customs and affections towards nature to conserve biodiversity including sacred trees and animals (totems). However, the results also indicated, currently, these cultural values of the communities to conserve biodiversity using indigenous knowledge were at a risk of getting extinct/endangered, which resulted in the loss of biodiversity in the study areas. The study result indicated specific values of biodiversity for the livelihood of the communities and strong ties between indigenous knowledge and biodiversity conservation. Therefore, we need to empower indigenous people to protect their culture embodying indigenous knowledge, belief systems of protecting nature, and cultural practices that promote sustainable biodiversity conservation.

Key words: Biodiversity, Indigenous knowledge, wildlife, Nature, Conservation, totem

INTRODUCTION

Background and justification of the study

According to Wilfred et al. (2007), biodiversity refers to a variety of life forms (genes, species, animals, plants and micro-organisms), ecosystems and the ecological process/ecological complexes in which these components are interacting. Biodiversity also refers to a reciprocal relationship between humans and non- human entities that include plants, animals, minerals; and the spiritual consciousness of the people concerning such relationship (Kimmerer, 2002).This implies that, for indigenous people, biodiversity is much broader than the scientific view of ecosystem as it includes spiritual values of nature through creation.

Biodiversity is directly responsible for 40% of the world's economy, 70% of the world's poor live in rural areas depend directly on biodiversity for their livelihood, and 80% of Africans depend on forest resources for food, shelter, medicine, rural architecture and engineering for their survival (World Bank, 2004; Anthwal et al., 2006; WHO, 2010). Moreover, another study also reflected, the value of biodiversity as indigenous cultures, and recognize biodiversity's value in religious traditions based on honouring the Earth. Proximity to nature has also been shown to enhance emotional and spiritual well-being (Atkinson et al., 2012). Atkinson et al. (2012), also explains, cultural ecosystem services include use-related values such as leisure and recreation, aesthetic and inspirational benefits, spiritual and religious benefits, community benefits, education and ecological knowledge, and physical and mental health.

Furthermore, biodiversity including Ecosystems also provide many services that sustain human health such as nutrition, regulation of vector-borne disease, or water purification and natural settings which could act as a catalyst for healthy behaviour leading for example to increase physical exercise, which affect both physical and mental health (Pretty et al., 2005; Barton and Pretty, 2010). Besides, simple exposure to the natural environment, such as having a view of a tree or grass from a window, can be beneficial, improving mental health status (Pretty et al., 2005). These values indicate a wide scope of biodiversity values for the livelihood of the community.

However, biodiversity loss has been a major concern to mankind, especially during the last quarter of the previous century. This concern culminated in the "Biodiversity Convention" that was opened for signature at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, June 1992. Since then different international fora, including e.g. the Beijing Conference for Women in 1995 echoed the problems of continuing environmental degradation. In spite of this, ten years after Rio, the World Summit on Sustainable Development (WSSD) was held in Johannesburg, South Africa, from August-September 2002, could only state that in spite of significant efforts, the loss of biodiversity worldwide was continuing at an unperceived speed and a reverse in this ongoing decline should urgently be realized (Hens and Nath, 2003).

What are the causes of continuing loss of biodiversity? The cause of biodiversity loss are multiple and complex. However, studies have shown that, one of the traditionally important causes were the unique focus on the biological factors for the biodiversity loss. During the recent times, extinction rates are ten to hundred times higher than during pre-human times (Sinclair, 2000a). Studies also indicate the main biological causes for this loss of biodiversity include: the loss of habitats, the introduction of exotic species, over-harvesting, illegal hunting, illegal settlements, climate change/ global environmental change, "knock-on" effects and pollution (Sinclair, 2000b; Nasi et al., 2008; SCBD, 2008; Peter, 2008). All these causes have one element in common: they are induced by human activities which threaten the world's biodiversity.

Moreover, a study carried in Ethiopia on Earth Trends: Forests, Grasslands, and Dry lands, states the loss of biodiversity indicating 4% forest cover and an estimated deforestation rate of 8% per year as of 2000 (World Resources Institute on Earth Trends: Forests, Grasslands, and Drylands, 2003 cited in USAID, 2008).The reasons for this deforestation are both direct such as the production of charcoal and timber and indirect such as lack of management capacity and population pressures (USAID, 2008). This makes the overall human activity, the most important cause of the current decline in biodiversity which needs immediate and integrated solution.

Therefore, understanding the many aspects of human influences on biodiversity, and their underlying driving forces, is of crucial importance for setting priorities and counteracting the current negative trends and all of these negative trends can be curved by integrated biodiversity conservation approach including the application of indigenous knowledge system.

Indigenous knowledge (IK) can be defined as a body of knowledge built up by a group of people through generations, of living in close contact with nature, specific to communities and local environments (Johnson, 1992). A broader definition holds that indigenous knowledge is the knowledge used by local people to make a living (livelihood) in a particular local environment (Warren, 1991).

Moreover, indigenous knowledge is much more complex and in fact, a variety of terms have been used to describe this form of unique knowledge. These include terms such as local knowledge, traditional knowledge, indigenous traditional knowledge, indigenous technical knowledge traditional environmental knowledge, rural

*Corresponding author. E-mail: aabbay_u@yahoo.com. Tel: +251911895949.

knowledge, traditional ecological knowledge, and so forth. In this study, the term “indigenous knowledge (IK) ‘’ was used to cover all those concepts of knowledge systems. IK develops in local contexts to solve local problems including conflict resolution, whether fore-casting, biodiversity conservation, solving local health problem in particular and maintaining human livelihood in general. It does not set itself in opposition to science and is just another form of knowledge (Peter, 2008).

Moreover, another study shows, the most notable biodiversity conservation practice were the protection of forests using IK. Wildlife takes refuge in these forests to escape from enemies including forest fires and hunters. The protected forests therefore play an important role as habitats for a high diversity of flora and fauna. Studies also show, plant species vary greatly in these forests, showing that each traditionally protected forest is invaluable as a conservation haven. Some forests were also protected by IK beliefs such as taboos that forbade people to enter them and some trees were declared as sacred and felling them constituted a breach of taboo. The effectiveness of the traditional sanctions is shown by the fact that the forest reserves have been virtually untouched for generations’ and they stand out as ecological museums of local vegetation (Laurel and Nyberg, 2000).

However, IK systems in Africa including Ethiopia have not been systematically recorded and are therefore not readily accessible to policy makers, researchers and development agents although several writers have provided detailed overviews of IK systems in agricultural development, pastoral management, and agro-forestry (Rajasekar and Warren, 1991; Babu, 1991). Morover, IK system is a crucial aspect of sustainable biodiversity conservation including land management (shifting cultivation, mixed cropping, intercropping), and development. These have been proven to be superior in many cases than alien technologies. Indigenous knowledge technologies and know-how rely on locally available skills and materials and are thus often more cost-effective than exotic technologies introduced from the outside (Peter, 2008).

There is historical and contemporary evidence that indicates indigenous peoples have also committed environmental wrongs through over-grazing, illegal settlement, over-hunting, or over cultivation of the land and it is misleading to think of indigenous knowledge as always being “good”, “right” or “sustainable”. Therefore, critically re-examining those beliefs is always useful to consider their purpose rather than their grounding (Peter, 2008).

Moreover, it has been widely argued that documentation of the indigenous knowledge system will motivate wide use, application and easy integration of such knowledge system into other forms of knowledge systems (Msuya, 2007; Shrestha et al., 2008), whereas, lack of documen-tation has been contributing to its decline and its role in biodiversity conservation. Furthermore, elders have been dying without passing on their knowledge system to their grandchildren (Kalanda-Sabola et al., 2007), which threatens its wide use, application and its integration with other forms of knowledge systems (Msuya, 2007).

In Ethiopia**,** with an estimated 85% of the population is dependent directly on the land for their livelihoods, but degradation of the land and biological system is critical that conservation becomes the top commitment of the government to reverse the danger encountered (USAID, 2008) and this needs a holistic approach including IK system to conserve biodiversity.

Rationale of the study

Biodiversity loss has been a major concern to mankind, especially during the last quarter of the previous century which needs an integrated approach including IK to curb this human and wildlife threats. IK can be summed up as the wisdom of a people for survival in their own local environment and it is necessary to integrate indigenous knowledge systems with scientific knowledge to enhance biodiversity conservation and bring about sustainable development.

IK plays an important role in biodiversity conservation and social and economic development of local communities. Sustainable development and biodiversity conservation are intricately linked, because biological resources are fundamentals to development. Conservation permits the continuing use of resources in ways that are non-destructive.

The sustainable use of natural resources by local populations must be based on an understanding of the relationships between human’s IK and their environment. Therefore, conservation of biodiversity using IK at worldwide in general and in Ethiopia in a particular will be the demand of the day.

Therefore, this research was targeted to answer the following questions:

1. What were the specific values of biodiversity for the livelihood of the communities?
2. What was the current status of biodiversity in the study areas?
3. What was the role of IK to conserve biodiversity conservation?
4. How did you compare biodiversity conservation of the past vis-à-vis with the present?

In line with the objectives of the‘’ Millennium Development Goals (MDGs), particularly global poverty reduction by the year 2015’’ the role of IK is paramount, and this research was aimed at to assess and document the values of biodiversity, its current status, and biodiversity conservation using IK, taking specific communities including Zeyse, Zergula and Ganta into account.

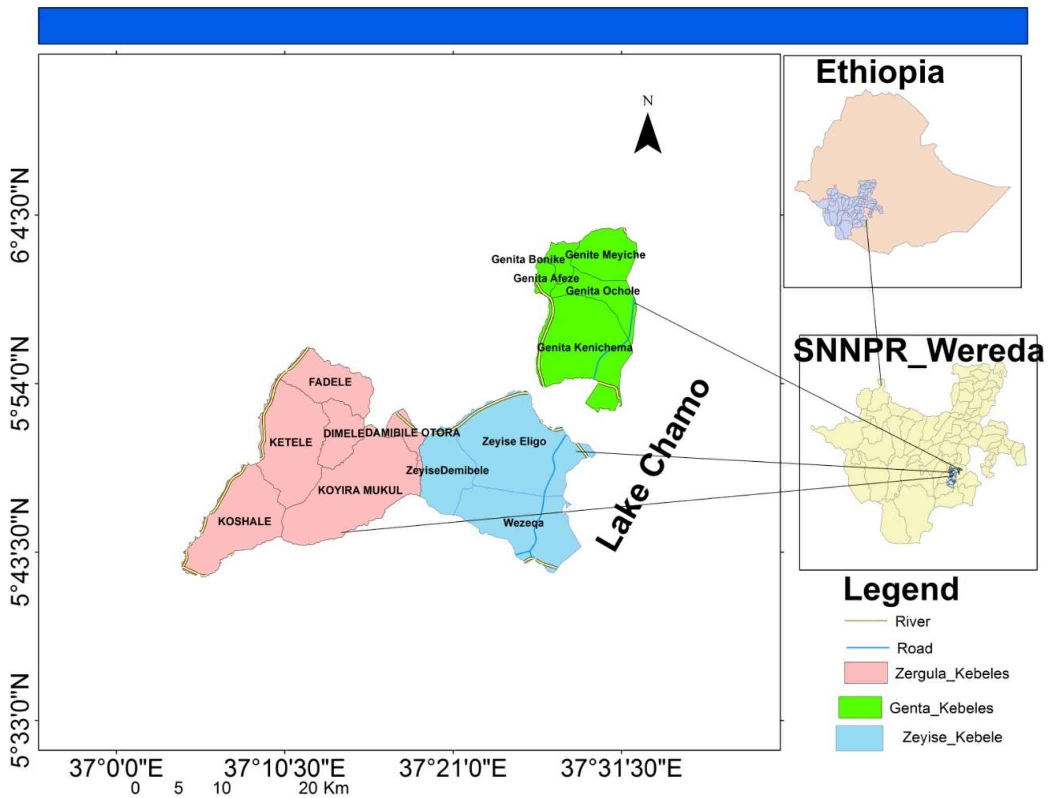

Figure 1. Study Sites (Source: Ethiopia GIS, 2007).

MATERIALS AND METHODS

Description of the study area

Ethiopia is a sub- Saharan African country located in the horn of Arica. It is extremely ethnically diverse country inhabited by more than 80 ethnic groups of which over 56% ethnic groups are indigenous to the Southern Nations, Nationalities and Peoples, Region (SNNPR). These ethnic groups are distinguished by their different languages, culture and socioeconomic organizations.

Among these indigenous Southern communities, Zeyse, Zergula and Ganta communities (Figure 1) are the targets of this study. They inhabit in GamoGofa Zonal region, in both low and high land areas. Lowland regions of Zeyse and Ganta communities are located around Lake Chamo, south of the capital (Arba Minch), but that of the Zergula is located at the western part of Zeyse area.

Like all other indigenous communities, these communities have indigenous knowledge which is important for their survival (livelihood), including biodiversity conservation and development. However, biodiversity conservation using IK of these communities was not studied well and documented. Therefore, assessing the application of IK on biodiversity conservation of these communities was the main concern of this study.

Study design

This study was conducted at Southern Ethiopia, involving assessment and documentation of values of biodiversity, its current status and conservation using the IK of "Zeyse, Zergula and Ganta'' communities. We targeted to these indigenous ethnic groups (= communities), because of their proximate geographical locations and the role of their IK on biodiversity conservation was not previously studied and documented well.

After conduction of pilot study on one of the communities selected, data collection were done using qualitative data collection method that included focus group discussion (FGD) with community adults and elders (Age range = 30-120), who were considered to be knowledgeable about the IK of the community. The study was conducted from June 2013 to January, 2015**.** Moreover, data collection, analysis and interpretation were done by the researchers.

Study participants, and method of sampling

This study was done by taking sample units of 55 participants and all of them were native individuals of the Zeyse, Zergulla and Ganta communities. Method of the study was qualitative design involving purposive sampling method and the key informants from each community were particularly relevant to the data collection based on the research objectives.

Methods of data collection

Preliminary survey including legal attachment with concerned zonal administration and Kebele representatives, pilot study survey was conducted. Pilot study was targeted to avoid unnecessary repetitions/redundancy of the questionnaire/, to assess both external and internal intervening factors, effective utilization of man power and budget (Figure 2).

Instrument used to collect data for this study was Focus Group Discussion (FGD) which covered themes on the values of biodiversity, its current status and biodiversity conservation using

Figure 2. Group discussion during the pilot study.

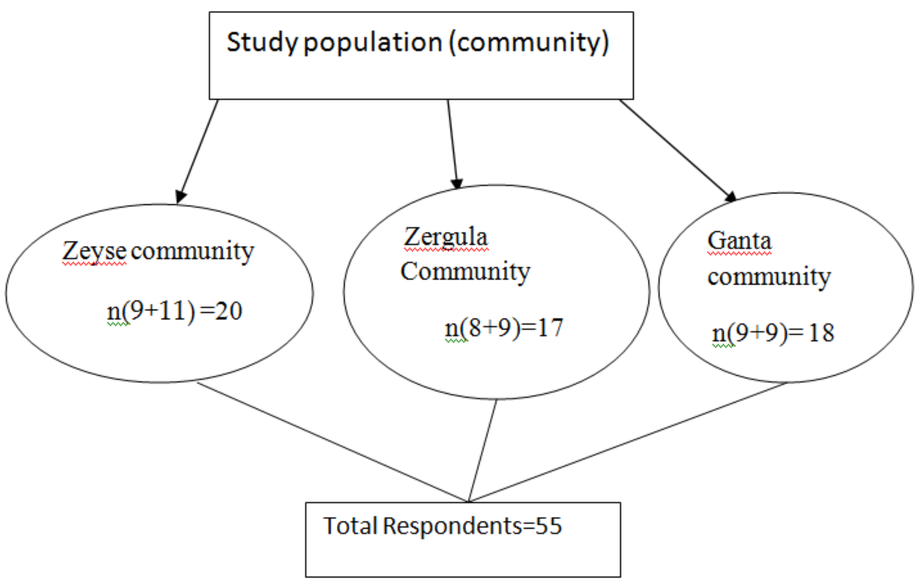

Figure 3. Schematic presentation of the sampling design.

indigenous knowledge system. The researchers had FGD with a total of fifty five persons including adults and community elders (Figure 3) expected to know the traditional/cultural practices of their communities. The discussants were categorized into six FGD groups (Age: 30-120), consisting of eight to eleven individuals including both sexes. The choice was purposeful selection because community adults and elders have a better traditional knowledge/ knowledgeable on biodiversity conservation (‘'In Africa, when an old person who is expertise of IK dies, it is like when a library burns down.”).

Moreover, questionnaire were also exposed to all participants to collect data on age, occupations, skills, Zonal, Woreda and Kebele

Table 1. Gender and age range of the respondents.

S/N	Items	Male/Female	Age range	Total	Frequency (%)
1	Gender	Male	30-40	4	7.2
			41-50	7	12.7
			51-60	13	23.6
			61-70	14	25.5
			71-80	7	12.7
			81-90	5	9.1
.			90-100	1	1.8
			101-110	0	-
			111-120	2	3.6
2		Female	41-50	2	3.6
		Total		55	100

addresses. During discussion on each item, the respondents were free to express their views with no intervention/limitation or no leading ideas/ clues were given to the respondents.

Data analysis

Responses of the FGD respondents were collected and interpreted using qualitative method of the research involving language oriented approach based on thorough descriptions and interpretations of indigenous knowledge and its role in biodiversity conservation within the communities.

Ethical consideration

Due to ethical reasons, researchers did not interfere directly into the privacy of the community. We made formal attachment with zonal and Woreda development office of the Agriculture and legal attachment was also done with kebele administrations. Moreover, individuals involved in the data collection process were given verbal consent and validity of the study was clearly explained to them as a prerequisite before the data collection.

RESULTS

Background information about the respondents

A total of 55 respondents of the community adults and elders, including both genders (males = 53(96.3%, Females = 2(3.7%) were included in the study and their background information was shown in Table 1. In Table 1, respondents' age grade indicated age variations (minimum age = 30, maximum age = 120) of adults and elders who participated during the FGD.

Values of Biodiversity and its current status

This survey showed different values of biodiversity for life supporting/ livelihood of the indigenous people of local inhabitants (Zeyse, Zergula and Ganta communities).

The case of Ganta community

The respondents from Ganta community reflected, values of biodiversity which included: ''Household materials including tables, chairs and house construction (e.g. *Juniperus procera*is a termite resistant and is used for the traditional house construction including its pillars). Trees and forests are used as a home- place for wild animal's protection from sun rays, and biological enemies. Grasses can be used as fodder for domestic animals, and bamboo plant (*Arundinaria alpine k*Sch.m.) has so many uses for the community (Figure 4). Other uses of plants for example: woods of *Cordia africana*, *Croton macrostachyus* Del. and *Olea europaea* subsp. Cuspidata L. were used for our local house construction, and making household furniture. On the other hand, domestic animals such as horses, donkeys and mules are used for loading goods; cattle are used for ploughing, meat and milk production used as a source of nutrient, and for income generating activity etc to support our livelihood.''

Bamboo plant (*Arundinaria alpine k.Schum (Dusha local name*)

1. Is native to Gamo highlands including Gantameyche.
2. Uses of bamboo plant includes: house and, fence construction, making beehive, toothbrush, house decoration, basket, materials used for feeding, leaves are used as fodder for cattle, preventing soil and water erosion.
3. Used as a totemic item (object associated with worship) etc to support the livelihood of the community'' (Figure 4).

The case of Zeyse community:

Respondents of the Focus group Discussion (Figure 5)

Figure 4. Bamboo plant as part of plant biodiversity, provides support for the livelihood of the community.

Figure 5. Respondents involved in Focus group discussion at Zeyse Kebele.

Zeyse community described the following values of the biodiversity for the livelihood of the community: As reflected by the respondents ''Variety of lives (plants and animals), have a lot of advantages for the livelihood of our community including: Protection of human as well as animals. E.g. during the Italian invasion, forests played a greater role for the protection and strategic offensive activities, that is, humans and animals used forests to hide themselves from their biological enemies, forests are used for ecological balance, woods of trees for house construction (e.g. woods of *Juniperus procera* and *Olea europaea* subsp.Cuspidata L. are resistant to termites and are used for the construction of traditional houses including pillars of the houses).

Woods of Plants/ trees are also used for making house goods such as chairs, stools, locally made bed (*digo), horse reddish tree (Moringa stenopetala L.)* is used by the community as a source of food and remedy for coughing and the plant is shown in Figure 6. Domestic animals including horses, donkeys and mules are used for loading goods; cattle are used for meat and milk consumption, ploughing, and income generating activity'' etc. to support our livelihood.

Horse reddish tree/Moringa stenopetala L./ (Local name: Talahae)

1. Elders claimed ''this *plant was Native to Zeyse Wozaka kebele, and had been spread later on to the*

Figure 6. Horse reddish tree as part of plant biodiversity and its holistic use for the livelihood of the community.

proximate communities including Derashe and Konso communities.*''*(= the diameter of the plant stem in Figure 6).

2. Leaves are used by the community as cultural daily food and remedy for coughing.

3. Roots are used to treat malaria and purify water

4. Resists drought used as shade

5. Used as a daily food source for the whole year'' by the community (Figures 6 and 7)

The case of Zargula community

Respondents of the FGD (Figure 8), Zergula community reflected the following values of biodiversity for the livelihood of the community, that is, ''Domestic animals including horses, donkeys and mules are used for loading goods; cattle are used for ploughing, income generating activity, and nutrients for humans. Wood of trees are used for construction of houses and house goods (chairs and tables), fire wood and grasses are used, for house construction and fodder for grazing animals and all of them support our livelihood.

Current status of plants and animals biodiversity

Respondents from each community reflected the following current status of biodiversity.

The case of Ganta community

Respondents from *Ganta* community described ''currently biodiversity (plants and animals biodiversity) were eroding, that is, ''There were trees and grasses that became extinct, regardless of our domestic usage. Some examples of wild animals disappeared from our area

Figure 7. Edible Leaves of *Horse reddish tree***/**cabbage-tree**/** and banana plant used for the livelihood of the community.

included *Garma (Pantheraleo)*, *Tolko* (*Crowta otocelta*) due to deforestation, *Doa* (*Tragelaphus strepsoceros)*, *Feletso (Traglaphus imberbis)*and *Urdyle (Syivicapra grimmia)* due to illegal hunting and birds such as *Kuro* (*Corvus albus*/the Ethiopian crow spp.), *Tsilo* (Eagle species), and *Anko* (*Necrosyrtesss monachus)* were reduced in number. Some plants such as *Bobile (Cordia africana Lam.), Ule (Olea europaea subsp.)* and *Boro (Erythrina brucei)* were lost due to deforestation. During these days, we do not even hear the sound of a lion, and a hyena in our area.''

Currently, why is biodiversity eroding?Respondents from the *Ganta* community reported their views on this question, that is:

1. ''Forests including sacred trees were indiscriminately being cut down for the construction purposes.
2. Due to impacts of religion on our traditional belief to protect sacred trees. One of the respondents described'' No sacred trees ever exist according to the protestant religion.''
3. Our children were influenced by the effect of globalization and were resistant to our tradition and belief system of conservation. Therefore, in short, our IK and biodiversity were eroding during these days (currently) because:

1. Wild animals were lost because, our tradition to protect animals was lost, that is, community norms, and customs to protect animals were lost.
2. We did not protect the tradition of our grandparents which allowed us to protect our nature including wildlife.
3. Due to loss of animals, we lost productivity and blessing.
4. Population pressure had also impacts on the loss of animals.''

The case of Zayse community

Respondents from Zeyse community also reflected the loss of biodiversity (plants and animals) by stating ''loss of our culture to conserve nature, led to loss of our ownership of the natural resources including the wildlife (plants and animals). The loss of our culture to conserve nature led to loss of our IK to protect animals and plants.''

''Some examples of animals and plants species which were lost from our area due to deforestation including: *Osso* (*Diceros bicornis*), *Zaka* (*Laxodonta africana*), *Meno* (*Syncerus caffer*), and animals that were reduced in number included *Gaash (Hyiochoerus meinertzhageni*), *Doge* (*Kobusellipsiprymnus defassa*), *Doa (Tragelaphus scriptus), Agazene* (*Antelope* species) *peletso* (*Traglaphusim berbis*) *Garma* (*Panthera leo*) and *urdyle (Syiviapra grimmia)*. Some plant species included *Galma* (*Cordia Africana Lam.*), *Demo* (local), Witse (local), *Gulta* (*Olea europaea* subsp.Cuspidata L.) *Salbena* (local), *Bibre* (*Junipers procera Hochestex. Engl.*) were dwindling in number, and *Sabune* (local) was lost from the area due to deforestation.''

Why is biodiversity currently eroding? Respondents from the *Zeyse* community reported their views on this question. ''Whenever, there was a forest, the probability of rainfall was higher. If forests were lost, how would we domesticate our animals to get our daily requirements including, flesh, milk, meat and skin/hide? One of the respondents also explained his observation by saying ''historically, starting from the king Menilik up to military government, protection of forests was fairly good and better attention was given to this mission. However, currently, "Everybody is indiscriminately cutting trees including the sacred trees' and even when the action taker was asked why he/she was doing so? The answer would be short ''it is my right to do so'' with no limitation. This act also reminded us'' when the tradition of a community to preserve nature is lost, generation who inherits, it is lost' (that is, no proper pass over of our custom of conservation to new generation) leading to loss of our natural resources including biodiversity. Currently, our boarder is not protected or even being invaded by some people from the proximate area of *Zeyse* indigenous people. These infiltrators, illegally cut down trees, using our land forfarming, destroying our forests including sacred trees, forests at the tomb sites, and consequently animals escaped away.''

Moreover, the respondents also said ''when the culture

Figure 8. Respondents of the *Zergula* Community involved in Focus Group Discussion.

embodying IK to protect wildlife is lost, system of transmitting IK to new generation would be lost. We also tried to advise our youngsters not to cut trees indiscriminately, but they are resistant to accept advice of community elders. When we reported the illegal activities against our forests and wild animals, no legal measures were taken against the infiltrators''. One of the respondents also explained the best episode which was happened during the past 'regime' by saying "If a person cut a tree illegally, he was ordered to plant the tree again in compensation", and this action was a good experience for us today. Therefore, currently we experience land ownership problem due to infiltrators and this also affected our culture of biodiversity conservation.'' We had a better culture of biodiversity conservation in the past vis-à-vis the present time.''

The case of Zergula community

The respondents from *Zergula* community also described current loss of biodiversity by considering some examples of wildlife. ''Currently due to weak biodiversity conservation, plants including: *Och* (*Syzgium guineense* Dc*.), Galunda* (local), *Ele* (local), *Bulo* (*Solanium marginatum*L.f), *Gurdade* (*Capparis decidua*), *Gerea* (Local), *Ambe* (local) and animals including *Urdo (Sylvicapra grimmia*), *Garma (Panthera leo*), *Aka* (*Guinea fowl species), Gabora* (*Traglaphus scriptus*), *Meno (Synceruscaffer*),*Dereanko*(*Necrosyrtesmonachus*),*Agaz ane*(*Antelope* species), *Osso* (*Diceros bicornis, Faro* (*Equus burchelli*), *Kulo* (*Francolinus species*), *Mahae* (*Panthera paradus)* and *Feletso* (*Tragelaphus imberbis)* were present in the past, but now they are absent.''

Why is biodiversity currently eroding? Respondents from the *Zergula* community reported their views on this question as described below by stating'' it is due to a loss of our culture to protect wildlife and population pressure, why our traditional values were being broken. The respondents also analysed the status of biodiversity by comparing biodiversity conservation of the past Vis-a- Vis the present by describing, 'Nobody attempted to cut trees unless it was allowed by the *Kat* (community leader), but currently, a person cuts trees as he wishes. We used to plant trees and protect our natural resources, but currently, our land is taken away by the flood (soil erosion). When there were forests, there were wild animals, but now forests are lost, and wild animals were either disappeared or lost or escaped to kola of "*Zala* desert.

In the past, ''community properties including forest and other personal properties were not affected or lost; all were protected, maintained or conserved and so is true for the plants and animals biodiversity. But these days, this traditional holistic ethics to protect our wildlife had become a history and youngsters do not listen to elders to use our IK to protect our wildlife.''

Biodiversity conservation using indigenous knowledge

The case of Ganta community

Respondents from the ***Ganta*** community described, biodiversity conservation using IK indicated as follows:

1.''Community had a strong traditional law/custom and a person who cuts trees or commits mistake or suspected being disobedient against traditional law/custom was punished by '*Maga*' (traditional leader of the kebele) because, people used to consider this act as illegal and the individuals would be disobedient. Furthermore, if the individuals were suspected of being disobedient against traditional law/ custom, he/she would be condemned and cursed.
2. Moreover, places of tomb sites were considered as taboos and trees including sacred trees were not cut down from these areas.
3. Assistant of " *Maga*" named as '*Demusa*' was used to conduct a proactive measure involving erecting totemic items' (objects associated with worship) such as bamboo plant or a bush tree with many branches or runners (serdo) at the site, which needs protection and this act was called a *Zir* (locally) according to a community custom. When a '*Zire*" was done, at a site which would be protected, nobody would act against the will of the community such as cutting trees, stealing the property of others. According to this custom, even lions and tigers were not killed. Therefore, any individual from *Meychekebele* did not dare to cut a tree from that of the *Bonkekebele* and vice versa (*Meyche* and *Bonke*are two kebeles of *Ganta* community) and this traditional measure was the basis for the protection of the forests.

Respondents also reflected the following traditional ways of specific measures against the illegal actors:

1. If lions were killed, *kanchememaga* was used to order the lion to kill the individual, who killed the lion.
2. *"Gero Kat*" was used to order lions to eat cattle of a person, whose cattle ate somebody's crops.
3. ''Ela*maga''* was used to order owls not to be killed because, this bird was considered as a messenger of the community (predicts the death of an individual).
4. Locusts were ordered to eat crops of individual, who made mistake against the tradition/custom of the community.

The respondents also agreed on the following points: '' we must: 1. protect the remaining animals and never kill animals. 2. We need to cover degraded and bare mountainous area by plantation, which needs support from the government. 3. Preserve our culture to protect our biodiversity.

The case of Zeyse community

Respondents from *Zeyse* community described, that they had a strong traditional law/ custom to protect forests and wild animals which was performed and guided by the active involvement of the kebele leaders called '*Mega* and *Chima (*elders) of the community. Accordingly: (i) ''Community used to consider, cutting trees from the burial area (tomb sites) (= e.g. *zhosha* burial site), as taboos because these places were considered as'' sacred areas'' where the spirit of ancestors were used to rest. (ii) Community leader (*Kat)* used to give, proactive, protective orders to community to maintain and protect forests, grasses and wildlife, and their boarder including their natural resources. For this purpose "*Maga*" used to slaughter a sheep or a goat as a sacrifice at the site, of protection as a religious ceremony/ ritual ceremony) for the ancestral spirits. Example, Goat was slaughtered as a sacrifice for this purpose between the boarder of *Zeyse* and *Ganta* community. *Kolta* hills were also considered as sacred hills where cattle were slaughtered for the ancestral spirits. This religious ceremony/ ritual ceremony was aimed at, for the prediction of good fate for the community, to safeguard the boarder,(= maintain safety of the boarder including natural resources), and for the prosperity of the community, so that nobody would dare to infiltrate into *Zeyse* boarder, and cut trees, kill animals, expand boarder and invade other properties. (iii) According to the tradition of the indigenous *Zeyse* people, there were animals and plants which were considered as cultural taboo (never be killed or touched or cut down) due to affection and beliefs towards nature, that is, some examples were:

1. There was a bird (locally named "*solo"*) which was immune to killing because it was considered/believed as *kat* of birds (=king of birds)and the feather of this bird was used:

a. During the burial ceremony of a *kat (*leader of the community*)*, as a symbolic sign on the head of mourners to give a special attention and an honour for the death of a *Kat.*
b. To indicate succession of *kat*'s son and for this ceremony, the feather of a''Solo'' was erected on the hair of the successor. Anybody who killed 'solo' was forced to pay compensation fee for the "*Kat*" of the community.
2. Nobody used to kill a mammal called "*Dul-o* due to cultural reasons ''but, if somebody used to kill it unknowingly, its skin should be given to the *Kat* and get excuse and blessing from the "*Kat*" of the community.
3. Nobody was allowed to kill *Gutus* (Ethiopian owl spp.), because it predicts the death of an individual. A person who used to kill *Gutus, leader of the kilan* would roll the seeds of *bulo (Solanum marginatum L.f)* around the killer's head as an excuse before entering to his house to be saved.
4. *Dobes'* (*phyton sabae*) immune to killing because, phyton was considered to be the king of snakes (*shosh kat*).
5. *Badite* (*Croton macrostachyus* Del): nobody was allowed to cut this plant because community considers this tree as a holy tree (totemic symbol), because the root and the leaf ofthis tree were used by the *Kat*and *Maga*to solve individuals and community problems.

“When culture embodying indigenous knowledge is lost, generation is lost, causing biodiversity loss.” Therefore, the respondents agreed (to): ‘’Be a guard for the protection of culture to preserve forests and animals through the following:

1. Plant trees, three times than usual and give protection for wild life.
2. Biodiversity (wildlife diversity) can be protected and sustained, only, if we protect our culture embodying our IK.
3. Have boarder and our boarder must be protected, so as to maintain our ownership and protect our natural resources including wildlife (animals and plants).
4. Practice “green development” and “Protect culture to protect biodiversity.”

The case of Zergula community

Respondents of the Zergula community explained, biodiversity conservation using IK by stating ’’Traditional tomb sites (burial area) of the community were considered as taboo sites, that is, not only cutting trees were forbidden, but also nobody is allowed to look at and enter illegally into the sites of the tomb.

There were 12 kebele leaders (*Magas)* under one community leader (*Kat*) who were used to conduct a ritual ceremony at worshiping sites between the boarders of each kebele. They used a sacrifice of cattle to predict good fate for the community including productivity, healthy child growth, blessing and prosperity for the community. In these areas, forests were maintained and considered to be taboos and nobody attempted to cut trees down, because they were the resting site for the ancestral spirits.’’

‘’Community also had a belief that *“Kat*” had a power to cause rainfall (rainmaking power) and for the feasibility of this belief, ‘*Kat*’ was used to pray to cause rainfall for the Community. When there was no rainfall, community gather together with “*Maga* and community elders (*chima*) and used to shout/report to the *‘Kat. ’*The *Kat used to* conduct a ritual ceremony in a ‘’clean selected area and say’ *’Let you prey and I would*’ prey, to god which caused rainfall, and this assisted biodiversity conservation’’.

Respondents also reported that ‘’anybody who used to breach traditional customs and attempt to steal, and cut trees would become sick and mad. If a person used to breach custom of a community***,*** *Kat* used to order a snake to bite custom breaker/ traditional law breaker to maintain law and order of the community. Respondents also reflected that community had a culture of succession to conserve wildlife and nature, but currently youngsters are resistant to accept this tradition. Therefore, we need to’’ teach our children formally at school level and informally at home to protect our culture embodying IK to conserve our wildlife.’’

DISCUSSION

Use of biodiversity for the livelihood of the community

This research investigated, the values of biodiversity, its past vis-à-vis the current status, and biodiversity conservation using indigenous knowledge of Zeyse, Zergula, and Ganta communities. All respondents from each community reflected the holistic values of biodiversity for the livelihood of the community.

This results agreed with other similar study results on many traditional societies over the world, which indicate a wide range of values of biodiversity including, a large number of plant species from the forests are used for food, fibre, shelter or medicine (Anthwal et al., 2006), forest has been the main source of plant materials used for household materials by various people in the World and about 80% of Africans depend on forest resources for shelter, medicine, rural architecture and engineering for their survival (WHO, 2010).

Moreover, another similar study also reflected, the value of biodiversity as indigenous cultures, sometimes recognize biodiversity's value in religious traditions based on honouring the Earth and proximity to nature, which has also been shown to enhance emotional and spiritual well-being (Atkinson et al., 2012). Atkinson et al. (2012), also explains, cultural ecosystem services include use-related values such as leisure and recreation, aesthetic and inspirational benefits, spiritual and religious benefits, community benefits, education and ecological knowledge, and physical and mental health.

Our study results, indicated, *Arundinaria alpine k* (locally *Dusha*) and *Moringa stenopetala (locally Talahae)* were considered as the explanatory component of plant biodiversity and their values for the livelihood of Ganta and *Zeyse* communities as indicated in Figures 4, 5 and 6, respectively were considered as asset for the indigenous people in the study areas.

This study showed the uses of*Arundinaria alpine k* at low scale level. However, our result was in conformity with the use of *Arundinaria alpine k* worldwide except Europe (Okumura et al., 2011). However, more research is needed to increase the knowledge on *Arundinaria alpine k* (Mazzini, 2006, cited in Okumura, 2011; Okumura, 2011) and its utilization including in Africa in general and Ethiopia in Particular.

This study also indicated diverse value of *Moringa stenopetala* (locally *Talahae*) (Figures 6 and 7) for the livelihood of *Zeyse* community. This result were inconformity with other study result on ‘’Nutritional and therapeutic role of *Moringa stenopetala* which states that traditional communities use the plant for multiple purposes such as source of food and medicine and the species is quite drought resistant (Mohammed, 2013). Moreover, the Njemb tribe, living in Kenya also utilizes this tree as medicinal plant (Berger et al., 1984).

Another study shows leaves are one of the best vegetable foods that can be found in the locality. In fact, all parts of the tree except the wood are edible, providing a highly nutritious food for both humans and animals (Padayachee and Baijnath, 2012). It was also reported that *Moringa stenopetala* foliage/leaf and fruit pods are rich sources of calcium, potassium, zink, and iron, and good sources of vitamins A, B, and C as well as sulphur-containing amino acids, methionine, cystine and a high percentage of carbohydrate (Abuye et al., 2003; Yisehak et al., 2011 cited in Mohammed, 2013). However, studies also indicate the presence of small amount of cyanogenic glucosides in *M. stenopetala* leaves may have a health risk in areas of high incidence of endemic goitre as an exacerbating factor if consumed more for a long period of time (Abuye et al., 2003). Therefore, still the overall values and demerits of the plant on health needs further studies.

Furthermore, Elders of the *Zeyse* community claimed that ''this plant was Native to *Zeyse Wozaka* kebele, and has been spread/cultivated, later on to the proximate communities including *Derashe* and *Konso*. ''Furthermore, elders of the community as a proof described'' Long years ago, the Leaf of *Moringa stenopetala was named as ''Duts'eMagaMisAbulo''* by the *DutseMagaMaldo (Maldo was the leader of Dutse tribe in Zeyse).* After naming the plant for the first time, *MagaMaldo,* consumed the leaf first time and allowed the community to eat the leaf of *Moringa stenopetala* (Abayneh, 2007). Therefore, though, *M. stenopetala* is endemic to east African countries mainly Ethiopia (South) and North Kenya (Abuye et al., 2003; Mohammed, 2013), still the origin of this plant in Ethiopia particularly in southern regions needs further study/investigation.

In relation to our study on values of biodiversity, other studies related to ecosystems also show many services to sustain human health such as nutrition, regulation of vector-borne disease, or water purification, and natural settings that could act as a catalyst for healthy behaviours. This leads to increase physical exercise, which affect both physical and mental health (Pretty et al., 2005; Barton and Pretty, 2010). Besides, simple exposure to the natural environment, such as having a view of a tree or grass from a window, can be beneficial, improving mental health status (Pretty et al., 2005). Therefore, these wide spectrum values of ecosystems indicate a wide scope of biodiversity uses for the livelihood of the community in general and communities in the study areas in particular.

Current status of biodiversity

This study also assessed current status of biodiversity vis-à-vis the past and the result showed biodiversity is eroding/dwindling in the study areas, that is, trees and grasses became reduced in number or became extinct, regardless of their domestic usage, plants and wild animals disappeared due to deforestation, and illegal hunting and birds were reduced in number during these days.

This result was in conformity with another study which describes recent times, extinction rates are ten to hundred times higher than during pre-human times (Sinclair, 2000a). Moreover, a study carried out in Ethiopia shows loss of Forests, Grasslands, and Drylands that indicates the loss of biodiversity indicates only a 4% forest cover and an estimated deforestation rate of 8percent per year as of 2000 (World Resources Institute: Earth Trends: Forests, Grasslands, and Drylands,(2003) cited in USAID, 2008), and this result supports our present findings.

Our study result also showed hunting in the areas was one of the reasons why animals were disappearing and this result was in agreement with similar study which explains, increased illegal hunting continues to be a major threat to forest biodiversity in many countries and the depletion of wildlife is intimately linked to the food security and livelihood of numerous tropical forest-region inhabitants (Nasi et al., 2008).

Our study results of current status of biodiversity vis-à-vis the past showed indigenous knowledge and biodiversity were eroding currently because; our tradition of wildlife protection was lost. For example: Sacred trees and trees growing at the tomb sites were cut down indiscriminately for the different purposes including construction. Our custom and belief system of conservation of wildlife, using IK was lost''. Moreover, one of the respondents also explained his observation by saying '' in the past, protection of forests were fairly good and better attention was given to this mission. 'Moreover, the respondents also said ''when the culture embodying IK protecting wildlife was lost, system of transmitting IK to new generation would be lost'. One of the respondents also explained the best episode which was happened during the past regime' by saying "If a person cut a tree illegally, he was ordered to plant the tree again in compensation", and this action was a good experience to save our forests including biodiversity.

Our results were in conformity with similar study conducted on biodiversity analysis, which states threats to Ethiopia's biodiversity, and tropical forests including, population growth/pressure, land degradation, weak cultural and modern management of forests and deforestation (USAID, 2008*).* This study also supports efforts to extend tenure or community use rights of land to forest areas, thereby encouraging the sustainable use and management of forest resources (USAID, 2008*).*

Our result also indicated that indigenous knowledge has a holistic purposes and this result was in line with similar study which states indigenous knowledge is intricately linked to the practical needs of use and management of local ecosystems and loss of this system caused biodiversity loss (Toledo, 1992).

In relation to our study results, different studies and declarations also show the ties between culture and biodiversity loss. According to Martin (2008), culture and nature have co-evolved over time to become intertwined and mutually dependent. ‘’When we lose one, we lose the other. Moreover, there is an inextricable link between cultural and biological diversity" (Belem Declaration, 1988). When this inextricable link” between people and the environment begins to break down and if people are displaced, or if their “place” and their way of life are radically transformed, people’s place-based values, knowledge, and behaviours begin to lose their significance (Maffi, 2010).

Furthermore, United Nation Declaration on the Rights of Indigenous People states ‘’ indigenous peoples have the right to the conservation and protection of their environment and productive capacity of their lands or territories and resources. Moreover, States shall establish and implement assistance program for the Indigenous Peoples for such conservation and protection without discrimination’’ (UN, 2007).

Therefore, indigenous people of the community in general, and that of the study areas in particularare the owner of their environment and need to protect and conserve their land including natural resources and biodiversity as part of their cultural values ((UN, 2007). Thus, this result indicated loss of biodiversity is a significant threat to the livelihood of the community in general and Zeyse, Zergula and Ganta communities in particular and hence needs greater attention of the community and the government.

Biodiversity conservation using indigenous knowledge

Our result showed biodiversity Conservation Using Indigenous Knowledge of each community included, strong traditional law/ custom, which considered trees oftomb sites and sacred trees as taboos which were not cut down from these areas, animals and plants were considered as cultural taboos (never be killed or touched or cut down) due to affection and beliefs towards nature, and communities had a custom of empowering indigenous people and community leaders and elders. For example, *Maga”* used to conduct proactive protective measures involving’ erecting totemicitems to protect cutting trees, killing animals (wildlife), and stealing the property of others. Moreover, community had a tradition that *Maga/Kat* had a power to order lions/snake to punish illegal individuals.

In support of our findings, similar study results show, some forests were protected by IK beliefs such as taboos that forbade people to enter them and some trees were declared as sacred and felling them constituted as a breach of taboo and virtually remained untouched for generations’ and they stand out as ecological museums of local vegetation (Laurel and Nyberg, 2000). Other recent study also shows, traditions, customs, beliefs and cultural rights play an important role in environmental conservation and biodiversity of the South and South west regions of Cameroon (Fongod et al., 2014).

Moreover, another study also shows all forms of vegetation in the sacred groves are supposed to be under the protection of the reigning deity of that grove, and the removal of even a small twig is taboo (Vartak and Gadgil, 1973 cited in Anthwal et al., 2006). In addition, sacred groves are one of the first instances of traditional conservation and nature worship has been a key force of shaping the human attitudes towards conservation and sustainable utilization of natural resources (Anthwal et al., 2006).

Furthermore, in conformity with our study result, another study also indicates affection towards nature was a zoolatry (worshipping of animals), totem (considering plants and animals sacred), *etc*, which in turn led to a sort of prudent conservation(Anthwal et al., 2006).

Our study result also indicated, all respondents expressed their genuine and ownership concern how to conserve their culture and biodiversity using their indigenous knowledge, but traditional way of biodiversity conservation using indigenous knowledge was hidden and being eroded due to weak transmission of culture to new generation.

In line with our study, similar studies show, the effective contributions of the indigenous people using their indigenous knowledge to forest conservation (Anthwal et al., 2006). However, in a paradoxical way, indigenous people have been ignored or less attention it was given, to their IK, even though they control most of the natural forest areas either consciously or unconsciously through their traditional practices, with strong conservation ethics (Babu, 1991; Daou, 2000; Advice, 2009). Moreover, another study also reveals that Indigenous Knowledge continues to be marginalized in development plans, and this has resulted in its limited use in the development process (Ocholla, 2007). Therefore, this basic human asset needs greater attention.

CONCLUSION AND RECOMMENDATIONS

Respondents from Zeyse, Ganta and Zergula communities described their future concern about biodiversity conservation using indigenous knowledge “When our culture embodying indigenous knowledge is lost, generation would be lost, causing biodiversity loss.” Therefore, we would/should: ‘’Be a guard for the protection of our indigenous knowledge to preserve the remaining forests through the following:

1. Plant trees three times than usual and give protection for wildlife.
2. Protect biodiversity in a sustainable way, only, if we protect our culture.
3. Maintain our ownership on our boarder and protect our natural resources including wildlife (animals and plants).

4. Cover degraded and bare mountainous area by plantation, which needs support from the government.
5. Teach our children formally at school level and informally at hometo protect our wildlife''.

Based on the findings, authors recommend:

1. Biodiversity has fundamental values to humans, because we are dependent on it for our nutritional, cultural, economic, and environmental/ecological well-being. Therefore, it is our moral responsibility to conserve the Earth's incredible biodiversity for our well-being and for our next generations.
2. Indigenous knowledge has a holistic nature because it is intricately linked to the practical needs of use and management of local ecosystems by the indigenous people.
Therefore, we need to:

(a) Recognize indigenous knowledge of the community to protect our culture and biodiversity.
(b) Protection of culture, nature and biodiversity are inseparable, because they have co-evolved over time to become mutually dependent. ''When we lose one, we lose the other''.
(c) To conserve biodiversity effectively, indigenous people need empowerment, and recognition of their knowledge in their own territories.
(d) Assign indigenous rights to land tenure, access resources and strengthen cultural integrity (Sobrevila, 2008).
(e) We need a holistic and integrated knowledge systems including IK and modern knowledge (should complement each other) to conserve biodiversity in a sustainable way.
(f) University scholars need to work on this agenda to end up with sustainable biodiversity conservation and development.

Conflict of Interests

The authors have not declared any conflict on interests.

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High passage rates and different seasonal migration strategies of birds along the lower Texas coast

Suzanne Contreras Walsh[1], Bart M. Ballard[1]*, David B. Wester[1], William P. Kuvlesky Jr.[1], Leonard A. Brennan[1], Michael L. Morrison[2] and Kathy Boydston[3]

[1]Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, Kingsville, TX, 78363, USA.
[2]Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas, USA.
[3]Texas Parks and Wildlife Department, Austin, Texas, USA.

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This research examined nocturnal and diurnal bird migration using an automated marine radar system during three autumn (August 15 to November 17) and three spring (March 15 to June 1) periods in 2007–2010 along the lower Texas coast. We quantified migration timing, magnitude, and flight altitudes for over 14 million targets during 16,360 h of radar operation. Autumn migration was prolonged in contrast to spring migration, which was concentrated within a four-week period in mid–April to mid–May. Mean migration traffic rate in autumn averaged 1,186 targets km^{-1} h^{-1} and was 46% greater than spring. Migration traffic rates at our northern site were at least 62% higher than at our southern site. We found bird passage to be similar between diurnal and nocturnal periods in autumn, but predominately nocturnal (68% of targets) in spring. Mean flight altitudes were 10-33% higher in spring than autumn. Our results confirm that the lower Gulf coast of Texas is a significant migration corridor concentrating millions of birds during migration. This new information on temporal and spatial dynamics of migration provides guidance for the placement and operation of wind power developments to reduce the risk to migratory birds along the lower Texas coast.

Key words: Bird migration, coast, flight altitude, marine radar, migration traffic rates, Texas, wind power.

INTRODUCTION

Migration behavior has evolved in many species of birds to take advantage of seasonally available resources in temperate regions to increase reproductive success (Pulido, 2007; Ramenofsky and Wingfield, 2007). Each year millions of birds migrate vast distances between their breeding and wintering areas to benefit from seasonal environments (Moore et al., 1993; Alerstam et al., 2003; Pulido, 2007; Ramenofsky and Wingfield, 2007), but we are still far from understanding many aspects of this important life cycle phase in birds

*Corresponding author. E-mail: bart.ballard@tamuk.edu.

(Faaborg et al., 2010). Much of our knowledge about bird migration along the Gulf of Mexico has pertained to broad-scale patterns of timing and spatial extent of trans-Gulf migration (Gauthreaux, 1971; Gauthreaux and Belser, 1998; Gauthreaux, 1999). Investigations have concentrated more on describing details of spring migration than autumn migration (Able, 1972; Buskirk, 1980; Gauthreaux, 1999), and most studies have been conducted on the northern Gulf coast (Gauthreaux, 1971; Gauthreaux and Belser, 1998; Gauthreaux, 1999). There has been considerably less research carried out in areas along the western Gulf Coast (Forsyth and James, 1971; Langschied, 1994; Arnold, 2009), and many fine-scale characteristics of bird migration have not been sufficiently studied in these areas. Consequently, most information on bird migration in this region comes from anecdotal observations or volunteer-driven surveys.

The Texas coast is well known as an important region that supports birds during migration with >400 species known to traverse the region during autumn or spring migrations (Rappole and Blacklock, 1985; Stutzenbaker and Weller, 198; Shackelford and Lockwood, 2005). The lower Texas coast contains large tracts of relatively undeveloped habitat that attracts birds during migration and is well situated to serve as a critical corridor for migratory birds (Fulbright and Bryant, 2002). Limited information makes it problematic to assess impacts of human development on migratory birds in this region, which has led to a great need for research to quantify bird migration characteristics along the lower Texas coast. Quantifying the temporal and spatial use of the landscape by migratory birds is important because this information can be coupled with factors that influence their movements, such as weather patterns, land use changes, etc. Such information on bird migration enables resource managers to predict how birds will be impacted by human development and improves their ability to curtail potential negative effects on birds. It also allows managers to determine whether management strategies are effective for bird-habitat conservation (Faaborg et al., 2010). The need to better understand bird migration is particularly relevant given the recent upsurge of development interests along the lower Texas coast, particularly large-scale wind farms (Kuvlesky et al., 2007). Wind energy development has the potential to greatly impact migratory birds through large-scale habitat alteration, as well as creating obstructions within the airspace that can become problematic when these man-made structures correspond to height of migratory movement (Kuvlesky et al., 2007). Because the spatial arrangement of stopover habitats and the temporal availability of resources along migration routes are important to the migration strategies of birds (Moore et al., 1995), it is essential to have a thorough understanding of the movement patterns of migratory birds.

Effectively monitoring bird migration has been difficult because many species migrate over a large geographic extent, migrate at night, or travel at altitudes that limit the utility of visual observations. Recent advances in technology have made radar an effective method to assess movements of migrating birds (Gauthreaux and Belser, 2005; Kunz et al., 2007; Bridge et al., 2011). Here, we applied radar technology to measure key metrics of bird migration to generate baseline information on bird migration patterns along the lower Texas coast. Our objective was to quantify the chronology, magnitude, and flight altitudes of migrating birds during migration along the lower Texas coast. Key information on peak migration timing and magnitude, as well as the flight altitudes during migration can be used to predict seasonal and daily periods when birds may be most at risk for collisions with wind turbines.

METHODOLOGY

Study area description

We conducted a three-year study using radar to monitor bird migration along a 200 km section of the lower coast of Texas from Corpus Christi to Brownsville (Figure 1). Padre Island, a barrier island, separates the mainland coast and Laguna Madre from the western part of the Gulf of Mexico (Blair, 1950; Judd, 2002; Tunnel, 2002). Private ranches and federally protected areas occupy a majority of the landscape (Hilbun and Koltermann, 2002). Dominant habitat types include wetlands, native prairies, shrublands, and woodlands (Fulbright and Bryant, 2002). We selected two study sites along the lower Texas coast to assess bird movements in the region. One site was ~20 km south of Corpus Christi (Site 1; 27° 25'N 97° 22'W, 8 m above sea level) on the Laureles Division of the King Ranch, Inc. and was 1 km inland from the mainland coast. A second site was located 134 km south of Site 1 on Laguna Atascosa National Wildlife Refuge (Site 2; 26° 12'N 97° 22'W, 6 m above sea level) 5.82 km inland from the mainland coast. We collected bird migration data at Site 1 from autumn 2007 to spring 2010 and at Site 2 during autumn 2008 to spring 2010. Our radar monitoring periods were 15 August to 17 November in autumn and 15 March to 1 June in spring, and were selected to correspond with known periods of migratory bird passage in the Gulf of Mexico region (Buskirk, 1980; Gauthreaux, 1999) and southern Texas in particular (Langschied, 1994; Arnold, 2009).

Radar equipment and data collection

An automated, marine radar system (Merlin™, Detect, Inc., Panama City, FL, USA) monitored birds continually at each site. Radar systems were equipped with one S-band surveillance radar that operated in a horizontal position and one X-band surveillance radar that was tilted 90° and operated in a vertical position. Both surveillance radars ran concurrently and sampled every 2.5 s during radar monitoring periods in autumn and spring at each site. The S-band surveillance radar (hereafter horizontal radar, JMA 5330, Japan Radio Company, Tokyo, Japan, slotted waveguide array antenna) had a peak output of 30 kW and transmitted at 3,050 MHz. The X-band surveillance radar (hereafter vertical radar, JMA 5320, Japan Radio Company, Tokyo, Japan, slotted

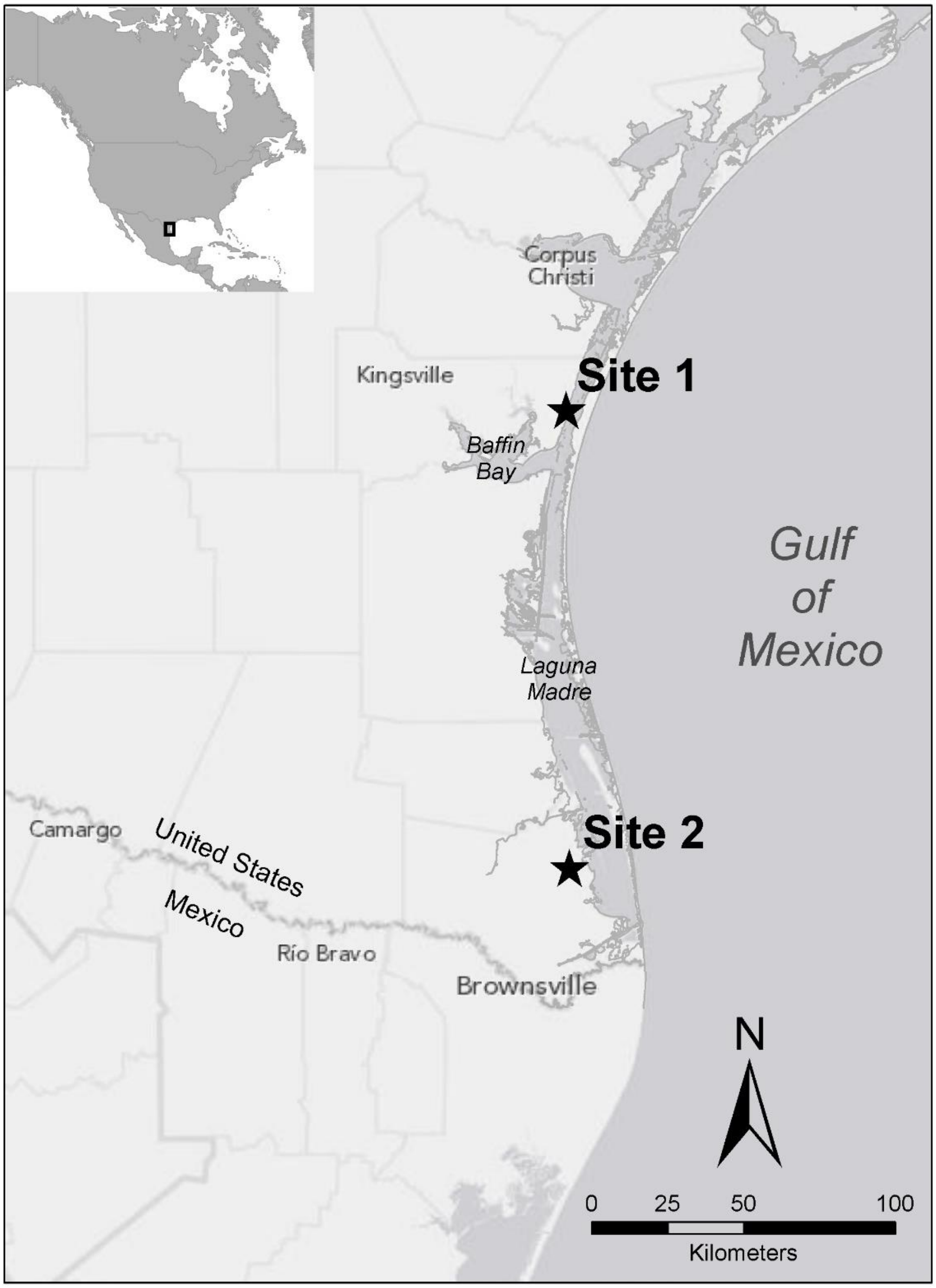

Figure 1. Location of two study sites for radar monitoring of migratory birds along the lower Texas coast from 2007–2010.

waveguide array antenna) had a peak output of 25 kW and transmitted at 9,410 MHz. Both radars were set to operate on short pulse length at a range of 3.704 km for the horizontal radar and 1.389 km for the vertical radar. The horizontal radar scanned 360° around the radar system and recorded data on flight direction and speed of birds. The vertical radar scanned 180° above the radar system and provided data on flight altitudes of birds. Data from the vertical radar were used to calculate migration traffic rates.

The marine radar system employed tracking and processing software (Merlin™, Detect, Inc., Panama City, FL, USA) that allowed automated recording of biological targets throughout the radar coverage. Site characteristics, such as vegetation or man-made structures, can create echoes which result as ground clutter on the radar screen. The software assigns reflectivity values from the ground clutter of the current environment and discounts those echoes from being considered as targets (Krijgsveld et al., 2011; Gerringer et al., 2016). Organisms identified on radar are referred to as targets given that it is difficult to discern the number and species (Mabee et al., 2006). The Merlin software recorded date, time, location, altitude, bearing, and over thirty radar signature characteristics for each target and automatically recorded the information to an Access database. For flight altitude data, the software recorded the height above ground level for each target. We also collected digital recordings of raw vertical radar data that showed biological activity within a 2.778 km radius. We post-processed radar data during the first season to determine the accuracy of the software to track bird-like targets consistently in the vertical radar (based on corroboration with digital recorded data). We plotted the images to display the geographic position of targets using different values for operational settings of clear air threshold, minimum target size, and minimum intensity. We examined the images to determine how changes in operational settings influenced the tracking of targets. From this review, we identified the optimal settings for the radar system to enhance the detection of birds and to minimize the recording of non-bird observations. These settings were applied to the vertical radar at both sites during all subsequent seasons.

We employed several measures to remove non-bird targets from our datasets. First, targets had to meet target size requirements to be tracked by Merlin software. We selected a minimum target size of 13 and 17 pixels, for the vertical and horizontal radar, respectively. Size requirements were held constant across the range settings of each radar. Second, we further excluded targets that tracked poorly. Targets had to be detected on at least 3 of 4 succeeding radar scans to be automatically recorded by the software as a track. Because of the shorter wavelengths of the vertical radar, insect contamination is common in radar studies (Bruderer, 1997; Mabee et al., 2006). We excluded targets from our vertical radar data that were tracked for < 5 detections to reduce tracking of insects. Third, because insects typically have slower airspeeds than birds (< 6 m/s for insects; Diehl et al., 2003; Mabee et al., 2006), we calculated the proportion of targets with airspeeds < 6 m/s from the horizontal radar data for each hour of each survey day and considered these to be non-bird targets. When the proportion of non-bird targets comprised >10% of the targets recorded for that hour, the hour was removed in the vertical radar dataset (Mabee et al., 2006). Birds and bats may overlap in air speeds which presents a problem in radar studies to classify targets as birds or bats (Larkin, 1991; Bruderer and Boldt, 2001; Kunz et al., 2007). Bats exhibit erratic flight patterns when foraging and this behavior may aid in discriminating between bats and birds (Kunz et al., 2007). We recognize that our data may contain some bat targets given that some species, such as, the Mexican free-tailed bat are known to occur in large concentrations in Texas (Tuttle, 1997).

Our final post-processing measure to reduce non-bird targets was to inspect radar data for periods when environmental conditions or clutter obstructed visible bird activity. We visually reviewed 17,799 h of vertical recordings to identify start and stop times of rainfall, fog, or smoke events. Vertical data occurring between these event times, including any questionable events, were omitted from the datasets. Although the horizontal radar is less susceptible to tracking non-bird targets, such as insects or rain, we plotted images to display the geographic position of targets and searched for target groupings that signified rainfall patterns. We also omitted targets from our horizontal radar data that tracked for < 5 detections to reduce observations that may have been caused from the false tracking of temporary clutter (that is, rain or wave clutter).

We automatically collected weather data (that is, temperature, relative humidity, dew point, barometric pressure, precipitation, and wind direction and speed) every 5 min during migration periods using a weather station (Vantage Pro2 weather station, Davis Instruments, Hayward, CA, USA) at each radar station. Ground-level wind measurements were selected for calculation of target airspeeds because winds aloft data from the National Weather Service stations nearest to each site were only available for two hours out of a 24-h period (that is, 0000 and 1200). Given the scale of our collected radar observations, missing wind values were replaced with interpolated values. We used the preceding wind direction to replace missing direction values. Missing wind speed values were replaced with the average of the preceding and subsequent values of wind speed.

Statistical analysis

Prior to analysis, we used a unique identifier to summarize the measurements of individual targets having multiple radar observations into a single observation for each dataset. A track identification number is given to a target track by the software after a target has been detected for 3 of 4 succeeding scans. Subsequent detections of the same target are associated with the identical track identification number. The track and associated track identification number ceases when the target has remained undetected for 3 succeeding scans by the radar (Krijgsveld et al., 2011; Gerringer et al., 2016). We treated each single observation as an individual record and did not distinguish between single or flock targets due to the unknown number and bird species of radar observations (Mabee et al., 2006). Because of this aspect of radar technology, we acknowledge that it is likely that we underestimated the magnitude of bird migration in our study (Fijn et al., 2015). For our comparison of migration characteristics between diurnal and nocturnal periods we used the onset and end of civil twilight to distinguish between nocturnal and diurnal time periods (Zehnder et al., 2001). Civil twilight times for each site were obtained from the U.S. Naval Observatory website (http://aa.usno.navy.mil/data/docs/RS_OneDay.php). To simplify our analysis, we categorized the time periods by the hours of the day that were always light throughout autumn and spring migration to denote the diurnal period (0700 to 1800 h), and the hours that were always dark to denote the nocturnal period (2000 to 0500 h).

We conducted a preliminary analysis using the first 30,000 observations recorded from the radars at each site and during each year and season to determine a threshold for distance from the radar for bird targets to include in our estimation of passage rate. We estimated detectability functions specific to year, season, and site using the half-normal key function and cosine adjustment term in program Distance (Laake et al., 1993). We used Akaike's Information Criterion (Akaike, 1973) to choose the appropriate key function and adjustment factors that provided the optimal model fit. From this initial analysis, the effective detection radius ranged from 607 m (95% CI: 585–629 m) to 745 m (95% CI: 704–789 m) for Site 1, and ranged from 492 m (95% CI: 480–504 m) to 620 m (95% CI: 602–638 m) at Site 2. Since each radar had an effective detection radius at or above 500 m during each year and season, we calculated the migration traffic rate (MTR) as the number of detected targets that crossed a line 500 m on each side of the radar per hour (that is, targets km^{-1} h^{-1}) (Lowery, 1951). We adjusted MTR because sampling effort sometimes varied within a given hour (that is, due to filtering times with rain, fog, etc.). We used the start and end times of radar operation and weather events to determine our actual observation time for each season and site. Next, we multiplied the number of targets during the actual observation time by the number of minutes of radar operation time for each hour. Given that MTR is a count datum, this variable is not well suited to a

Table 1. Mean migration traffic rate (MTR, targets km^{-1} h^{-1}) and flight altitude (m agl) for autumn (August 15–November 17) and spring (March 15–June 1) migration at two sites along the lower Texas coast from 2007–2010.

Study location	Season	Year	Observation period[a]	*n*[b]	No. of tracks[c]	Mean ± SE	
						MTR	Flight altitude
Site 1	Autumn	2007	Aug 21–Nov 9	77	2,021,609	1,250 ± 117	508 ± 4
		2008	Aug 15–Nov 14	88	3,255,060	1,704 ± 150	457 ± 4
		2009	Aug 28–Nov 18	78	2,451,815	1,485 ± 139	450 ± 4
	Spring	2008	Mar 15–Jun 2	80	1,463,224	796 ± 73	558 ± 4
		2009	Mar 11–Jun 1	83	1,304,670	701 ± 63	592 ± 4
		2010	Mar 19–Jun 2	46	377,578	406 ± 49	477 ± 5
Site 2	Autumn	2008	Aug 15–Nov 19	90	1,108,335	575 ± 46	319 ± 4
		2009	Aug 13–Nov 8	96	1,527,012	918 ± 71	315 ± 4
	Spring	2009	Mar 14–Jun 2	76	567,664	347 ± 30	425 ± 4
		2010	Mar 23–Jun 1	71	738,875	476 ± 43	419 ± 4

[a] Exact start and end dates of fieldwork. [b] Number of nights of radar monitoring. [c] Number of radar observations included in data analysis obtained from vertical radar.

normal distribution. Analysis of count data generally uses a Poisson distribution, but this requires for the mean and variance to be equal. Most often, count data exhibit over-dispersion that indicates the variance is larger than the mean. Thus, we used a Chi-Square Goodness-of-Fit test to assess the fit of a negative binomial distribution for MTR. Based on this test, we chose to model MTR assuming that it followed a negative binomial distribution to account for over-dispersed data (McCullagh and Nelder, 1989).

Because we initiated sampling at Site 1 a year prior to initiating sampling at Site 2, we conducted two separate analyses to enable inclusion of all 3 years of sampling. Thus, we compare all 3 years using only data from Site 1, and compare sites using data from years 2 and 3 when both radar systems were operational to provide a detailed analysis of movement along the lower Texas coastline. Given that we could not replicate our two sites in the classical sense, we consider our two sites as our populations of interest; statistical inferences are limited to these two sites. First, we used ANOVA to describe variation in mean MTR and mean flight altitude among three factors: season, year, and site. Second, ANOVA was used to describe variation in mean MTR and mean flight altitude for Site 1 between two factors: season and year. Third, we also used ANOVA to describe variation in mean MTR and mean flight altitude for each site among three factors: season, year, and time of day (that is, diurnal vs. nocturnal periods). The main factor of year in all ANOVAs was based upon a biological year: Year 1 = (autumn 2007–spring 2008); Year 2 (autumn 2008–spring 2009); and Year 3 (autumn 2009–spring 2010). Lastly, we performed post hoc contrasts to further investigate significant three-way interactions using CONTRAST statements. All post hoc contrasts held year constant to examine the other two-way effects on mean MTR or mean flight altitude. When 3-way interactions were non-significant, we performed a post hoc mean comparison test to partition significant two-way interactions using SLICE statements. Post hoc means were separated using the Fisher's protected LSD test. We used the GLIMMIX procedure for comparisons of mean MTR and used GLM procedure for comparisons of mean flight altitude. Least square (LS) means were used for comparisons of MTR. We performed statistical analyses in SAS (SAS Institute, Inc. 2009) or statistical program R (CirStats and Circular Packages, R Development Core Team, 2006).

RESULTS

We monitored bird migration during 16,360 h of radar operation during 452 days and nights at Site 1 and during 333 days and nights at Site 2. We excluded 657.7 h due to environmental contamination (precipitation, fog, and smoke) for Site 1, and 781.9 h for Site 2. Missing observations due to radar system shutdown (routine generator maintenance or equipment failure) occurred for 1,032 h for Site 1 and 336 h for Site 2. From our horizontal dataset, we initially included 11,466,254 radar tracks in our calculations of airspeed and omitted 208,439 targets (1.81%) because these targets were not within our airspeed thresholds. Consequently, we also excluded 0.4% of targets from our vertical dataset that corresponded to hours with >10% of targets with airspeeds below our threshold in our horizontal dataset. We analyzed 14,815,842 radar tracks from our vertical dataset.

Migration traffic rate

MTR varied considerably between seasons and sites (Table 1). Mean daily MTR (that is, 24 h period) varied between 27 and 5,457 targets km^{-1} h^{-1} during autumn and between 7 and 3,484 during spring (Figures 2 and 3). Nocturnal MTR varied between 16 and 7,156 targets km^{-1} h^{-1} in autumn and between 5 and 5,883 targets km^{-1} h^{-1} in spring. Overall MTR was 57–266% greater in autumn than in spring at both sites (Table 2). Additionally, MTR at Site 1 was 62–196% greater than at Site 2. We experienced maintenance issues with the radar system at Site 1 in spring 2010 and were unable to monitor during

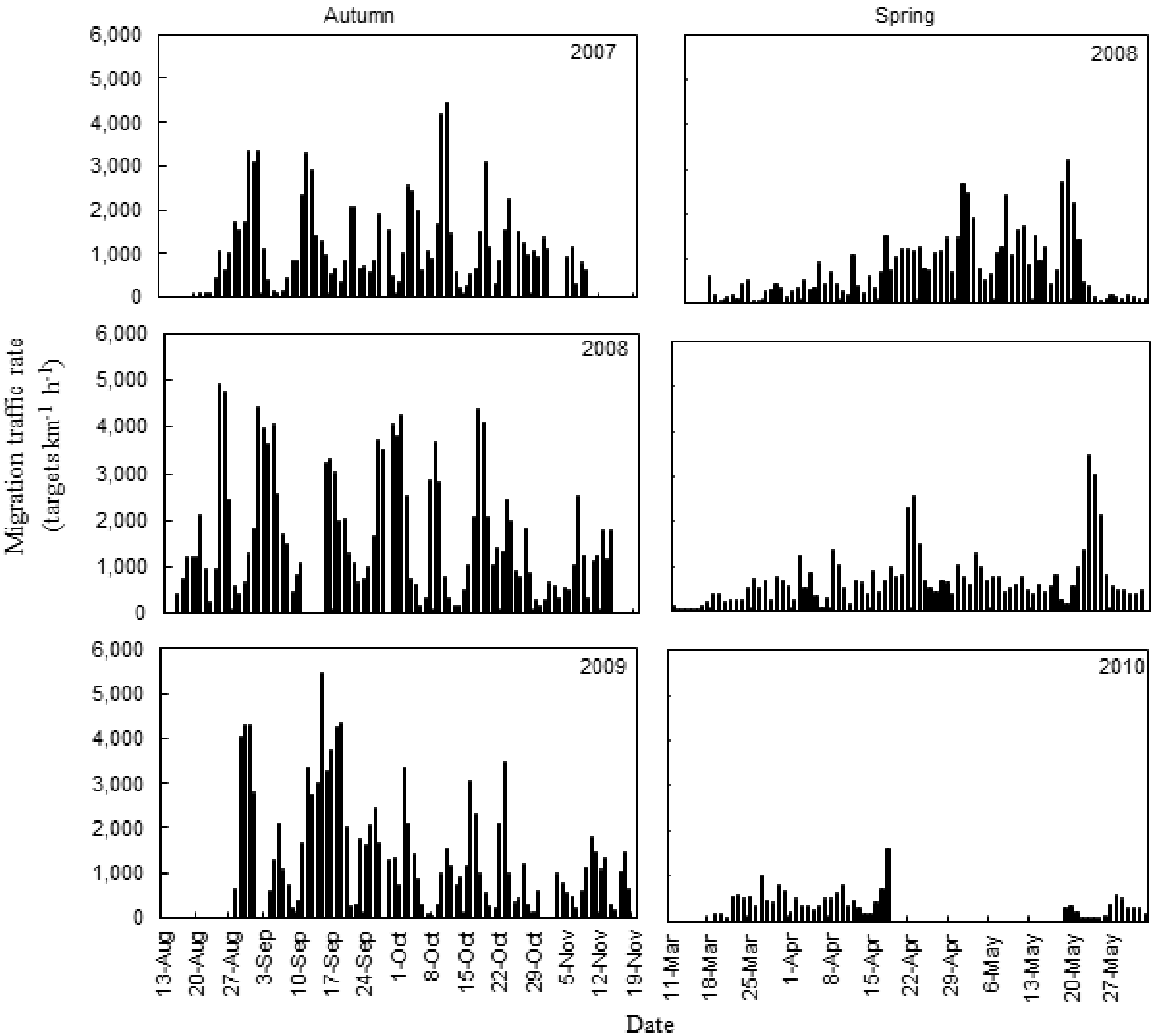

Figure 2. Mean migration traffic rates (targets km^{-1} h^{-1}) during autumn (August 15–November 17) 2007 to 2009 and spring (March 15–June 1) 2008 to 2010 at Site 1 along the lower Texas coast.

the majority of the period of peak movement. Thus, the MTR estimated at Site 1 in spring 2010 is likely conservative.

Autumn MTR: Overall MTR during autumn was similar across years varying from 1,250 ± 117 to 1,704 ± 150 targets km^{-1} h^{-1} at Site 1 and from 575 ± 46 to 918 ± 71 targets km^{-1} h^{-1} at Site 2 (Tables 1 and 3). Mean daily MTR exhibited an undulating pattern across autumn with no distinct peak apparent, but rather a protracted migration throughout our defined migration period (Figures 2 and 3). The magnitude of the peaks was consistently lower after mid-October each year.

The pattern of bird passage throughout the day and night was relatively uniform during autumn, as diurnal (1,562 ± 150 targets km^{-1} h^{-1}) and nocturnal (1,492 ±150 86 targets km^{-1} h^{-1}) passage rates were similar; a pattern consistent between sites (Tables 4 and 5). The highest bird passage typically occurred around mid-day followed by a decline to about 1800 h when in general the lowest passage rates occurred (Figure 4). There was a sharp increase at 1900 when MTR remained relatively high

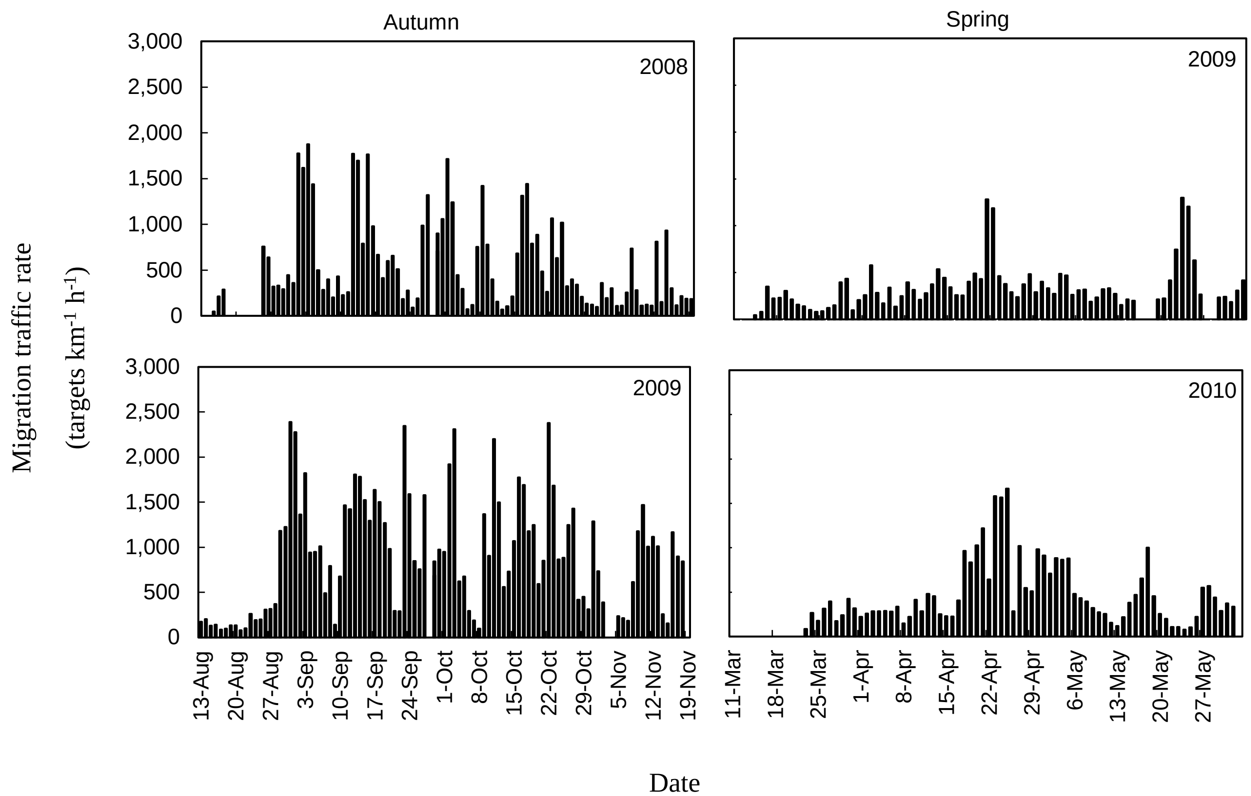

Figure 3. Mean migration traffic rates (targets km^{-1} h^{-1}) during autumn (August 15–November 17) 2008 to 2009 and spring (March 15–June 1) 2009 to 2010 at Site 2 along the lower Texas coast.

until immediately prior to sunrise.

Spring MTR: We found little annual variability in our estimates of spring MTR (Tables 1 and 3). Consistent with our finding during autumn, spring MTR was 102% higher at Site 1 than at Site 2, except in spring 2010 when data collection was greatly reduced at Site 1. Whereas, bird passage showed a cyclic pattern across autumn migration periods, during spring it was less cyclic with peaks in mid- to late April and mid- to late May and otherwise remained relatively low (Figures 2 and 3). Although MTR was roughly equivalent between nocturnal and diurnal periods during autumn, we found large differences in spring. For instance, we found bird passage rates to be two to three times greater during nocturnal hours than during diurnal hours at both sites (Tables 4 and 5). We found that peak passage in spring occurred between 2000 and 0300 h, as MTR remained stable throughout the night, and was considerably lower during crepuscular and diurnal hours (Figure 4).

Flight altitude

Most bird passage occurred below 1,000 m above ground level each season at Site 1 (≥ 86%) and below 800 m above ground level each season at Site 2 (≥ 84%) (Tables 6 and 7). Mean flight altitudes were relatively consistent across years within each season (Table 8). Although statistically significant, mean flight altitudes among years differed by only 1-13% within seasons at a site. Two distinct patterns that emerged from our analysis of flight altitudes were that birds traveled at altitudes ~40% higher at Site 1 than at Site 2, and that mean flight altitudes were 10-33% higher during spring than autumn each year and at each site (Tables 1 and 8).

We found inconsistent results in flight altitudes between diurnal and nocturnal periods. For instance, birds flew at 10 to 28% higher altitudes during nocturnal periods than diurnal periods at Site 1 in year 1, and at Site 2 in year 2, and year 3 (Table 4). We did not find that flight altitudes were higher during diurnal periods than nocturnal periods at any time; thus, in half our comparisons, birds tended to fly higher at night.

Partitioning flight altitudes across the hours of the day reveals fairly consistent patterns during autumn (Figure 5). Highest flight altitudes occurred at 2100–2200 h and gradually declined through the nocturnal hours to sunrise. Another period of relatively high flight altitudes occurred during mid-afternoon hours (~1400–1600) and declined

Table 2. Three-way ANOVAs comparing mean migration traffic rates (MTR, targets km^{-1} h^{-1}) and flight altitude (m agl) by season, year, and site along the lower Texas coast in 2008–2010.

Migration metric	Source[a]	*Post hoc* tests	Num df	Den df	F	*P*
MTR	Season × year × site		1	620	1.00	0.32
	Season × year		1	620	4.67	0.03
		Slice effect by season				
		Year (Autumn)	1	620	3.83	0.05
		Year (Spring)	1	620	1.36	0.24
		Slice effect by year				
		Season (Year 2)	1	620	65.84	<0.001
		Season (Year 3)	1	620	103.95	<0.001
	Season × site		1	620	15.73	<0.001
		Slice effect by site				
		Season (Site 1)	1	620	132.68	<0.001
		Season (Site 2)	1	620	44.7	<0.001
		Slice effect by season				
		Site (Autumn)	1	620	86.53	<0.001
		Site (Spring)	1	620	7.83	0.01
	Year × site		1	620	32.58	<0.001
		Slice effect by site				
		Year (Site 1)	1	620	12.99	0.0003
		Year (Site 2)	1	620	20.39	<0.001
		Slice effect by year				
		Site (Year 2)	1	620	108.27	<0.001
		Site (Year 3)	1	620	2.81	0.09
Flight altitude	Season × year × site		1	13655	89.19	<0.001
		Contrast within year 2				
		Site × season	1	13655	15.30	<0.001
		Contrast within year 3				
		Site × season	1	13655	83.57	<0.001

[a] Season = autumn (August 15–November 17) and spring (March 15–June 1) migration. Year = 2 (autumn 2008–spring 2009) and 3 (autumn 2009–spring 2010).

18-25% by 1800-1900 h. Lowest flight altitudes were associated around crepuscular periods at 0400–0500, 0800–0900, and 1800–1900 h (Figure 5). Flight altitudes during spring did not show the distinct pattern across the hours of the day as exhibited in autumn, particularly at Site 1. However, birds appeared to travel at relatively low altitudes around crepuscular periods, and generally fly higher during nocturnal hours compared to diurnal hours, particularly at Site 2 (Figure 5).

DISCUSSION

Given our considerable sample sizes, statistical significance was commonly found among differences that appeared to be biologically similar. Thus, we focus our discussion on several pronounced patterns in the temporal and spatial distribution of migrating birds that became evident from multiple year comparisons that we believe have biological merit.

Migration traffic rate

We documented MTR of well over 5,000 targets km^{-1} h^{-1} during many nights in autumn along the lower Texas coast. Coastal areas in other regions have also demonstrated high nocturnal passage rates. Zehnder et al. (2001) reported a mean nocturnal MTR of 1,319 targets km^{-1} h^{-1} at a coastal site in south Sweden with nocturnal bird passage as high as 6,618 targets km^{-1} h^{-1}. Likewise, Fortin et al. (1999) estimated a mean nocturnal MTR to be ~ 1,000 targets km^{-1} h^{-1} along the northwest coast of the Mediterranean Sea with peak nocturnal

Table 3. Output from 2-way ANOVAs comparing migration traffic rates (MTR, targets km^{-1} h^{-1}) and flight altitudes (m agl) by season and year for Site 1 along the lower Texas coast in 2007–2010.

Migration metric	Source[a]	*Post hoc* tests	Num df	Den df	F	*P*
MTR	Season × year		2	446	8.85	0.0002
		Slice effect by season				
		Year (Autumn)	2	446	2.91	0.06
		Year (Spring)	2	446	10.22	< 0.001
		Slice effect by year				
		Season (Year 1)	1	446	11.73	0.0007
		Season (Year 2)	1	446	49.59	< 0.001
		Season (Year 3)	1	446	71.35	< 0.001
Flight altitude	Season × year		2	10052	103.64	< 0.001
		Slice effect by season				
		Year (Autumn)	2	10052	65.90	< 0.001
		Year (Spring)	2	10052	166.21	< 0.001
		Slice effect by year				
		Season (Year 1)	1	10052	86.98	< 0.001
		Season (Year 2)	1	10052	673.88	< 0.001
		Season (Year 3)	1	10052	18.04	< 0.001

[a] Season = autumn (August 15–November 17) and spring (March 15–June 1) migration. Year = 1 (autumn 2007–spring 2008), 2 (autumn 2008–spring 2009), and 3 (autumn 2009–spring 2010).

Table 4. Migration traffic rates (MTR, targets km^{-1} h^{-1}) and mean flight altitude (m agl) during diurnal (0700–1700 hr) and nocturnal (2000–0400 hr) time periods for autumn (August 15–November 17) and spring (March 15–June 1) migration at two sites along the lower Texas coast from 2007–2010.

Study location	Season	Year	No. of tracks	MTR		*P*	Altitude		
				Diurnal	Nocturnal		Diurnal	Nocturnal	*P*
Site 1	Autumn	2007	1,790,482	1,400 ± 143	1,216 ± 124	0.33	481 ± 15	562 ± 15	0.001
		2008	2,779,155	1,869 ± 179	1,674 ± 160	0.42	450 ± 14	490 ± 14	0.04
		2009	2,116,393	1,457 ± 151	1,630 ± 165	0.44	456 ± 15	461 ± 15	0.81
	Spring	2008	1,298,391	477 ± 48	1,297 ± 130	<0.001	539 ± 15	595 ± 15	0.01
		2009	1,160,574	377 ± 37	1,168 ± 115	<0.001	617 ± 14	578 ± 14	0.05
		2010	327,705	213 ± 28	636 ± 84	<0.001	473 ± 19	503 ± 19	0.27
Site 2	Autumn	2008	932,861	745 ± 73	375 ± 36	<0.001	292 ± 14	348 ± 14	0.01
		2009	1,248,326	960 ± 91	864 ± 82	0.44	329 ± 14	318 ± 14	0.56
	Spring	2009	479,412	222 ± 24	506 ± 54	<0.001	426 ± 15	488 ± 16	0.01
		2010	638,458	370 ± 41	633 ± 69	0.001	381 ± 16	487 ± 16	<0.001

migration of 1,600 targets km^{-1} h^{-1} soon after sunset. Coastal areas often concentrate bird migration because they border large water bodies that are energetically challenging for birds to cross without the opportunity to refuel or rest. This appears to be true for the Texas coast as well, as our estimates of MTR (1,200–1,700 targets km^{-1} h^{-1}) in autumn are ≥ 600% higher than estimates of MTR from other radar studies monitoring bird movements in North America. For instance, Mabee et al. (2006) reported mean MTR of 199 targets km^{-1} h^{-1} along an Appalachian ridge in West Virginia. Harmata et al. (2000) estimated a mean MTR of 41 targets km^{-1} h^{-1} at a grassland site in Montana. Similarly, Mabee and Cooper (2004) reported mean MTR of 19.0–26.3 targets km^{-1} h^{-1} at two wind energy sites in eastern Oregon and Washington during autumn. Following the coast is often a

Table 5. Output from 3-way ANOVAs comparing migration traffic rates (MTR, targets km^{-1} h^{-1}) by season, year, and time of day at two sites along the lower Texas coast in 2007–2010.

Study location	Migration metric	Source[a]	*Post hoc* tests	Num df	Den df	F	*P*
Site 1	MTR	Season × year × time of day		2	888	0.37	0.69
		Year × time of day		2	888	0.61	0.54
		Year		2	888	12.07	<0.001
		Time of day		1	888	70.87	<0.001
		Season × year		2	888	17.93	<0.001
			Slice effect by season				
			Year (Autumn)	2	888	4.75	0.01
			Year (Spring)	2	888	21.64	<0.001
			Slice effect by year				
			Season (Year 1)	1	888	25.09	<0.001
			Season (Year 2)	1	888	102.19	<0.001
			Season (Year 3)	1	888	146.69	<0.001
		Season × time of day		1	888	84.19	<0.001
			Slice effect by season				
			Night (Autumn)	1	888	0.32	0.58
			Day (Spring)	1	888	139.94	<0.001
			Slice effect by time of day				
			Season (Night)	1	888	22.87	<0.001
			Season (Day)	1	888	313.50	<0.001
Site 2	MTR	Season × year × time of day		1	650	9.02	0.003
			Contrast within year 2				
			Season × Time of day	1	650	54.86	< 0.001
			Contrast within year 3				
			Season × Time of day	1	650	9.78	0.002

[a] Season = autumn (August 15–November 17) and spring (March 15–June 1) migration. Year = 1 (autumn 2007–spring 2008), 2 (autumn 2008–spring 2009), and 3 (autumn 2009–spring 2010). Time of day = nocturnal (movement between 2000–0400 h) and diurnal (movement between 0700–1700 h) periods.

safer route and typically optimal when migration speed is not of primary importance (Alerstam and Lindström, 1990). Although birds that detour along the coast rather than making a direct crossing of a large water body may increase their migration distance, they are allowed to make stopovers more frequently to rest and refuel and are not required to store as much energy as they would for a long, nonstop flight (Alerstam and Lindström, 1990; Alerstam et al., 2003).

Migration traffic rates in autumn were 124% greater than spring across our study. This substantial difference in bird passage is possibly explained by two potential causes. First, mortality during migration and winter at least partially contributes to a lower return passage rate (Sillett and Holmes, 2002). Second, migrants may be using different migration pathways between autumn and spring. The timing of arrival on breeding areas in spring can have a significant effect on the fitness of migratory birds (Kokko, 1999). Early-arriving individuals can benefit from reduced competition for better territories and mates, a longer breeding season that allows more time to renest if the first nest fails (Smith and Moore, 2005), and more food resources for young, which is important because available food resources tend to become reduced as the breeding season progresses (Guyn and Clark, 1999). The benefits of arriving early on breeding areas have led to a faster migration for many birds in spring (Karlsson et al., 2012; Tøttrup et al., 2012). Because migrants are under greater time constraints in spring (Fransson, 1995; Kokko, 1999), more birds may use routes that are more direct during spring (e.g. trans-Gulf or inland). The notion of more direct migratory routes during spring is also supported by the more directed flight paths of birds in spring compared to autumn in this region (Contreras, 2013).

We found that migration during spring is largely

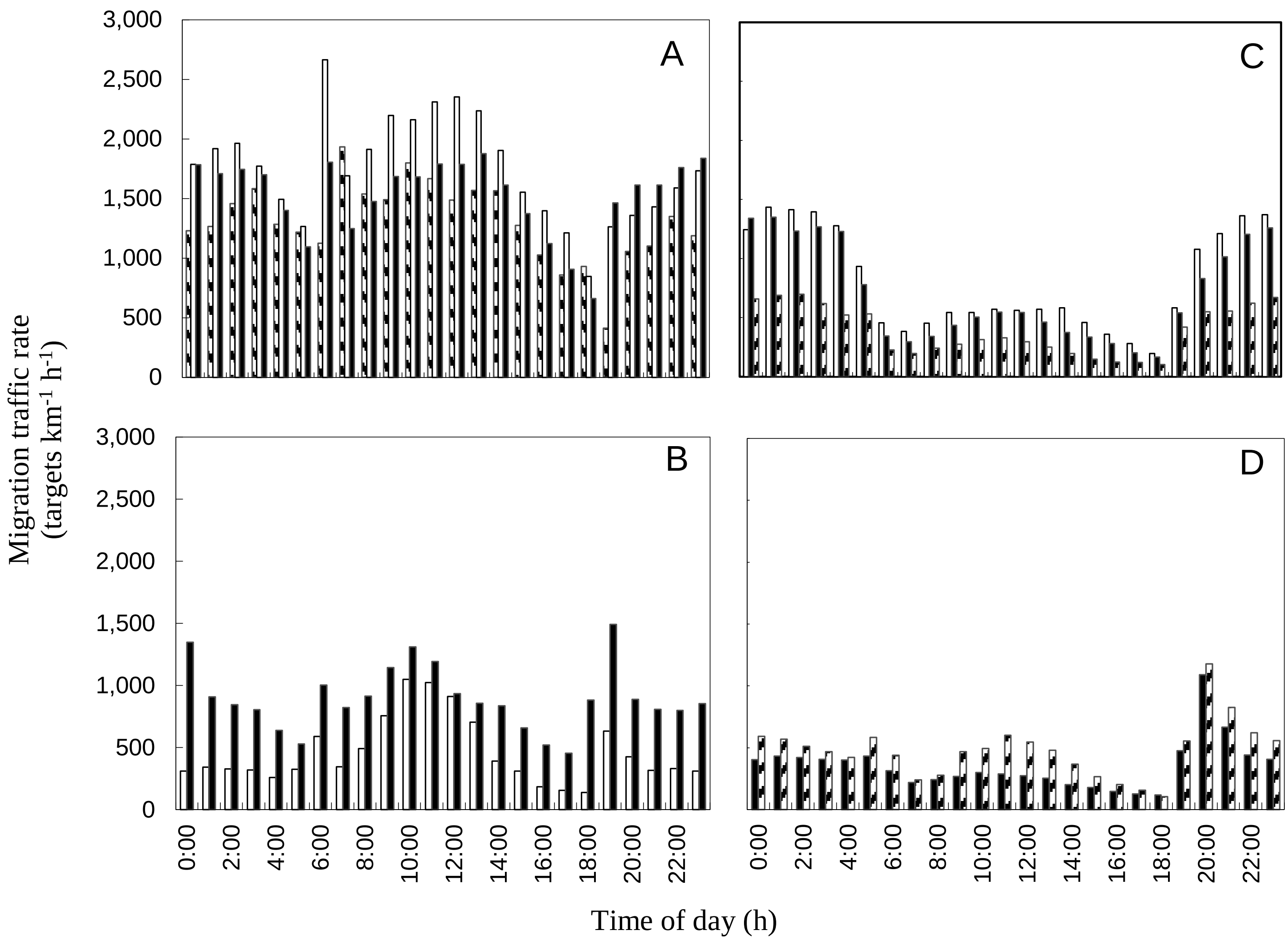

Figure 4. Mean migration traffic rates (birds km^{-1} h^{-1}) by hour of day for autumn (15 August to 17 November) at Site 1 (**A**) and Site 2 (**B**), and during spring (March 15–June 1) at Site 1 (**C**) and Site 2 (**D**) during 2007 to 2010 along the lower Texas coast. Data are shown as 2007 = ▧ , 2008 = □ , 2009 = ■, and 2010 = ▨.

nocturnal, as mean MTR was 157% greater at night than during the day across the entire study. Forsyth and James (1971) similarly reported a higher number of nocturnal migrants along the western Gulf coast than diurnal migrants in the spring. This pattern of largely nocturnal flights in the Gulf region is also strongly supported by the steady number of birds appearing in early morning hours (Forsyth and James, 1971; Lowery, 1951). The timing of peaks in spring migrants differs depending upon arrival location along the Gulf coast. Migrants that appear in southern areas arrive in higher numbers earlier than those migrants along northern areas in which peaks correspond as spring advances (Gauthreaux and Belser, 1999). However, our findings indicate that nocturnal migration is a strategy that birds use in the spring to be more efficient with their time spent en route to breeding areas. Because most birds are visual foragers and are unable to forage at nighttime, migrants use the night to travel and can spend time foraging to replenish energy reserves during the daytime (Kerlinger, 1995; Newton, 2010). It is also possible that nocturnal migration is more likely for migrants covering long distances between breeding and wintering areas, and travelling in cool air temperatures at night may minimize overheating and dehydration risks during these lengthy flights (Kerlinger, 1995; Newton, 2010).

We found that autumn migration was far more protracted with numerous peaks in MTR across the entire autumn period. Similarly, Tøttrup et al. (2012) demonstrated that the length of time that a passerine migrant was in migration in autumn extended well beyond that of spring due to lengthy autumn stopovers. Most

Table 6. The distribution of targets (percentage) in 200 m altitudinal levels (m agl) for autumn (August 15–November 17) and spring (March 15–June 1) migration at Site 1 along the lower Texas coast from 2007–2010.

Flight altitude	Site 1					
	Autumn			Spring		
	2007 (*n*=2,021,609)	2008 (*n*=3,255,060)	2009 (*n*=2,451,815)	2008 (*n*=1,463,224)	2009 (*n*=1,304,670)	2010 (*n*=377,578)
≤200	11.55	17.57	19.55	10.92	10.40	14.49
201–400	29.75	29.54	30.40	23.07	22.14	32.44
401–600	23.47	23.72	23.07	23.47	23.90	26.80
601–800	15.71	14.26	12.89	17.37	18.25	13.67
801–1,000	9.88	7.97	7.27	12.10	11.76	6.51
1,001–1,200	5.71	3.96	3.71	7.19	6.73	3.17
1,201–1,400	2.32	1.51	1.68	3.52	3.33	1.42
1,401–1,600	0.89	0.77	0.93	1.44	1.92	0.77
1,601–1,800	0.36	0.31	0.30	0.53	0.86	0.42
1,801–2,000	0.17	0.16	0.11	0.22	0.39	0.16
2,001–2,200	0.10	0.09	0.04	0.11	0.18	0.08
2,201–2,400	0.07	0.06	0.02	0.05	0.09	0.04
2,401–2,600	0.03	0.05	0.01	0.02	0.04	0.02
2,601–2,800	0.01	0.04	0.01	0.01	0.01	0.01

Table 7. The distribution of targets (percentage) in 200 m altitudinal levels (m agl) for autumn (August 15–November 17) and spring (March 15–June 1) migration at Site 2 along the lower Texas coast from 2008–2010.

Flight altitude	Site 2			
	Autumn		Spring	
	2008 (*n*=1,108,335)	2009 (*n*=1,527,012)	2009 (*n*=567,664)	2010 (*n*=738,875)
≤200	33.39	34.46	28.79	24.64
201–400	34.57	33.31	24.00	29.83
401–600	20.17	17.32	18.76	20.93
601–800	7.95	8.28	12.08	11.90
801–1,000	2.48	4.07	6.92	6.72
1,001–1,200	0.76	1.59	3.62	3.26
1,201–1,400	0.32	0.53	2.31	1.27
1,401–1,600	0.19	0.25	1.76	0.73
1,601–1,800	0.11	0.10	1.00	0.41
1,801–2,000	0.04	0.05	0.43	0.15
2,001–2,200	0.02	0.03	0.17	0.07
2,201–2,400	0.01	0.02	0.10	0.04
2,401–2,600	0.01	0.01	0.04	0.02
2,601–2,800	0.001	0.004	0.01	0.01

birds in autumn are not under the same time constraints as they are in spring. Thus, birds in autumn may choose to minimize energy costs rather than time, and may be more selective about wind assistance and therefore delay departure until assisting tailwinds occur (Alerstam, 1979; Grönroos et al., 2012). Prevailing wind patterns in autumn are mostly favorable for migrants to detour along the western Gulf coast in a circum-Gulf route (Able, 1972; Moore et al., 1995) and generally do not support a more direct trans-Gulf route (Able, 1972; Gauthreaux et al., 2005).

Migration during spring was largely concentrated around a four-week period between mid-April and mid-May. Our findings coincide with the reported peak of spring magnitude along the Gulf coast in northern areas (Gauthreaux and Belser, 1999) and in western areas

Table 8. Output from 3-way ANOVAs comparing mean flight altitudes (m agl) by season, year, and time of day at two sites along the lower Texas coast in 2007–2010.

Study location	Migration metric	Source[a]	*Post hoc* tests	Num df	Den df	F	*P*
Site 1	Flight altitude	Season × year × time of day		2	888	2.78	0.06
		Season × time of day		1	888	2.15	0.14
		Season		1	888	56.95	< 0.001
		Time of Day		2	888	21.85	0.001
		Season × year		2	888	12.16	< 0.001
			Slice effect by season				
			Year (Autumn)	2	888	10.01	< 0.001
			Year (Spring)	2	888	20.97	< 0.001
			Slice effect by year				
			Season (Year 1)	1	888	9.68	0.002
			Season (Year 2)	1	888	80.27	< 0.001
			Season (Year 3)	1	888	2.85	0.09
		Year × time of day		2	888	5.78	0.003
			Slice effect by year				
			Time of day (Year 1)	1	888	21.30	< 0.001
			Time of day (Year 2)	1	888	0.00	0.98
			Time of day (Year 3)	1	888	1.06	0.30
			Slice effect by time of day				
			Year (Night)	2	888	18.00	< 0.001
			Year (Day)	2	888	9.64	< 0.001
Site 2	Flight altitude	Season × year × time of day		1	649	7.07	0.01
			Contrast within year 2				
			Season × Time of day	1	649	0.03	0.86
			Contrast within year 3				
			Season × Time of day	1	649	15.33	< 0.001

[a] Season = autumn (August 15–November 17) and spring (March 15–June 1) migration. Year = 1 (autumn 2007–spring 2008), 2 (autumn 2008–spring 2009), and 3 (autumn 2009–spring 2010). Time of day = nocturnal (movement between 2000–0400 h) and diurnal (movement between 0700–1700 h) period.

(Forsyth and James, 1971). Within these weeks, our data shows that MTR was up to four times greater than the rest of the season. Spring migration in most areas typically occurs over a relatively narrow time span compared to autumn (Fransson, 1995). Our findings support that peaks in spring migration occur at times when southerly winds along the Gulf of Mexico are reliable and steady between late April and early May (Gauthreaux, 1999; Moore et al., 1995). Forsyth and James (1971) found that the majority of spring migrants were taking advantage of southeasterly winds from eastern Mexico. Thus, southerly winds are important to migrants by providing wind assistance for northward movements from southern wintering areas (Gauthreaux, 1999; Moore et al., 1995). Furthermore, prevailing wind patterns in spring are especially critical for migrants that must cross directly over the Gulf of Mexico (Gauthreaux, 1999; Moore et al., 1995). Migrants that exploit favorable winds can minimize their migration distance, as well as, increase their migration speed to reach breeding grounds early (Gauthreaux, 1999).

Flight altitude

Several patterns emerged from our analyses of flight altitudes of migratory birds along the lower Texas coast. First, the majority of targets detected by our radars (57% to 88%) occurred at altitudes within 600 m above ground level across seasons and sites, and 34% flew ≤200 m above ground level. Although this is partly due to the limitation of our radar units, this finding is consistent with previously described altitudes for nocturnal migrants in other parts of North America (Able, 1970; Gauthreaux, 1991; Mabee et al., 2006; Gagnon et al., 2011). This study shows that a relatively large proportion of targets

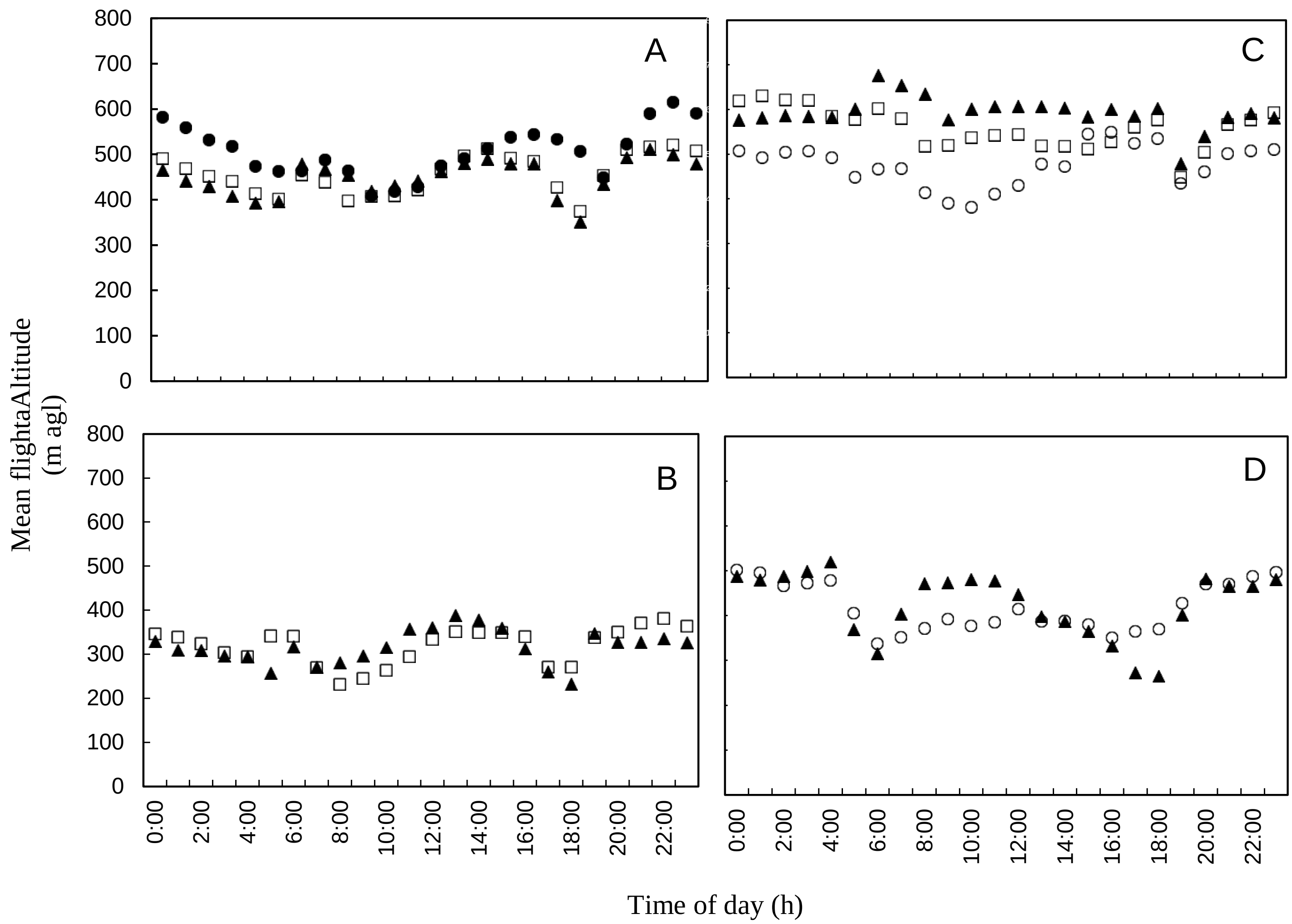

Figure 5. Mean flight altitudes (m agl) by hour of day during autumn (August 15–November 17) at Site 1 (**A**) and Site 2 (**B**), and during spring (March 15–June 1) at Site 1 (**C**) and Site 2 (**D**) in 2007-2010 along the lower Texas coast. Data are shown as 2007 = ●, 2008 = □, 2009 = ▲, and 2010 = ○.

used the airspace at altitudes that are greater than modern wind energy development; however, flock size and specific species remain unknown. Yet, there are situations that may force migrants to fly at lower altitudes. For example, migrants that must contend with the Gulf of Mexico may come upon adverse weather conditions (that is, strong rain and unfavorable winds (Gauthreaux and Belser 1998, Gauthreaux 1999). Forsyth and James (1971) reported that highest number of spring migrants grounded along the western Gulf coast corresponded to unfavorable weather conditions of frontal activity. Consequently, these type of situations may increase the number of migrants susceptible to impacts with wind turbines along the lower Texas coast. The rotor swept zone area in which migrants may be at risk is generally from 50 to 150 m above ground level (Katzner et al., 2012). Thus, the minimum number of migrants at risk across a 1-km front in our study is between 5 to 10% at Site 1 and 13 to 19% at Site 2 (Tables 6 and 7).

Second, we found that flight altitudes were higher in spring than autumn. Schmaljohann et al. (2007) also reported birds to fly at higher altitudes during spring migration, and suggested that water loss may be an important factor in seasonal difference in flight altitudes. Other factors such as weather, time of day, location, geographic features, and type of flight (e.g. flapping vs. soaring) have also been found to influence the altitudinal distribution of birds in the airspace (Berthold, 2001; Newton, 2010). Wind conditions exert a pronounced influence on the altitudinal distribution of migratory birds. The higher flight altitudes we observed in spring may be partly explained by the prevailing wind patterns in spring, which are advantageous for northern movement (Gauthreaux, 1999; Moore et al., 1995). By selecting altitudes with the best wind conditions, birds can minimize energy costs and increase migration speed (Richardson, 1978, 1990; Alerstam, 1979; Alerstam and Lindström, 1990). In contrast, prevailing wind patterns along the lower Texas coast are opposing the southward movement of birds in autumn. Previous findings have demonstrated that birds flying in headwinds (that is, unfavorable wind conditions) generally occur at lower altitudes than those birds migrating in tailwinds (that is, favorable wind conditions) (Kerlinger and Moore, 1989).

Lastly, consistent with previous views (Berthold, 2001; Newton, 2010), we found that flight altitudes were typically higher at night than during the day. Many studies have concentrated on flight altitudes of nocturnal migrants (Able, 1970; Gauthreaux, 1991; Zehnder et al., 2001; Mabee et al., 2006; Gagnon et al., 2011) or diurnal migrants (Mateos-Rodriguez et al., 2012), but our study is among the few to examine both nocturnal and diurnal migrants. Our results indicate that during spring, birds may be performing longer flights because nocturnal migrants are thought to primarily be those birds covering longer distances during migration (Newton, 2010). This result is also consistent with the higher flight altitudes that we report during spring. Our findings of a difference in altitudinal differences in time of day are consistent with reports at northern areas along the Gulf coast. Migrants making trans-Gulf flights appeared at greater altitudes than flights that were performed after in the daytime hours (Gauthreaux and Belser, 1999).

To be successful, migratory birds need to be able to acclimate to changing environments, successfully compete for common resources, avoid predation, and appropriately react to adverse weather (Moore and Simons, 1990; Moore et al., 1993). Therefore, many competing factors play a role in the successful completion of the migration journey, and safe arrival to breeding and wintering areas each year is of great importance to the stability of migratory bird populations. Understanding the migratory behavior of birds requires knowledge of the temporal and spatial patterns of migration to ensure that management and conservation measures put into place are effective (Faaborg et al., 2010). Information on the distribution of birds in autumn and spring will be increasingly important in areas known to concentrate birds during migration. Because of its geographic position and diverse habitats, the lower Texas coast has been considered to act as a major migration corridor for birds (Kuvlesky et al., 2007), and our study provides the first empirical evidence to support this claim. Thus, special attention should be directed to the lower Texas coast to ensure that birds passing through this region have the necessary stopover areas along their migration route. The ability to assess potential effects of ongoing human development along the lower Texas coast has been hindered by limited data; thereby making it difficult to guide management efforts. In recent years, coastal areas in this region have been targeted for wind energy development because of its high wind-power potential.

Our study establishes a baseline on key migration characteristics, notably passage rates, migration timing, and flight altitudes, for future monitoring to increase our understanding of potential interactions between migratory birds and wind-energy development. These migration characteristics are critical to identifying those migrants at risk from wind energy development, particularly those birds found within the rotor swept zone. The peak timing and magnitude of migration provided by our study can be used to predict seasonal and daily periods when birds may be at risk for collisions. Further, the fine-scale data on bird movements of our study will allow for the monitoring over time to detect changes in the timing of migration. Based on our study, there is still considerable bird passage at flight altitudes that correspond to the rotor-swept area of wind turbines. Future monitoring of the spatial distribution of birds would enable the detection of avoidance behavior of wind turbines by birds. Most importantly, our data provide guidance on the operating times when migratory birds may be at higher risk of collision and on the placement of wind farms in sensitive areas known to funnel significant concentrations of migratory birds. Although migrants may be impacted directly by wind energy developments (that is, collisions), the footprint of the wind energy development may also have indirect impacts to birds (Kuvlesky et al., 2007; Belaire et al., 2014). Wind energy development will alter the availability and quality of stopover habitat that millions of migrants have traditionally depended upon along the lower Texas coast. Habitat loss and alteration of stopover areas may have significant impacts to migratory bird species at a continental level. Our study on baseline migration characteristics can be used to aid in detecting stopover habitats and migration pathways that birds use in this region.

Our study also highlights the significance of the lower Texas Gulf coast to migratory birds. Moreover, our estimates of MTR should be considered conservative for this region because an unknown proportion of targets were flocks rather than individual birds. Interestingly, there was a striking difference in migration magnitude observed between coastal sites. Differences in location relative to the coast or in local topography might explain the contrasting magnitude in our study (Fortin et al., 1999). Variation in migration volume within coastal sites stresses the importance of continued research efforts to study the movements of migratory birds along the lower Texas coast. In addition, further research is warranted to assess how migrating birds respond to landscape features. The dispersion of migration traffic inland remains relatively unknown. Future research should focus on providing insight into the change of migration magnitude from the mainland coastline to areas further inland.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Structure and regeneration status of woody plants in the Hallideghie wildlife reserve, North East Ethiopia

Ahmed Endris[1,2], Ali Seid[1] and Addisu Asefa[2]*

[1]Department of Biology, College of Science, Bahir Dar University, P. O. Box 3052, Bahir Dar, Ethiopia.
[2]Ethiopian Wildlife Conservation Authority, P. O. Box 386, Addis Ababa, Ethiopia.

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In this study, we examined vegetation structure and regeneration status of woody plants in the Hallideghie wildlife reserve, Ethiopia. We collected data on abundance, height and diameter at breast height (DBH) of woody plant species with DBH >2.5 cm within sixty-six 20 m × 20 m sample plots and counted number of individuals of seedlings (that is, individuals with height <1.5 m) and saplings (height >1.5 m and DBH <2.5 cm) of each species within five 1 m × 1 m subplots nested within each main plot. To describe vegetation structure, we computed DBH and height size frequency distributions of individuals and species importance value indexes (IVI). Overall, we recorded 986 individuals of tree/shrub stems, belonging to 46 woody plant species. Both the number of species and individuals represented in each DBH size class and height size class showed decreasing trends with increasing size classes. However, different species showed varying patterns of DBH size structure. IVI of species varied from 0.3 to 69.1. The average density of seedlings, saplings and matured woody plants in the HWR were 1345, 899 and 374 individuals/ha, respectively. *Balanites aegyptiaca* and *Acacia tortilis*, species with high IVIs, were also among those species that exhibited poor regeneration status.

Key words: DBH, importance values index (IVI), *Prosopis juliflora*, density, invasive species.

INTRODUCTON

Tropical forests and woodlands are being lost at an alarming rate due to increasing human populations and corresponding land use changes (Pimm et al., 2006; Jhariya et al., 2014; Kittur et al., 2014; Behera et al., 2017). Most of natural vegetation losses are occurring in the tropical developing countries like Ethiopia where the livelihoods of their nations are directly or indirectly linked to natural resources (UNFAO, 2010). Such unprecedented rate of deforestation results in rapid transformation in plant and animal communities, drastically altering not only the ecological processes and functions that maintain appropriate ecosystem services but also is adversely impacting the socio-economic development and well-fare of human-beings (Hurni, 1988; Lemenih and Woldemariam, 2010). Thus, having better ecological information, such as vegetation structure and regeneration status, in protected areas has been growing globally to prioritize species for conservation

*Corresponding author. Email: aa.mitiku@gmail.com

management actions so as to mitigate the adverse effects posed on them due to the increasing rate of deforestation (Aliyi et al., 2015).

Ethiopia has the fifth largest floral diversity in tropical Africa (Soromessa et al., 2004), which mainly is as a result of the great variations in altitude (ranging from 110 m b.s.l to over 4530 m a.s.l), topography, rainfall and temperature in the country that have provided favorable environmental conditions necessary for the evolution and persistence of a wide variety of floral, as well their-associated faunal species (Yalden and Largen, 1992; Awas, 2007; Lemenih and Woldemariam, 2010; Bayeh, 2013). However, this tremendous wealth of natural resources and biological diversity of the country has been facing serious conservation challenges due to the high (~3% per annum) growth rate of the country's human population (World Bank, 2013). This high population increase has been causing rapid and widespread conversion of natural habitats (forests, woodlands and grasslands) in the country for human settlements, cultivation, livestock grazing, charcoal and firewood harvesting (Hurni, 1988; Campbell, 1991). These human-associated threats to vegetation cause changes in species' (i) reproduction and recruitment status of that vegetation (Burju et al., 2013; Aliyi et al., 2015), (ii) population structure (Senbeta, 2006; Aliyi et al., 2015) and (iii) ecological significance (Bekele et al., 2014). Currently, relatively intact natural habitats in Ethiopia are found in protected areas such as National Parks and Wildlife Reserves (Soromessa et al., 2004). However, most of such protected areas of the country have been mis-managed, and lack adequate ecological information on the status of the biophysical resources they contain which would help managers to develop biodiversity conservation plans. This is especially the case of some remotely located protected areas such as the Hallideghie Wildlife Reserve (HWR), which was established in 1965 mainly to conserve the remnant population of the globally endangered Gravy's zebra (*Equus gravii*) and other ungulates occurring in the area (Tadesse, 2009; Wami and Mekonnen, 2013).

In addition to its significance for the conservation of several key wildlife species, HWR area is also the major communal livestock grazing area for Afar and Ethiopian Somali pastoral communities (Tadesse, 2009; Kebede et al., 2012). Despite its immense importance for biodiversity conservation and socio-economic development of the surrounding community, the reserve has been subjected to a number of threats, including deforestation, overgrazing, uncontrolled fire, invasion of alien plant species and bush encroachment (Tadesse, 2009). These factors are supposed to lead to decrease in diversity and cover of native and palatable woody plant species, poor regeneration of ecologically important plant species (Khumbongmayum et al., 2006), degradation of wildlife habitats, reduced number of wild animal populations and further promotion of ecosystem invasion by exotic plant species (particularly *Prosopis juliflora*) in the reserve (Kebede et al., 2012). However, ecological studies on vegetation of the reserve, that would help develop and implement appropriate ecosystem and species management measures, have not been undertaken so far. Specifically, there is lack of information on population structure and regeneration status of vegetation of the reserve. The availability of such information would have helped to (i) understand past and present disturbance histories to species, (ii) forecast the future trend of the populations of different priority species and (iii) to develop threat mitigation strategies (Shimelse et al., 2010). The present vegetation study was, therefore, intended to fill this knowledge gap and to provide valuable ecological information on vegetation of the reserve needed for managers of the reserve to practice informed management decisions. The specific objectives of the study were to examine the population structure (DBH, height, density, frequency and Importance values) and to assess the regeneration status of woody plant species in Hallideghie Wildlife Reserve.

MATERIALS AND METHODS

Study area

The study was conducted in the Hallideghie Wildlife Reserve, which is located in the Great Rift Valley in the southwestern Afar Regional State (at 8°30' to 9°30' N and 39°30' to 40°30' E), northeastern Ethiopia (Figure 1). It was established in the 1965 with the main aim to protect the endangered Gravy's zebra (*Equus grevyi*) and other several conservation significant mammal and bird species (Hillman, 1993; Tadesse, 2009; Kebede et al., 2012). The reserve covers an area of 1,832 km^2 and altitude ranges from 700 m to 945 m a.s.l (Hillman, 1993). The area is characterized by a semiarid ecosystem with annual rainfall ranging between 400 and 700 mm (Gemechu, 1977). The mean seasonal temperature ranges from 25 to 30°C, but the daily maximum temperature may be as high as 38°C in June, while the minimum daily temperature can drop to 15°C in December (Gemechu, 1977).

The landscape in the Halledeghi Wildlife Reserve area is dominated by grassland plain with high mountains rising on the eastern border (Tadesse, 2009). The vegetation of the reserve consists of grasslands, bush land, shrub land, wooded grassland, shrub grassland, gallery/reverie forest and highland forest (Tadesse, 2009; Wami and Mekonnen, 2013). The reserve hosts ~31 and ~213 species of mammals and birds, respectively (EWNHS, 1996). At present, the reserve is home to Ethiopia's largest population of Grevy's zebra (Kebede et al., 2012).

Data collection

A reconnaissance survey was undertaken form 2 to 5 September 2015 to get a general overview of the vegetation physiognomy of the study area and identify sampling sites for the data collection. Field data were collected from 6-17 September 2015 along five transects of 2.4-3 km long. Transect layout was done systematically in stratified way to ensure that sample sites cover representatives of major vegetation types occurring in the reserve; namely, savanna (3 transects), riverine (1), thicket bush land (1) and deciduous

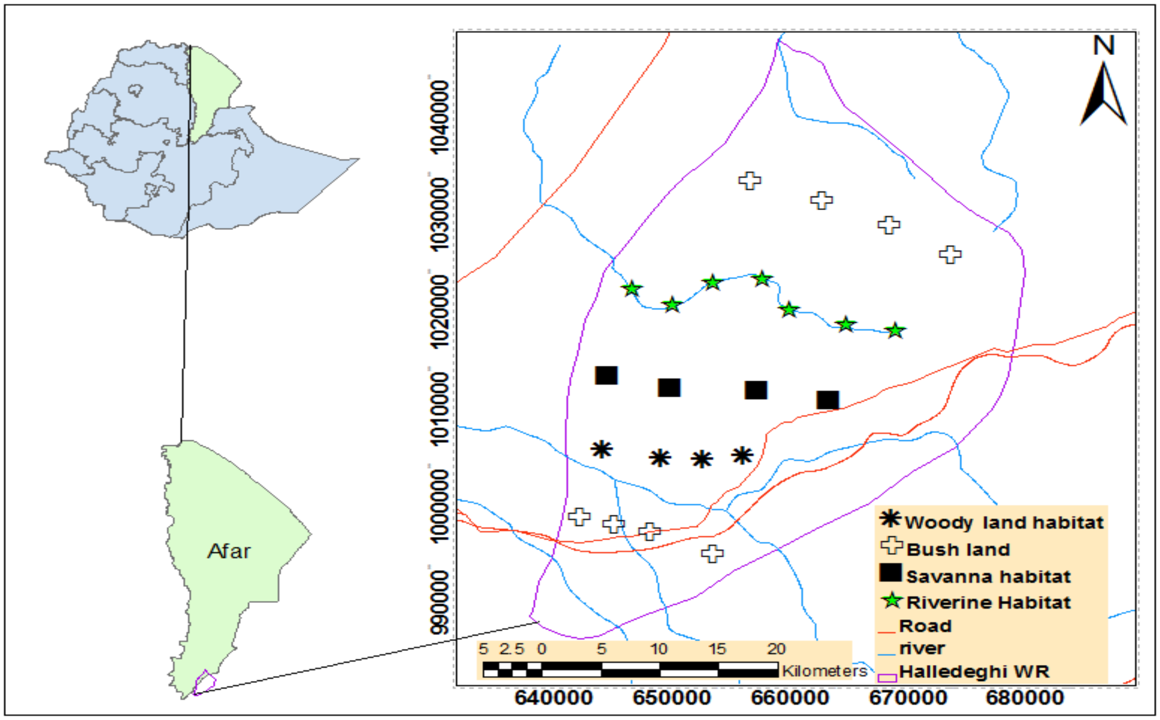

Figure 1. Map showing the location of the study area.

woodlands (1). Along each transect, twelve to fifteen 20 m by 20 m quadrats (totaling to 66 quadrats) were established at ~200 m distance interval. Accordingly, 12 quadrats in the savanna, 12 in the riverine, 27 in the thicket bush land and 15 in the deciduous woodlands were sampled. For assessment of regeneration status of woody species, number of seedlings and saplings of each species were counted and recorded in five 1 m by 1 m subplots established at each corner and center of each main quadrate. GPS locations of each transect and quadrates were fed in to Garmin 60 GPS and were used for navigation to sampling points.

A complete list of all woody plant species (trees and shrubs; as only three species of lianas were recorded they were treated with shrubs) encountered in each quadrate was made, and for each species number of individual stems were counted and measurements of their diameter at breast height (DBH) and height were taken. Trees and shrubs, and matured/adults, saplings and seedlings were defined following the descriptions of Mueller-Dombois and Ellenberg (1974) and Van der Maarel (1979). Accordingly, trees were defined as a single-stemmed woody plant taller than 5 m; shrub as a multiple stemmed woody plant; seedling as a young woody plant with height less than 1.5 m; and sapling as a woody plant with height greater than 1.5 m but whose DBH is less than 2.5 cm. Circumference of each tree/shrub was measured by meter tape and DBH values were estimated by dividing circumference by phi (3.14) and height was estimated using Santo Clinometers (Newton, 2007). For shrubs and trees possessing several stems rising from below breast height, DBH and height were measured separately for each branch and their average was used for data analysis (Mueller-Dombois and Ellenberg, 1974). In addition, disturbance conditions of the reserve were assessed by recording the presence and degree of different disturbance types (grazing/browsing, fuelwood collection, burning, charcoal production, etc) in and around each quadrate, following Asefa et al. (2015). Species identifications were made at field using floral guidebooks (Fitchlt and Adi, 1994; Bekele, 2007) and further confirmed at Ethiopian National Herbarium using existing specimens and Ethiopian flora books.

Data analysis

Woody plant structural composition of the study area was described based on the analyses of the distribution of individual plants in various DBH and height size classes, and computation of basal area (the actual space covered by the tree and shrub stems), dominance, density, frequency), and Importance Values Index.

To examine tree/shrub DBH size distribution, DBH data were classified into nine size classes as: 1= 2.5-6 cm, 2 = 6.01-12 cm, 3 = 12.01-18 cm, 4 = 18.01-24 cm, 5 = 24.01-30 cm, 6 = 30.01-36 cm, 7 = 36.01-42 cm, 8 = 42.01-46 cm and 9 = >46 cm. Similarly, tree/shrub height data were classified into seven height size classes as: 1 = 1.5-3 m, 2 = 3.01-6 m, 3 = 6.01-9 m, 4 = 9.01-12 m, 5 = 12.01-15 m, 6 = 15.01-18 m, and 7 = 18.01-21 m. The number and percentage of individual tree/shrub stems in each DBH and height size classes were then calculated and graphically illustrated. In addition, the relationship between the number of species and number of individual tree/shrub stems represented in each DBH size class category was examined using Pearson's correlation coefficient. Similar procedure was used to examine the relationship between the number of species and number of individual tree/shrub stems represented in each height class category. Both analyses were undertaken in SPSS version 20 software (IBM Corporation, 2001).

The following equations were used to analyze the rest of vegetation structural variables.

Frequency (Fi) = $(Qi/Qt) * 100$ (N

Where Fi = frequency of species i; Qi = number of plots in which a species i occurred; and Qt = Total number of quadrates surveyed.

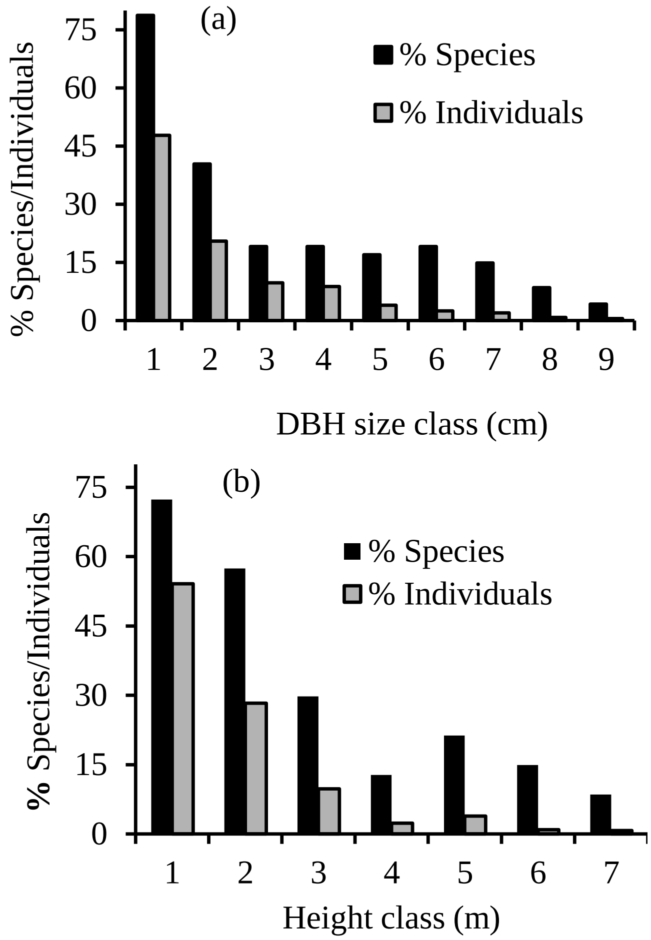

Figure 2. Frequency distribution of number of species of woody plants and number of individual tree/shrub stems (expressed in percentages) represented in each DBH (a) and height (b) size classes (where DBH size classes were defined as: 1= 2.5-6.0 cm, 2 = 6.01-12 cm, 3 = 12.01-18 cm, 4 = 18.01-24 cm, 5 = 24.01-30 cm, 6 = 30.01-36 cm, 7 = 36.01-42 cm, 8 = 42.01-46 cm and 9 = >46 cm; and height size classes as: 1 = 1.5-3 m, 2 = 3.01-6 m, 3 = 6.01-9 m, 4 = 9.01-12 m, 5 = 12.01-15 m, 6 = 15.01-18 m, and 7 = 18.01-21 m).

Relative Frequency (RFi) = $(Fi/\sum_{i=1}^{s} Fi) * 100$

Where Fi is frequency of species *i*; *s* = total number of species.

Density (Di) = $(N\text{i}/A)$

Where Di = density of species I; Ni = total number of individuals of species *i* recorded; and A =total area sampled (in ha).

Relative Density (RDi) = $(Di/\sum_{i=1}^{s} Di) * 100$

Where, RD*i* = relative density of species *i*; *s* = as defined above.

Basal area, for stems with DBH of > 2.5 cm, (BA in m^2) = $((\pi di^2)/(4 * 10\ 000)$

Where di = average DBH (in cm) of individual stems of species *i*.

Dominance (DOi) = (Mean basal area of a species i × Total number of stems of a species i).

Relative dominance (RDOi) = = $(DOi/\sum_{i=1}^{s} DOi) * 100$

Where RDOi = dominance value of a species i; others = as defined above

Importance Value Index (IVIi) = RDi + RFi + RDOi.

Where IVIi = importance value index of species i; others = as defined above.

To assess patterns of regeneration status of woody plants in HWR, sum of number of individuals of seedlings, saplings and matured trees/shrubs counted for each plant species was computed and these values were standardized (that is, converted to density values) to account for the different sample sizes used for counting both seedlings and saplings (which were sampled within five 1 m by 1 m plot) and for matured trees (which were sampled within 20 m by 20 m). Then, the relationship between species' stem density of seedlings vs saplings, seedlings vs matured, and vs saplings vs matured woody plants were examined using Pearson's correlation coefficient in SPSS version 20 software (IBM Corporation, 2001).

RESULTS AND DISCUSSION

DBH size class distributions

Of the 46 species of woody plants included in this study, the majority of them were represented in the first (37 species, 79%) and second (19 species; 40%) DBH size classes, while only few species were found in the last two size classes (6 species, 13%) (Figure 2a; Appendix 1). Similar trend was found when the number of individual woody plants (stem abundance) represented in each DBH size class was considered, with the largest number of individuals being represented in the first and second DBH size classes and the lowest in the last two classes (Figure 2a). These findings suggested that there was a monotonic declining, with a strong and statistically significant ($r = 0.99$, $n = 9$, $P < 0.001$), relationship between the number of species and individual tree/shrub from the first to the last DBH size classes. Only 33 (3.3%) individuals of woody plants belonging to nine species (19% of total species) had DBH values greater than 36 cm (that is, in the last three DBH size classes) (Figure 2a). Among species that attained such over 36 cm DBH size included: *Acacia tortilis, Balanites aegyptiaca, Dobera glabra* and *Ziziphus pubescens*. The occurrence of highest number of individual stems in the lower DBH size classes and a gradual decrease towards the higher classes in vegetation of a particular area is often referred to as an 'inverse J-shape' curve, which is indicative of good reproduction and recruitment status of that vegetation (Burju et al., 2013; Aliyi et al., 2015).

The general pattern of 'inverted J-shape' curve seen when all the species was considered together was not detected when species-specific DBH size distributions was examined separately. Three different patterns were revealed based on the analysis of the number of

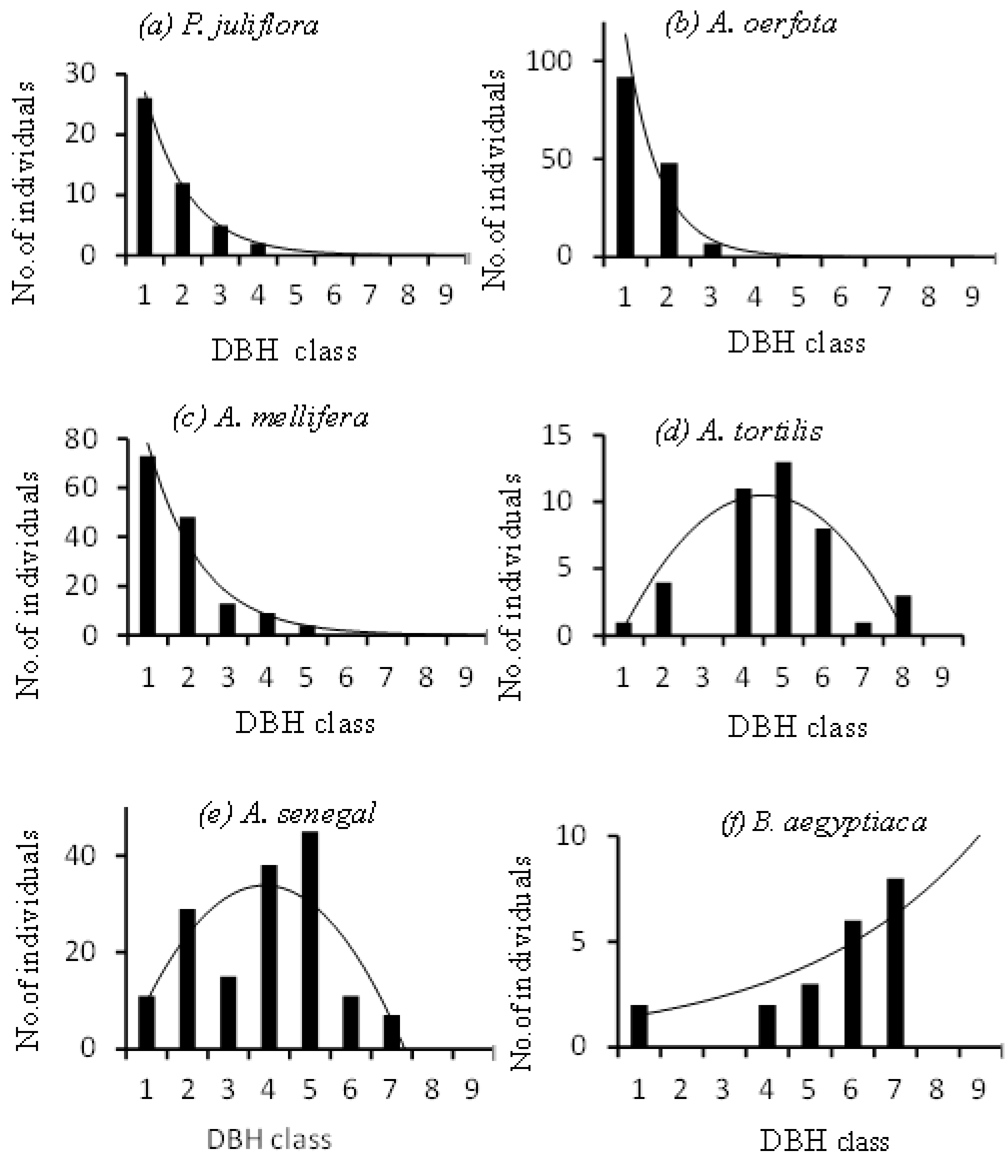

Figure 3. DBH (in cm) distribution of number of tree/shrub individuals over DBH size classes for six selected tree species in the HWR. DBH size classes were as defined in Figure 2.

individuals in each DBH size class for six selected species. Three of these species, *P. juliflora, Acacia mellifera* and *Acacia oerfota*, showed 'inverted J-shape' pattern (Figure 3a-c), having many individuals at the lower diameter classes and decreasing number of individuals at successively higher diameter size classes. Species with such population structural pattern can be considered as in a good reproduction and healthy regeneration condition (Senbeta, 2006). Other species, such as *A. tortilis* and *Acacia senegal* showed relatively a 'bell-shape', where number of individuals in the middle diameter classes are high but are low in lower and higher diameter classes (Figure 3d-e). These species, therefore, can be considered to be with poor reproduction and recruitment, which could be associated with intense competition from the surrounding trees and/or other forms of disturbances such as browsing activities (Senbeta, 2006; Gebrehiwot and Hundera, 2014). Finally, a 'J-shape' pattern was displayed by *B. aegyptiaca*, with low number of individuals in the lower DBH size classes and high number of individuals in the higher DBH size classes (Figure 3f). Several studies (e.g. Senbeta, 2006; Gebrehiwot and Hundera, 2014; Tilahun et al., 2015) have also reported such declining population of *B. aegyptiaca* in different parts of Ethiopia. These authors, given that this species is one of the most economically important tree species in the country across all its ranges (Beyene, 2010), have attributed their findings of poor

Table 1. Density (number of individual stems/ha) of matured, saplings and seedlings of woody plant species in HWR.

Species	Matured	Sapling	Seedling	Species	Matured	Sapling	Seedling
Abutilon figarianum	6.820	8.333	22.348	*Dichrostachys cinerea*	0.760	2.652	1.894
Acacia abyssinica	2.270	2.652	1.894	*Dobera glabra*	2.650	7.197	2.652
Acacia mellifera	54.170	88.636	140.152	*Ehretia obtusifolia (Ledy*	10.980	13.636	23.864
Acacia nilotica	1.140	1.136	0.000	*Entada abyssinica*	3.410	5.682	6.439
Acacia oerfata	55.680	123.106	232.197	*Erythrina abyssinica*	0.760	0.758	0.000
Acacia oliveri	3.410	28.409	39.015	*Flueggea virosa*	1.520	2.652	0.379
Acacia prasinata	1.520	7.955	9.470	*Grewia bicolor*	4.920	29.167	50.758
Acacia senegal	59.090	107.955	81.061	*Grewia flavescens*	1.140	0.000	0.000
Acacia seyal	1.890	1.515	0.000	*Grewia schweinfurthii*	2.270	14.015	10.227
Acacia tortilis	16.290	12.121	9.470	*Grewia tanax*	17.800	43.939	74.621
Acalypha fruticosa	16.290	105.303	181.061	*Grewia trifollia*	2.270	12.500	6.061
Balanites aegyptiaca	7.950	1.894	0.758	*Grewia villosa*	19.700	42.424	66.288
Berchemia discolor	1.140	1.136	0.758	*Jasminum abyssinicum*	1.140	4.167	1.894
Boswellia papyrifera	0.380	0.000	0.000	*Maerua angolensis*	1.520	4.167	1.136
Cadaba farinosa	7.950	10.985	23.106	*Maerua sp.*	1.890	9.848	8.712
Cadaba rotundifolia	13.640	44.318	82.576	*Phyllanthus sp.*	1.520	4.545	3.409
Calotropis procera	4.550	5.303	10.985	*Prosopis juliflora*	17.050	41.667	146.591
Capparis tomentosa	3.030	4.167	14.015	*Ricinus communis*	12.500	21.212	29.545
Carissa spinarum	3.030	1.894	0.000	*salvodora persica*	2.650	3.030	1.136
Celosia polystachia	1.140	6.818	10.606	*Senna sp.*	0.380	1.136	0.000
Commiphara erythraea	0.380	1.136	0.000	*Ziziphus mucronata*	0.380	1.136	0.000
Cordia monoica	0.380	2.273	0.758	*Ziziphus pubescens*	1.890	2.652	1.136
Cordia sinensis	1.140	0.000	0.000	*Ziziphus spina-christi*	1.140	1.515	0.758
				Total density	**373.480**	**899.242**	**1344.697**

regeneration state of the species to: 1) over-exploitation of matured trees that might have led to reduced reproduction (that is, flower production, pollination and seed production); and, 2) livestock browsing activities (uprooting/removal and cropping of seedlings) that might have probably inhibited seedling/sapling growth and recruitment.

Basal area and dominance

The total basal area of woody plants in HWR was 0.997 m^2 per ha (Table 1), which is found to be lower compared with what has been reported from other areas with similar semi-arid savanna vegetation [e.g. in Yangudi Rasa National Park: BA = 3.120 m^2/ha, Beyene 2010); in Babile Elephant Sanctuary: BA = 13.9 m^2/ha, Belayneh and Demissew (2011); and, in Nechisar National Park: BA = 882.23 m^2/ha, Shimelis et al. (2010)]. Nonetheless, woody plant basal area in the HWR was greater than that of other ecologically similar areas such as Taltalle woodland [BA = 0.44 m^2/ha; Lemessa (2009)]; Awash National Park [BA = 0.822 m^2/ha; Yohannes et al. (2013)]; and, Dalfaqar National Park [BA = 0.84 m^2/ha; Mekonnen (2006)].

Basal area provides a better measure of the relative importance of the species than simple stem count (Alemu, 2011; Aliyi et al., 2015). Thus, species with the largest contribution to the total basal area in a given ecosystem/habitat can be considered as the most important species in that habitat. Otherwise, in most cases shrubs could be the dominant species, if only we consider density as a measure to indicate the overall dominance of the species. In this study, *D. glabra* had the highest basal area 0.1828 m^2/ha (14%), followed by *Acacia nilotica* 0.1390 m^2/ha (13%), *Berchemia discolor* 0.0837 m^2/ha (9%) and *Ziziphus spinachristi* 0.0836 m^2/ha (9%) (Appendix 1). However, basal area of most species (~93% of woody plant species) recorded in the area was found to lie in the ranges between 0.0005-0.0500 m^2/ha, may be indicating that most of these species display, as is true for may savanna ecosystems, small growth habit due to the constrains posed on them by ecological factors (moisture deficit and high temperature) and/or anthropogenic disturbances (e.g. livestock browsing and human exploitation for house construction and charcoal making) (Lemessa, 2009).

The top six dominant woody plant species in HWR were *A. senegal*, *A. tortilis*, *B. aegyptiaca*, *A. mellifera, D. glabra* and *A. oerfota,* collectively accounting for 82% of the total dominance value of woody plant species in the reserve (Table 1). According to Mueller-Dombois and

Ellenberg (1974), such dominant species can be seen as the most ecologically significant, and the most successful species in regeneration, pathogen resistance and/or the least preferred by animals.

Height size class distribution

Overall, both the number of species and of individual woody plants represented in each height size class showed decreasing trends with increasing height size classes (that is, an 'inverted J-shape' pattern) (Figure 2b), with strong positive correlation between the number of species and of individual woody plants represented in each height size class (r = 0.974, n = 7, P <0.001). The majority of individuals contributing to the first and the second height size classes came from *A. mellifera, A. senegal, A. oerfota, Grewia villosa, Grewia bicolor, Capparis tomentosa, Cadaba rotundifolia* and *Grewia tanax* (Data not shown). Only 16 individuals (~2%) of the woody plant individuals from four species (*z. pubescens, A. tortilis, Acacia seyal* and *Acacia abyssinica*) attained height sizes of greater than 15 m (that is, represented in the last two het classes). The decreasing trend in number of individuals represented as one moves from lower to higher height size classes (that is, inverted J-shape' curve) indicates the dominance of small-sized individuals, which could be a characteristic of high rate of regeneration and/or high rate of mortality in large-sized individuals. Such type of population structure is referred to as stable size distribution which is common in many natural forests (Gemechu, 2014). Vegetation vertical structure (height) can be used as an indicator of age distribution of vegetation of a particular site and its importance as a wildlife habitat; the more structurally complex a habitat is, the more diversity of animal species it harbors (Newton, 2007). However, height size class distribution of dry land vegetation is not good indicator of the vegetation regeneration, reproduction and recruitment status because most plant species found in such areas are usually dwarf due to environmental and genetic factors or browsing activities (Newton, 2007).

Density and frequency of woody plants

The total density of woody plants (DBH > 2.5 cm) in HWR was 374 individuals per ha and density among species ranged between 0.5-67.4, with most species (~45%) having density values of >50 individuals per ha (Appendix 1). Species contributing most to the total plant population density of the area were *A. senegal* (67 individuals /ha, or 19%), followed by *A. mellifera* (60 /ha, 179%) and *A. oerfota* (60, 17%) (Appendix 1). Comparing the total density of woody plants reported here with other similar savanna ecosystem sites in Ethiopia indicated that it was comparable to that of Dilfaqar National Park (Mekonenn, 2006) and Taltalle woodland (Lemessa, 2009), but was greater than that of Nechisar National Park (Shimelse et al., 2010), Yangudi Rasa National Park (Beyene, 2010), and Awash National Park (Yohannes et al., 2013).

Analysis of species-specific frequency of occurrence across the sampling plots showed that three species (*A. Senegal, A. mellifera* and *A. oerfata*) appeared to be disproportionately the most frequent; occurring in more than 90% of the plots, they together contributed over one-third (36%) of the cumulative relative frequency of the entire species. However, most species (20 species or 44%) occurred only in less than four plots (Appendix 1).

Importance Value Index (IVI)

Importance Value Index (IVI) is a good measure for summarizing vegetation characteristics of a given habitat and is useful to compare the ecological significance of species and for conservation practices (Bekele et al., 2014; Gedefaw and Soromessa, 2014; Tilahun et al., 2014). It reflects the degree of dominance and abundance of a given species, and thus its ecological importance, relative to the other co-occurring species in the community (Kent and Cooker, 1992). In the present study, IVI of species varied from 0.3 (0.1% of the total IVI) to 69.1 (23.4%) and only five species contributed over 60% of the IVIs: *A. Senegal* (23%), *A. mellifera* (11%), *A. oerfota* (10%), *A. tortilis* (9%), *B. aegyptiaca* (4%) and *G. villosa* (4%) (Appendix 1). Over half of the all species [25 (54%) species] had IVI of greater than 1, while species relatively considered to be the most rarest in the HWR included *Senna sp.* 0.30 (0.10%), *Boswellia papyrifera* 0.33 (0.11%), *Commiphara erythraea* 0.34 (0.11%), *Dichrostachys cinerea* 0.41 (0.14%), *Erythrina abyssinica* 0.70 (0.23%) and *Cordia sinensis* (0.76 (0.25) (Appendix 1).

Regeneration status

Assessment of regeneration status of plant communities has a paramount importance for sustainable conservation and management (Khumbongmayum et al., 2006). The average density of seedlings, saplings and matured woody plants in the HWR were 1344.70, 899.24 and 373.5 per ha, respectively (Figure 4a). According to Khumbongmayum et al. (2006), when the number of seedlings of woody plants is greater than saplings and of sapling is greater than mature trees/ shrubs, as was the case in the present study, it indicates that the vegetation has a good regeneration status. However, when species-specific contributions to the overall regeneration of woody plants of the study area was considered, some species such as *A. oerfota, Acalypha fruticosa, A. mellifera, A. senegal and P. juliflora* had the highest seedling density in the reserve, whilst other species such as *Flueggea*

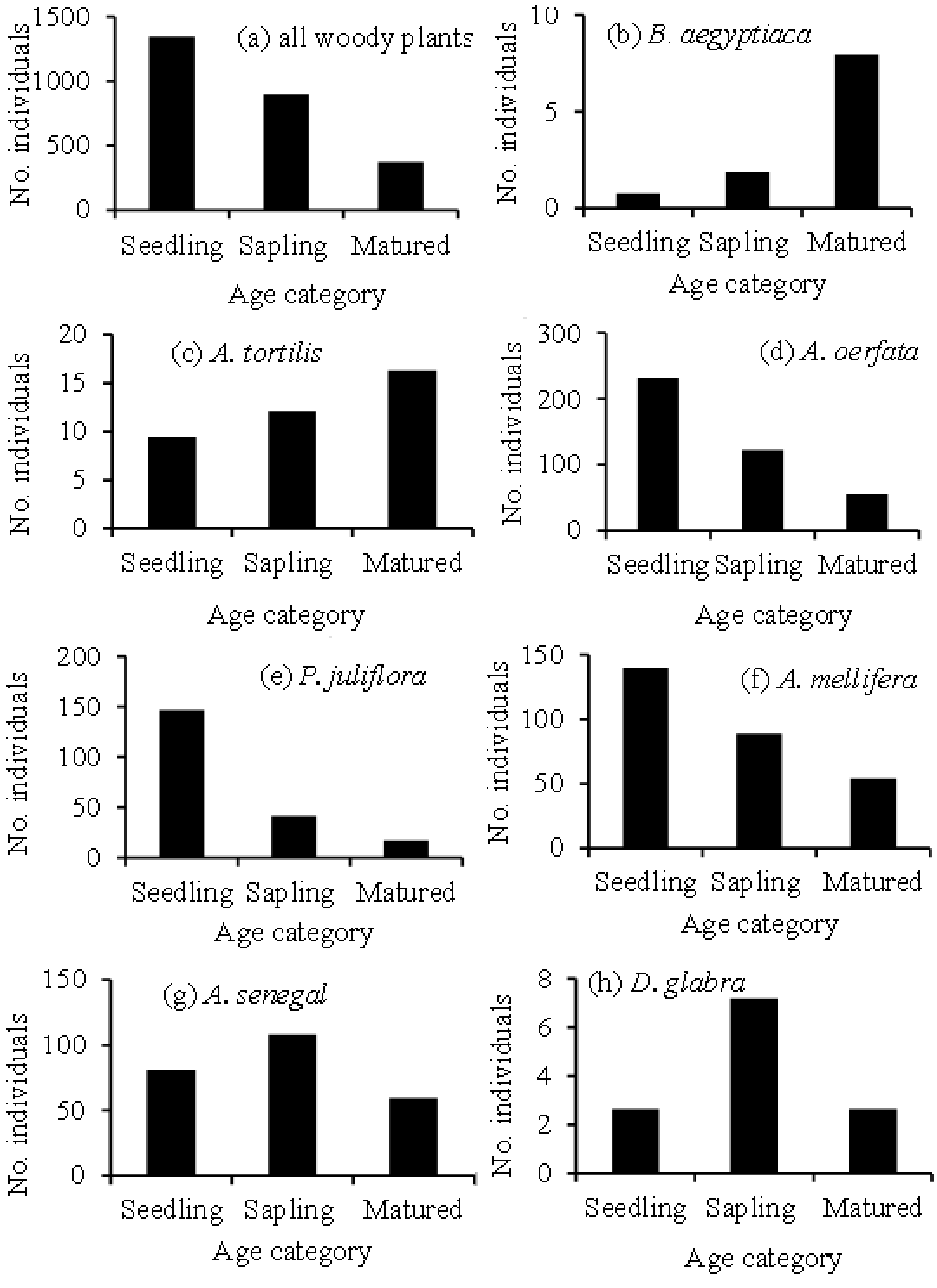

Figure 4. Patterns of regeneration status (density/number of individual trees/shrubs represented in seedlings, sapling and matured age categories) of woody plants in HWR for overall woody species (a) and for seven selected species (b-h).

virosa, B. aegyptiaca, Z. spinachristi and *Berchemia discolor* were characterized by the lowest densities of seedlings (Table 1). Furthermore, three species (*Boswellia papyrifera, Cordia simensis* and *Grewia flavescens*) had no individuals at both seedling and sapling stages and seven more species (15%) had no seedlings (Table 1). Species characterized by such lack of individuals at seedling stage are considered as not regenerating and are most vulnerable to local extinction (Khumbongmayum et al., 2006). Nonetheless, there was strong positive correlation between stem density of seedlings and saplings (r = 0.93, n = 46), but very weak relationships between each of them and density of matured plants (Matured vs seedling, r = 0.09; matured vs saplings, r = 0.12), indicating that species with abundant seedlings were also represented abundantly by saplings, but are not necessarily represented by matured individuals.

Detailed examination of the regeneration status of seven selected species (based on their dominancy, ecological and economic importance) revealed three general patterns of regeneration (Figure 4 b-h). The first distribution pattern was characterized by lowest density of seedling, medium density of sapling and highest density of matured individuals, a pattern often referred to as ‘J-shape’ curve and was displayed by *B. aegyptiaca* and *A. tortilis* (Figure 4b and c). These findings contrast with results from other studies (Mekonnen, 2006; Mekonnen et al., 2009; Belayneh and Demissew, 2011) that both *A. tortilis* and *B. aegyptiaca* have reported to show ‘U-shape’ regeneration curve, and *A. tortilis* exhibited an inverse ‘J-shape’ curve (Beyene, 2010). These tree species are more palatable to livestock and have more economical importance for the local people (for house construction, charcoal and firewood) compared with other woody plant species in the HWR. Thus, the discrepancy among previous studies and the present study could be due to varying nature and levels of biotic pressures (tree cutting and browsing) posed on the different age sizes of these species at different sites. In HWR, it seems that selective removal of pole-sized (saplings) individuals by people and livestock browsing of seedlings or samplings might have led the population structures of these species to exhibit such poor regeneration and/or abnormal recruitment. From conservation point of view, these two species are at higher risk of local extinction and hence should be prioritized for conservation management actions.

The second distribution pattern was that highest number of seedlings than saplings and decreasing number of individuals successively at saplings and matured stages (that is, inverted ‘J-shape’ curves, indicating good regeneration status (Khumbongmayum et al., 2006). Species that exhibited this pattern of regeneration status were *A. oerfota, P. juliflora* and *A. mellifera* (Figure 4d-f). The finding that these three species are at good regeneration state is unsurprising given that they, particularly the exotic invasive *P. juliflora*, have been reported to be expanding in the region in expense of the other natural vegetation (Tadesse, 2009). The third group of species, *A. senegal* and *D. glabra*, displayed a ‘bell-shaped’ distribution pattern where the highest population was represented in sapling stage class and medium in seedling and matured age classes (Figure 4g and h), which is an indication of a poor regeneration and recruitment status (Senbeta, 2006; Tilahun et al., 2015). There are a number of factors that could potentially contribute to such type of regeneration pattern; for example, seed predation, seedling browse, canopy cover for seedling recruitment, nature of seeds dormancy breakage in relation to environmental factors and pathogen attacks could affect the germination and growth of seedlings (Mekonnen et al., 2009; Kebede et al., 2014).

Conclusion

The present study has provided valuable information on structure and regeneration status of woody plants in the HWR that would be used as an input for effective conservation of the area. In this study, although the observed decreasing pattern of frequency distribution of individuals with increasing DBH size classes, when all species were treated together, is an indication of healthy regeneration status (Khumbongmayum et al., 2006; Beyene, 2010), this pattern was not detected when each species were examined separately. These results indicate that studies aimed to examine vegetation structure and regeneration should be analyzed both by treating all species together and each species separately. Furthermore, our results also showed that species with high IVIs, such as *A. tortilis* and *B. aegyptica* were also those that exhibited poor regeneration status with low level of seedlings and/or saplings. This may suggest that unless management actions that promote the regeneration status of such species would be in place, the sustainability of appropriate ecosystem processes and functions of the reserve will be doubtful. Therefore, studies that promote our understandings of factors that hindered the regeneration and structure of some important species that are currently presumed to be with poor regeneration status or unhealthy population structure are indispensible.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Diversity Analysis in Awash National Park, Ethiop. J. Biodiv. Manag. For. 2(2):1-7.

Appendix 1. Density (D), relative density (RD), frequency (FR), relative frequency (RFR), basal area (BA), dominance (DO), relative dominance (RDO) and Importance Values Index (IVI) of woody plant species in HWR.

Species	D (ha)	RD	FR	RFR	BA (m^2)	DO (m^2)	RDO	IVI	IVI%
Abutilon figarianum	6.820	1.830	12.121	1.553	0.001	0.013	0.081	3.460	1.153
Acacia seyal	1.890	0.510	6.061	0.777	0.059	0.296	1.891	3.176	1.059
Acacia senegal	59.090	15.820	95.455	12.233	0.041	6.416	41.054	69.109	23.036
Acacia abyssinica	2.270	0.610	9.091	1.165	0.001	0.008	0.052	1.826	0.609
Acacia mellifera	54.170	14.500	92.424	11.845	0.007	1.025	6.557	32.905	10.968
Acacia nilotica	1.140	0.300	4.545	0.583	0.139	0.417	2.668	3.556	1.185
Acacia oerfata	55.680	14.910	89.394	11.456	0.004	0.546	3.495	29.860	9.953
Acacia Oliveri	3.410	0.910	19.697	2.524	0.002	0.014	0.092	3.524	1.175
Acacia prasinata	1.520	0.410	6.061	0.777	0.002	0.007	0.046	1.237	0.412
Acacia tortilis	16.290	4.360	50.000	6.408	0.058	2.483	15.885	26.654	8.885
Acalypha fruticosa	16.290	4.360	25.758	3.301	0.001	0.022	0.140	7.801	2.600
Balanites aegyptiaca	7.950	2.130	18.182	2.330	0.054	1.133	7.246	11.710	3.903
Berchemia discolor	1.140	0.300	3.030	0.388	0.127	0.380	2.429	3.123	1.041
Boswellia papyrifera	0.380	0.100	1.515	0.194	0.005	0.005	0.030	0.325	0.108
Cadaba farinosa	7.950	2.130	24.242	3.107	0.001	0.030	0.191	5.428	1.809
Cadaba rotundifolia	13.640	3.650	33.333	4.272	0.001	0.048	0.308	8.536	2.845
Calotropis procera	4.550	1.220	13.636	1.748	0.001	0.010	0.061	3.026	1.009
Capparis tomentosa	3.030	0.810	7.576	0.971	0.002	0.019	0.119	1.902	0.634
Carissa spinarum	3.030	0.810	4.545	0.583	0.001	0.007	0.042	1.436	0.479
Celosia polystachia	1.140	0.300	3.030	0.388	0.001	0.002	0.015	0.710	0.237
Commiphara erythraea	0.380	0.100	1.515	0.194	0.006	0.006	0.036	0.331	0.110
Cordia monoica	0.380	0.100	1.515	0.194	0.005	0.005	0.031	0.520	0.173
Cordia sinensis	1.140	0.300	3.030	0.388	0.003	0.009	0.061	0.753	0.251
Dichrostachys cinerea	0.760	0.200	1.515	0.194	0.001	0.002	0.011	0.408	0.136
Dobera glabra	2.650	0.710	9.091	1.165	0.183	1.279	8.185	10.064	3.355
Ehretia obtusifolia	10.980	2.940	33.333	4.272	0.009	0.253	1.618	8.832	2.944
Entada abyssinica	3.410	0.910	10.606	1.359	0.002	0.015	0.094	2.366	0.789
Erythrina abyssinica	0.760	0.200	1.515	0.194	0.023	0.047	0.301	0.698	0.233
Flueggea virosa	1.520	0.410	3.030	0.388	0.001	0.003	0.018	0.812	0.271
Grewia bicolor	4.920	1.320	12.121	1.553	0.001	0.018	0.117	2.684	0.895
Grewia flavescens	1.140	0.300	4.545	0.583	0.003	0.009	0.060	0.943	0.314
Grewia schweinfurthii	2.270	0.610	6.061	0.777	0.001	0.009	0.056	1.450	0.483
Grewia tanax	17.800	4.770	40.909	5.243	0.001	0.037	0.236	10.246	3.415
Grewia trifollia	2.270	0.610	4.545	0.583	0.001	0.004	0.023	1.215	0.405
Grewia villosa	19.700	5.270	40.909	5.243	0.001	0.055	0.354	10.870	3.623
Jasminum abyssinicum	1.140	0.300	4.545	0.583	0.001	0.002	0.010	1.106	0.369
Maerua angolensis	1.520	0.410	4.545	0.583	0.004	0.016	0.103	1.091	0.364
Maerua sp.	1.890	0.510	4.545	0.583	0.002	0.008	0.051	0.731	0.244
Phyllanthus sp.	1.520	0.410	4.545	0.583	0.001	0.005	0.034	1.022	0.341
Prosopis juliflora	17.050	4.560	33.333	4.272	0.005	0.214	1.372	10.207	3.402
Ricinus communis	12.500	3.350	12.121	1.553	0.001	0.024	0.154	5.055	1.685
salvodora persica	2.650	0.710	10.606	1.359	0.001	0.007	0.046	2.115	0.705
Senna sp.	0.380	0.100	1.515	0.194	0.001	0.001	0.003	0.299	0.100
Ziziphus mucronata	0.380	0.100	1.515	0.194	0.077	0.077	0.490	0.786	0.262
Ziziphus pubescens	1.890	0.510	6.061	0.777	0.084	0.418	2.676	3.961	1.320
Ziziphus spina-christi	1.140	0.300	3.030	0.388	0.076	0.228	1.459	2.153	0.718
	373.480	100.000	780.303	100.000	0.997	15.629	100.002	300.023	100.008

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Hydroclimatic variability and flood risk on Naglanou and Akissa forests areas in Mono River Delta (West Africa)

Amoussou E.[1*], Osseni A.A.[2], Totin Vodounon S. H.[1], Lange U.[2] and Preuss S.[2]

[1]Department of Geography, University of Parakou, BP 123, Parakou, Benin.
[2]Deutsche Gesellschaftfür Internationale Zusammenarbeit (GIZ) GmbH, Germany.

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This study aims to analyze hydroclimatic variation (meaning rainfall and flow decrease or increase, regime irregularity, …) in Mono River basin and flood risk for ecological conservation of Naglanou (Benin) and Akissa (Togo) hydrosystems. Climate, hydrology and planimetry data were used for descriptive statistical and spatial interpolation to determine rain/flow relationship, climate balance (rainfall less potential evapotranspiration), flow coefficient (relationship between rainfall and flow), flood risk thresholds (base on Standardized Precipitation Index) return period. Naglanou and Akissa forest areas record heavy rainfall ranging 161 to 277 mm in June and 90 to 130 mm in October, representing respectively 16 and 13% of annual rainfall (1961-2015). This unequal spatiotemporal rainfall distribution determines surface flows and moisture of these forest sites during water level rise periods. Moreover, increase of flow rate by 20.38% over 1961-2015 and 14% over 1961-2000 linked to rainfall since 1990 and impoundment of Nangbeto dam since 1987. Flood hazard thresholds are limited (424.8 $m^3.s^{-1}$), moderate (609.3 $m^3.s^{-1}$), significant (709.1 $m^3.s^{-1}$), and critical (824.1 $m^3.s^{-1}$). Return periods correspond to 2, 10, 20 and 50 years.

Key words: Naglanou and Akissa Forest, biodiversity, mono River Delta, standardized precipitation index, flood risk threshold.

INTRODUCTION

Transboundary Biosphere Reserves were areas of a sustainable natural resources management in West Africa (Davis, 1994; Doumenge et al., 2001; Fournier et al., 2007). But recent population growth and climate change harmful effects has led to deterioration of these ecosystems (Ngandjui and White, 2000; IPCC, 2001; Mengue-Medou, 2002). Indeed, the project "Transboundary Biosphere Reserve of Mono River Delta" led by GIZ under UNESCO-MAB program aims was to contribute in a sustainable development of the ecological

*Corresponding author. Email: ernestamoussou@gmail.com, ajernest@yahoo.fr.

sites of Naglanou (Benin) and Akissa (Togo) within a global environmental change context. Both of the sites shelter the floodplain forests of the Delta of Mono River. Beck et al. (2013) demonstrates that meso- to macroscale catchment studies (>1 and >10 000 km^2, respectively) in the tropics, subtropics, and warm temperate regions have mostly failed to demonstrate a clear relationship between river flow and change in forest area. According to Hughes et al. (2003), changes in floodplain forests have been directly affected by changing nature of river systems as they have responded to climate change.

Then climate change is a potential major threat to environment and sustainable development. There is mounting evidence that climate change is increasing the frequency of extreme hydro-meteorological events such as heat and cold waves, tropical hurricanes, windstorms, flooding and mudslides (IPCC, 2001). This causes loss of life and socioeconomic impacts, compromising significantly development and socioeconomic growth, especially in countries with fewer resources (GFDRR, 2012; Di Minin et al., 2017). Thus in West Africa Benin-Togo area in particular, observed climate change over the past forty years induces unavoidable impacts on the Mono River delta hydrological cycle (Amoussou et al., 2012; Tramblay et al., 2014).

Among consequences of this hydroclimatic variation resulting from flood events, are observed loss of life and property, mass migration of people and animals, ecological disasters.

So flood risk constitutes a major concern for planning and land management for ecosystems (GIZ, 2016). Currently, gaps in research exist for country-wide analyses at a fine resolution that encompass the full set of biological and socio-economic data needed to inform conservation decision-making in developing countries (Kukkala and Moilanen, 2013; Kullberg and Moilanen, 2014). On the Mono basin, natural resources are also affected by human activities (land use changes, Nangbeto dam and soon Adjarala dam on the same River). The lack of information about how hydroclimatic variation affects forest ecosystems and ecosystem services on the floodplain is a major constraint to the development of conservation planning. Indeed, effective management of humid tropical forests is a mean way of the prevention of their disappearance as their biological resources in context of climate change (Game et al., 2011) and hydrometeorological risk. Such is the example of swamps and flooded forests of Naglanou in Benin and of Akissa in Togo, located on the Mono River lower valley (Figure 1).

Naglanou and Akissa forest areas are located on the subequatorial climate domain, characterized by two alternative dry and rainy seasons. Sudanian rains through flows contribute also to the provision of water resources to these forests. Linked rain-flow induces submergence of Naglanou and Akissa forest sites during flooding periods,contributing to habitat and biota degradation (GIZ, 2016). Well, both of the two forest sites, on the Mono River flood plain, receive fluvial water. Thus they are characterized by hydromorphic soils and lithosoils on sandstone and types of aquatic vegetation and semi aquatic which constitute ecological habitat for a specific wild fauna.

Therefore, to face global environmental change, the project "Transboundary Biosphere Reserve on the Mono River Delta" aims to contribute to sustainable development of Naglanou (Benin) and Akissa (Togo) ecological sites. 'Zoning of flood-prone lands as ecological reserves or protected wetlands can often help to meet broader environmental or biodiversity goals...' (Dudley et al., 2015). To this end, it is important first to characterize climate and hydrological variation in the Mono River basin and secondary to determine flood risk for ecological conservation of the Naglanou (Benin) and Akissa (Togo) hydrosystems.

METHODOLOGY

Daily rainfall from databases of the National Meteorology Directorate (DMN) in Benin and Togo and Athiémé station flow data provided by the General Directorate of Water in Benin are used. These climate and hydrological data cover the period 1961-2015. Among the 28 hydrometeorological stations of the Mono Basin, 4 (Anèho, Grand-Popo Tabligbo and Athiémé) near the forest sites help for local level analysis. Also satellite image (Landsat TM scenes and OLI, respectively over a period of 1986 to 2015 years), topography (DTM of STRM30) and field work data were helpful for spatio-temporal analysis.

Hydroclimatic functioning analysis

Rainfall data distribution mapping by Kriging is made to better analyze spatial hydroclimatic variability on the forest sites. It involves direct estimation of rainfall as well as its variance from daily data of the 28 stations.

To better implement this type of Kriging interpolation, a variogram analysis (Hennequi, 2010) was made to explore data spatial structure and check their autocorrelation. The semivariogram which discloses semi-variance as a distance function between monitoring stations and allows spatially link data was defined as follows:

$$\gamma(h) = \frac{1}{2} Var\big(Z(s+h) - Z(s)\big) \quad \forall s \in D$$

or $Z(.)$ is the regionalized variable studied is the vector of coordinates is the distance vector and is the geographic area studied (21,500 km²).

To characterize surface water resources of the two forest sites, a good knowledge of the hydroclimatic functioning of Mono River basin is necessary.

Rainfall/flow relationship was used to measure the link or dependence level between rains and runoff on the watershed Mono.

Correlation coefficient (Amemiya, 1980; Jobson, 1992; Abudu

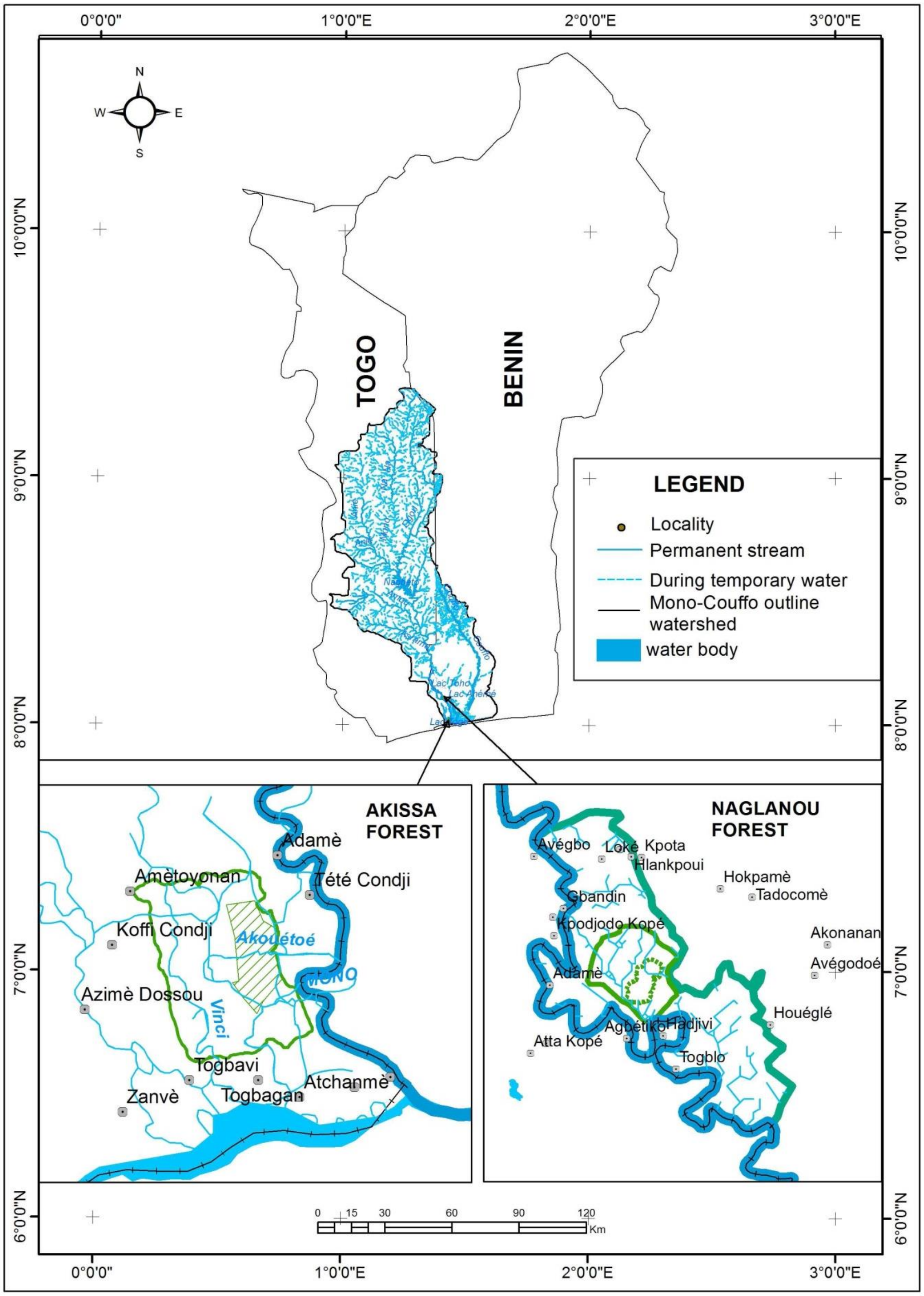

Figure 1. Geographical location of the Naglanou (Benin) and Akissa (Togo) forest areas.

Kasei, 2013) is defined by:

$$r = \frac{\frac{1}{N}\sum \left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sigma(x).\sigma(y)}$$

Where N is the whole individual number; x_i and y_i, the series values; $\bar{x}$ and $\bar{y}$ are average rainfall and flow ; $\sigma(x)$ and $\sigma(y)$ represent their standard deviations.

The flow coefficient (C) expresses relationship between rainfall

(a) (b)

Photo 1. Water level above soil surface to 110 cm (a) and 50 cm (b) at high water periods. Source: Amoussou and Totin (March, 2016).

and runoff (Mahe and Olivry, 1995) and analyzes role played by the geological substratum of Naglanou and Akissa sites in the Mono Basin. It is calculated considering the wet period and cumulative rainfall of the period May-October by the formula: $C = \frac{L}{P} \times 100$, where: L correspond to the flow (mm) and P the rains (mm).

Estimation of the water retention capacity of the Naglanou and Akissa forest sites is by development of slope maps, river systems, determination of wet areas and their depths. The formula used to estimate the volume of mobilized water (Savané et al., 2001) is: $V = S.10^6 \times H$, with: V = the volume of mobilized water (m^3); *S* = the wetted surface area (km^2) of the site and *H* = the water depth (m).

On the lowest areas where grasslands are developing, water level on both of the sites is determined from a comparison of interviews results with ecological markers of water level change (Photo 1). So, two water levels data are considered: 50 cm for less rainy years (Photo 1b) and 110 cm for exceptional rainfall years (Photo 1a). In almost normal year, seasonal variation in water levels within the limits of 50 cm is the basis of observed micro-reliefs (gilgaï) formation (Photo 1b) on Naglanou forest site.

The volume mobilized water on Naglanou and Akissa forest sites is evaluated from marshy grassland area and temporal variation in water levels on each of the sites.

Flood risk thresholds on Naglanou and Akissa forests sites

Detection of rainfall hazards of flood risk is carried from the SPI (Standardized Precipitation Index) and its classifications (McKee et al., 1993; WMO, 2012). The SPI is used for drought analysis (Vicente-Serrano et al., 2010; Karavitis et al., 2011; Dutra et al., 2013; Xie et al., 2013; Trenberth et al., 2014), but it can be good for flooding (Seiler et al., 2002; Guerreiro et al., 2008; Diakakis, 2012; Du et al., 2013). For the flows hazards, the SFI (Standardized Flow Index) of the same formula as SPI (below) was used.

These standardized indices (WMO, 2012) are calculated based on the daily and monthly rainfall for multiple time scales. According to Cancelliere and Bonaccorso (2009), the standardized index is based on an equiprobability transformation of precipitation values aggregated at k-months into standard normal values, with k generally fixed according to the purpose of the analysis (example: k = 1, 3, 6, 9, 12, 24, 36 months).

Originally, McKee et al. (1993) propose for the calculation of the SPI Gamma distribution. This index is used with no monthly or multi-monthly time. But for this work, the classic standardized index (denoted Z) was used with time scale change to daily scale. Using rainfall and flow data, it is calculated by the formula: $Z = \frac{Y - \mu}{\sigma}$, *Y* is daily rain or flow, μ and σ are respectively the mean and standard deviation of the study series.

In more detail, the standardized precipitation index (SPI) or the normalized flow index (SFI) (Bordi et al., 2001; Lloyd-Hughes and Saunders, 2002; Khadr et al., 2009) is divided as:

$$SPI/SFI = \begin{cases} -\left(t - \dfrac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), 0 < H(x) \le 0{,}5 \\ +\left(t - \dfrac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), 0{,}5 < H(x) \le 1{,}0 \end{cases}$$

Where t is determined by: t = $\begin{cases} \sqrt{\ln \dfrac{1}{(H(x))^2}}, 0 < H(x) \le 0{,}5 \\ \sqrt{\ln \dfrac{1}{(1 - H(x))^2}}, 0{,}5 < H(x) \le 1{,}0 \end{cases}$

With the coefficients: c0 = 2.515517; c1 = 0.80285; c2 = 0.010328; d1 = 1.432788; d2 = 0.189269; d3 = 0.001308.

Detection of rainfall and hydrological thresholds of flood risks was

Table 1. Classification of SPI values, categories and flood risk levels.

Class of SPI/SFI	Flood categories	Risk thresholds
2.0+	Catastrophic	Critical
1.5 to 1.99	Serious	Significant
1 to 1.49	Negligible	Moderate
0 to 0.99	None effect	Limited

Extract from McKee et al. (1993) and WMO (2012) and completed. NB: In the case of work, the operation of Table 1 is made on the values ranging from 0 to 2 and more.

Table 2. Correspondence between standardized indices values and flood risk levels.

Values of standardized indices	Risk levels	Warning level
2.0+	Critical	Red
1.5 to 1.99	Significant	Orange
1 to 1.49	Moderate	Yellow
0 to 0.99	Limited	Green

from the categorization of SPI / SFI values (Table 1). This allowed classifying daily rain and flowing data in terms of flood hazards, for different risk levels (limited, moderate, significant and critical) in the Mono River Basin. This hazards categorization has been possible due to a transposition of McKee et al. (1993) classification to use daily data. Thresholds were determined from a standard series of annual daily flows peak at Athiémé hydrometric station. Seasonal cumulative rainfall corresponded to the related years for these thresholds were calculated. Different risk thresholds, into four classes are categorized as shown in Table 2.

Return period of Gumbel method

Frequency analysis enables to determine recurrence of hydroclimatic events and to estimate their return time (Lubès and Masson, 1991; Hubert and Bendjoudi 1997; Goula et al., 2006; Bois et al., 2007). Frequency model of this prediction is an equation describing the statistical behavior of a process.

The model describes occurrence probability of a hydroclimatic event. A frequency model often used to describe the statistical behavior of extreme values (Ghanmi, 2014) is the statistical Gumbel distribution (double exponential law or Gumbel). Gumbel distribution of law F (x) is expressed as follows:

$$F(x) = \exp[-\exp((-x-a)/b)],$$

The reduced variable $u = (x-a)/b$, where *a* and *b* are the Gumbel model parameters. The distribution is then written: $F(x) = \exp[-\exp(-u)]$ and $u = -\ln[-\ln(F(x))]$

This is for the purpose of estimating the probability of exceeding F (xi) to be attributed to each value xi of rainfall and hydrological series as did by Mimikou et al. (1994); Bonaccorso et al. (2003) and Totin et al. (2009) to determine return periods of normal, abnormal, exceptional (rare) or very exceptional (very rare) hydroclimatic events.

For this empirical frequency Hazen: $r - 0{,}5/n,$ where *r* is the rank in the series of classified data by increasing values, n the sample size and *x* [*r*] the rank r value.

The return period T of a rainy or hydrologic event is defined as the inverse of the probability of the event frequency occurrence.

$$T = \frac{1}{1 - F(x_i)}$$

RESULTS

Rainfall and hydrological variability in the catchment of Mono River at Athieme

Two types of years are distinguished in Mono Delta basin: a wet year with five or six months (May to October) with surplus rainfall ranging from 0.5 to 49.3 mm and a dry year with two wet months (May-June) with surplus water range from 9.95 to 93.57 mm. Reduction of wet sequences affects the rain/flow relationship which is illustrated by the Figure 2 at Athiémé hydrometric station at the daily time scale. Peak flows are recorded with a shift in precipitation optimum. Years of heavy rains generate abundant flows and therefore heavy flooding in Naglanou and Akissa forest areas. In addition, in dry years, marshes of the Mono Delta are also submerged following the of water release from Nangbéto dam as told by 95% of the surveyed populations. Dam water releases improve flow and humidify hydromorphic soil of Naglanou and Akissa forest. Thus soil profiles in a state of permanent water saturation, the first rainfall events cause

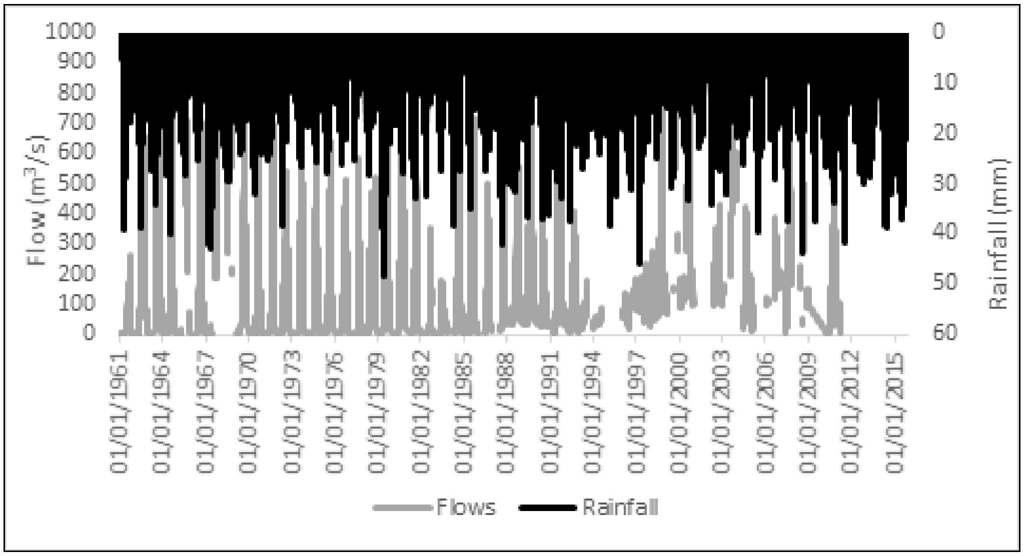

Figure 2. Monthly rainfall / flow relationship on the lower valley at Athiémé.

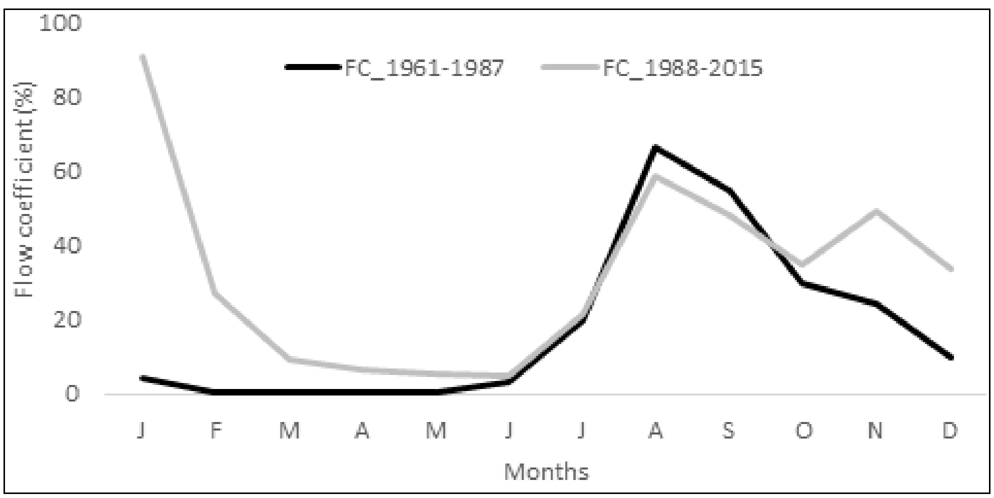

Figure 3. Monthly variation of flow coefficient in the Mono catchment at Athieme.

very quickly floods with a range of water depths 20 - 55 cm.

Hydrological incidence of Nangbeto Dam

Flow coefficient reflects changes on rainfall, role of geological bedrock and impact of vegetation cover (Mounier et al., 1993; Mahé et al., 2000). Runoff coefficient average at Athieme station is 20.38% over 1961-2015.

Analysis of monthly variation of flow coefficient before and after Nangbéto dam functioning (Figure 3) confirms water increase in recent years on the lower valley, but especially influence of dam water releases.

Water reserves on Naglanou and Akissa forest sites

Figure 4 shows water accumulation levels and its distribution on Naglanou and Akissa forest areas. Assessment of water volume on Naglanou and Akissa forests need first assessment of the area of marshy grassland area for the years 1986 and 2015. Swampy formations areas have increased from 64.5 to 77.4% in Akissa and 35.9 to 66.9% in Naglanou.

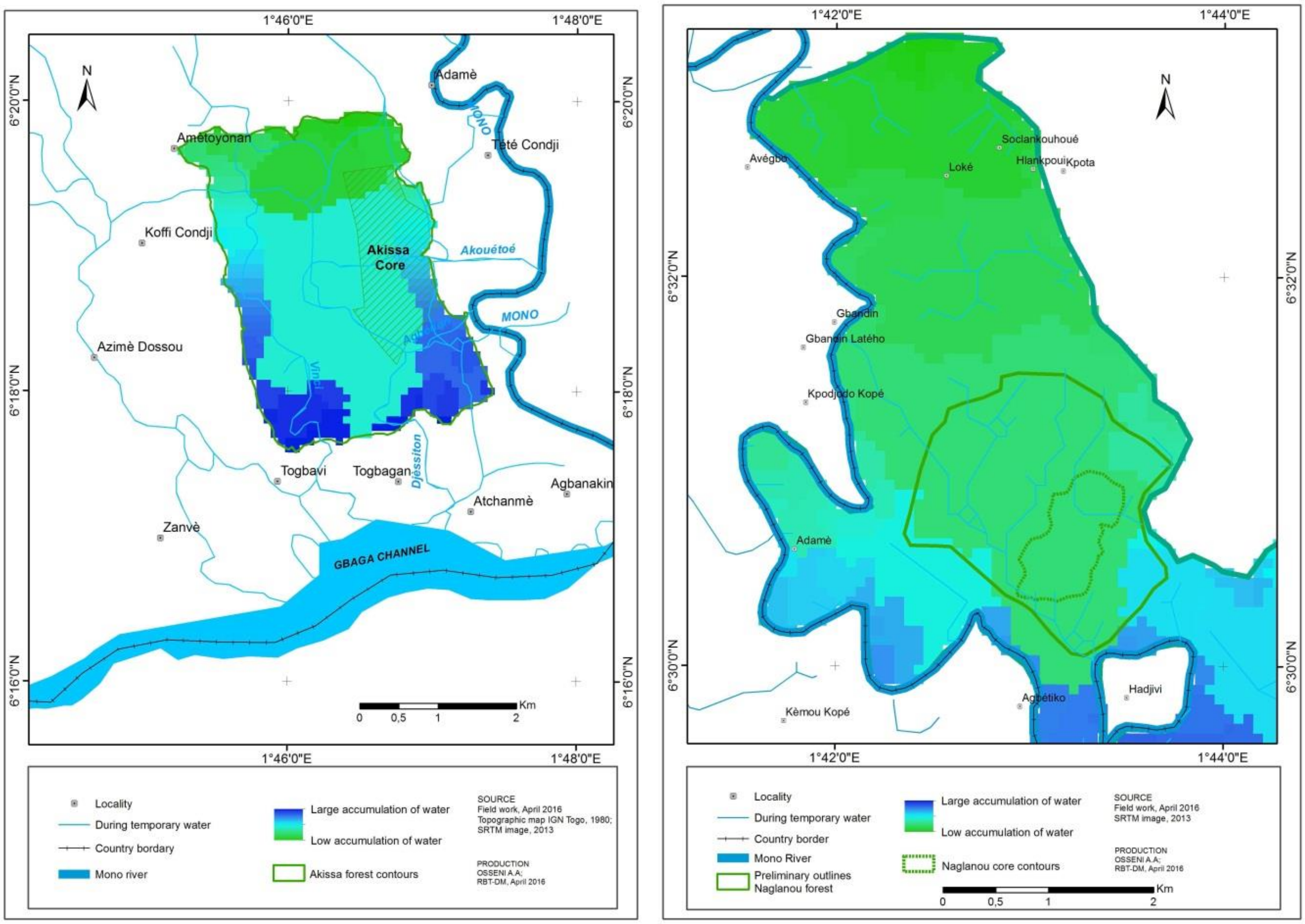

Figure 4. Level and degree of water accumulation on Naglanou and Akissa forest areas.

Table 3 illustrates water volume to be mobilized on the Naglanou and Akissa sites for the two different water levels.

In the dry periods, with substantially 50 cm water height, only the marshy grassland areas are flooded. On the other hand, in the very wet period (water level ≈110 cm), savannas located more on the exposed land is flooded following the grasslands.

Spatiotemporal variation rate of water volume changes by 0.03 to 86.76% on the forest sites. This variation is more marked at level of 50 cm water depth (from 20.48 to 86.76%) than that of 110 cm (from 0.03 to 0.49%). This low change rate in exceptional rainy year nevertheless shows that these extreme events still occur, but are rare in time. Thus, in recent years, as in the Mono Valley the sites recorded a slight recovery of hydroclimatic events that flood regularly savannas. But water inflows are greater at Naglanou than Akissa.

Flood risks in the forest sites

Quantitative and qualitative assessment of flood risks on Naglanou and Akissa areas helped in its categorization and deduction of its consequences.

Characterization of hydrometeorological hazards of flood risks

Characterized flood hazards on Naglanou and Akissa forest sites are extremes rainfall and flow which could lead to the hydro-climatic disaster.

The annual daily peak rates at Athieme from 1961 to 2015 (Figure 5) varies from 90 to 951 m^3/s. These help to identify the various risks of floods thresholds in Naglanou and Akissa sites based on the classification of McKee et al. (1993), implemented in the daily time.

Table 3. Volume of mobilized water (m^3) on Naglanou and Akissa forest sites.

Parameter	Naglanou		Akissa	
Water level	**0.5 m**	**1.10 m**	**0.5 m**	**1.10 m**
1986	769 500	4 722 300	3 459 300	11 792 440
2015	1 437 100	4 723 510	4 167 900	11 850 300
Change rate (%)	**86.76**	**0.03**	**20.48**	**0.49**

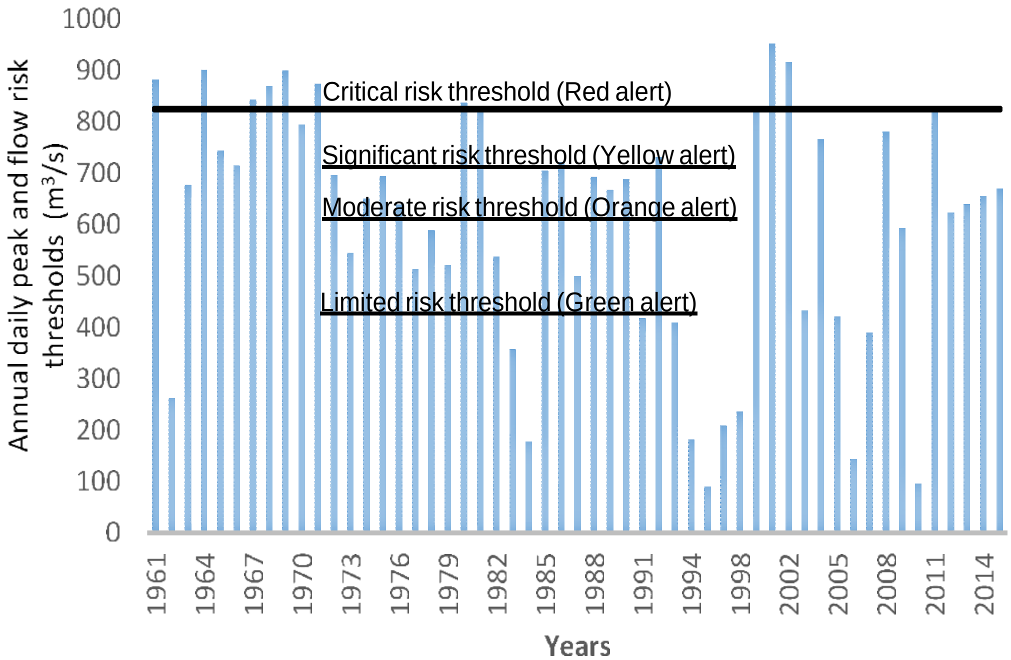

Figure 5. Rates of annual daily flow peak and flood risks thresholds in Naglanou and Akissa forest sites.

Flood hazards showed that 78% of flow annual peak rates are recorded from September to October. This is consistent with the rainy months (May to October) which concentrate more of 75% of seasonal rainfall (Houndénou, 1999; Totin et al., 2016) in the Sudanian area where rises the main River that feeds Naglanou and Akissa sites. Flows thresholds are 424.8 m^3/s for limited flood risk, 609.3 m^3/s for moderate flood risk, 709.1 m^3/s for significant flood risk and 824.1 m^3/s of critical flood risk (Figure 5).

Levels of green and yellow vigilance correspond to hydroclimatic events without major influence on ecological functioning of the forest sites. Moreover, levels of orange and red vigilance refer to the rare frequencies events but catastrophic for biodiversity. In consequence, it is important to establish an early warning system for efficient management of hydroclimatic crises on Naglanou and Akissa forest sites by also focusing on hazards return periods.

Return periods of flood hazards in Naglanou and Akissa forest sites

Annual daily peak rates on the Mono Basin at Athieme and seasonal cumulative rainfall (May to October) are presented in Table 4.

The rare frequency rates (≥ 25 years or = 50 years) for wet and very wet recurrences calculated over different periods on the Mono Basin are respectively 1077.5 and 1203.8 $m^3.s^{-1}$. For normal or abnormal events of frequency ≥ 2 years or 5 years, or 10 years or 20 years, flow rates were 568.9, 772.5, 907.3 and 1036.5 $m^3.s^{-1}$, respectively.

On the Mono River Delta, high flow rates are due to total seasonal rainfall. Thus, rare frequency flows are generated by total seasonal rain: 1056.4 mm and 1152.4 mm for ≥ 25 years or = 50 years return period. On the other hand, recurrent rain events (≥ 2 years or 5 years) or of 10 or 20 years frequency are respectively 669.9 mm,

Table 4. Return periods of seasonal rainfall hazards (May to October) and annual daily flow peak of flood risks on the Mono Basin.

Stations		Return periods (years) of predicted rainfall (mm)					
		2 years	5 years	10 years	20 years	25 years	50 years
Mono River Catchments							
Rains jauge		669.9	824.6	927.1	1025.3	1056.4	1152.4
Station of the two forest sites	Tabligbo	689.6	842.9	944.5	1041.9	1072.8	1167.9
	Aneho	682.1	893.6	1033.7	1168.1	1210.7	1341.9
	Athieme	636.3	812.0	928.4	1040.0	1075.5	1184.5
	Grand-Popo	640.4	866.8	1016.6	1160.4	1206.0	1346.5
Thresholds rates (m^3) of annual daily flow for flood risks							
Flows jauge station at Athieme		568.9	772.5	907.3	1036.5	1077.5	1203.8

824.6 mm, 927.1 mm and 1025.3 mm.

On the Naglanou and Akissa forest sites scale, rare frequency total seasonal rainfall (≥ 25 years or = 50 years) which can lead to exceptional hydrological events are respectively 1072.8 to 1210.7 mm and 1167.9 to 1346.5 mm. Seasonal cumulative rainfall are 636.3 to 689.6 mm for 2 years return period; 812.0 to 893.6 mm for 5 years'; 928.4 to 1016.6 mm for 10 years' and from 1040.0 to 1160.4 mm for 20 years'.

In comparison, the years 1999, 2010 hydro-climatic events, in the Mono Basin, are comparable to those of 1963, 1968, but less intense. This confirms to certain extent a certainty of exceptional hydrological events return periods on the basin and in particular the two forest sites.

These frequent events of hydro-climatic disasters could be due not only to slight increase in rainfall but certainly also to combined effect of water releases from Nangbéto dam and vegetation cover degradation of in the basin.

DISCUSSION

In the current context of hydroloclimatic variation, it is important to quantify the impact on the hydrosystems. Thus, this study investigated climate and hydrological variation in the Mono River basin and to determine flood risk for ecological conservation of the Naglanou (Benin) and Akissa (Togo) hydrosystems. Relationship between rainfall and flow is perfect (r = 0.64) on the Mono River basin of 1961-2010. This flow dependence on rainfall is also highlight in Niger River basin (0.81) by Vissin (2007) on 1955-1992 and 0.65 by Babatolu and Akinnubi (2014) on 1955-2010. But, in the White Volta River basin at Pwalugu, this correlation coefficient is 0.78 over the period 2003-2009 (Kasei et al., 2013) on due to largely dependence of surface runoff on rainfall of the basin. Thus, these peaks of hydrological flow succeed the rainfall peak with a two to three lag month corresponding to the basin response time and soil horizons saturation. This corroborates the results of Totin et al. (2016) on the Ouémé River basin at Bonou. Nevertheless, the correlation gap could be linked land use land cover (Mahé, 2006; Tramblay et al., 2014; Roudier et al., 2014). In recent decades West Africa has seen major changes in land use, with strong impacts on runoff (Wittig et al., 2007).

These rainfall variations have led to strong fluctuations in river discharge with a generally negative trend from 1960 to 2010 (Descroix et al., 2013), especially in Sudanian areas. In Guinean areas the decrease has been more moderate. Mahe et al. (2013) underlined the nonlinear effect of this rainfall drop over much of West Africa, with a −20% decrease in rainfall resulting in a decrease of −60% in runoff.

Runoff coefficient average at Athieme station is 20.38% over 1961-2015 against 14% over the period 1961-2000 (Amoussou et al., 2012). Increasing flow coefficient is the direct result of improved rainfall on the decades 1990 and 2000, degradation of vegetation cover (Mahe and Olivry, 1995; Dhakal et al., 2012; Tramblay et al., 2014) increase of evapotranspiration, rising of the subsurface aquifer and presence of sandstone covered by hydromorphic soils with low retention capacity.

Monthly flow coefficient which was 2.3% (1961 to 1987) has almost increased (4.4%) between the years 1988 and 2015 mainly confirming significant contributions of Nangbéto dam in dry periods as already reported by Blivi and Rossi (1995) and Klassou (1996). This is an advantage in terms of water balance for Naglanou and Akissa areas biodiversity.

Studies concerning climate variability in the Mono River watershed revealed a slight increase of precipitation in the period after 1990 (Amoussou et al., 2012; Houéssou et al., 2015). Cumulative seasonal rainfall (May to October) is the mean factors of flood risk on the areas of Naglanou and Akissa.

Floodplain connectivity indicates a broad range of ecological functions including the current and potential floodplain connectivity indicates a broad range of ecological functions including the current and potential capacity of floodplains to store and convey floods, transport sediment and wood, retain and transform water pollutants, support forest ecosystems, and provide habitats for aquatic species, ….

In addition, flooding poses a risk to many facilities located on floodplain including those that provide vital services (Konrad, 2015). Thus, frequent floods are read preferable than eventual floods for a better conservation of the ecosystems. Then, the lower return period (2 to 5 years) is desirable than the maximum return period (10 to 20 years), due to its almost permanent moisture role in the biodiversity conservation on the Naglanou and Akissa forests.

Conclusion

It appears that water availability in Naglanou Akissa forest sites depends on temporal distribution of rainfall, Mono River flows and its tributaries during periods of high water especially floods and dam Nangbéto water releases. The latter contributed to 97% of runoff in time of base flow in the basin and therefore to soils moistening.

Flow coefficient increase from 20.38% (1961-2015) to 14% (1961-2000) confirms rainfall increase since the end of the 1990s and Nangbéto dam water releases in the basin. Morphological, pedo-geological and hydro-climatic factors induced large water accumulation on Naglanou and Akissa forest areas. So water reserve varies from 0.03 to 97% depending on the seasons, but more pronounced in the wet' period (from 20.48 to 97%). Forest areas have a high water retention capacity. This is a great advantage for the conservation of aquatic and semi- aquatic biodiversity on these areas.

Characterization of flood hazards on Naglanou and Akissa areas is determined from the categorization of rainfall and hydrometric thresholds. The different hazards thresholds determined are ranked in terms of limited (424.8 $m^3.s^{-1}$), moderate (609.3 $m^3.s^{-1}$), significant (709.1 $m^3.s^{-1}$), and critical (824.1 $m^3.s^{-1}$). Significant and critical thresholds for orange and red warning levels associated with rare frequency events are sometimes catastrophic for a biodiversity.

Return periods of flood hazards are at least 20 to 50 years for rare and very rare events, but more disastrous than events of a range from 2 to 10 years frequency. These cases are the most desired events for the protection of ecological habitat and aquatic biota.

Facing the Naglanou and Akissa forest areas vulnerability to floods, the subject of the next step will focus on development of an early warning system for hydro-climatic crises efficient management and better ecological monitoring.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Climate change research trends in Tanzania: A bibliometric analysis

S. R. Lukwale[1] and A. S. Sife[2]*

[1]Library Services, Ardhi University, Dar es Salaam, Tanzania.
[2]Sokoine University of Agriculture, Morogoro, Tanzania.

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Research enhances the efforts to address climate change through improved understanding of the causes, effects and likely impacts as well as formulation of climate change policies and strategies for adaptation and mitigation measures. A bibliometric analysis was conducted to assess research trends on climate change in Tanzania for the period between 2006 and 2016. Data were extracted using the Publish or Perish programme which uses Google Scholar to retrieve the number of publications, citation counts and related metrics. The study findings show that there were 319 scholarly publications for the 10-year period, giving an average of about 32 publications per year. As the rate of growth of publications increased, the corresponding doubling time decreased. Journal articles were the dominant (56.1%) type of publications. Areas with relatively higher number of articles were "climate change adaptation" (25.2%), "climate change impacts/implications" (23.3%) and "climate variability" (13.8%). Many (68.9%) publications were multiple-authored and the degree of collaboration among scholars was 0.69. The top 10 ranked scholars contributed nearly one third (31%) of the publications. These results suggest that research productivity in the area of climate change in Tanzania is generally low compared to other countries in the world. Concerted efforts are therefore necessary to foster the research on climate change in Tanzania.

Key words: Bibliometrics, climate change, research, publications, Tanzania.

INTRODUCTION

Climate change is a global phenomenon that results from increased concentration of Greenhouse Gases (GHGs) in the atmosphere primarily from industrialization, deforestation and increased use of fossil fuels. These lead to higher temperatures, unreliable rainfalls, unpredictable synchromes and storms as well as rise in sea level all of which have adverse effects on living organisms and the environment (IPCC, 2007). Climate change has direct and indirect impact on water resources, agriculture, forests and biodiversity, health, infrastructure development, tourism, and livelihoods. Generally, there is no country that does not face the

*Corresponding author. E-mail: slukwale@yahoo.com.

consequences of climate change, though they may be affected at different levels. Developing countries including Tanzania are more vulnerable to the adverse effects of climate change because majority of their populations depend on climate sensitive natural resources and they have lower adaptive capacities (UNFCCC, 2007). In Tanzania, the impacts of climate change on various socio-economic sectors, environment and livelihoods are already vivid and these impacts threat to undermine and even undo development efforts attained so far (Nindi and Mhando, 2012).

Individual countries and the international community are making efforts to address the causes and impacts of climate change (IPCC, 2014). Several adaptation and mitigation measures are being formulated and enforced in many countries in order to address climate change and associated impacts. Research contributes to the efforts that aim at addressing climate change through increased understanding of the causes, effects and likely impacts of climate change as well as formulation of climate change policies and strategies for adaptation and mitigation measures. Scientific research enables informed decision-making and planning including the ability to measure and predict climate change and the implications of its adverse effects on the economy, society and the environment. Globally, climate change research has grown considerably in the past few years following increased magnitude of climate-related effects (Newton et al., 2005).

Assessment of research productivity in a particular discipline or location is an essential step to understand the strength of research activities, identify priority areas and uncover those areas that are less researched. Bibliometric techniques are used to measure research productivity trends and output. These techniques are concerned with the growth, structure, interrelationship and productivity of scientific disciplines (Hood and Wilson, 2001). Bibliometrics use quantitative analysis and statistics to describe distribution patterns of publications within a given topic, field, institution and country. Major data sources for bibliometric studies include the Web of Science, Scopus and Google Scholar databases. Google Scholar uses Publish or Perish (PoP) programme to retrieve publications, citation counts and associated metrics. Comparative studies (Saad, 2006; Bar-ilan et al., 2012; Harzing and Wal, 2013) indicate that PoP retrieves more publications and citations than Web of Science and Scopus. The PoP software programme provides statistics such as the number of publications, citation counts and indices such as the h-index, g-index, Hc-index and HI-norm index (Harzing and Wal, 2008). The h-index simultaneously measures number of publications and citations of a scholar (Hirsch, 2005). Since the h-index is not influenced by very highly cited papers, Egghe (2006) proposed the g-index which gives more weight to highly cited articles. Sidiropoulos et al. (2007) developed the Hc-index by adding a weight related to the age of each cited article. Furthermore, the HI-norm index offers a better approximation of the author's impact on the number of citations (Braun et al. 2006).

Understanding climate change research trends in Tanzania could help to establish strategies for improving the volume and quality of research in this field. The results would also help to identify research gaps that climate change studies could focus on in the future. In Tanzania, no bibliometric studies have been carried out to measure productivity and trends in climate change research. The present study therefore, analyses the climate change research productivity trends in Tanzania for the period between 2006 and 2016. The chosen period is based on the fact that serious international and national efforts to combat climate change causes and effects started in mid 2000s following the release of assessment reports by the Intergovernmental Panel on Climate Change (IPCC, 1995; 2001, 2007). Specifically, this study analysed the growth of the climate change scholarly literature, determined authorship collaborations, established the distribution of subject categories on climate change, established citations trends of publications, and analysed individual researchers' productivity.

LITERATURE REVIEW

Some bibliometric studies have been conducted in recent years around the world to measure research trends on climate change. Wang et al. (2014) analysed the global scientific performance in climate change vulnerability in the Web of Science database from 1991 to 2012. Among other issues, the results show that the vulnerability researches on climate change have experienced a rapid growth since 2006, and the publications are distributed in several journals. The cooperation at author level was on the rise, and the most widely focused research topics include health issues in the socioeconomic system, food security and water resource management. Venkatesan et al. (2014) also analysed global research productions on climate change using Web of Science databases for the period between 1999 and 2012. The findings show that there were 94,756 records contributed worldwide with an average of 6,769 articles per year. The Relative Growth Rate (RGR) and Doubling Time of the publications indicate that there was an increasing trend in the research production. More than half of the contributions are collaborative research and over 87% of the publications were journal articles. More than two-thirds (66.47%) of the documents were published in three research areas namely Environmental Sciences and Ecology (29,121), Ecology (18,997) and Meteorology Atmospheric Sciences (14,865).

A worldwide scientometric analysis of climate change research conducted by Husain and Mushtaq (2015) using the Web of Science database analysed 17,266 publications covering the period between 2009 and 2013. The highest number (4,788) of publications was produced in the year 2013 and the lowest (2,238) was in the year 2009. The highest number of publications was produced by USA followed by England. The most prolific author in the field of climate change was W. Thuiller followed by P. Smith. Journal articles were the most widely used document forms followed by reviews. The prolific journals were 'Climatic Change' and 'Global Change Biology'. The study also assessed the citation patterns including the country's citations, citations of affiliated institutes, and average, self and unique citations received of select years. A more recent bibliometric analysis involved 222,060 papers obtained through Web of Science custom data for the period between 1980 and 2014. The findings show a strong increase of papers with a doubling every 5 to 6 years. Continental biomass related research was the major subfield, closely followed by climate modeling. The Journal of Geophysical Research, the Journal of Climate, the Geophysical Research Letters, and Climatic Change appear at the top positions in terms of the total number of papers published (Haunschild et al., 2016).

Alex and Preedip (2010) mapped the climate change research output of India in five-year period from 2005 to 2009 based on papers abstracted in the Web of Science database. The findings revealed that there were 25,081 publications all over the world; of which Indian subcontinent had published 391 papers in all, and these were published in more than 101 scholarly journals. Another study quantitatively analysed the literature on climate change published from five developing countries namely Argentina, Brazil, China, India and Mexico based on Web of Science for the period between 1991 and 2012. A total of 7,065 records were retrieved for climate change for the studied countries. Country-wise results clearly show that China (4,121 publications) and India (1,147 publications) are the countries that produce the maximum outputs quantitatively. Authorship and collaboration trend was towards multi-authored papers (Saravanan et al., 2014).

In Tanzania, no bibliometric studies have been conducted to provide insights on research patterns and trends in the area of climate change. Research has been conducted on climatic extremes and how they have affected agricultural production and food security in Tanzania (Downing et al., 1997; Kijazi and Reason, 2009; Shemsanga et al., 2010; Tumbo et al., 2010). Most of these studies report that both extreme droughts and floods can occur within one season, and that the frequency and severity of these extreme events is expected to increase. There are also studies on the impacts of climate change on crop production (Mwandosya et al., 1998; Munishi et al., 2010; Rowhani et al., 2011). These have reported a general decline in crop productivity as a result of the changing climate. Other studies focused on climate change adaptations or coping measures mainly in agriculture (Mongi et al., 2009; Lyimo et al., 2010; Kangalawe et al., 2011; Shemdoe et al., 2009).

RESEARCH METHODOLOGY

A bibliometric analysis was conducted to assess the research trends on climate change in Tanzania for the period between 2006 and 2016. The chosen period was based on the fact that, as pointed out earlier, serious efforts to combat climate change causes and effects in Tanzania started in mid 2000s following the release of assessment reports by the Intergovernmental Panel on Climate Change (IPCC, 1995, 2001, 2007). Data were obtained using the PoP software which retrieves data through Google Scholar. Google Scholar is often recommended for bibliometric studies because it covers all scholarly publications that are listed and that are not by many databases (Harzing, 2013). In order to ensure that all retrieved publications are those addressing climate change issues in Tanzania, a search strategy was developed in such a way that only those publications with the words "climate" and "Tanzania" in their titles were retrieved. Search results were carefully refined to ensure that only intended works were captured and duplicates were removed. However, the intended publications were once again re-searched via Google scholar to determine whether they are actually on climate change issues in Tanzania. A total of 357 publications were retrieved, however, 38 were found irrelevant and were removed.

For the purpose of this study, the types of publications considered were peer reviewed journal articles, books, chapters in books, technical reports, theses and dissertations, working papers and articles in conference proceedings. The retrieved metrics were the total number of publications, number of authors for each publication, total citation counts, average citations per paper, average citations per year, h-index, g-index, Hc-index and the HI-norm. The limitation of this study is that PoP only retrieves data that are available on the web. This means that any publications and citations that were not available online could not be retrieved. The PoP software programme also has some limitations including the fact that search by affiliation and subject is not possible. In addition, the comprehensive nature of Google Scholar requires that data retrieved through PoP be thoroughly cleaned manually to remove duplicates and unanticipated publications.

RESULTS AND DISCUSSION

The findings focus of the growth of the climate change literature, collaboration patterns, subject categories citations trends as well as individual researchers' publication productivity.

Publication productivity

The findings in this study indicate that there were 319 scholarly documents on different aspects of climate change in Tanzania for the period of 2006 to 2016. It should be noted however, that these data were collected in February 2016 and hence they do not present a

Table 1. Year-wise publication productivity.

Year	No. of publications	Percent	Cumulative publications	lnN_1	lnN_2	RGR	Mean RGR	Dt	Mean Dt
2006	15	4.7	15		2.71	-		-	
2007	10	3.1	25	2.30	3.22	0.92		0.75	
2008	25	7.8	50	3.22	3.91	0.69		1.00	
2009	25	7.8	75	3.22	4.32	1.10	1.06	0.63	0.69
2010	28	8.8	103	3.33	4.63	1.30		0.53	
2011	38	11.9	141	3.64	4.95	1.31		0.53	
2012	43	13.5	184	3.76	5.21	1.45		0.48	
2013	34	10.7	218	3.53	5.38	1.85		0.37	
2014	43	13.5	261	3.76	5.56	1.80	2.04	0.39	0.36
2015	45	14.1	306	3.81	5.72	1.91		0.36	
2016	13	4.1	319	2.56	5.77	3.21		0.22	
		Mean				**1.41**		**0.48**	

Source: Google scholar, 2016.

complete picture for the year 2016. The Relative Growth Rate (RGR) which is the increase in the number of publications per unit of time was calculated as RGR = $(\ln N_2 - \ln N_1) / (t_2 - t_1)$ where N2 and N1 are the cumulative number of publications in the years t_2 and t_1. The study findings in Table 1 indicate that RGR had increased from 0.92 (2006) to 3.21 (2016) with some fluctuations in the years in-between. Similarly, the mean RGR for the block periods of five years increased from 1.06 (2007 - 2011) to 2.04 (2012 - 2016).

The doubling time which is the period of time required for publications to become double of the existing quantity is directly related to RGR in that if the number of articles doubles during a given period then the difference between the logarithms of numbers at the beginning and end of this period has a value of 693. Thus the corresponding doubling time is calculated as Dt = 0.693/RGR (Mahapatra, 1994). The findings show a decreasing trend from 0.75 (2006) to 0.22 (2016) with some fluctuations in the years in-between. The mean Dt for the block periods of five years decreased from 0.69 (2007 - 2011) to 0.36 (2012 - 2016). The whole study period records the mean RGR and Dt of 1.41 and 0.48 respectively; meaning that as the rate of growth of publications increased, the corresponding doubling time decreased. This shows that the number of publications in the area of climate change in Tanzania had increased over the period of 10 years. However, the total number of publications in climate change research in Tanzania was generally low as compared to the statistics reported in other countries such as China (4,121 publications) and India (1,147 publications) (Saravanan et al., 2014). This suggests that although climate change has become a topical area in the past few years, it has not gained wide attention among scholars in the country. The research productivity is low perhaps because of the recent nature of the research topic itself and inadequate financial resources to carry out research activities.

The findings in Figure 1 show that majority of literature has been published in the form of journal articles (56.1%) followed at a distant by technical reports (18.5%) and articles in conference proceedings (12.9%). Other publications were theses and dissertations (6.0%), working papers (5.0%), book chapters (1.3%) and books (0.3%). This was expected because most scholarly articles are often published in journals.

Distribution of subject categories on climate change research

The retrieved publications were grouped into 15 different subject categories. A quarter (25.2%) of the publications was on “climate change adaptation” followed by those on “climate change impacts/implications” (23.3%) and “climate variability” (13.8%). In other words, these three areas occupied nearly two-thirds (62.3%) of all climate change scholarly publications produced in Tanzania for the period of 2006 to 2016 as presented in Table 2.

Joint research

The authorship pattern in the area of climate change in Tanzania during the period of 2006 to 2016 shows a joint research trend. Only 99 (31%) publications have been produced by single authors and the rest (68.9%) have been jointly authored by two or more authors as shown in Table 3. The average number of authors per paper was 2.61. The degree of collaboration among scholars in the area of climate change computed as the ratio of the total number of collaborative publications (Nm) to the total

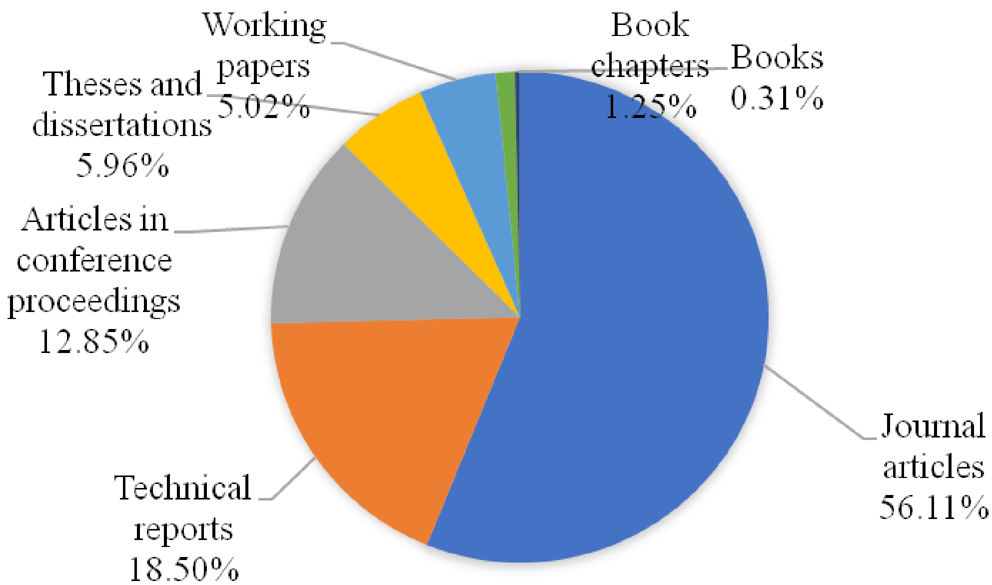

Figure 1. Publication distributions by type.

Table 2. Distribution of subject categories on climate change research.

S/N	Subject category	Frequency	Percent
1	Climate change adaptation	82	25.2
2	Climate change impacts/implications	76	23.3
3	Climate variability	45	13.8
4	Climate change mitigation	31	9.5
5	Climate change vulnerability	28	8.6
6	Climate change effects	14	4.3
7	Economics of climate change	7	2.1
8	Climate change finance	7	2.1
9	Climate extremes	7	2.1
10	Climate resilience	7	2.1
11	Climate volatility	6	1.8
12	Climate scenarios	6	1.8
13	Climate change projections/prediction	5	1.5
14	Seasonal forecasts	3	0.9
15	Climate change awareness	2	0.6
	Total	**326***	**100.00**

*The total output is more than the actual output as some publications addressed more than one sub-discipline.

number of multi-authored publications plus the number of single-authored (Ns) publications (that is, C = Nm/Nm + Ns) (Subramanyan, 1983) was 0.69. This indicates a relatively high degree of teamwork in climate change research. This might be due to the fact that research in climate change is multidisciplinary in nature which calls for researchers from diverse fields to share their expertise. However, when a number of authors collaborate on a particular article, the actual contribution of each scholar is difficult to determine.

Indices for all publications

The h-index of the retrieved publications was 19 which means that the authors' 19 publications had been cited

Table 3. Joint research patterns in climate change.

Authorship pattern	No. of publications	Percentage
Single authored publications	99	31.0
Publications with 2 authors	69	21.6
Publications with 3 authors	52	16.3
Publications with 4 authors	53	16.6
Publications with 5 authors	37	11.6
Publications with 6 or more authors	9	2.8
Total	**319**	**100.0**

Table 4. Average indices for all publications.

Metrics	Statistics
h-index	19
g-index	34
hc-index	19
hI, norm	13
hI, annual	1.30
hm-index	13.95

19 or more times each, and the rest of the publications had fewer than 19 citations. When more weight is given to his/her highly cited publications, the g-index was 34 and when more weight is given to newly published works, the hc-index is 19. The hI norm-index which evaluates the effects of co-authorship and estimates the "per author impact" was 13. The hI, annual which is an indicator of an individual's average annual research impact 1.30 (Table 4).

Citation pattern of the research output

Citation analysis measures the impact of each article by counting the number of times they were cited in other articles. High levels of citations to a scientific publication are interpreted as signs of scientific influence, impact and visibility. The citation status of Tanzanian publications on climate change reveals that over half (179; 56.1%) of the publications were cited at least once. These 179 publications were cited 1676 times at the rate of 5.14 average citations per publication and 167.60 cites per year. The top 10 highly cited publications contributed over one third (622; 37.1%) of the total citation counts. The most cited article is titled "Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania" published in Environmental Science and Policy in 2008 with 26 cites/year. This is followed by an article titled "Impacts of climate change, variability and adaptation strategies on agriculture in semi-arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania" published in African Journal of Environmental Science and Technology in 2008 which had 22.2 cites per year (Table 5).

Table 6 lists the top 10 most prolific authors on climate change in Tanzania during the ten-year period. These 10 most productive authors contributed nearly 37% of the total publications with an average of 12 publications per author. Of these seven most productive authors, six (P. Z. Yanda, R. Y. M. Kangalawe, A. E. Majule, E. T. Liwenga, A. Mascarenhas and J. G. Lyimo) are affiliated to the University of Dar-es-Salaam and two (S. D. Tumbo and P. K. T. Munishi) to the Sokoine University of Agriculture. In other words, these two institutions (that is, University of Dar es Salaam and Sokoine University of Agriculture) had contributed the most in the climate change research in Tanzania.

CONCLUSION AND RECOMMENDATIONS

The present study analysed the climate change research output in Tanzania for the period between 2006 and 2016 using bibliometric techniques. The results have demonstrated a predictable growth of climate change literature in the country, although the total number of publications was generally low despite the fact that climate change has been a topical area for over ten years. Most literature on climate change in Tanzania was contributed by scholars from the University of Dar-es-Salaam and Sokoine University of Agriculture and the larger proportion was in the form of journal articles. The most research areas were "climate change adaptation", "climate change impacts/implications" and "climate variability". There was a good level of team spirit with many publications having multiple authors. Indices such as h-index were generally low indicating the low level of research output and its impact. A good number of publications had been cited by other scientists.

Given the growing incidence of the phenomenon, it is necessary to enhance research on climate change in Tanzania. Research institutions, funding agencies and

Table 5. Highly cited publications.

S/No	Publication's bibliographic details	Citation count	Cites/year
1	Pavavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. Environmental Science and Policy, 11 (7):642–654	208	26.0
2	Rowhani, P., Lobell, D. B., Linderman, M. and Ramankutty, N. (2011). Climate variability and crop production in Tanzania. Agricultural and Forest Meteorology, 151 (4):449-460.	111	22.2
3	Lema, M. A. and Majule, A. E. (2009). Impacts of climate change, variability and adaptation strategies on agriculture in semi-arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania. African Journal of Environmental Science and Technology, 3 (8):206-218.	95	13.6
4	Ahmed, S. A., Diffenbaugh, N. S., Hertel, T. W., Lobell, D. B., Ramankutty, N., Rios, A. R. and Rowhani, P. (2011). Climate volatility and poverty vulnerability in Tanzania. Global Environmental Change, 21(1):46-55.	51	10.2
5	Mongi, H., Majule, A. E. and Lyimo, J. G. (2010). Vulnerability and adaptation of rain fed agriculture to climate change and variability in semi-arid Tanzania. African Journal of Environmental Science and Technology, 4 (6): 371-381.	54	9.0
6	Tacoli, C., 2011. Not only climate change: mobility, vulnerability and socio-economic transformations in environmentally fragile areas in Bolivia, Senegal and Tanzania (No. 28). IIED.	43	8.6
7	Zahabu, E. (2008). Sinks and sources: a strategy to involve forest communities in Tanzania in global climate policy. Doctoral thesis. University of Twente.	50	8.3
8	Nelson, V. and Stathers, T., 2009. Resilience, power, culture, and climate: a case study from semi-arid Tanzania, and new research directions. Gender & Development, 17(1):81-94.	53	7.6
	Jones, A.E., Wort, U.U., Morse, A.P., Hastings, I.M. and Gagnon, A.S., 2007. Climate prediction of El Niño malaria epidemics in north-west Tanzania. Malaria Journal, 6(1), p.1.	40	4.4
9	Jonsson, P., Bennet, C., Eliasson, I. and Lindgren, E.S., 2004. Suspended particulate matter and its relations to the urban climate in Dar es Salaam, Tanzania. Atmospheric Environment, 38(25), pp.4175-4181.	47	3.9

Table 6. Most productive authors in the area of climate change.

S/N	Authors	No. of publication
1	P. Z. Yanda	19
2	R. Y. M. Kangalawe	18
3	S. D. Tumbo	17
4	P. K. T. Munishi	13
5	A. E. Majule	12
6	E. T. Liwenga	10
7	J. G. Lyimo	10
8	R. S. Shemdoe	7
9	A. Mascarenhas	6
10	A. S. Kebede	6
Total		**118**

the government should make concerted efforts to foster the research on climate change. The main limitation of this study is its focus on publications and citations that were available online and those that had "climate" and

"Tanzania" as keywords in their titles. This means that publications and citations that were not available on the web were not retrieved.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Daily activity, feeding ecology and habitat association of Gelada baboon (*Theropithecus gelada*) around Debre-Libanos, Northwest Shewa Zone, Ethiopia

Kassahun Abie[1]*, Afework Bekele[2] and Addisu Mekonen[2]

[1]Department of Wildlife and Ecotourism Management, College of Agriculture and Natural Resource, Wolkite University. P. O. Box 07, Wolkite, Ethiopia.
[2]Department of Zoological Sciences, College of Natural Sciences, Addis Ababa University, P. O. Box. 1176, Addis Ababa, Ethiopia.

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Daily activity, feeding ecology and habitat association of Gelada baboon around Debre-Libanos was investigated using direct field observations from August 2012 to March 2013. Instantaneous scan sampling method was used to collect behavioral data from two selected study groups of gelada baboons on an average of 7 days per month. The focal groups were identified by the natural marking, size, coat color and facial features of some distinctive members of each of these groups. Data were analyzed using descriptive statistics, and responses were compared using Chi-square tests. On average, Gelada baboons spent more time on feeding (56.12%) than any other activity. They spent 16.76% of their time moving, 16.05% socializing, and 9.42% resting. Other activities such as vocalization, defecation and looking at the observer occurred infrequently (1.66%). They depended fully on grass during the wet season (82.1%), but during the dry season, they fed on roots (21.35%) and leaves (20.04%) in larger proportion. There was significant variation among the activity time budget of gelada baboons in the whole study period (χ^2=46.779, df=4, p<0.05). The vegetation type utilization and distribution of Gelada baboon of the study area indicated a marked preference for open cliffy grassland habitat. The overall gelada baboon's habitat utilization showed statistical difference in the study area (χ^2=742.660, df=2, p<0.05).

Key words: Foraging, Gelada baboon, habitat association, daily activity.

INTRODUCTION

The daily activity pattern of Gelada baboons is influenced by seasonal and climatic conditions. Departure from the sleeping site, the time spent traveling, the maximum distance covered per day, and the number and length of resting and feeding periods are all variable from one day to the next and among groups of baboons (Strum, 1987).

*Corresponding author. E-mail: kassahun.abie@wku.edu.et.

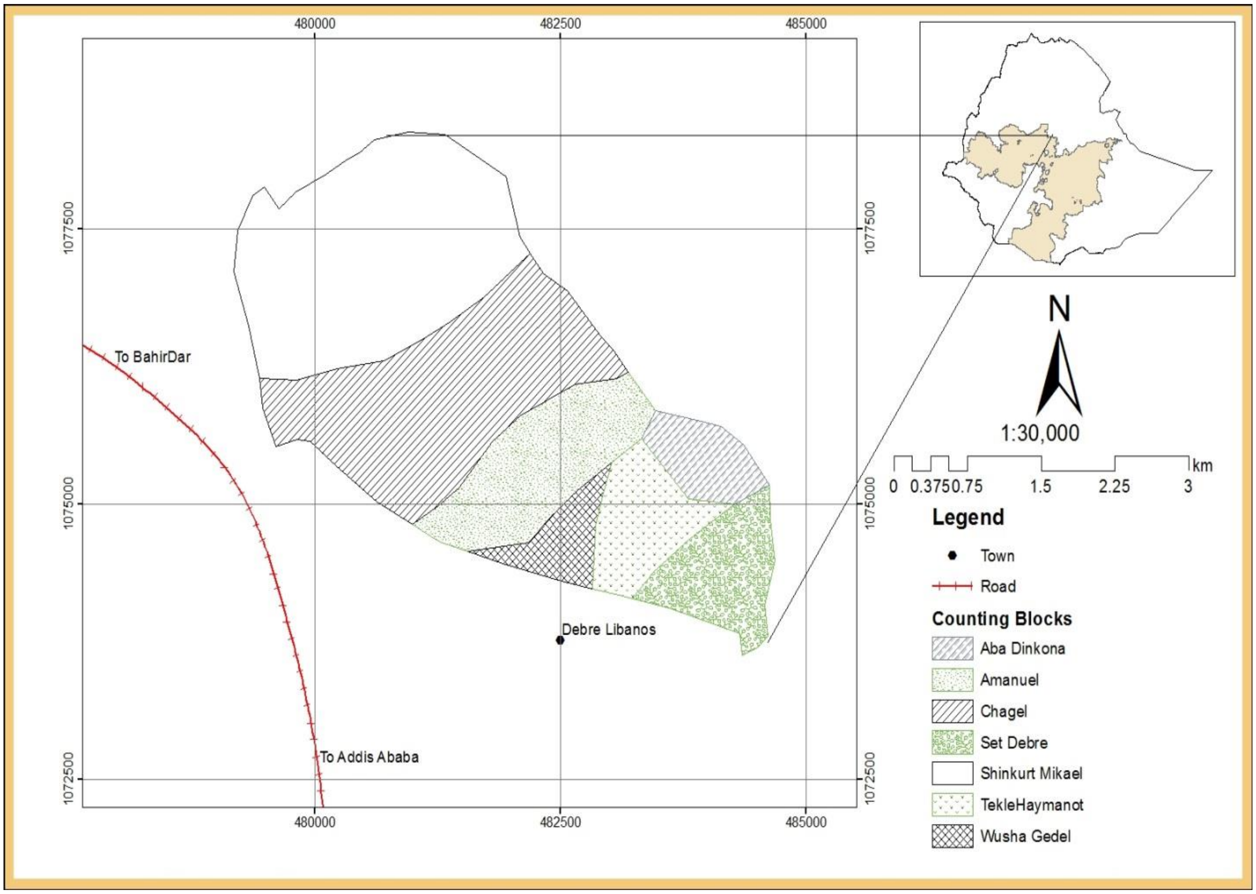

Figure 1. Map of the study area.

Although, over 90% of gelada baboon's diet is grass blades, Gelada baboons are flexible foragers; they change their diets in response to changes in available resources (Hamilton et al., 1978; Barton and Whiten, 1993). When the availability or nutritional value of available grass changes, they shift to flowers and digging for rhizomes and roots and foraging for herbs (Richard, 1985; Dunbar, 1998). Baboons consume a variety of grasses, fruits, flowers, seeds, pods, leaves, gum and underground plant parts such as corms, bulbs, rhizomes and tubers (Rowell, 1966; Altmann and Altmann, 1970).

Ecological factors, such as food distribution and availability are among the most important determinant of the social organization of gelada baboons. It also has an impact on social structure and mating system. Gelada baboons form large groups or aggregations on a permanent or regular basis. These large groupings can be determined by various ecological needs such as predation avoidance, optimal habitat use and foraging, male mate defense and infanticide avoidance (Dunbar, 1983).

Gelada baboons need cliffs for sleeping and the use of relatively treeless and montane grasslands for foraging (Yalden et al., 1996). Gelada baboons prefer the gorge side that provides refugia from the incursion of man, protection from predators, and a habitat to which the species is particularly well adapted (Jolly, 1972; Dunbar, 1980).

Even though, the gelada baboon population is recorded in the northwest Shewa zone of Oromia Regional State, no research has been conducted on daily activity, feeding ecology, habitat association, and other relevant issues about the species in the area. Therefore, the intention of this research was to fill this gap and provide relevant baseline information for different stakeholders.

MATERIALS AND METHODS

Description of the study area

The present investigation was conducted at Debre-Libanos area, which is located in the central highlands of Ethiopia (9° 43' 0" North, 38° 52' 0" East). Debre-Libanos is found in the Oromia Regional State, within the Northwest Shewa zonal administration (Figure 1). It is located 104 km northwest of the capital city, Addis Ababa and 16 km from the zone capital (Fiche). The area has extremely steep

Table 1. Major activities of Gelada baboons recorded during the study period.

Major activity	Observed characteristics
Feeding	Manipulated, masticated, and ingested a particular food item
Moving	Walking, jumping or running at a steady pace
Resting	Sitting or lying
Grooming	Using hands to explore or to clean its body or the body of another gelada baboon
Playing	Chasing, hitting, and other vigorous activities involving exaggerated movements and gestures by two or more gelada baboons interacting in a non-aggressive manner
Aggression	Chasing, biting, grabbing, displacing, or threatening another gelada baboon or crying as a result of aggression
Sexual activity	Groomed the sexual organs, mounted another gelada baboon, or engaged in mating activity
Other activities	Performing activities such as vocalization, defecation, looking towards the observer, or other activities that do not fit in any of the above categories

escarpments leading up to a strip of plateau, with altitude ranging from 2150 to 2650 m above sea level.

It has a bi-modal rainfall pattern, with rainfall ranging from 800 to 1200 mm during May to September. The dry season is from December to March. The annual average maximum and minimum temperature of the study area are 23 and 15°C, respectively.

Data collection methods

The study was conducted from August 2012 to March 2013 to cover both wet and dry seasons. Quantitative and qualitative data were collected on the diurnal behavioural activity patterns, feeding behaviour, and habitat utilization of gelada baboon.

A preliminary survey was conducted in the study area in the first week of August 2012. During this period, the distribution of gelada baboon in the study area was assessed and vegetation type was classified. The survey revealed that the vegetation cover and topography of the study area was not homogenous.

Instantaneous scan sampling method was used to collect behavioural data on multiple group members (Altmann, 1974). Activity types and dietary data were collected from two selected and partially habituated neighbouring study groups of gelada baboons, Groups A and B, on an average of 7 days per month from August 2012 to March 2013. The focal groups were identified by natural markings, size, coat colour and facial features of some distinctive members of each of these groups.

The behaviour of gelada baboon was investigated by approaching the individual as much as possible with binoculars to observe activities and food items consumed. All identifiable daily activity was recorded on separate behavioural data sheets (Sutherland, 1996). To record the activity pattern of gelada baboon, the methods described by Dunbar (1992) and Mekonen et al. (2010) were used. The activity of each gelada baboon individual in each group under observation was recorded at 15 min intervals from 07:00 to 12:00 and 13:00 to 18:00 when the animals were most active and visibility was good (Dunbar, 1992).

The major activities were recorded following Fashing (2001a, b). Major activities displayed by Gelada baboons during the study were identified (Table 1).

Activity time budget was calculated by dividing the proportion of the number of behavioural records for each activity category by the total number of activity records each day. Then, it was summed within each month to construct monthly proportions of time budgets. The grand mean proportion of the monthly budgets provided the overall wet and dry season time budgets, as well as the overall time budgets during the entire study period (Di Fiore and Rodman, 2001).

During instantaneous scan sampling, feeding data were collected at 15-min intervals on members of the study groups. An animal was followed during active feeding time to observe the plant species that were consumed. Focal animals were observed with the naked eye and with binoculars depending on the distance between the observer and gelada baboons. During activity scan sampling, if geladas were observed feeding, the type of food item was recorded on a standardize data sheet (Fashing et al., 2007). The species consumed was noted in the field if possible and unidentified species were collected for further taxonomic identification in the National Herbarium, Addis Ababa University.

Diet composition was evaluated by calculating the proportion of different food items and species consumed by gelada baboons. The daily food items and type of species consumed by the groups were summed up within each month to construct monthly proportion of food items and food types consumed. The monthly proportion of each food item in the scans was calculated as the total number of monthly individual scans for each food item divided by the total number of individual scans for all food items. The relative proportion of plant species used as food for gelada baboons was calculated from the monthly percentage contribution of different species (Fashing, 2001b; Di Fiore, 2004).

Grand means of the monthly proportions of food items and species consumed were used to calculate the overall wet and dry season diets as well as the overall diets for the entire study period. The percentage contribution of food items and the species consumed by the combined study groups between seasons were compared by using Chi-square test.

During each census, the type of vegetation where the animals were observed and the food taken were recorded for each season (Campton et al., 1988). Utilized vegetation type refers to the habitat where most gelada baboons were observed grazing alone or in groups at a definite time (Andere, 1981). The method of Norton-Griffiths (1978) was used to describe the dry and wet season's distribution and utilization of the vegetation type.

Data analysis

The data were pooled and SPSS software for Windows Evaluation Version 20 was used for statistical analysis using descriptive statistics and Chi-square test. Statistical tests used were two-tailed with 95% confidence intervals. Chi-square test was used to compare behavioural ecology of gelada baboons between wet and dry seasons.

Table 2. Percentage of time spent in each activity during wet and dry seasons.

Activity	Wet season	Dry season	Average	χ2	df	P-value
Feeding	54.14	58.1	56.12	6.967	1	0.008
Moving	15.03	18.50	16.76	12.409	1	0.000
Socializing	18.12	13.98	16.05	11.782	1	0.001
Resting	11.13	7.70	9.42	12.399	1	0.001
Others	1.60	1.73	1.66	0.269	1	0.604

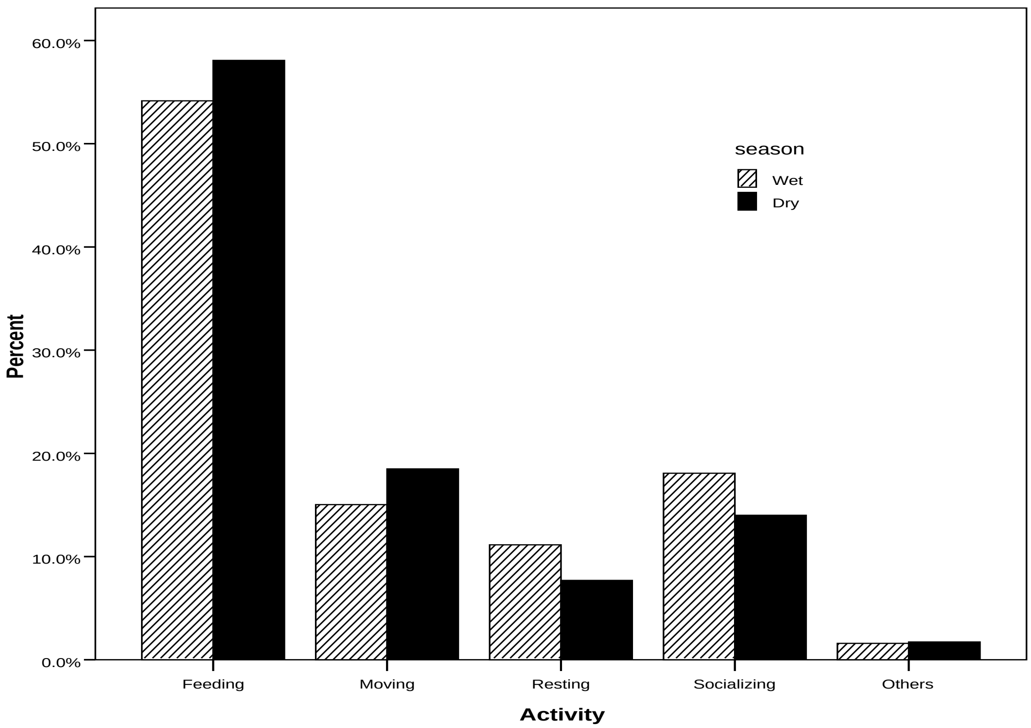

Figure 2. Activity time budget of gelada during wet and dry seasons during 2012-2013.

RESULTS

A total of 5600 individual behavioural observations on the various activities were recorded throughout the study period. Feeding accounted for the >50% of the activities in both the wet and dry seasons (Table 2).

During the study period, gelada baboons spent more time in feeding (58.1%) during the dry season than during the wet season (54.14%). The difference was statistically significant. There was a significant difference in moving, resting and socializing between wet and dry seasons. However, as compared to the whole activities, only less amount of time was spent in other activities like vocalization, defecation and looking at the observer (1.60%) during the wet season and (1.73%) during the dry season (Figure 2).

A total of 3150 feeding behaviour observations were recorded from scan sampling of the total activities of the two combined study groups. Gelada baboons depended on variety of food resources that are important for overcoming harsh conditions. A total of 19 species were identified in the study area as a major feeding item of gelada baboons (Table 3).

The average time spent feeding on grass (63.23%), herb leaves (13.25%), herb roots (11.59%), corms (3.07%), unidentified food items (6.4%) and others(2.48%) is shown in Table 4.During the wet season, the feeding habit covered nearly 82.1% grass, of which long grass blades, short grass blades, and grass roots formed 19.01, 36.6 and 26.39%, respectively, and 6.45% herb leaves, 1.82% herb roots, 0.74% of corms, 6.2% of unidentified tubers and 2.7% on others. Roots

Table 3. List of plat species consumed by gelada baboons in the study area (L, leave; R, root; FR, fruit; SGB, short grass blade; LGB, long grass blade).

Local name	Scientific name	Family	Food items consumed
Agam	*Carissa spinarum*	Apocynaceae	FR
Akrma	*Eleusine floccifolia*	Gramineae	L
Arum	*Anthricus sylvestris*	Apiceae	L, R
Chifrg	*Sidas chimperiana*	Malvaceae	L
Dhittacha	*Dodonea angustifolia*	Sapindaceae	L
Embacho	*Rumex nervosus*	Polygoneceae	*L,R*
Girar	*Acacia negrii*	Fabaceae	L
Kega	*Rosa abysinica*	Rosaceae	FR
Koshim	*Dovyalis abysinica*	Flacourtiaceae	FR
Kulkual	*Opuntia ficusindica*	Cactaceae	FR
Mech	*Guizotia scabra*	Asteraceae	L, F
Qarasoo	*Hyparrhenia hirta*	Poaceae	SGB, R
Serdo	*Cynodon dactylon*	Gramineae	L
Serdo	*Andropogon zdistachyos*	Poaceae	LGB, R
Serdo	*Cyperus erectus*	Cyperaceae	SGB, R
Serdo	*Isole piscostata*	Cyperaceae	SGB, LGB, R
Serdo	*Brachiaria comate*	Poaceae	SGB, LGB
Warka	*Ficus vasta*	Moraceae	FR, L
Weyra	*Olea europaea*	Oleaceae	FR

Table 4. Proportion of food intake during wet and dry seasons of 2012-2013.

Food items	Wet season (%)	Dry season (%)	Average (%)
Grass	82.10	44.35	63.23
Unidentified	6.20	6.60	6.40
Corms	0.74	5.40	3.07
Others	2.70	2.26	2.48
Herb leaves	6.45	20.04	13.25
Herb roots	1.82	21.35	11.59

and leaves are consumed more during the dry season than the wet season. During the dry season, the availability of grass was lower as compared to the wet season, so baboons fed on the roots of dried grass and leaves and roots of perennial plants in larger proportion.

During the dry season, grasses, herb leaves, and herb roots comprised most of the diet. There was a significant difference in time spent feeding on grass between the wet and dry seasons (χ^2=234.228, df=1, $p<0.05$)

Gelada baboons spent more time feeding on herb roots and leaves during the dry season as compared to the wet season. There were significant differences between wet and dry seasons in feeding on herb leaves (χ2=93.889, df=1, $p<0.05$) and herb roots (χ2=240.286, df=1, $p<0.05$). The difference in time spent for feeding on corms between wet and dry seasons was also statistically significant (χ2=51.194, df=1, $p<0.05$). There was a significant difference in time spent feeding on other food items between wet and dry seasons (χ2=1.282, df=1, $p<0.05$).

The distribution of gelada baboons across habitats is based on the availability of food and the distance from human settlement. They are distributed in open cliffy grassland. In Debre-Libanos area, Gelada baboons are distributed into three habitat types: open cliffy grassland, bushland and farmland (Table 5). The distribution varied between wet and dry seasons.

More than half of the population was encountered in open cliffy grassland. During the wet season, 79.54% of gelada baboons were counted in the open cliffy grassland area, 15.4% in the bushland with few scattered trees, and only 5.05% in farmland habitats. During the dry season,

Table 5. Number of Gelada baboons counted in different habitats during 2012-2013.

Season	Open cliffy grassland	%	Bushland	%	Farmland	%
Wet	1306	79.54	253	15.41	83	5.05
Dry	788	50.09	421	26.76	364	23.140
%	64.82		21.08		14.1	

their distribution in farmland increased (23.14%), because the farming land was abandoned. Their distribution showed a very high utilization for grass. They were observed primarily as grazers, mainly preferred to graze on grasses during both seasons. However, during the dry season, they fed on herb leaves and roots dominantly due to the less availability of grasses to satisfy their need. There was a significant difference on gelada baboon's habitat utilization in the study area (X^2=742.660, df=2, p<0.05).

DISCUSSION

According to Dunbar (1992), time spent for different activities in animals is an indication of balancing energy budget. Gelada baboons that can easily obtain food spend more time resting and grooming than feeding and moving. However**,** gelada baboons of Debre-Libanos spent more time feeding and moving than resting and socializing. Grooming maintains social relationships, and more time has to be devoted to grooming in order to maintain the cohesion of large groups, yet these activities accounted for a relatively small proportion of the time budget of the baboons in the study area. Gelada baboons in this study may have had to spend more time feeding, as the cliffy habitats did not appear to provide enough amount of food and other resources.

In the study area, gelada baboons spent more time feeding during the dry season than the wet season. The possible reason may be due to a reduction in availability and quality of food during the dry season. Gelada baboons spent more time moving during the dry season as compared to the wet season as well. This might be due to the restriction in small and cliffy areas during the wet season. As crops are harvested, the farmland becomes free during the dry season. When they feed, they do not forage in one place for a long time, rather they move from one place to another. As a result, moving takes the second position in their daily activity patterns. Ayalew (2009) also obtained similar results on the activity time budget of gelada baboons. During the dry season, due to shortage of food, baboons covered a greater distance in search of food. The seasonal difference in activity time budgets of animals may be due to environmental variables (Shah, 2003). Food availability, weather condition, nutritive demand and protection from predation may be the determining factors for slight variation during the wet and dry season's activity patterns (Delany and Happold, 1979; Roberts and Dunbar, 1991).

Gelada baboons are efficient grazers. Grasses are the most preferable diet of gelada baboons. However, when the availability of grasses is restricted, they shift their food preference to herb leaves, roots and corms. As reported by Iwamoto (1993), Gelada baboons predominantly feed on grasses, but during the dry season, when the availability of grass decreases, they shift to leaves and roots of herbs. They are forced to feed on young leaves and roots of herbs, even though gelada baboons preferred grass.

Dunbar (1983) showed that gelada baboons prefer open grassland habitats; however in Debre-Libanos gelada baboons preferred cliffy habitats. This may be due to the anthropogenic effect on the area. During the wet season, they were able to get enough food and water, and also most of the study area was farmed. As a result, gelada baboons concentrated themselves on cliffy part of the study area. During the dry season, the farmland was harvested and consequently they had more space to move around. Availability and quality of food deceases during dry season, therefore, gelada baboons migrated to different areas adjacent to the study site, as food can be limited at the edges of the cliff (Wallace, 2006). Their distribution is based on the availability of food and distance from humans. To avoid human conflict and other predators such as leopards, they are concentrated at the edge of the cliff. The change in the quality of the habitat could be the major factor for differences in distribution across habitats during wet and dry seasons. The difference in food requirements also forced them to move to different parts of the study area.

Conclusion

Due to high altitude and isolation from the surrounding habitats, the Ethiopian highlands are confounded with endemism (Kingdon, 1989). Debre-Libanos is a part of the Ethiopian highlands and is the home for *Theropithecus gelada* which is an endemic primate of the country. The data collected in the present study provides information on daily activity, feeding behaviour and ecology of gelada baboons. Their distribution in the habitats varied during the wet and dry seasons, likely to meet the food intake demands when the habitat quality decreased in the dry season. Conservation efforts of Gelada baboons must include the protection of habitats used during both seasons.

RECOMMENDATIONS

The following points are suggested to reduce the problems and conserve the population of gelada baboon properly:

1. Public awareness and develop sense of ownership showed be created among the local community.
2. The area should be demarcated and declared as a community conservation area.
3. Buffer zones should be established to reduce the movement of wildlife and as a result it would reduce human-wildlife conflicts during the crop growing period.
4. The local people should be resettled to the buffer zone to reduce negative anthropogenic impacts in the study area.
5. Prior to this study, no comprehensive Gelada baboon census of the area has been carried out. Gelada baboon population censuses should be carried out in the future to determine the population trends at Debre-Libanos.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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