Impacts of Industrial Crop Expansion on Biodiversity: Evidence from case study in Ethiopia

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Abstract: Sub-Saharan Africa is one of the key region for the conservation of biodiversity as it hosts nine out of the 34 global biodiversity hotspots. The rapid expansion of industrial crops such as cotton and sugarcane in this region grow into a source of concern for its biodiversity impacts. We assessed biodiversity impacts with a case study area in Ethiopia where sugarcane is rapidly expanding. This study employed a trait based approach to assess the detrimental effects of sugarcane expansion to five taxonomic groups: trees, mammals, birds, insects and rodents. We selected these groups to understand their response to environmental risk from sugarcane farm, ethanol and sugar production process as a proxy for the response of wider biodiversity. List of the groups and their population trend was acquired through field survey and key informant interview. In addition, the study employed the previous study which compared nearby bushland with sugarcane farm in terms of rodent populations. We compiled species resource requirement against five key sugarcane related environmental risks, i.e. a) land clearing and grabbing; b) use of agrochemicals; c) harvest time fire; d) hunting and poaching by workforces; and e) effluent from the factory. Resource requirement matrixes were prepared, based on key informant interview and secondary sources. Using the overlaps of species resource requirement and environmental risk we calculated the risk score for each species to identify the past impacts of sugarcane farm, sugar and ethanol production processes. The result showed a decrease in the diversity and richness of indigenous tree species, decrease in insect and rodents across the landscape. The population of mammals and birds adapted to human disturbance remained the same while forest species decreased.

Key words: *Biodiversity, Industrial crops, Sugarcane, Cross-taxonomic index, Environmental Risk*

1. INTRODUCTION

Sub-Saharan Africa is one of the key region for the conservation of biodiversity as it hosts nine out of the 34 global biodiversity hotspots. Yet, despite the high desire for conservation priority, there is rapid loss of biodiversity in this region. Agriculture is the primary driver of habitat loss and threat to biodiversity in all human-dominated landscapes[1)]. In the same way, agricultural expansion and intensification driven by population growth has hastened a decline of biodiversity in Sub-Saharan Africa[2)]. Unfortunately, in the past decade biodiversity in Sub-Saharan Africa has faced additional challenges from the expansion of industrial crops[3)]. Chiefly, industrial crops for biofuels tend to replace and/or push the traditional mosaic agriculture to the natural habitat. This will have a detrimental effect on biodiversity which continue to exist outside of the protected areas in agriculture or marginal lands.

Biofuel expansion globally is driven by energy security and climate change mitigation goals. In Sub-Saharan Africa there are additional drivers such as attractions of foreign investment, revenue from export earnings, and a contribution to economic development[4)]. The desire to ensure economic and climate change mitigation goals has obscured policy measures to counter biofuel related biodiversity loss. So currently, there is deep-seated concern that biodiversity loss could reverse the envisaged benefits of biofuels.

However, there are multiple ways of biodiversity loss by industrial crops for biofuels. The notable way is to measure land use change when it replaces the natural ecosystems [5)]. For instance, oil palm was a cause for 2.8% and 6.5% of direct deforestation in Indonesia and Malaysia, respectively, while soybean for biodiesel in the Brazilian state of Mato Grosso is responsible for up to 5.9% of deforestation[6)]. Converting biodiversity rich habitats to homogenous biofuel crops reduces species' density to the level where they can no longer play their ecological role. In opposite, planting of environmentally friendly biofuel crops on the degraded land has a potential to create additional habitat for biodiversity.

The other way of biodiversity impact of biofuel is through indirect land-use change (iLUC), when biofuel crops displaces previously productive land use (e.g., agriculture or pasture) to other areas, causing deforestation or conversion of natural habitat[7]. ILUC is more complex to measure as it involves areas far away from biofuel farm in the same region, in different region of the same country or even in different countries. The indirect land use change due to sugarcane expansion in Brazil was estimated as 0.23 to 0.38 ha per 1000 liters of ethanol[8].

Soil, water and air pollution from biofuel cultivation, transportation, harvest and refining also hasten biodiversity loss[9]. Intensive application of agrochemicals is key source of pollution followed by harvest time sugarcane burning. Agrochemicals residue and effluents from industrial processes leads to eutrophication while repeated tillage and longtime irrigation are a cause for soil erosion and salinity respectively. Moreover, expansion of industrial crops to the natural ecosystem cause more CO_2 emission than emission reductions that these biofuels would provide by replacing fossil fuels[10].

Biofuel crop production and industrial processing consume too much water which competes with other crops and biodiversity[11]. For instance, the water footprint of sugarcane per liter of ethanol is 2,450, 2,995, 2,775 liters in Brazil, India, USA respectively [12].

Moreover, some of the biofuel crops are either invasive or agent for invasive species. The International Union for Conservation of Nature (IUCN) indicated that many plant species currently considered as biofuel are potentially invasive[13], they pose greater risk to biodiversity. On top of this, biofuels may also result in the spread of wildlife related diseases[14].

As the biodiversity impact of biofuel varies with crops types, original habitat types, farm practices, technologies and refining practices, researches on biodiversity loss specific to particular crop and locality in SSA is crucial to recommend appropriate biodiversity conservation scheme. But researches on biodiversity change is often limited by lack of time series data[15] which was also a problem to evaluate implementation of CBD target 2010. To bridge data gaps land cover change from satellite image has frequently used as a proxy measure however land cover change gives only a general information of habitat quantity with relatively little information on habitat quality or component species.

Recently, pressure based biodiversity change assessment was applied in broad scale assessments including in series of Global Biodiversity Outlooks (GBOs). Natural Capital Index (NCI)[16] and Biodiversity Intactness Index (BII)[17] are popular pressure based biodiversity metrics. The NCI measures ecosystem quantity (proportion of original vegetation cover) and ecosystem quality (proportion of original species composition). The later was measured indirectly as ratio of current to historic percentage of crown cover which is difficult to apply on farmland biodiversity assessment and non-vegetation components. Hence, Cross-taxonomic Sustainability Index (CSI)[18] estimates biodiversity loss by examining the overlaps of species resource needs and environmental change brought by projects, policy or programmes. Industrial crops for biofuel specially sugarcane has got much attention in Ethiopia. The government has established new sugar factories, expanded sugarcane farm and upgraded the crushing capacity of existing factories in the last decade. Wonji Shoa, for instance, was expanded three times but the implication for biodiversity and food security have never seen in detail[19]. Therefore, in this study, we employed trait based approach to measure the detrimental effect of sugarcane industry on biodiversity in Wonji-Shoa.

2. METHOD AND MATERIALS

(1) Study Area

The assessment was conducted in January and February, 2016 at Wonji Sugar Factory in Ethiopia. Wonji Sugar Factory is located in Adama and Bora Districts of Oromia Regional State, about 110km from Addis Ababa and about 10km south of Adama town **(Fig. 1)** with latitude 8°31’N and longitude 39 °12’E, at altitude of 1550 meter above sea level. The average annual rainfall of Wonji is 800mm with maximum and minimum temperatures 26.9°C and 15.3 °C respectively.

Initially state farm was supplying the sugarcane. Twenty years later contract farming was introduced in 1975. Currently, 12,000 hectares of land is covered by sugarcane out of which 7,000 hectares is owned by out-growers with 7633 household members [19].

(2) Method

Semi-structured questionnaire was administered to twenty key informants. Elderly persons who lived in the area for long time were purposefully selected due to their knowledge of pre-sugarcane condition. The key informants were asked to list species belongs to the four taxonomic groups they are very familiar with; their foraging and nesting habitat information;

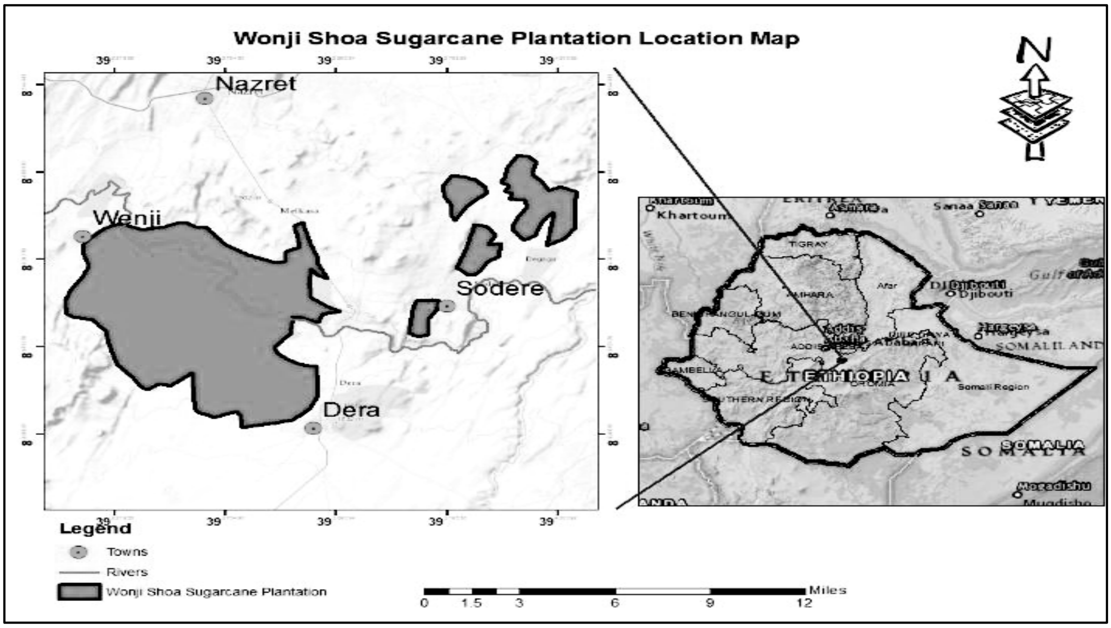

Fig 1: Location Map of the Study area

their insight on qualitative population trends of those species (increasing, the same, decreasing); and they were also asked to list environmental risks from the sugarcane industry they consider responsible for the decline or disappearing of species. Joint field walk was made to the remnant forest patches to identify species of trees listed by key informants. Scientific name, local name and English name of the species were recorded. Plant specimens of unidentified species were taken to plant herbarium of Addis Ababa University. Information on ten rodent populations and their resource requirements were gathered from literature[20)21)].

In addition to the primary sources, information on the species resource requirement was gathered from secondary sources. Five key environmental risk of sugarcane industry which contributed to the decline of biodiversity were ranked by key informants (**Fig. 2**). The top responsible five environmental risks were identified as i.e. a) land clearing and grabbing; b) use of agrochemicals; c) fire; d) hunting and poaching by workforces; and e) effluent from the factory.

Using the overlaps of five top environmental risk risks and species' resource requirements, we calculated risk score for each species. The risk score reflects the proportion of a species' resource requirements affected by that change and, when summed across all five changes, provide an overall risk score which represents the impact of sugarcane related risks on that species.

The risk assessment framework applied to bird species in UK farmland[18)] was adopted. The framework assumed that each source of risk has equal weight in terms of its relationship to population growth and different risk sources have an additive effect[22)].

Species which are found in one or two habitat/biotope were scored as having a major reliance (R=1), those that utilize three or four as having moderate reliance (R=2), five of more biotopes were scored as having minor reliance on the subject farmland (R=3).

The risk score for each taxon was calculated as per the risk framework developed for UK farmland biodiversity[22)]:

(a) Rodents

$$RS = (Dt + Nt)/R \tag{1a}$$

Where RS is risk score, D_t is the risk associated with food abundance or availability, N_t is the risk score associated with reduced breeding success and R is the species' reliance on habitat at stake.

$$Dt = A/(D * F) + B/F \tag{2a}$$

where A = number of points of overlaps of risks and species' use of dietary components, B = number overlaps points between risks and species' use of foraging habitat components, D = total number of dietary components used by the species and F = total number of foraging habitat components used by the species.

$$Nt = C1/N + C2/N \tag{3a}$$

where C1 and C2 = number of points risk overlaps on species' use of nesting habitat components which leads to condition of reduced nesting success in existing habitat and loss of habitat respectively and N = number of nesting habitat components used by the species.

b) Mammals

The risk score for mammals include additional risks associated directly with hunting and poaching of reproductively viable members on breeding success.

$$RS = \left(A/(D*F) + B/F + C1/N + C2/N + C3/Ra \right) / R \quad (1b)$$

Where C3 is risk on reproductive active male or female or on both, Ra is number of reproduction active components.

c) Birds

The risk score for birds depends on the impact of sugarcane on the food availability and nesting success which is similar with the risk framework of rodents detailed under (a).

d) Honey bee

The impact on resource requirement of honeybee is associated with reduced foraging activity potential, reduction in forage plant availability, reduced nest site availability.

$$RS = (Pt + Ft + Nt)/R \quad (1d)$$

where Pt is the risk score associated with reduced foraging activity potential, Ft is the risk score associated with the reduction in forage plant availability, Nt is the risk score associated with reduced nest site availability and R is the species' reliance on farmland.

$$Pt = Gt/(G*H) \quad (2d)$$

where Gt = number of generations of a species active in the activity periods aff ected by loss of habitat, G = total number of life cycle components (i.e. sum of the number of generations in all activity periods) and H = number of habitat components used by the species.

$$Ft = A/F \quad (3d)$$

where A = number of points of coincidence between the impact on and species' use of forage plant families and F = points of coincidence between habitat use by a species and the location of its forage plants.

$$Nt = B/(N*Hn) \quad (4d)$$

where B = number of points of coincidence between the impact on the species' use of nest sites, N = number of nest sites used and Hn = number of habitats used where nest sites are likely to occur.

e) Plant

The current study has compared trees in the small patches in sugarcane farm area with the adjacent bushland however the factory has dense vegetation of exotic trees around the head office. Four 10m by 20m plots were laid on the adjacent bushland close to Awash river. Remnants on rocky areas in sugarcane territory was sampled. Only tree species with ≥10cm DBH were recorded. Species evenness and diversity were computed as per Margalef' richness index and Shanon Diversity Index.

$$Spp.Richness = S - 1/\ln N \quad (1e)$$

Where S=number of species and N=total number of individuals.

$$D = -\sum_{i=1}^{20} (Pi)(\ln Pi) \quad (2e)$$

3. RESULTS

(1). Environmental Risks

Risk is the environmental change which affects species composition indirectly through diminishing species' resource requirement or directly by causing death of organisms. The sugarcane related environmental risks which drive alteration of biodiversity in the study area were ranked by key informants **(Fig. 2).** About 81% of the respondents feel that biodiversity modification was very high that current species composition bares virtually no resemblance to the natural condition. Only 19% of the respondents believed low to high level of modification. The residents specified that chiefly habitat destruction for sugarcane expansion has caused wildlife loss. However, some mammals and birds are still sheltered the sugarcane where they can also get foraging materials such as fresh leaves.

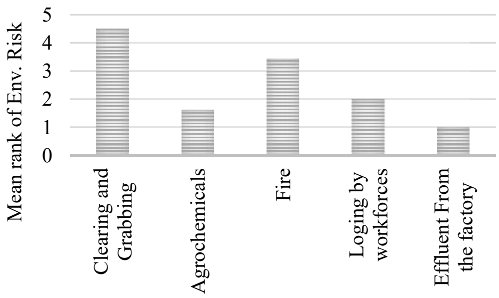

Fig. 2: Ranks of environmental risks

Table 1 Mammals' resource requirement and the corresponding risk score

Scientific Name	English name	Forage types	Habitat types	IUCN category	Risk score
Tragelaphus scriptus	Lesser Kudu	Herbs, twigs, Leaves, crops, flowers, grasses	Forest edge Bush lands, Riparian vegetation, Sugarcane	Least concern	3.28
Phacochoerus aethiopicus	Warthog	Grass, bulbs tubers, invertebrates and leaves of woody plants	Bush land Open wood land Sugarcane	Least concern	2.88
Canis aureus	Common Jackal	Small animals Plants	Grassland, scrub forest	Least concern	6.24
Hippopotamus amphibius	Hippopota mus	Grass,	Water Body/Awash river	Vulnerabl e	7.25
Cercopithecus ethiopis	Vervet monkey	Acacia seeds, flowers, foliage and gum, fruits	Open woodland, forest-grassland mosaic, riparian vegetation	Least concern	1.65
Papio anubus	Anubus baboon	Grass, fruit and insect	Woodland, forest patch, agricultural area	Least concern	1.93
Hystrix cristata	Crested Porcupine	Roots, tubers, cultivated crops, bark, and fallen fruit	Shrub land, abandoned farmland, steppe, forest and dry rocky areas (den deep burrow or a cave)	Least Concern	0.85
Crocuta crocuta	Spotted hyena	Small animals Scavenges	Open wood land Forest Patch	Least Concern	2.32
Lepus habessinicus	Abyssinia n Hare	Leaves seeds, grains, and nuts, flowers, crops	Open grassland, steppe, shrub land , sugarcane	Least Concern	0.85
Sylvicapra grimmia	Grey Duiker	Foliage, herbs, fruits, seeds, and cultivated crops	Woodland, agricultural land, Sugarcane	Least Concern	2.27

(2) Risk Score of mammals

The risk associated with the sugarcane industry depicted by (**Fig. 2**) on foraging habitats, forage availability, resting habitats and breeding success of ten mammals were estimated. The mean risk score (±Sd) of ten mammals in **Table 1** was 2.95±1.58. The risk scores range from 0.85 risk score of *Lepus habessinicus* (Abyssinian Hare) to *Hippopotamus amphibius* (Hippopotamus). The majority of the species has IUCN Least Concern conservation status. The list of mammals, their resource requirements and risk score are detailed in **Table 1**.

Table 2: Rodents' resource requirement and the corresponding risk score

Species	*Foraging Habitat wet season	*Foraging Habitat Dry season	Food** type	Risk Score	Abundance in %
Mastomys natalensis	NPGIOBC	NPGIOBC	ABC	1.29	27.33
Arvicanthis dembeensis	OBGC	IOBGC	BCD	1.34	16.00
Stenocephalemys albipes	NPIOB	NIOB	ABC	1.84	14.53
Pelomys harringtoni	*IOB*	*BIO*	*BCD*	2.66	*8.62*
Mus mahomet	IOB	IO	ABC	3.18	7.90
Mus musculus	IOB	IOBG	ABCD	1.56	5.42
Arvicanthis niloticus	BGC	IOBG	B	1.93	4.40
Rattus rattus	B	IOBC	ABCD	2.14	3.70
Crocidura flavescence	NPIOB	NIOB	ABC	1.79	6.40
Crocidura fumosa	NIOB	IOB	C	4.80	5.7

**Food: (A= Sugarcane fibers, B= Grass, C= Animal matter, D= Monocot seed)

*Habitat: (I=Immature Sugarcane, O=Old Sugarcane, B=Bush Land, C=Cropped area, W=wetlands, K=Close to canals, N=Natural forest, P=Plantation, G=Grass land)

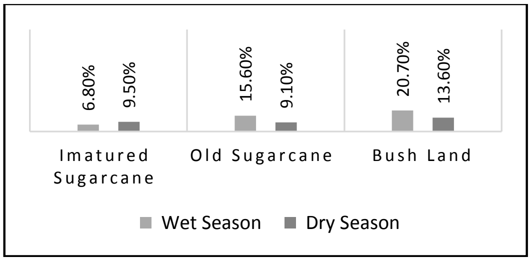

Fig 3: Rodents' trap success in different habitat

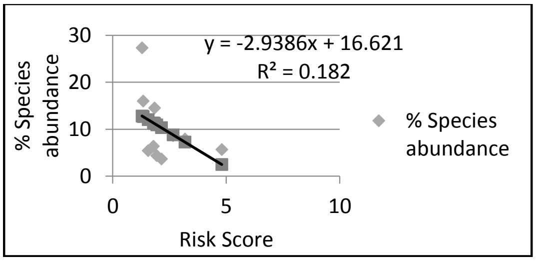

Fig 4: Risk Score versus species abundance

(3) Risk Score of Rodents

A comparison was made between bushland, old sugarcane and immature sugarcane of Wonji Shoa in terms of rodent abundance. From 294 trap nights during the wet season and 441 in dry season there were high trap successes in bushland than in the different growth stage of sugarcane[20] as shown (**Fig. 3).** Irrespective of the plentiful forage materials such as fresh leaves in sugarcane rodents continue to exist more in bushland. Shannon diversity index of rodents shows 2.13, 1.94 and 2.07 in immature sugarcane, old sugarcane and bushlands. Species diversity in old sugarcane and bushland are significantly different at P (0.05) =0.76, df=18.

The rodents have a risk score of 2.25 ±0.78 as illustrated in **Table 2**. The risk score and species abundance shows weak inverse relationship. Species with high risk score are less abundant in the area **(Fig. 4)**. The high score implies that large portion of species resource needs are likely affected by the environmental change associated with the sugarcane.

(4) Floristic diversity and richness

A total of 19 tree species belongs to 14 families were recorded from adjacent areas and in the sugarcane farm. The result shows species richness of 3.97 and species diversity of 2.60 while the patches on a place unsuitable for machinery has a richness of 1.14 and diversity of 1.77. The diversity and richness could be different with more samples representative proportional to the influenced area.

Table 3: Risk Score of Trees

List of trees	Family	Local name	# Popn. as per key info. perception	#indiv. in Sample. Plot	Rel. Abundance bushland	Relative Abundance Sugarcane
Acacia albida	Mimosaceae	Gerbi	Declined	14	0.12	0.33
Acacia tortolis	Leguminosae	Tedeche	Declined	11	0.11	0.17
Bolanities aesyptica	Balanitaceae	Bedeno	Declined	11	0.11	0.06
Acacia nilotica	Fabaciae	Kesele	Declined	9	0.10	0.17
Acacia mellifera	Fabaciae	Sebensa	Declined	9	0.10	0.11
Ficus sycomorus	Moraceae	Oda	Declined	8	0.09	0.00
Acacia orfata	Leguminosae	Ajo	Declined	7	0.08	0.06
Croton macrostachyus	Euphorbiaceae	Makanisa	Declined	5	0.07	0.11
Olea africana	Oleaceae	Ejersa	Declined	4	0.06	0.00
Ziziphus mauritiana	Rhamnaceae	Kurkura	Declined	2	0.04	0.00
Cordia africana	Boraginaceae	Wadesa	Declined	2	0.04	0.00
Ficus thoningii	Moraceae	Dambi	Declined	2	0.04	0.00
Grewia bicolor	Malvaceae	Aroresa	Declined	2	0.04	0.00
Grewia ferruginea	Tiliaceae	Dheka	Declined	2	0.04	0.00
Acacia abyssinica	Mimosaceae	Lafto	Declined	1	0.02	0.00
Rubus pinnatus	Rosaceae	Gora	Declined	1	0.02	0.00
Casuarina equisetifolia	Casuarinaceae	Shewshewe	Declined	1	0.02	0.00
Grewia villosa Hochst	Tiliaceae	Ogombdi	Declined	1	0.02	0.00
Rhus natalensis	Anacardiaceae	Debobesa	Declined	1	0.02	0.00

(5) Honey bee

The risk score for honey bee is limited by lack of exhaustive list of foraging plants. Only tree species listed as honey bee forage that we could identify during preliminary survey were considered in the risk score assessment. The total risk score of honey bee was 0.73. The result could be slightly different with the complete list of honey bee forages in the study site.

(6) Birds

The risk score of three birds (*Bucorvus abyssinicus, Numida meleagris and Francolinus francolinus* which can easily be recognized by farmers were estimated based on the UK bird diversity risk assessment framework[18]. The risk score of these birds are 1.97, 1.89, 1.89 respectively. *Bucorvus abyssinicus* has decreased over time while the other two species remain the same according to key informants. But all the species have IUCN Least Concern conservation status and their risk score are also close to score of UK birds with green list conservation status which was 2.2 ± 0.4 [18].

4. DISCUSSION

This study has shown that Cross Taxonomic Sustainability Index is a good alternative to assess farmland biodiversity loss brought by environmental changes from specific project, policy or programmes. Cross Taxonomic Sustainability Index has superior performance in disentangling the biodiversity loss caused by impacts of different origins. In this study we tried to show the level of damage of environmental change brought by sugarcane industry.

The result highlights that environmental change from sugarcane has disproportionate impacts on constituent species. The level of risk depends on the degree of species' resource needs. The specialist species with narrow resource requirements are more disadvantageous than generalist species with broad resource requirements. For instance, *Hippopotamus amphibious* is more affected by environmental change from sugarcane industry than *Hystrix cristata* due to its specialized roosting habitat requirement. Any environmental change with water quality and quantity problem has disproportionate detrimental effect on hippopotamus. Likewise, *Mastomys natalensis* which feeds multiple foods and depends on wide range of habitats for foraging and nesting has lower risk score than *Crocidura fumosa* which is food specialist (feed on only animal matters). Both *Hippopotamus amphibious* and *Crocidura fumosa* are vulnerable while the remaining have 'least concern' IUCN conservation status. The risk scores of the three birds assessed in this study are close to the risk score of UK birds with blue conservation status[22]. The risk is relatively less for Species with small area requirement such as *Numida meleagris* and *Francolinus francolinus* which can persist in highly fragmented patches[23].

The result has also highlighted that the species abundance and the risk score have weak inverse relationship. Because the species abundance is governed by many other factors such as abundance of predator population. But the risk score clearly shows the underprivileged species. Rodents with the high risk score are less abundant. Absence of population growth rate of other taxonomic groups has limited this study to further illustrate the relationship of the risk score with population trend.

5. CONCLUSION

It is inevitable that biofuel continue to affect ecosystem in a way that impinging on constituent taxa. Biodiversity change from biofuel expansion is complex and need continuous research. However, assessing pressure from biofuel using as many indicator species as possible allow us to better realize the relationship. In this study we considered only five top environmental risks. Assessing all types of environmental change posed by biofuel against as many indicator species could help better understanding. Besides, parallel studies with other models alongside of cross-taxonomic sustainability index would complete the assessment.

The sugarcane industry of Ethiopia can be more sustainable if appropriate agronomic management practices or biodiversity management scheme such as green harvesting, green fertilization, water treatment and recycling, no till production, etc. are explored.

ACKNOWLEDGMENT: This study was supported by Food Security Impacts of Industrial Crop Expansion in Sub-Sahara Africa (FICISSA) project. We thank FICISSA for supporting the field work.

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(Received August 26, 2016)