Land-use change driven biodiversity loss under future global socio-economic and climate scenarios

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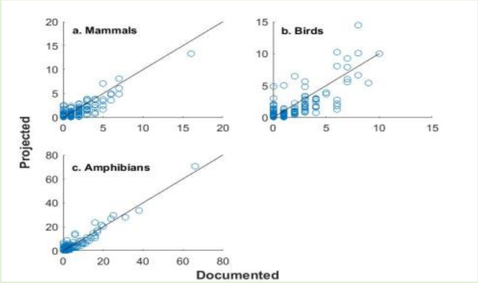
Background

- Sustainable development entails avoidance of trade-offs across social, economic and environmental goals (17 SDGs)
- Species-area relationship (SAR) models provide an easy yet effective way to explore the consequence of future alternative land use change trajectories on species extinctions
- Here we combine countryside SAR with future global gridded land use databases to project how many additional species (of mammals, birds and amphibians) will get threatened with extinction in which countries and ecoregions

Countryside species-area relationship model

$$S_{lost,g,j}^{countryside} = S_{org,j} - S_{org,j} \cdot \left(\frac{A_{new,j} + \sum_{i=1}^{n} h_{g,i,j} \cdot A_{i,j}}{A_{org,j}}\right)^{z_j}$$

- Model Parameters
  - Total number of species currently and their identities (IUCN)
  - Habitat classification scheme of each species (IUCN)
  - Areas of different land use types including primary vegetation at grid level (LUH2 database)
  - SAR exponent (literature, usually between 0.15 – 0.5)



- Model output
  - Number of species threatened with extinction (i.e. committed to exticntion)
  - Output agrees well with IUCN Red List database

(Chaudhary, A. & Brooks, T.M. (2017). National consumption and global trade impacts on biodiversity. *World development*)

Countryside SAR model parameterization example – '*Sao Tome and Principe moist lowland forests*'

- $S_{lost,g,j}^{countryside} = S_{org,g,j} - S_{org,g,j} \cdot \left(\frac{A_{new,j} + \sum_{i=1}^{n} h_{g,i,j} \cdot A_{i,j}}{A_{org,j}}\right)^{z_j}$
- $h_{g,i,j} = \left(\frac{S_{org,i,j}}{S_{org,g,j}}\right)^{1/z_j}$
- *Z = 0.44 (Island ecoregion)*

***Passer domesticus*: Tolerant to all human land uses**
***Adenomera martinezi:* pasture and agriculture only**
***Arctocebus calabarensis:* forests only**
Info from IUCN habitat classification scheme database

Send_mammals	Send_birds	Send_amphibians
4	24	6

Aorg	Anew	A_agriculture	A_Pasture	A_Urban	A_managed forests
967.3	131.6	114.5	173.9	8.3	538.9

	h_agriculture	h_pasture	h_urban	h_managed forests
Mammals	0	0	0	0
Birds	0.028	0.000	0.009	0.344
Amphibians	0.017	0.000	0.017	0.661

Projected extinctions by countryside SAR		
Slost_mammals	Slost_birds	Slost_amphibians
2.34	9.25	1.55

#Species documented as threatened by IUCN 2017		
Mammals	Birds	Amphibians
3	7	2

Chaudhary & Brooks (2017) *World Dev.*

Moving beyond species richness loss – Noah's Ark

- It has been argued that the biodiversity value of a region is better estimated by the amount of phylogenetic diversity (PD or evolutionary history) hosted by it rather than just its species richness (Faith, 1992; Crozier, 1997; Mace *et al.,* 2003; Safi *et al.,* 2013; Jetz *et al.,* 2014).
- PD in a region measures the evolutionary information within its flora/fauna, and more PD offers the region both more functional diversity (and so, e.g., more resilience) and more options to respond to a changing world through complementarity (see, e.g., Mace *et al.,* 2003; Collen *et al.,* 2011).
- This contention has been tested in a small-scale biodiversity–ecosystem function experiment, which found that combining more distantly related species (i.e. high PD region) rather than more closely related ones in managed landscapes increased biomass production and carbon sequestration (Cadotte, 2013).

Chaudhary et al. (2018). Projecting global land use driven evolutionary history loss. *Diversity & Distributions,* 24, 158-167

Land use harmonization database

- In 2017, as a part of the Coupled Model Intercomparison Project (CMIP6), the updated land use harmonization dataset (LUH2 v2f) for the period 2015–2100 was released (http://luh.umd.edu/data.shtml), providing annual gridded fractions of 12 land-use types at 0.25° × 0.25° resolution under six scenarios varying in representative concentration pathways (RCP) denoting climate target and shared socioeconomic pathways (SSPs). The dataset also provides annual land use maps for the past (850–2014). Provides opportunity to predict future hotspots
- Each RCP describes an alternative future climate scenario with a specific radiative forcing (global warming) target (e.g., 2.6, 3.4, 4.5, 6.0, or 8.5 W/m2) to be reached by the end of the century through the adoption of mitigation efforts. Radiative forcing under each scenario is often considered as a proxy for the expected amount of atmospheric warming.

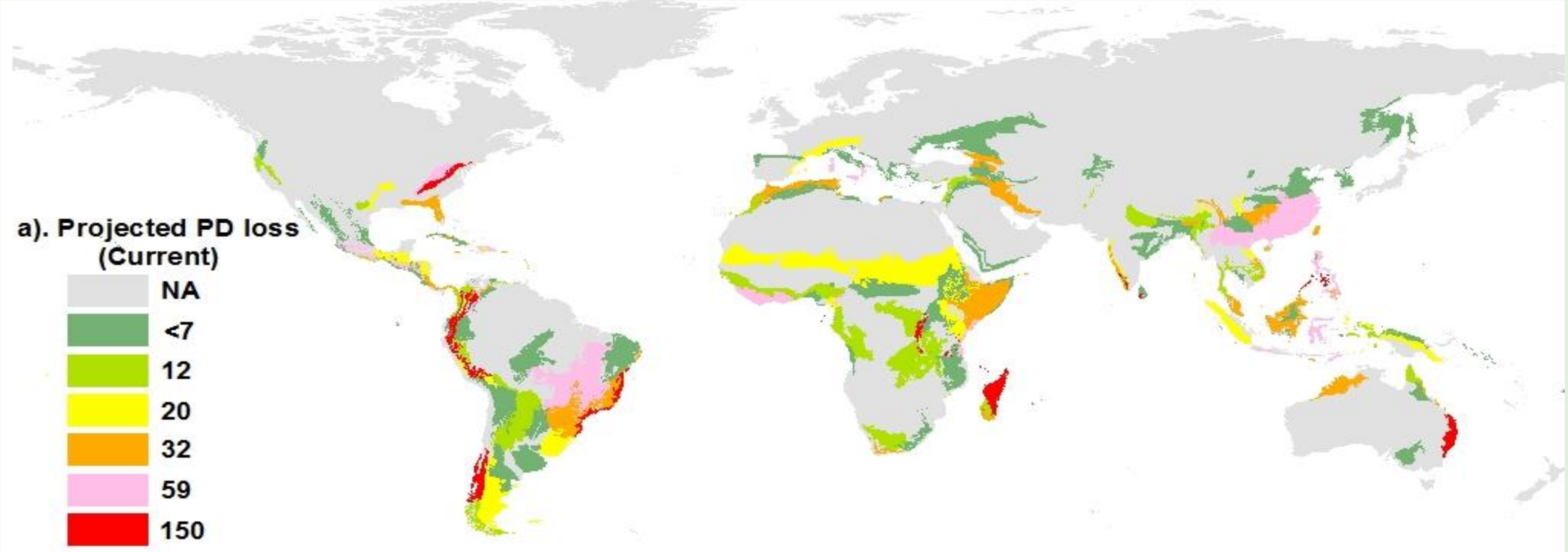
SSPs

- The SSP-1 (*sustainability—taking the green road*) scenario represents a world shifting towards a more sustainable path, characterized by healthy diets, low waste, reduced meat consumption, increasing crop yields, reduced tropical deforestation, and high trade, which, together collectively "respects the environmental boundaries".
- SSP-2 is a business-as-usual (*middle of the road scenario*) scenario characterized by development along historical patterns such that meat and food consumption converge slowly towards high levels, trade is largely regionalized, and crop yields in low-income regions catch up with high-income nations, but the land use change is incompletely regulated, with continued tropical deforestation (although at declining rates).
- The SSP-3 (*regional rivalry—a rocky road*) scenario represents a world with resurgent nationalism, increased focus on domestic issues, almost no land use change regulations, stagnant crop yields due to limited technology transfer to developing countries, and prevalence of unhealthy diets with high shares of animal-based products and high food waste.
- In SSP-4 (*inequality—a road divided*), the disparities increase both across and within countries such that high-income nations have strong land use change regulations and high crop yields, while the low-income nations remain relatively unproductive with continued clearing of natural vegetation. Rich elites have high consumption levels, while others have low consumption levels.
- The SSP-5 (*fossil fueled development—taking the highway*) scenario is characterized by rapid technological progress, increasing crop yields, global trade, and competitive markets, where unhealthy diets and high food waste prevail. There are medium levels of land use change regulations in place, meaning that tropical deforestation continues, although its rate declines over time.

Projected number of endemic species in million years (MY) committed to extinction under past (850, 1900 AD), present (2015) and future (2050, 2100) land use (mean values).

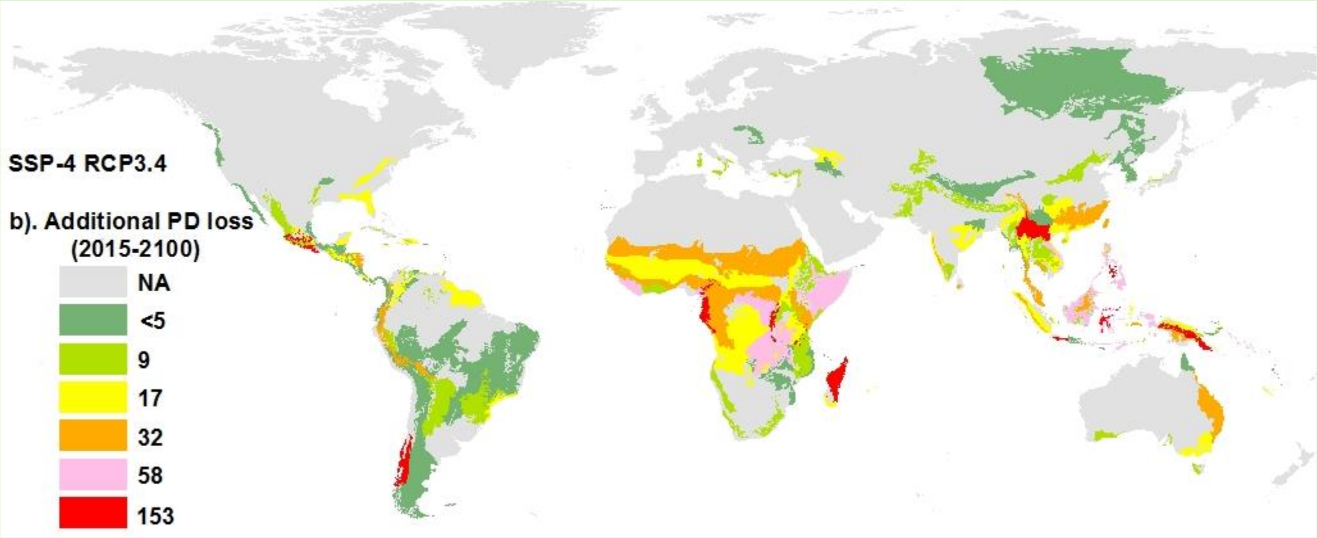
Year	Scenario	Projected Endemic Extinctions							
		M	B	A	T				
850	Past	6	5	15	25				
1900	Past	74	86	212	372				
2015	Present	199	222	602	1023				
2050	RCP2.6 SSP-1	219	236	665	1120				
	RCP4.5 SSP-2	239	255	720	1214				
	RCP7.0 SSP-3	249	260	746	1255				
	RCP3.4 SSP-4	267	270	764	1301				
	RCP6.0 SSP-4	252	253	735	1241				
	RCP8.5 SSP-5	241	255	747	1244				
2100	RCP2.6 SSP-1	241	256	734	1232				
	RCP4.5 SSP-2	297	317	816	1430				
	RCP7.0 SSP-3	302	301	883	1485				
	RCP3.4 SSP-4	398	408	1035	1841				
	RCP6.0 SSP-4	320	319	883	1522				
	RCP8.5 SSP-5	278	281	825	1385				

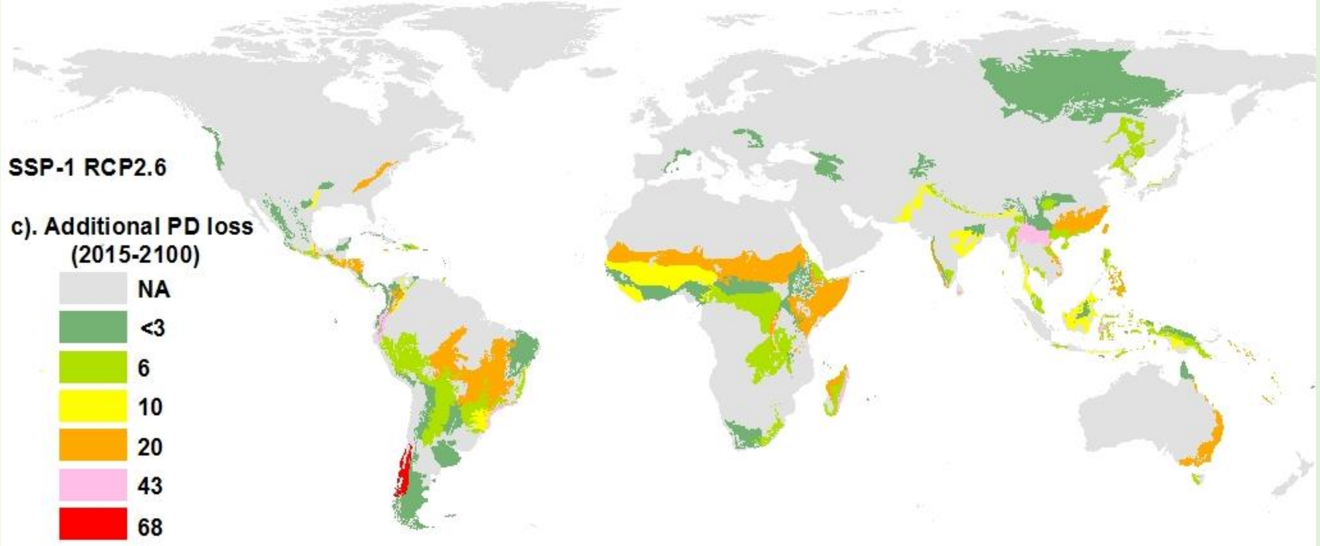
Global hotspots of PD loss



Projected loss of evolutionary history (in million years) per ecoregion due to current human land use for mammals, birds and amphibians combined (associated with endemic species only).

Future scenarios and hotspots of PD loss





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Country	Additional number of endemic species committed to extinction between 2015-2050					
	SSP-1 RCP2.6	SSP-2 RCP4.5	SSP-3 RCP7.0	SSP-4 RCP3.4	SSP-4 RCP6.0	SSP-5 RCP8.5
Indonesia	9	25	23	37	20	16
Madagascar	4	5	15	35	36	11
Tanzania	1	2	12	10	8	12
Philippines	4	13	6	20	9	8
DR Congo	1	3	7	7	7	7
India	8	16	21	23	19	21
Cameroon	1	2	6	6	5	6
China	4	6	6	9	7	8
Mexico	6	10	8	16	10	7

Table. Additional number of endemic species richness (SR) committed to extinction (for mammals, birds, and amphibians combined) in seven World Bank regions

	Period	Scenario	EAP	EU&CA	LAC	MENA	N. America	S. Asia	SSA
SR	2015–2050	SSP-1 RCP2.6	30	0	28	0	3	14	13
		SSP-2 RCP4.5	60	2	68	1	3	22	34
		SSP-3 RCP7.0	58	0	59	0	3	27	77
		SSP-4 RCP3.4	96	0	49	0	4	32	88
		SSP-4 RCP6.0	55	0	40	0	4	27	82
		SSP-5 RCP8.5	50	0	66	0	3	29	62
	2050–2100	SSP-1 RCP2.6	45	1	41	0	2	8	17
		SSP-2 RCP4.5	176	6	110	2	4	26	79
		SSP-3 RCP7.0	65	2	63	0	1	3	95
		SSP-4 RCP3.4	281	7	100	1	1	7	137
		SSP-4 RCP6.0	101	4	42	2	0	6	127
		SSP-5 RCP8.5	65	3	31	0	1	4	43

Table. Contribution of different human land use types (in %) to total number of species (mammals, birds, and amphibians combined) committed to extinction.

Land Use Type	Past		Present	% of Total Projected Extinctions in 2100 AD					
	850 AD	1900 AD	2015 AD	RCP2.6 SSP-1	RCP2.6 SSP-2	RCP7.0 SSP-3	RCP3.4 SSP-4	RCP6.0 SSP-4	RCP8.5 SSP-5
Sec. Veg. (forests)	0	28	28	35	35	28	21	30	35
Sec. Veg. (non-forests)	0	19	9	13	11	8	8	8	11
Pasture	7	13	21	11	13	17	15	20	16
Rangeland	44	16	11	8	7	10	8	10	8
Urban	0	0	2	3	3	3	3	4	3
C3 annual crops	20	9	11	9	12	13	11	11	10
C3 permanent crops	13	7	9	11	10	10	13	8	8
C4 annual crops	9	4	5	3	5	6	4	4	6
C4 permanent crops	2	1	1	5	1	1	13	3	1
C3 Nitrogen fixing crops	4	2	2	2	3	3	2	2	3

Key results

- The results show that the current rate (1900–2015) of projected biodiversity loss is ~20 times the past rate (850–1900) and is set to first increase in the period 2015–2050 under all scenarios (except under RCP2.6 SSP-1), and then decrease to levels below the current rate in the period 2050–2100 (expect under RCP3.4 SSP-4).
- We found that out of the six future scenarios, the most aggressive one in terms of climate change mitigation effort (RCP2.6 SSP-1) is also the one projected to result in lowest land use change driven global biodiversity loss because of adoption of a sustainable path to global socio-economic development.
- All future scenarios show an increase in secondary vegetation area at the cost of the natural habitat primarily to meet the increasing wood demand. We found that this leads to substantial biodiversity loss in all six scenarios, indicating that, regardless of climate mitigation, sustainable forest management will be critical for future biodiversity conservation. This lends support to the call for low-intensity wood harvesting techniques, such as reduced impact logging, to protect biodiversity
- The SSP-4 RCP 3.4 (the worst-case scenario for projected land use change driven biodiversity loss) has the climate mitigation measures (deployment of bioenergy crops) and SSP factors (high population growth, lower crop yields, and weak land use change regulation in the tropical countries) working synergistically and leading to large amounts of natural habitat loss in biodiversity hotspots, and consequent biodiversity loss.

Counterintuitive Insights

- We identified hotspots of biodiversity loss under current and alternative future scenarios and note that these hotspots of future biodiversity loss differ depending upon the scenario, taxon, and metric considered. This lends support to calls to carry out multi-indicator analyses in order to get a more comprehensive picture of biodiversity change.
- However, the poor performance of the RCP3.4 SSP-4 scenario relative to RCP6.0 SSP-4 demonstrates that strategies to mitigate climate change (e.g., replacing fossils with fuel from bioenergy crops) can result in adverse global biodiversity outcomes if they involve clearing of natural habitat in the tropics.
- Even in the best case RCP2.6 SSP-1 scenario, more than 10 million km^2 of primary habitat is projected to be converted into secondary vegetation for wood production or into permanent crops for bioenergy production in species-rich countries (Brazil, Colombia, Ecuador, Mexico, China, Sri Lanka) by the year 2100, potentially committing an additional 200 species and 1000 million years (MY) of evolutionary history to extinction.

Conclusions

- Climate mitigation interventions such as deployment of bioenergy crops might create problems for biodiversity (need to consider habitat tolerance)
- Approach to calculate land use driven evolutionary history loss associated now available!
- Hotspots of species loss and evolutionary history loss do not overlap.
- Including additional drivers such as climate change, habitat fragmentation, overexploitation/hunting, invasive species, and pollution would likely increase all biodiversity loss estimates
- Additional measures should focus on keeping the natural habitat intact through regulating land use change in species-rich areas, reducing the impact at currently managed areas through adoption of biodiversity-friendly forestry/agriculture practices or restoration efforts, and further controlling the underlying drivers such as human consumption to reduce land demand.
- Actions needed
  - Healthy & less land intensive diets,
  - low food waste,
  - reduced discretionary consumption,
  - increasing crop yields,
  - reduced tropical deforestation, regulating land use change in species-rich areas,
  - reducing the impact at currently managed areas through adoption of biodiversity-friendly forestry/agriculture practices or restoration efforts,
  - and further controlling the underlying drivers such as human consumption to reduce land demand

Thank You

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Chaudhary, A., & Mooers, A. O. (2018). Terrestrial vertebrate biodiversity loss under future global land use change scenarios. *Sustainability*, *10*(8), 2764.