Supplement

Figure S1. Location of case studies.

Table S1. Definitions and key features of PA types, adopted from IUCN.

Classification	Description	Key Features
Ia Strict Nature Reserve	Protected areas that are strictly set aside to protect biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.	Largely complete set of expected native species in ecologically significant densities; have a full set of native ecosystems; largely intact; be free of direct intervention by modern humans; not require substantial interventions
Ib Wilderness Area	Protected areas that are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.	Be free of modern infrastructure, and industrial extractive activity; be characterized by a high degree of intactness; be of sufficient size to protect biodiversity, maintain ecological processes and ecosystem services; be free of inappropriate or excessive human use or presence
II National Park	Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and	Typically, large and conserve a functioning ecosystem, but may need to be complemented by sympathetic management is some areas; should contain representative examples of major

	culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.	natural regions, and biological and environmental features or scenery; should keep composition, structure, and function of biodiversity in a "natural" state
III Natural Monument or Feature	Protected areas set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.	Usually relatively small sites that focus on one or more prominent natural features and the associated ecology; includes natural geological and geomorphological features; culturally-influenced natural features; natural-cultural sites
IV Habitat/Species Management Area	Protected areas aiming to protect particular species or habitats and management reflects this priority. Many category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.	Aim to protect or restore: flora species, fauna species, and/or habitats of international, national, or local importance. Most contain actitive management to maintain target species, natural habitats, or culturally-defined ecosystems
V Protected Landscape/Seascape	A protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.	Result from biotic, abiotic, and human interaction. Its essential for Category V protected areas to include landscape and/or coastal and island seascape of high and/or distinct scenic quality and with significant associated habitats, flora and fauna and associated cultural features; include a balanced interaction between people and nature; unique or traditional land-use patterns
VI Protected area with sustainable use of natural resources	Protected areas that conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is	Aim to have the sustainable use of natural resources as a means to achieve nature conservation, together and in synergy with other actions such as protection; not designed to accommodate large-scale industrial harvest

seen as one of the main aims of the area.

Table S2. Reclassification schema for ESA-CCI land cover dataset.

Original Code	*Land Cover Description*	*Reclass Code*	*Reclass Description*
10	Cropland, rainfed	1	Cropland
11	Herbaceous cover	5	Shrubland
12	Tree or shrub cover	5	Shrubland
20	Cropland irrigated or post-flooding	1	Cropland
30	Mosaic cropland (crop land >50% / tree, shrub, herbaceous cover <50%)	2	Mosaic cropland
40	Mosaic natural vegetation (tree, shrub, herbaceous cover >50% / cropland <50%)	3	Mosaic vegetation
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	4	Forest
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	4	Forest
61	Tree cover, broadleaved, deciduous, closed (>40%)	4	Forest
62	Tree cover, broadleaved, deciduous, open (15-40%)	4	Forest
70	Tree cover, needle-leaved, evergreen, closed to open (>15%)	4	Forest
71	Tree cover, needle-leaved, evergreen, closed (>40%)	4	Forest
72	Tree cover, needle-leaved, evergreen, open (15-40%)	4	Forest
80	Tree cover, needle-leaved, deciduous, closed to open (>15%)	4	Forest
81	Tree cover, needle-leaved, deciduous, closed (>40%)	4	Forest
82	Tree cover, needle-leaved, deciduous, open (15-40%)	4	Forest
90	Tree cover, mixed leaf type (broadleaved and needle-leaved)	4	Forest
100	Mosaic Tree and shrub (>50%) / herbaceous cover (<50%)	5	Shrubland
110	Mosaic herbaceous cover (>50%) / T and shrub (<50%)	5	Shrubland
120	Shrubland	5	Shrubland
121	Shrubland evergreen	5	Shrubland
122	Shrubland deciduous	5	Shrubland
130	Grassland	6	Grassland
140	Lichens and mosses	7	Other
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	5	Shrubland

151	Sparse tree (<15%)	5	Shrubland
152	Sparse shrub (<15%)	5	Shrubland
153	sparse herbaceous cover (<15%)	5	Shrubland
160	Tree cover, fresh or brackish water	4	Forest
170	Tree cover, flooded, saline water	4	Forest
180	Shrub or herbaceous cover, flooded, fresh/saline/brackish water	5	Shrubland
190	Urban areas	7	Other
200	Bare areas	7	Other
201	consolidated bare areas	7	Other
202	Unconsolidated bare areas	7	Other
210	Water bodies	7	Other
220	Permanent snow and ice	7	Other

Table S3. Comparison of land cover following deforestation results from this study and previous studies [15, 16]. Shown as percent of total deforested area.

Study Region	**Study**	**Agriculture[1]**	**Forestry**	**Grassland/Shrubland**	**Other**
Indonesia (national)	**Austin (2019)**	67.0%	9.3%	19.7%	4.0%
	This Study	60.7%	30.0%	9.0%	0.3%
Indonesia (PAs)	**Austin (2019)**	40.4%	32.4%	18.3%	8.9%
	This Study	38.2%	47.4%	7.9%	6.5%
South America	**De Sy (2015)**	20%	Not included	69% (pasture)	11%
	This Study	44.2%	NA[2]	44.4%	11.4%

[1.] Agriculture land classes include Industrial Cropland, Mosaic Cropland, and Mosaic Vegetation

[2.] Deforested land returning to forestry was excluded for the purpose of comparison

12 **Table S4.** Total tree cover estimates (1000 ha), tree cover loss estimates from 2001-2018 (1000 ha), relative tree cover loss from 2001-2018 (%), tree cover loss followed by
13 agricultural land type (industrial, mosaic, and total) from 2001-2014 (1000 ha), and proportion of total tree cover loss followed by agriculture (%) within PAs at the national
14 level[1].

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Country	Name	PA Tree Cover 2018	PA Tree Cover Loss 2001-2014	PA Tree Cover Loss 2015-2018	PA Tree Cover Loss 2001-2018	% Tree Cover Loss in PAs 2001-2018	PA Loss followed by Industrial Agriculture 2001-2014	PA Loss followed by Mosaic Agriculture 2001-2014	Total PA Loss followed by Agriculture 2001-2014	% PA Loss followed by Ag 2001-2014
BRA	Brazil	207,450	2697	2051	4749	2%	25	208	232	9%
RUS	Russian Federation	49,940	2793	1031	3825	8%	15	17	33	1%
USA	United States of America	29,890	2451	762	3214	11%	25	17	42	2%
CAN	Canada	32,130	1851	646	2497	8%	1	37	38	2%
COD	Congo, Democratic Republic of the	24,640	522	311	833	3%	44	68	112	21%
KHM	Cambodia	3,090	665	122	787	25%	84	69	153	23%
NIC	Nicaragua	2,820	330	267	597	21%	1	2	3	1%

[1] The summation across countries included in the table may not match to the Total listed due to rounding, and the exclusion of countries that did not experience tree cover loss within PAs from 2001 to 2018.

POL	Poland	5,780	387	189	576	10%	6	7	12	3%
GTM	Guatemala	2,830	435	137	573	20%	72	36	108	25%
CIV	Côte d'Ivoire	2,250	427	142	569	25%	117	63	180	42%
VEN	Venezuela (Bolivarian Republic of)	31,410	359	194	553	2%	31	28	59	16%
AUS	Australia	9,940	314	170	483	5%	13	6	19	6%
PRY	Paraguay	3,080	335	115	450	15%	2	14	15	5%
BOL	Bolivia (Plurinational State of)	18,100	341	95	436	2%	11	17	27	8%
IDN	Indonesia	16,780	47	327	374	2%	2	8	10	20%
VNM	Viet Nam	3,010	264	100	364	12%	8	19	28	11%
FRA	France	5,710	285	77	362	6%	8	6	15	5%
DEU	Germany	6,770	290	64	355	5%	7	5	11	4%
COL	Colombia	13,890	188	85	273	2%	5	7	12	6%
TZA	Tanzania, United Republic of	4,510	210	53	263	6%	8	20	28	13%
HND	Honduras	1,490	137	107	244	16%	2	0	3	2%
ESP	Spain	3,540	166	77	243	7%	4	3	7	4%
LAO	Lao People's Democratic Republic	3,450	160	79	239	7%	3	5	8	5%
MDG	Madagascar	1,480	105	86	191	13%	3	3	6	6%
MNG	Mongolia	930	148	21	169	18%	1	1	2	1%
ZMB	Zambia	3,440	120	46	167	5%	3	1	4	4%
PHL	Philippines	3,060	75	76	152	5%	9	19	27	36%
ZAF	South Africa	660	113	37	149	23%	3	3	6	5%

THA	Thailand	7,700	110	32	143	2%	12	8	19	18%
ARG	Argentina	3,790	109	34	143	4%	2	5	8	7%
MEX	Mexico	6,730	101	40	141	2%	4	3	8	8%
ROU	Romania	2,890	108	31	139	5%	2	1	3	3%
NGA	Nigeria	1,400	84	53	137	10%	35	7	43	51%
SVK	Slovakia	1,300	94	32	125	10%	1	1	2	2%
GHA	Ghana	1,260	70	54	124	10%	24	11	35	50%
PRT	Portugal	350	73	49	122	35%	1	1	3	3%
DOM	Dominican Republic	1,260	91	21	111	9%	4	2	6	7%
GBR	United Kingdom of Great Britain and Northern Ireland	990	87	20	106	11%	0	0	0	1%
PER	Peru	19,370	71	29	100	1%	2	0	2	3%
CHL	Chile	5,710	85	14	99	2%	5	3	8	9%
UGA	Uganda	1,110	68	29	97	9%	23	12	35	52%
CZE	Czechia	1,100	60	26	86	8%	1	1	1	2%
MOZ	Mozambique	1,150	43	37	80	7%	2	2	4	9%
KEN	Kenya	930	59	19	78	8%	13	6	19	32%
CHN	China	2,800	64	12	76	3%	2	2	3	5%
AUT	Austria	1,210	58	18	75	6%	0	1	1	1%
ITA	Italy	2,740	45	30	75	3%	2	1	3	7%
LTU	Lithuania	660	51	20	71	11%	0	1	1	2%
JPN	Japan	5,450	50	19	70	1%	3	2	5	10%
MMR	Myanmar	3,530	50	18	68	2%	1	1	2	4%
HUN	Hungary	830	50	15	65	8%	3	1	4	8%
COG	Congo	3,760	40	24	64	2%	1	2	3	8%

BLR	Belarus	1,110	38	25	63	6%	1	0	1	4%
CUB	Cuba	510	10	54	63	12%	0	0	0	5%
SWE	Sweden	1,850	42	13	55	3%	1	0	1	2%
GAB	Gabon	4,800	39	13	52	1%	1	1	2	4%
ETH	Ethiopia	980	36	12	48	5%	9	3	11	32%
BGR	Bulgaria	2,120	36	12	48	2%	2	3	5	13%
FIN	Finland	1,260	33	14	47	4%	2	1	3	10%
UKR	Ukraine	810	33	14	47	6%	2	1	2	7%
CAF	Central African Republic	3,070	32	12	44	1%	2	3	5	15%
GRC	Greece	1,290	39	5	44	3%	1	1	2	4%
IND	India	2,650	31	14	44	2%	2	3	5	16%
BEL	Belgium	400	35	8	44	11%	1	1	2	5%
SLE	Sierra Leone	260	21	19	40	15%	3	4	7	33%
MWI	Malawi	160	27	9	36	23%	0	1	1	5%
LVA	Latvia	430	24	7	32	7%	0	1	1	4%
HRV	Croatia	990	21	9	31	3%	0	0	0	1%
BLZ	Belize	730	21	7	29	4%	0	0	1	3%
LKA	Sri Lanka	1,370	22	7	29	2%	2	1	3	15%
SVN	Slovenia	770	13	14	28	4%	0	0	1	6%
ECU	Ecuador	3,890	20	7	27	1%	0	0	1	4%
GUF	French Guiana	4,240	20	6	26	1%	0	0	0	2%
ZWE	Zimbabwe	70	17	9	26	37%	0	0	0	2%
AGO	Angola	410	21	4	25	6%	0	0	1	4%
PAN	Panama	1,330	15	8	23	2%	0	1	1	6%
IRL	Ireland	90	16	6	22	24%	0	0	0	1%
CRI	Costa Rica	1,020	10	10	20	2%	0	0	1	7%
MYS	Malaysia	1,970	0	20	20	1%	-	-	-	0%
GIN	Guinea	250	11	9	19	8%	2	1	4	33%

PNG	Papua New Guinea	980	12	6	18	2%	0	1	1	12%
DNK	Denmark	160	13	3	16	10%	0	1	2	12%
PRI	Puerto Rico	40	1	15	16	40%	0	0	0	8%
MAR	Morocco	220	11	3	15	7%	0	0	0	4%
KOR	Korea, Republic of	770	11	3	14	2%	0	0	1	8%
EST	Estonia	450	7	5	12	3%	0	0	0	2%
TTO	Trinidad and Tobago	140	11	1	12	9%	0	0	0	3%
NLD	Netherlands	160	9	2	11	7%	0	0	0	2%
SRB	Serbia	380	7	4	11	3%	0	0	0	4%
JAM	Jamaica	260	9	1	10	4%	0	0	1	8%
DZA	Algeria	40	3	6	9	23%	0	0	0	4%
BGD	Bangladesh	90	5	3	8	9%	1	0	1	19%
DMA	Dominica	20	0	6	7	35%	-	-	-	0%
URY	Uruguay	90	6	2	7	8%	0	0	0	3%
TWN	Taiwan, Province of China	640	6	0	6	1%	0	0	1	9%
NPL	Nepal	770	4	2	6	1%	0	0	0	12%
GNQ	Equatorial Guinea	440	4	2	5	1%	0	0	0	12%
LUX	Luxembourg	60	4	1	5	8%	0	0	0	9%
NOR	Norway	470	4	1	5	1%	0	0	0	3%
SLV	El Salvador	80	3	2	5	6%	0	0	1	17%
SSD	South Sudan	370	5	1	5	1%	0	0	0	9%
ALB	Albania	110	4	0	4	4%	0	0	0	6%
HTI	Haiti	30	1	3	4	13%	0	0	0	8%

MTQ	Martinique	50	3	0	3	6%	0	0	0	6%
AZE	Azerbaijan	250	1	0	2	1%	0	0	0	29%
CHE	Switzerland	110	1	0	2	2%	0	0	0	3%
CYP	Cyprus	50	1	1	2	4%	0	-	0	1%
GNB	Guinea-Bissau	10	1	1	2	20%	0	0	0	27%
KAZ	Kazakhstan	290	2	0	2	1%	0	0	0	21%
LBR	Liberia	270	1	1	2	1%	0	0	0	2%
MKD	North Macedonia	70	2	0	2	3%	0	0	0	3%
REU	Réunion	100	2	0	2	2%	0	0	0	10%
TUN	Tunisia	30	1	0	2	7%	-	-	-	0%
BDI	Burundi	50	1	0	1	2%	-	-	-	0%
BHS	Bahamas	10	0	0	1	10%	0	-	0	0%
ISR	Israel	10	1	0	1	10%	0	0	0	14%
MNE	Montenegro	30	1	0	1	3%	0	0	0	3%
NCL	New Caledonia	40	1	0	1	3%	0	0	0	30%
RWA	Rwanda	120	1	0	1	1%	0	0	0	7%
TGO	Togo	10	1	0	1	10%	0	0	0	27%
Total		**631,570**			**25,460**	**4%**	**698**	**796**	**1,494**	**6%**

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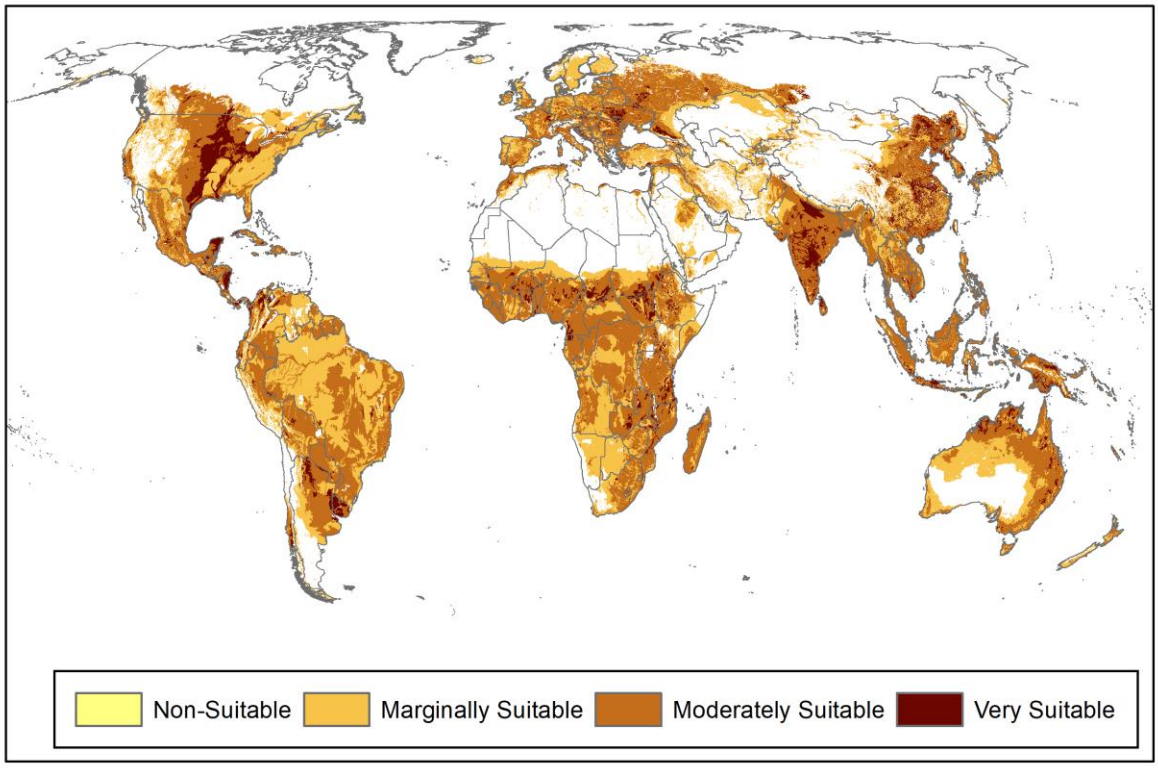
Supplementary Analysis – Agricultural Suitability and Tree Cover Loss

One additional question we set out to answer was the degree to which agricultural suitability correlated with the likelihood of suitable land being converted from forest to other land use types. If a given protected forest was on land that was highly suitable for cropland, would that land be more likely to be converted for agricultural purposes?

We based this analysis on a cropland suitability raster dataset developed using multi-criteria analysis developed by Zabel et al. (2014) [28]. The dataset incorporated factors including climate, topography, and soil characteristics and represented the suitability for 16 major global crops.[2] Ranges for suitability varied between 0 and 100, which we reclassified into four categories according to guidance from [28]: 0 for not suitable, 1-33 for marginal, 34-74 for moderately suitable, and > 74 for highly suitable. We further refined this dataset to reclassify urban areas and water bodies (as classified in [20]) from suitable to non-suitable, with the assumption that these would not be used as agriculture (SI Figure 2). Our analysis incorporated several scenarios of IUCN protected areas, including one where we plotted the most stringently protected areas (classified as Ia, Ib, and II) as suitable and another variation that plotted all IUCN defined protected areas. We analyzed these datasets against the forest loss data [1] to derive where forest loss occurred and used ESA-CCI land cover data [20] to establish what land use change had occurred following the loss of forest land cover. This analysis was conducted for each individual PA to obtain the level of agricultural suitability for each area. All raster datasets were resampled to the same 30m resolution to enable harmonized analysis and we overlaid them using ArcGIS with a cylindrical equal area projection to retain true size of PAs throughout the global map.



[2] The study used criteria for 16 major crops including barley, cassava, corn, groundnut, millet, oil palm, potato, rapeseed, rice, rye, sorghum, soy, sugarcane, sunflower, summer wheat, and winter wheat.

Figure S2. Agricultural suitability map.

We found that for protected forests; agricultural suitability, as a percentage of total land, was not a good indicator of agricultural conversion. Figure 3 demonstrates that there was a negligible difference in tree cover loss across the full spectrum of suitability of the protected area. If the proportion of land deemed suitable was a predictive indicator of tree cover loss, we would have expected to see a positive slope in the agricultural land cover class, with the percent of forest loss increasing as the proportion of land [3] suited to cultivate crops increased. Instead, we see no relationship.

[3] Proportion of land suitable for crop cultivation from total protected area.

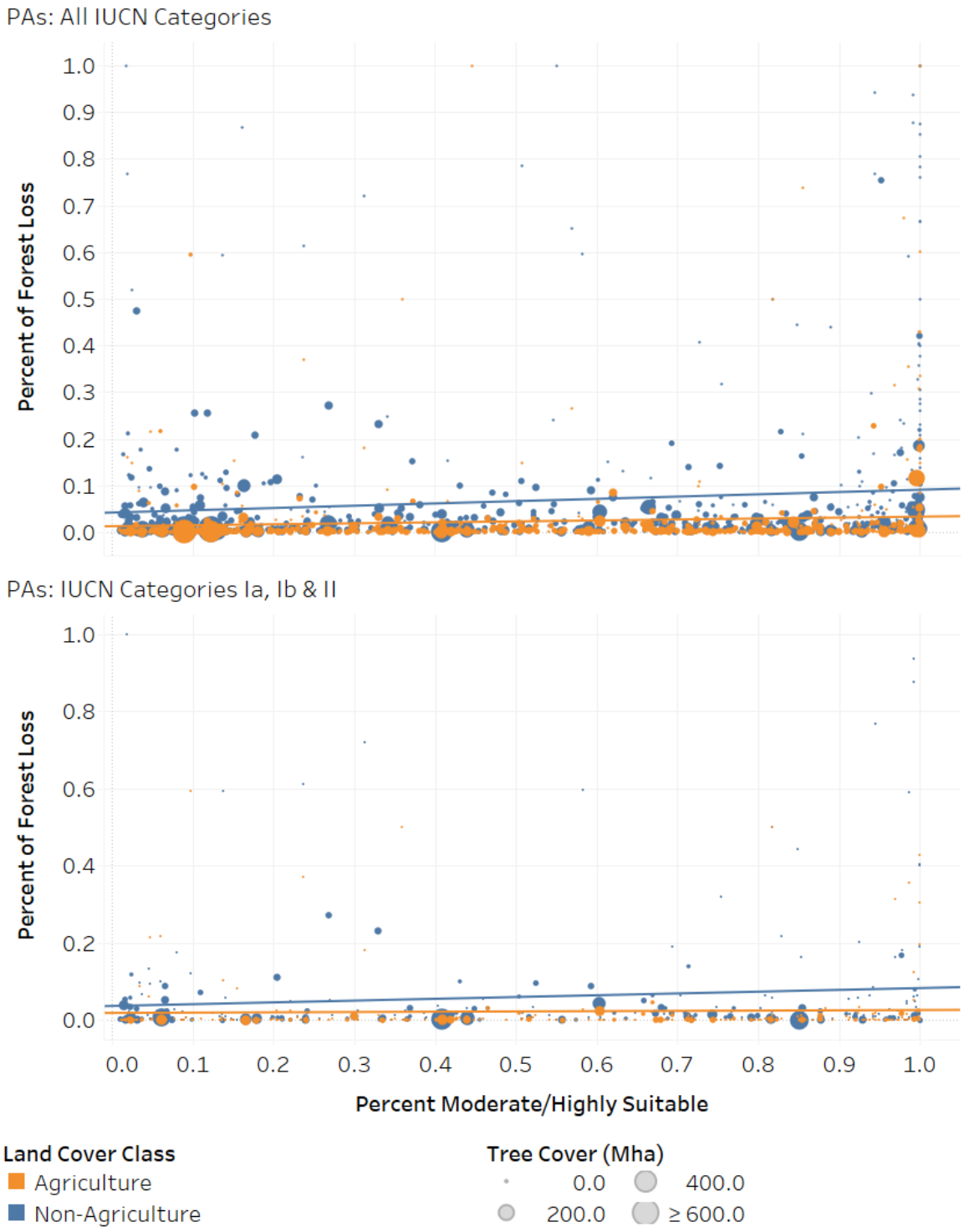


Figure S3. Relationship between agricultural suitability and land cover class following deforestation event within all IUCN categories (Top), and within more stringent IUCN categories (categories Ia, Ib, and II) (Bottom), shown as percent of tree cover within a PA lost between 2001-2014, where each dot is a PA.

Contrary to our expectations, we did not find a relationship between agriculturally driven forest loss and agricultural suitability[4], either in all PAs or in strict PAs (SI Figure 3). One potential explanation is that agriculture encroachment into PAs is not planned according to optimal suitability, but rather occurs in an opportunistic manner influenced by other factors such as access, cost of conversion, and likelihood of avoiding PA enforcement (e.g., situated farther from PA management offices). This explanation is supported by a study that found that deforestation within PAs in the tropics were more likely to be linked to small farms that were locally opportunistic, rather than large-scale agriculture that would be more strategic in citing operations [29].

While agricultural suitability data on a global scale might be useful to identify where there is suitability for cultivation, our analysis did not find a correlation between higher levels of agricultural suitability and higher incidents of forest loss and conversion to agriculture. There are further lines of inquiry to explore, however, that could inform the relationship between suitability and agricultural expansion in PAs. This includes, for example, refining suitability maps with locally specific information, or analyzing whether contagious deforestation occurs (e.g., parcels adjacent to suitable lands deforested for agriculture irrespective of their suitability category) [30, 31].

[4] For this analysis we included cropland, mosaic cropland, and mosaic vegetation (which, by definition, contains less than 50% of mosaic cropland within each pixel) as agricultural lands.