Integrating Participatory Methods and Remote Sensing to Enhance Understanding of Ecosystem Service Dynamics Across Scales

Jennifer Hodbod [1,*], Emma Tebbs [2], Kristofer Chan [2] and Shubhechchha Sharma [1]

[1] Department of Community Sustainability, Michigan State University, East Lansing, MI 48824. USA.
[2] Department of Geography, King's College London, WC2B 4BG, London, United Kingdom.
* Correspondence: jhodbod@msu.edu; Tel.: +1 5173550312

1. Ecosystem Services expected to be found in the region

Table S1. Ecosystem services found in the Nyangatom woreda, based on literature, prior research, and transect walks within the region, to be annotated during focus groups.

ESS cat	Sub-cat	Indicator	Importance ✓ (None/ Low / Medium/ High)	Bare ground	Urban	Cropland	Forest	River	Ponds	Lakes	Grassland	Shrubland	Other landscape features (e.g. roads)?
Provisioning	Food (including meat, blood, milk)	Dry season grazing - cattle											
		Dry season grazing - sheep and goats											
		Wet season grazing - cattle											
		Wet season grazing - sheep and goats											
		Poultry											
		Subsistence Crops – Sorghum, Maize, Cowpeas											
		Commercial Crops – Sugar, Cotton											
		Fish											
		Crustaceans											
		Honey											
		Wild foods (plants)											
		Bush meat (dikdik, antelope, porcupine, crocodile, guinea fowl)											
		Other_____											
	Fibre	Building materials - grass thatch for house											
		Building materials - wood for house construction, fences											

Provisioning		Cut grass for animals
		Materials for clothing
		Wood for chairs and spoons
	Fuel	Firewood
		Grass
		Dung
		Charcoal
	Shade	Trees that you use for shade
	Med	Medicinal resources
	Fresh water	Drinking water for people - natural
		Drinking water for people – man made
		Drinking water for animals - natural
		Drinking water for animals – man made
		Irrigation water - subsistence
		Irrigation water - commercial
	Salt	Salt lick for animals
		Emomket - salt for tobacco
Cultural	Hunting	Buffalo (meat; hide; whip
		Elephant (ivory; heroic act);
		Giraffe (dancing decoration);
		Crocodiles (meat, eggs);
		Lion (prestige);
		Ostrich (cultural tradition, age sets);
		Leopards;
		Jackals;
		Other_____
	Recreation	Where do the tourists visit?
		Where do you go to feel relaxed?
		Where do you go swimming in the river for fun?

	Identity	What areas are important for your family?
		What areas are important for the Nyangatom?
		What areas are important for other groups?
	Knowledge	Where are the schools?
		Are there any other places used for education?
	Spiritual	Where are the sites of spiritual importance?
	Insp	Are there places you go to feel inspired?
	Aesthetic	What do you think is the most beautiful place in the area?
	Social relations	Are there any places used for talking with groups?
		Are there any places used for resolving conflict?
	Sense of place	Where is your home?
	Heritage	Where are the villages?
Supporting	Biodiversity	Where are the highest number of *different* types of wild animals found?
		Where are the highest number of *different* types of wild plants found?
	Primary Prod	Where is the most vegetation?
Regulating	Air qual	Dust

| Regulating		
	C storage	Trees
	Moderation of extreme events	Are there places that are safe when the river floods? Or unsafe? Are there places that are safe when there are fires? Or unsafe? Are there places that are safe when there are storms? Or unsafe? Are there places where there are landslides when it rains?
	Purif + reg	Where is the water cleanest?
	Reten	Does water pool on the surface?
	Erosion + fertility	Where do crops grow best? Where do crops grow worst? Where does the soil wash away? (Gullies)
	Pollination	Where is the best place to put hives? Where do you see the most bees?
	Biological control	Where are the main pest outbreaks? Locusts Where are the main pest outbreaks? Worms

2. Digitized Participatory Maps
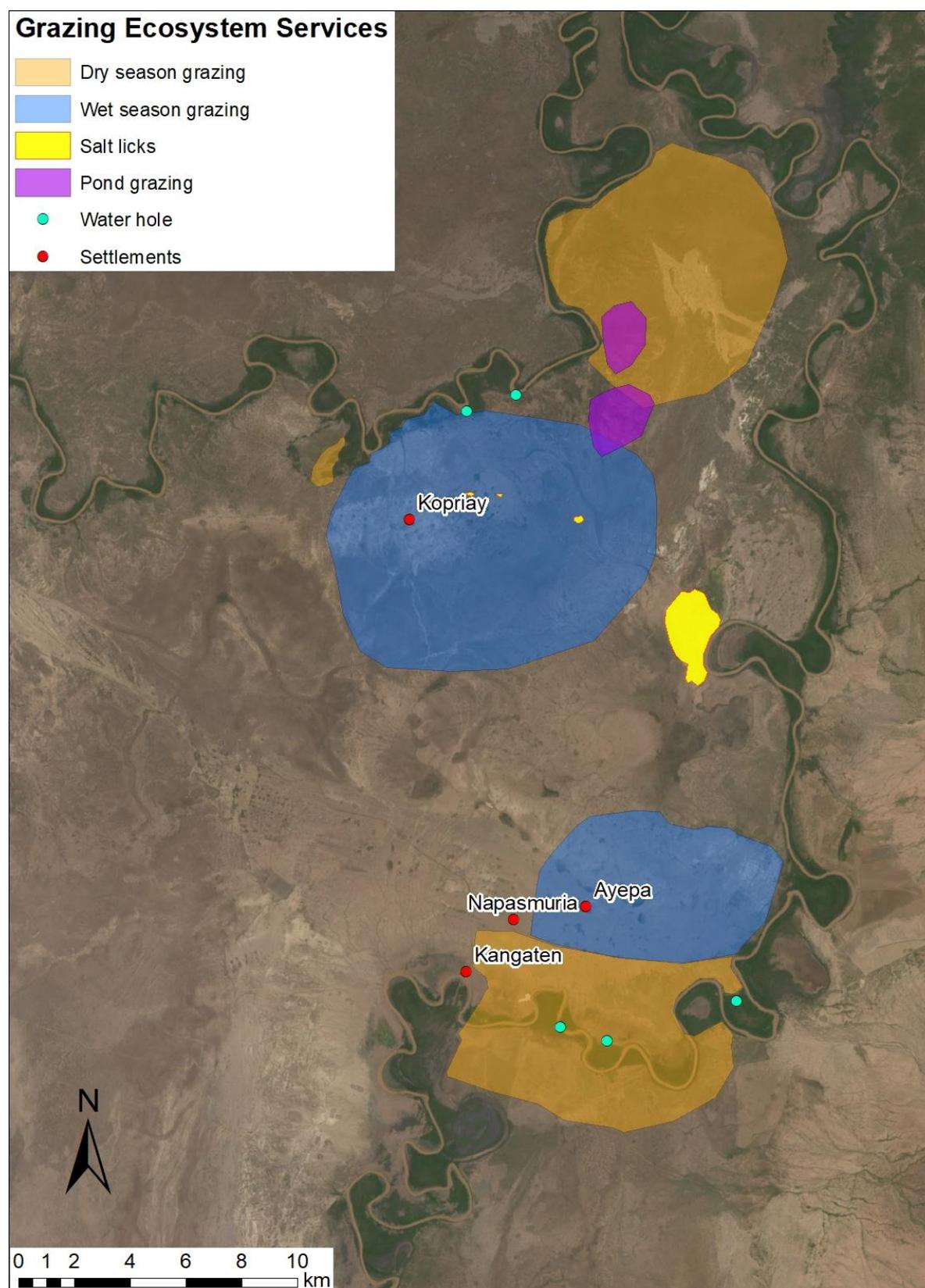
Figure S1. Digitized participatory map showing provisioning ecosystem services related to grazing, compiled from all six focus groups.
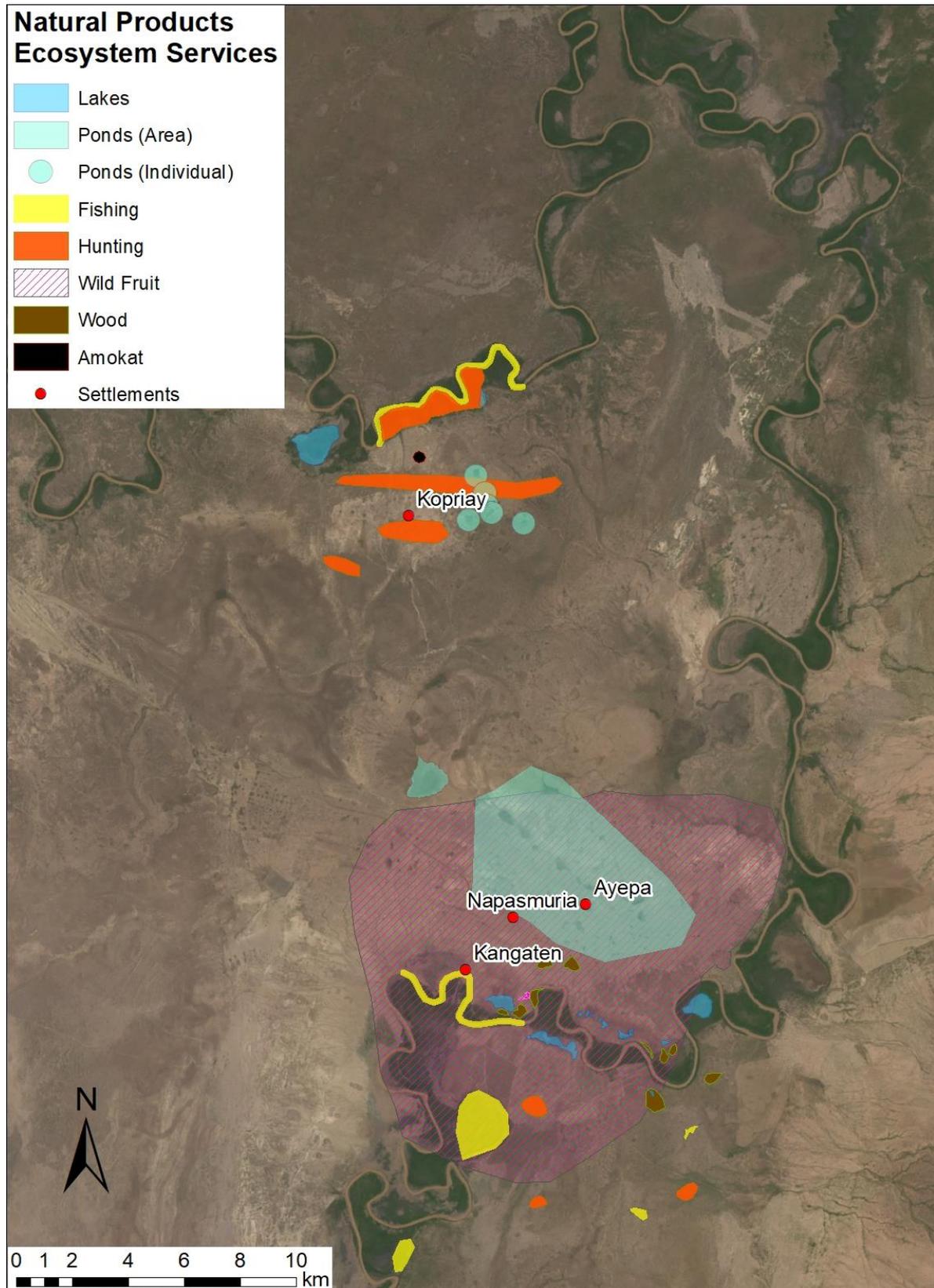
Figure S2. Digitized participatory map showing provisioning ecosystem services related to natural products (i.e. other than agriculture and grazing), compiled from all six focus groups.
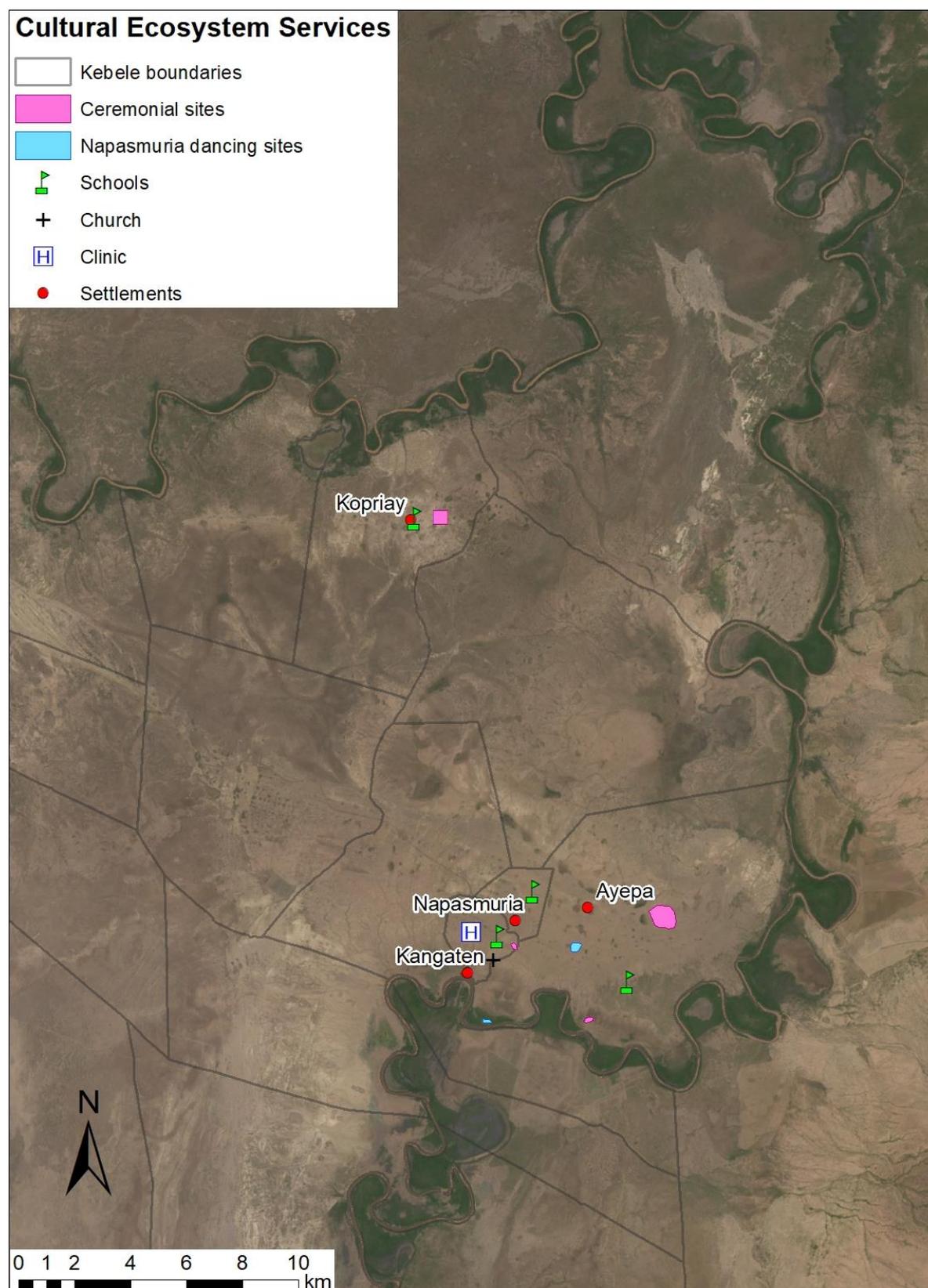
Figure S3. Digitized participatory map showing cultural ecosystem services, compiled from all six focus groups.

2. Land-use Classes

Table S2. Land cover categories and description.

Land Cover	Description
Water	Permanent standing surface water pixels
Wetland	Mixed land/water pixels with greater than a third standing water or seasonally inundated
Bare	Pixels with less than a third vegetation or other cover
Grassland	Pixels predominantly covered by grass or herbaceous cover
Shrubland	Pixels predominantly covered by shrubs
Forest	Pixels with greater than a third vegetation cover and tree* crown cover of at least 10%

*Trees are defined as woody plants (typically single-stemmed) which typically reach a height of over 5m.

Figure S4. Photographs of representative Land Cover types. A & B – Water in the river; C – Bare; D – Forest; E & F – Wetland (Photographs taken from the same location, E – in the wet season, F – in the dry season); G & H – Grassland; I & J – Shrubland.

3. Land Cover Classification Accuracies

Table S3. Error Matrix for 2016-2019 Classified Land Cover.

Classified Data	Reference Data						Classified Total	Producer's Accuracy	User's Accuracy
	Water	Wetland	Bare	Grassland	Shrubland	Forest			
Water	**201**	7	0	0	0	0	208	98.0%	96.6%
Wetland	3	**43**	0	1	0	0	47	70.5%	91.5%
Bare	0	3	**127**	9	2	0	141	96.9%	90.1%
Grassland	0	1	4	**87**	9	0	101	86.1%	86.1%
Scrubland	0	4	0	4	**107**	6	121	81.1%	88.4%
Forest	1	3	0	0	14	**66**	84	91.7%	78.6%
Total	*205*	*61*	*131*	*101*	*132*	*72*	*702*		
						Overall Classification Accuracy:			*89.9%*
						Overall Kappa Statistic:			*0.874*

Table S4. Error Matrix for 2001-2003 Classified Land Cover.

Classified Data	Reference Data						Classified Total	Producer's Accuracy	User's Accuracy
	Water	Wetland	Bare	Grassland	Shrubland	Forest			
Water	**162**	5	0	0	0	0	167	99.4%	97.0%
Wetland	1	**18**	0	0	0	0	19	75.0%	94.7%
Bare	0	0	**84**	6	0	0	90	100%	93.3%
Grassland	0	0	0	**33**	5	0	38	82.5%	86.8%
Scrubland	0	1	0	1	**49**	2	53	87.5%	92.5%
Forest	0	0	0	0	2	**37**	39	94.9%	94.9%
Total	*163*	*24*	*84*	*40*	*56*	*39*	*406*		
						Overall Classification Accuracy:			*94.3%*
						Overall Kappa Statistic:			*0.924*

4. Summary of ecosystem services mapped by each group

Table S5. ES listed by each focus group during the mapping activity (K = Kopriay, A = Ayepa, N = Napasmuria, W = Women, M = Men).

Community	Total number of ES	Provisioning	Regulating	Cultural
K-W	14	12	0	2
K-M	19	14	0	5
A-W	21	14	2	5
A-M	25	16	2	7
N-W	24	16	4	4
N-M	20	8	2	10
Average	*21*	*13*	*3*	*6*
Average – Women	*20*	*14*	*3*	*4*
Average - Men	*21*	*13*	*2*	*7*

However, there are some limitations to the robustness of this data – given time limitations, after the initial few annotations to the map, we purposely focused the conversation around provisioning ES first, then cultural, then regulating. Because we often finished the provisioning conversation earlier with the male focus groups, they had more time to discuss cultural services. There is also potentially some bias with the first focus group (Kopriay Women) taking longer as we were less practiced in our methodology, leading to lower scores.