

Involving citizens in monitoring the Kunming–Montreal Global Biodiversity Framework

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Supplementary Table 1. Results of 8 experts' independent assessment of a random sample of 10% of the indicators of the targets in the Kunming-Montreal Global Biodiversity Framework.

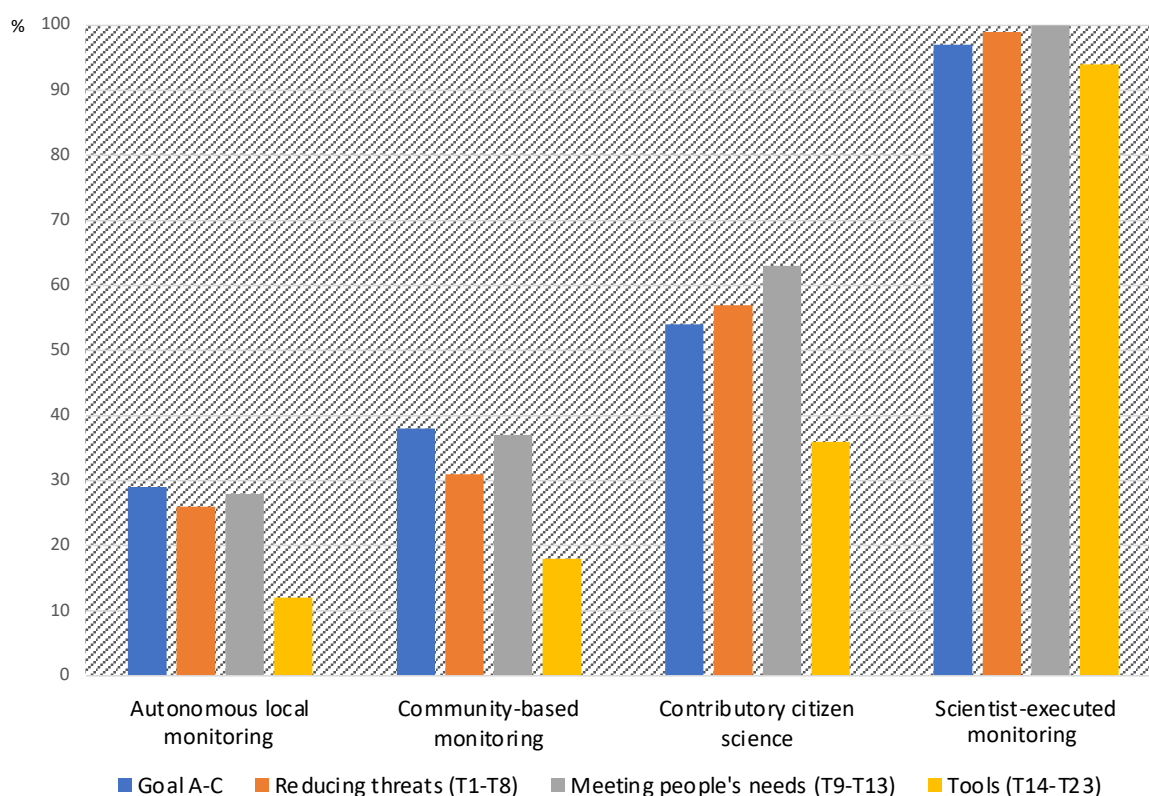
Region of expert (expert number)	Monitoring approaches (n = 140)		Monitoring challenges (n = 175)		Total (n = 315)	
	% agreement	Kappa	% agreement	Kappa	% agreement	Kappa
Latin America (1)	0,83	0,66	0,72	0,44	0,77	0,53
Latin America (2)	0,60	0,23	0,74	0,47	0,68	0,36
Latin America (3)	0,87	0,73	0,71	0,43	0,78	0,56
Asia (4)	0,70	0,38	0,76	0,50	0,73	0,45
Asia (5)	0,76	0,50	0,59	0,15	0,67	0,31
Africa (6)	0,72	0,42	0,68	0,36	0,70	0,39
Europe (7)	0,74	0,47	0,69	0,37	0,71	0,42
Oceania (8)	0,62	0,17	0,57	0,07	0,59	0,11
Average	0,73	0,45	0,68	0,35	0,70	0,39

Supplementary Table 2. Headline indicators of the targets of the Kunming-Montreal Global Biodiversity Framework that all parties to the Convention on Biological Diversity will need to report progress against and that are amenable to citizen involvement in their monitoring. For each indicator, the table shows the biomes and taxa that are addressed, the potential role of citizens in monitoring the indicator, and examples of existing monitoring programs in the Global South and North that could contribute to tracking the indicator.

		Biome	Taxon												Citizen potential		Example of monitoring program with citizen involvement	
Target	Headline indicator	Terrestrial	Freshwater	Marine	Arachnida	Insecta	Reptiles	Amphibia	Mammals	Aves	Osteichthyes	Plantae	Fungi	Collecting data	Analysing data	Global South	Global North	
1	Red List of Ecosystems	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100s of contributory citizen science programs. BirdLife International's monitoring of Bae Customary conservation regimes (Sheil et al. 2015); participatory mapping (https://geokey.org.uk/)	100s of contributory citizen science programs. Monitoring by volunteer wardens at nature reserves	
1	Extent of natural ecosystems	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Customary conservation regimes (Tomsini and Thelade 2019); volunteers monitoring of vegetation	Customary conservation regimes (Tomsini and Thelade 2019); volunteers monitoring of vegetation	
2	Area under restoration*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Volunteer monitoring of seagrass (Jones et al. 2016). Customary conservation regimes. Community-based monitoring programs in Africa, SE Asia & Latin America (e.g., Constantino 2020)	Anglers & water managers assessment of river barriers w/ the AMBER Barrier Tracker & the NZ Fish Passage Assessment Toolapps (Beletti et al. 2020; Franklin et al. 2022); volunteers monitoring of vegetation	
3	Coverage of protected areas and OECMs	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Indigenous Peoples' mapping their territories w/ the Mapco app & other platforms (CCA Consortium. 2023). See also T2	Same as for T1 ("Extent of natural ecosystems") above	
4	Red List Index	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100s of citizen science programs. Citizens reporting baboon spiders (Araneae: Theraphosidae) in S. Africa (Campbell et al. 2018) & lemur in Madagascar (Andriana andrasana et al. 2022)	100s of citizen science programs. Monitoring by volunteer wardens at nature reserves and by amateur naturalists	
4	The proportion of populations within 1 km of water	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Local populations counting White-necked Picathartes (<i>Picathartes gymnocephalus</i>) nests in Sierra Leone (https://en.wikipedia.org/wiki/White-necked_picathartes)	Hunter, fishing, and farmer clubs' monitoring of, e.g., moose (<i>Alces alces</i>), bears (<i>Ursus</i> spp.), trout and salmon (<i>Salmo</i> spp.), Hunters' census of muskoxen (<i>Ovibos moschatus</i>) (Greenland (Cwyler et al. 2020)	
5	Proportion of fish stocks within biologically sustainable levels	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Community-based monitoring programs Latin America, e.g., fishers' monitoring of Piracut (<i>Arapaima</i> spp.) in the Amazon (Campos-Silva et al. 2019; Eyng et al. 2022). Customary conservation regimes	Pelagic fishers monitoring Scotland (Mackinson et al. 2023). Community-based monitoring in the Arctic, e.g., in Greenland (PI SUNA: https://eloka-arctic.org/pisuna-net/en). Recreational fishermen (Støttrup et al. 2020). Anglers reporting their catch (Venturelli et al. 2017).	
6	Rate of invasive alien species establishment	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100s of contributory citizen science programs, e.g., monitoring rose-ringed parakeet (<i>Papadaura frameri</i>) in S. Africa (Shwambue et al. 2022); Naturalist (Soroye et al. 2022)	Community-based monitoring (Hauser et al. 2021). Fishers records (Peci et al. 2019; Peria et al. 2023). Monitoring by volunteer wardens at nature reserves and by amateur naturalists. Boblitzes (Meeus et al. 2023). Naturalist; IRECord (https://irecord.org.uk/); Local Environmental Observer Network (www.localnetwork.org)	
7	Index of coastal eutrophication	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100s of contributory citizen science programs. Citizens' measurements of nutrients & turbidity in Tanzania (Moshi et al. 2022) and Sierra Leone (https://www.freshwaterwatch.org/pages/about)	100s of contributory citizen science programs, e.g., seafarers use of a Secchi Disk to collect ocean transparency data (Kirby et al. 2021)	
9	Benefits from the sustainable use of wild species*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Same as for T5 for fish. Community members reporting forest resources & illegal forest activities in Africa, SE Asia & Latin America (Brofeldt et al. 2018; Constantino 2020; Moustard et al. 2021; Chiara Valobit et al. 2022)	Same as for T5. Indigenous guardian programs (Reed et al. 2020); volunteers monitoring of toxic algal blooms (Anderson et al. 2019). Many community-based monitoring programs in the Arctic (e.g., Alaska Arctic Observatory and Knowledge Hub; Sealice for Walrus Outlook) & New Zealand (Lyver et al. 2017)	
9	Percentage of the population in traditional occupations*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Focus group discussions of well-being-nature relationships in Rwanda & Malawi (https://online.ucpress.edu/cse/article/5/1/1425104/118512/Towards-Capturing-Human-Well-Being-Nature ; Schaafer et al. 2021)	FAO collects this as SDG indicator https://www.fao.org/sustainable-development-goals-data-portal/data/indicators/indicator2.4.1-proportion-of-agricultural-area-under-productive-and-sustainable-agriculture/en	
10	Proportion of agricultural area under productive and sustainable agriculture	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	FAO collects this as SDG indicator https://www.fao.org/sustainable-development-goals-data-portal/data/indicators/indicator2.4.1-proportion-of-agricultural-area-under-productive-and-sustainable-agriculture/en	FAO collects this as SDG indicator https://www.fao.org/sustainable-development-goals-data-portal/data/indicators/indicator2.4.1-proportion-of-agricultural-area-under-productive-and-sustainable-agriculture/en	
10	Progress towards sustainable forest management	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Community-based forest resource monitoring programs in Africa, SE Asia & Latin America, e.g., Tanzania, Madagascar, Philippines, Indonesia, Cambodia (e.g., https://www.globalforestwatch.org)	Citizens' reports on forest interventions and imports to the Danish Ministry of Environment (300-400 citizen reports per year, i. Thelade in lit.)	
11	Services provided by ecosystems*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Community-based monitoring programs in Africa, SE Asia & Latin America. Pollinator monitoring in S. Africa (Taylor et al. 2020); see also T5 and T9 ("Benefit...") above	Community-based monitoring programs in the Arctic and New Zealand. Pollinators: European Butterfly Monitoring scheme (eBMS), Biodiversity4All; see also T4, T5, and T9 above	
13	Indicator on monetary benefits received*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Community-Based carbon & biodiversity monitoring (e.g., Boissière et al. 2017)	Hunter, fishing, and farmer clubs' monitoring of, e.g., income from hunting moose & bears, and fishing trout & salmon	
13	Indicator on non-monetary benefits*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Access to health care, safe water, cooking fuel, food security, child school attendance, child survival (https://repositorio.cepal.org/bitstream/handle/11362/44452/1/S1801161_en.pdf)	Same as for T4 ("The proportion of populations...") and T5 above	
18	Positive incentives in place to promote biodiversity conservation and sustainable use	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Community members reporting forest resources & illegal forest activities, Cambodia (Brofeldt et al. 2018); civil society associations' monitoring of above-ground biomass in REDD+ programs (Boissière et al. 2017)	The OECD PINE (Policy Instruments for the Environment) data base on taxes, fees and charges, tradable permits, and subsidies (https://www.oecd.org/environment/resources/tracking-economic-instruments-and-finance-for-biodiversity-2020.pdf)	

*) For indicators marked with an asterisk, an agreed-up-to date methodology does not exist

Supplementary Fig. 1. Proportion of indicators of Goal A-C and of the three groupings of targets (1) “Reducing threats to biodiversity” (targets 1-8), (2) “Meeting people’s needs through sustainable use and benefit-sharing” (targets 9-13); and (3) “Tools and solutions for implementation and mainstreaming” (targets 14-23) for tracking the Kunming-Montreal Global Biodiversity Framework that can be assessed using autonomous local monitoring programs, community-based monitoring programs, contributory citizen science programs, and scientist-executed monitoring programs.



Supplementary Information References. References used in Supplementary Table 2.

- Anderson, C. R., Berdalet, E., Kudela, R. M., Cusack, C. K., Silke, J., O'Rourke, E., ... & Morell, J. (2019). Scaling up from regional case studies to a global harmful algal bloom observing system. *Frontiers in Marine Science*, 6, 250.
- Andrianandrasana, H. T., Savage, J., Volahy, A. T., Long, P. R., & Jones, N. (2022). Participatory Ecological Monitoring (PEM): Participatory research methods for sustainability-toolkit# 4. *GAI- Ecological Perspectives for Science and Society*, 31(4), 231-233.
- Belletti, B., Garcia de Leaniz, C., Jones, J., Bizzi, S., Börger, L., Segura, G., ... & Zalewski, M. (2020). More than one million barriers fragment Europe's rivers. *Nature*, 588(7838), 436-441.
- Brofeldt, S., Argyriou, D., Turreira-García, N., Meilby, H., Danielsen, F., & Theilade, I. (2018). Community-based monitoring of tropical forest crimes and forest resources using information and communication technology—experiences from Prey Lang, Cambodia. *Citizen Science: Theory and Practice*, 3(2).
- Boissière, M., Herold, M., Atmadja, S., & Sheil, D. (2017). The feasibility of local participation in Measuring, Reporting and Verification (PMRV) for REDD+. *PLoS One*, 12(5), e0176897.
- Campbell, H., & Engelbrecht, I. (2018). The Baboon Spider Atlas—using citizen science and the 'fear factor' to map baboon spider (Araneae: Theraphosidae) diversity and distributions in Southern Africa. *Insect Conservation and Diversity*, 11(2), 143-151.
- Campos-Silva, J. V., Hawes, J. E., & Peres, C. A. (2019). Population recovery, seasonal site fidelity, and daily activity of pirarucu (*Arapaima* spp.) in an Amazonian floodplain mosaic. *Freshwater Biology*, 64(7), 1255-1264.
- Chiaravalloti, R. M., Skarlatidou, A., Hoyte, S., Badia, M. M., Haklay, M., & Lewis, J. (2022). Extreme citizen science: Lessons learned from initiatives around the globe. *Conservation Science and Practice*, 4(2), e577.
- Constantino, P. A. L (2020). Challenges of forest citizen involvement in biodiversity monitoring in protected areas of Brazilian Amazonia. In: *Handbook of Citizen Science in Conservation and Ecology*, 237-247.
- Cretois, B., Linnell, J. D., Grainger, M., Nilsen, E. B., & Rød, J. K. (2020). Hunters as citizen scientists: Contributions to biodiversity monitoring in Europe. *Global Ecology and Conservation*, 23, e01077.
- Cuyler, C., Daniel, C. J., Enghoff, M., Levermann, N., Møller-Lund, N., Hansen, P. N., ... & Danielsen, F. (2020). Using local ecological knowledge as evidence to guide management: A community-led harvest calculator for muskoxen in Greenland. *Conservation Science and Practice*, 2(3), e159.

- Eyng, V., Gomes, M., Câmpere, L., & Hercos, A. (2022). Engagement in a citizen science Project in the Amazon basin. *Citizen Science: Theory and Practice*, 7(1).
- Franklin, P. A., Sykes, J., Robbins, J., Booker, D. J., Bowie, S., Gee, E., & Baker, C. F. (2022). A national fish passage barrier inventory to support fish passage policy implementation and estimate river connectivity in New Zealand. *Ecological Informatics*, 71, 101831.
- Hauser, D. D., Whiting, A. V., Mahoney, A. R., Goodwin, J., Harris, C., Schaeffer, R. J., ... & Zappa, C. J. (2021). Co-production of knowledge reveals loss of Indigenous hunting opportunities in the face of accelerating Arctic climate change. *Environmental Research Letters*, 16(9), 095003.
- ICCA Consortium (2023). Mapeo for ICCAs: new app to support Indigenous Peoples and local communities to document and map their territories of life.
<https://www.iccaconsortium.org/2023/05/19/mapeo-for-iccas-app-support-indigenous-peoples-local-communities-document-map-territories-of-life/>
- Jones, B., Unsworth, R., Cullen-Unsworth, L. C., & Lilley, R. (2016). SeagrassSpotter.
<http://www.seagrassspotter.org>
- Kirby, R. R., Beaugrand, G., Kleparski, L., Goodall, S., & Lavender, S. (2021). Citizens and scientists collect comparable oceanographic data: measurements of ocean transparency from the Secchi Disk study and science programmes. *Scientific Reports*, 11(1), 15499.
- Lyver, P. O. B., Timoti, P., Jones, C. J., Richardson, S. J., Tahi, B. L., & Greenhalgh, S. (2017). An indigenous community-based monitoring system for assessing forest health in New Zealand. *Biodiversity and Conservation*, 26, 3183-3212.
- Moustard, F., Haklay, M., Lewis, J., Albert, A., Moreu, M., Chiaravalloti, R., ... & Artus, D. (2021). Using Sapelli in the field: Methods and data for an inclusive citizen science. *Frontiers in Ecology and Evolution*, 9, 638870.
- Mackinson, S., Brigden, K., Craig, J., Clarke, E. D., Angus, C., & Pert, C. C. (2023). The road to incorporating Scottish pelagic industry data in science for stock assessments. *Frontiers in Marine Science*, 10, 1075345.
- Meeus, S., Silva-Rocha, I., Adriaens, T., Brown, P. M., Chartosia, N., Claramunt-López, B., ... & Groom, Q. J. (2023). More than a Bit of Fun: The Multiple Outcomes of a Bioblitz. *BioScience*, 73(3), 168-181.
- Moshi, H. A., Kimirei, I., Shilla, D., O'Reilly, C., Wehrli, B., Ehrenfels, B., & Loiselle, S. (2022). Citizen scientist monitoring accurately reveals nutrient pollution dynamics in Lake Tanganyika coastal waters. *Environmental Monitoring and Assessment*, 194(10), 689.
- Pecl, G. T., Stuart-Smith, J., Walsh, P., Bray, D. J., Kusetic, M., Burgess, M., ... & Moltschaniwskyj, N. (2019). Redmap Australia: challenges and successes with a large-scale citizen science-based approach to ecological monitoring and community engagement on climate change. *Frontiers in Marine Science*, 349.

- Perzia, P., Cillari, T., Crociata, G., Deidun, A., Falautano, M., Franzitta, G., ... & Castriota, L. (2023). Using Local Ecological Knowledge to Search for Non-Native Species in Natura 2000 Sites in the Central Mediterranean Sea: An Approach to Identify New Arrivals and Hotspot Areas. *Biology*, 12(9), 1158.
- Reed, G., Brunet, N. D., Longboat, S., & Natcher, D. C. (2021). Indigenous guardians as an emerging approach to indigenous environmental governance. *Conservation Biology*, 35(1), 179-189.
- Sheil, D., Boissière, M., & Beaudoin, G. (2015). Unseen sentinels: local monitoring and control in conservation's blind spots. *Ecology and Society*, 20(2).
- Shivambu, T. C., Shivambu, N., & Downs, C. T. (2022). Citizen science survey of non-native Rose-ringed Parakeets *Psittacula krameri* in the Durban metropole, KwaZulu-Natal, South Africa. *African Zoology*, 57(2), 90-97.
- Soroye, P., Edwards, B. P., Buxton, R. T., Ethier, J. P., Frempong-Manso, A., Keefe, H. E., ... & Bennett, J. R. (2022). The risks and rewards of community science for threatened species monitoring. *Conservation Science and Practice*, 4(9), e12788.
- Støttrup, J. G., Kokkalis, A., Brown, E. J., Olsen, J., Andersen, S. K., & Pedersen, E. M. (2018). Harvesting geo-spatial data on coastal fish assemblages through coordinated citizen science. *Fisheries Research*, 208, 86-96.
- Taylor, P. J., Vise, C., Krishnamoorthy, M. A., Kingston, T., & Venter, S. (2020). Citizen science confirms the rarity of fruit bat pollination of baobab (*Adansonia digitata*) flowers in Southern Africa. *Diversity*, 12(3), 106.
- Tomasini, S., & Theilade, I. (2019). Local ecological knowledge indicators for wild plant management: autonomous local monitoring in Prespa, Albania. *Ecological Indicators*, 101, 1064-1076.
- Venturelli, P. A., Hyder, K., & Skov, C. (2017). Angler apps as a source of recreational fisheries data: opportunities, challenges and proposed standards. *Fish and Fisheries*, 18(3), 578-595.