Annex D: Evidence and options for ecological mitigation

The argument that ecological mitigation ('ecomitigation,' or 'nature-based mitigation') has much to contribute to reducing net GHG emissions rests on assumptions and considerations about carbon density and flux within ecosystems such as tropical forests, including:

- that old-growth natural forests contain large and approximately stable amounts of fixed carbon in biomass and necromass (evidence in Box 1);
- that carbon in forests is released as carbon dioxide (CO_2), methane (CH_4), soot, etc. when the ecosystem burns or decays (evidence in Box 2);
- that damaged forests absorb carbon as they re-grow (evidence in Box 3);
- that information on carbon density and flux can tell us something useful about the mitigation value of forests (evidence in Box 4); and
- that various kinds of ecomitigation investment are possible, some of them with very high mitigation cost-effectiveness (evidence in Box 5).

Box 1: Evidence that old-growth natural forests contain large and approximately stable amounts of fixed carbon in biomass and necromass

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Forest means an ecosystem that is visually dominated by trees; **old-growth** means a forest that has not been grossly disturbed by human or natural agency for at least a human lifetime; **natural** describes an ecosystem that is free of recent gross human disturbance and retains most of its native species, gene pools, ecological relationships, and intrinsic evolutionary processes; and **stable** refers not to a static condition but to a dynamic equilibrium.

Perfect definitions are not to be expected, given the immense diversity in structure, biomass density and species composition among natural forests, and the subtle and/or unknown nature of human influence and the legacies of past disturbance. All forest stands are unique, and unless they happen to have been very well studied they are also largely unknown, so expectations of any given feature (from species present to carbon content) must be based on careful extrapolations from other forests and informed judgements on how comparable they are.

The resulting uncertainties cannot reasonably be used to block assumptions about a forest stand if it is necessary to make them (e.g. to support urgent REDD+ calculations or to justify urgent conservation measures), so long as they are acknowledged and handled competently. That said, many researchers have tried over many years to generate and use robust and reliable data on the carbon content of old-growth forests, for example:

- Nasi et al. (2009) in Sonwa et al., (2016: 121): "the estimated average carbon stock in the Humid forest of Cameroon is 185 tons/ha. However, depending on the land cover type, the carbon stock is seen to vary between 45 tons and 192 tons/ha."
- Saatchi et al. (2011) condense data from 16 equatorial countries, calculated and corrected in various explicit ways to yield headline means over 2.458 billion hectares of 100, 115 and 124 tonnes/ha at 10%, 25% and 30% canopy cover respectively.
- Pan et al. (2011): "The C stock density in tropical and boreal forests is comparable (242 versus 239 Mg C ha–1 [t/ha]), whereas the density in temperate forests is ~60% of the other two biomes (155 Mg C ha–1 [t/ha - Note 1]. Although tropical and boreal forests store the most

carbon, there is a fundamental difference in their carbon structures: Tropical forests have 56% of carbon stored in biomass and 32% in soil, whereas boreal forests have only 20% in biomass and 60% in soil."

- Soepadmo (1993), concluded: (a) that in the 1970s, the total area of tropical closed moist forests was about 1.044 billion hectares; (b) that organic carbon was about 50% of organic matter and amounted to about 394 billion tonnes stored in all forests (58% in the vegetation, 41% in soil, 1% in litter), and around 50% of the total storage was contributed by tropical moist and rain forests; and therefore (c) that gross mean carbon storage in tropical forests was about 200 t/ha.
- Review of forest carbon content from Cid-Liccardi et al. (2012); deFries et al. (2002); IPCC (2006); Houghton (2003, 2005) in Robledo-Abad (2015): (a) neotropical rainforests 120-400 t/ha; (b) African rainforests 130-510 t/ha; (c) Asia-Pacific rainforests 120-680 t/ha (but in excess of 1,000 t/ha for peat swamp forests); (d) neotropical montane forests 60-230 t/ha; (e) African montane forests 40-190 t/ha; (f) Asia-Pacific montane forests 50-360 t/ha; (g) neotropical seasonal forests 210 t/ha; (h) African seasonal forests 140 t/ha; Asia-Pacific seasonal forests 130 t/ha.
- Donato *et al.* (2011): "Here, we quantified whole-ecosystem carbon storage by measuring tree and dead wood biomass, soil carbon content, and soil depth in 25 mangrove forests across a broad area of the Indo-Pacific region - spanning 30° of latitude and 73° of longitude ... These data indicate that mangroves are among the most carbon-rich forests in the tropics, containing on average 1,023 Mg [tonnes] carbon per hectare."

The range of figures among gross forest types is substantial; the types themselves are not clearly defined; and there are questions over, for example, the maximum 30% forest cover category used in Saatchi *et al.* (2011). This is referenced to UNFCCC (2006, Note 2), is presumably based on FAO assumptions, is implausible when applied to 'tropical closed moist forests', and may bias the carbon content of 'tropical forests' excessively towards that of savannah-type woodlands.

So, for the purposes of considering portfolios of potential investments that may cover multiple forests in multiple locations, it would be reasonable to take as conservative average the narrower range of 160-240 t/ha carbon [mid-point 200 t/ha] for natural moist tropical lowland forests, and 40-120 t/ha [mid-point 80 t/ha] for natural seasonal and montane forests. It seems unlikely that further evidence will much affect these approximations, even if any could be obtained from the fragmented and residual tropical forest estate that now exists.

Notes:

1) 1 megagramme (Mg) = 1 tonne (1,000 kilogrammes); and 1,000 terragrammes (Tg) = 1 gigagramme (Gt) = 1 petagramme (Pg) = 1 billion tonnes.

2) Where 'forest' is defined as "a minimum area of land of 0.05–1.0 hectare with tree crown cover (or equivalent stocking level) of more than 10–30 per cent with trees with the potential to reach a minimum height of 2–5 metres at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10–30 per cent or tree height of 2–5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest".

Box 2: Considerations on the release of carbon as (CO_2, CH_4, soot, etc.) from forests on burning or decay

Because of the complexity of factors, including different kinds of disturbance in different forests, all with different implications for current and future emissions and the likelihood of further disturbance of various sorts, some kind of 'rule of thumb' approach is needed for tropical forests, such as a series of 'steps' in forest condition between 'almost pristine' and 'imminent loss', for example:

- **Step 1 - almost pristine**, with pressures limited to traditional hunting and harvesting of non-timber forest products, with 0-10% carbon loss and a low carbon accretion rate of up to about 0.5 t/ha/yr (see Box 3);
- **Step 2 - moderately disturbed**, with low-intensity shifting cultivation, 'hacking' for timber, and/or careful selective logging, with 25-50% (mid-point 37.5%) carbon loss and a moderate carbon accretion rate of about 1.5 t/ha/yr (see Box 3);
- **Step 3 - very disturbed**, with high-intensity shifting cultivation or repeated selective logging, with 50-75% (mid-point 62.5%) carbon loss and a high carbon accretion rate of about 2.8 t/ha/yr (see Box 3); and
- **Step 4 - imminent loss**, with liquidation felling, plantation clearance, and/or severe and repeated fires, with 100% carbon loss and zero carbon accretion.

Box 3: Evidence that damaged forests absorb carbon as they re-grow

Questions of how much carbon is absorbed, how fast and for how long when forests are allowed to regenerate after being damaged are informed by Suarez *et al.* (2019: 1): "As part of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, we incorporate aboveground net biomass change (ΔAGB) data available from 2006 onwards, comprising 176 chronosequences in secondary forests and 536 permanent plots in old-growth and managed/logged forests located in 42 countries in Africa, North and South America and Asia. We generated ΔAGB rate estimates for younger secondary forests (≤20 years), older secondary forests (>20 years and up to 100 years) and old-growth forests and accounted for uncertainties in our estimates. In tropical rainforests, for which data availability was the highest, our ΔAGB rate estimates ranged from 3.4 (Asia) to 7.6 (Africa) Mg ha^{-1} $year^{-1}$ [t/ha/yr] in younger secondary forests, from 2.3 (North and South America) to 3.5 (Africa) Mg ha^{-1} $year^{-1}$ [t/ha/yr] in older secondary forests, and 0.7 (Asia) to 1.3 (Africa) Mg ha^{-1} $year^{-1}$ in old-growth forests."

If these ΔAGB rates are accepted, and halved to yield carbon accretion rates, the mid-points would be about 2.8 t/ha/yr in young forests, 1.5 t/ha/yr in older secondary forests, and 0.5 t/ha/yr in old-growth forests. For comparison, the estimated total annual forest carbon sequestration in managed forests in 1992-2012 given by Framstad *et al.* (2013): 0.39 t/ha/yr in Finland, 0.46 t/ha/yr in Norway and 0.31 t/ha/yr in Sweden.

The fact that even old-growth forests continue to absorb carbon is remarked upon by Framstad *et al.* (2013: 10-11) as follows: "Old forests were previously thought to be carbon neutral because maintenance (loss of carbon) would equal production (uptake of carbon) and thus evolve towards equilibrium with the atmosphere with increasing forest age. ... Although changes in soil or total ecosystem carbon stocks are difficult to monitor, and the various methods have their problems, the consistent direction of the results of the various studies provide convincing evidence that old forests function as carbon sinks for a long time. The carbon stocks in biomass of old forests continue to increase with age, possibly for several hundred years, although the rate of biomass accumulation and thus the carbon sink will decrease with increasing age."

Box 4: Evidence that information on carbon density and flux can tell us something useful about the mitigation value of forests

Based on information in Boxes 1 and 2, and taking an example from an Ecosystem Restoration Concession in Sumatra, Indonesia (i.e. the Harapan rainforest), the carbon content of a 100,000 ha forest on mineral soils, which contains 25% pristine forest (Step 1 in Box 2), 25% lightly logged forest (Step 2 in Box 2), and 50% heavily logged forest (Step 3 in Box 2) would be expected to have a minimum current carbon content, using the mid-points of carbon loss ranges, of (25,000 ha x 200 t/ha) + (25,000 ha x 125 t/ha) + (50,000 ha x 75 t/ha) = about **10 million tonnes of carbon**.

If that forest was allowed to regenerate for 20 years without further damage, based on the evidence in Box 3, and assuming mid-point values for carbon accretion in young/older secondary forests (i.e. midway between 1.5 and 2.8 t/ha/yr, or 2.15 t/ha/yr), it would accumulate (25,000 ha x 0.5 t/ha x 20 years) + (75,000 ha x 2.15 t/yr x 20 years) = about **3.5 million tonnes of carbon**.

This at least indicates the close order of magnitude of carbon savings available where a damaged Indonesian rainforest that would have been converted to farmland or plantation is instead saved and allowed to regenerate, and also draws attention in this case to the three-fold larger and much earlier (and hence more valuable) mitigation gains available from avoiding forest loss relative to forest regeneration. The reliability of the 'saving process', the share of the carbon savings that ought to be accounted in Year 1 through to Year 20 (thereby attracting dated mitigation values), the value of only deferring deforestation, and the value of the non-carbon benefits involved, are all open to further discussion.

Box 5: Considerations on the various possible kinds of ecomitigation investment, some of them with very high mitigation cost-effectiveness

The ideas of 'precaution', 'intervention' and 'restoration' as applied to investments in ecological mitigation are founded on different principles and should be distinguished in analysis.

'Precaution' - to secure an existing protected area of forest against unknown future threats. In an example based on a project in Myanmar (Annex U), 20,000 ha of intact mangrove was estimated to contain about 20 million tonnes of carbon (based on the mean figure of about 1,000 t/ha from Donato *et al.*, 2012), and was to be secured against future destruction and carbon release. Because the mangrove was already legally protected and not imminently at risk, protecting it would only be justified on a precautionary basis. But the rapidity with which undefended mangroves and other tropical forests are destroyed these days, and the global consequences of releasing a further 20 Mt of carbon are so severe in terms of climate chaos, or expensive in compensatory mitigation investments elsewhere, that it may still be rational to invest in protecting it. In this case (and in many similar cases globally), those 20 Mt of carbon (plus very valuable co-benefits in the form of environmental security and livelihood resources) would be extremely cheap to protect effectively, probably in the range USD 1-5/ha/year (or USD 0.001-0.005/t/yr for the carbon) if the funding was provided continuously, reliably and indefinitely, and managed effectively [Notes 1 and 2]. Such precautionary investments are now essential if mitigation efforts worldwide are to have a detectable effect, let alone an adequate one, on atmospheric GHG concentrations.

'Intervention' - to extend protection to areas of forest that are damaged and imminently threatened. Here, using the same example, 10,000 ha of damaged and threatened mangrove was to be brought under legal and practical protection and allowed to regenerate. Even damaged mangrove contains large amounts of carbon, and at 10% of the original this would still amount to a million tonnes secured against immediate release. In this case, there is clear incrementality and active carbon conservation would start immediately, further augmented by carbon absorbed in the re-growing ecosystem at a rate of several t/ha/yr over 20 years or more. The initial carbon content and its later increase would all be counted (along with the value of co-benefits and an early delivery date premium) as returns on the investment and management costs.

'Restoration' - to replant and restore damaged forests. Here, again using the same example, 200 ha of damaged mangrove was to be actively replanted each year under community and Forest Department supervision, so carbon would be captured over the next 20 years or so (at an increasing rate for the first few years). The resulting accumulation of carbon, and increasing co-benefits from the recovering ecosystem, would all be accounted as returns on the investment and management costs.

These categories of 'precaution', 'intervention' and 'restoration' are not entirely separable from one another in practice, but they have different foundations and should in principle be distinguished in analysis and planning for mitigation. An important implication of the precautionary approach is **the immediate need for a global protected area fund** to pay for ecosystem protection indefinitely (Note 3), on top of intervention and restoration investments.

Notes:

1) A cost of about USD 0.26/ha/year for two years is reported for community monitoring of the 500,000 ha Prey Lang Wildlife Sanctuary in Cambodia, including expenditure by the Prey Lang Community Network and local partners on patrols and meetings, by the University of Copenhagen on training, data management and reporting, and on software development and other set-up costs (Theilade *et al*., in press). A cost of about USD 1.00/ha/year is reported for effective community protection of 6,200 hectares of forest in the IP Monteverde territory of Bolivia by Bosques del Mundo (2019). An all-in cost of DKK 512.7 million (ca EUR 69 million) for Danish support to community land tenure in Bolivia in 1995-2010 (Schwensen *et al*., 2017) averted deforestation that would otherwise have released a large share of about 4 Gt of carbon (Theilade, 2020), an overall cost of about EUR 0.02/tonne, plus on-going carbon sequestration and co-benefits.

2) The parts of the Bolivian Amazon where indigenous territories received community land titles with Danish help have now often become green islands in a sea of new soya plantations. This, supported by other evidence from Perú and Brazil, strongly suggests that indigenous territories are the only effective governance mechanism capable of withstanding deforestation pressures under modern conditions in the Amazon Basin. This amplifies earlier understandings that such territories are at least as effective as national parks at protecting biodiversity and natural forests in many countries (e.g. Nepstad *et al*., 2006; Porter-Bolland *et al*., 2012; Schleicher *et al*., 2017), and that local communities can mount very effective forest monitoring and protection activities with very modest levels of external support, also in many countries (e.g. Danielsen *et al*., 2013; Brofeldt *et al*., 2015; Brofeldt *et al*., 2018; Theilade *et al*., in press).

3) In September 2020, Fauna & Flora International delivered an open letter to the UN General Assembly on behalf of some 180 affiliated conservation organisations, calling for an initial USD 500 billion annual funding commitment "to reverse ecosystem degradation and protect the natural world" (FFI, 2020: 9). In January 2021, the UK announced that it would commit GBP 3 billion to biodiversity/nature conservation over five years, as part of an GBP 11.6 billion climate finance initiative (https://www.bbc.co.uk/news/science-environment-55621664), and the Terra Carta ('Earth Charter') appeal for USD 10 billion (EUR 8.2 billion) by 2022 for nature conservation was launched by Prince Charles and the Natural Capital Investment Alliance (https://www.bbc.co.uk/news/uk-55613924).

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