A frog's eye view: logging roads buffer against further diversity loss

In a recent debate triggered by a thought-provoking editorial (*Front Ecol Environ* 2014; **12[3]**: 147), in which Laurence and Edwards proposed several immediate actions to be taken to safeguard biodiversity in logged tropical forests, Bicknell *et al.* (2015) stressed that closing roads immediately after logging operations have ceased is one of the most efficient measures to minimize further biodiversity losses. This is a view that has already been promoted and reiterated (Fimbel *et al.* 2001; Meijaard *et al.* 2005). However, in their response, Kleinschroth *et al.* (2016) pointed out that reusing existing roads can actually spare forest and prevent additional biodiversity loss in subsequent logging rotations. Consequently, they argued against discarding logging roads permanently and called for maintaining them in a state that will make reopening them both logistically feasible and economically viable.

Both contributions focus on the avoidance of forest destruction and degradation by regulating and managing road networks and assume the subsequent deceleration of biodiversity loss to be an intrinsic logical consequence. This is based on the notion that roads directly replace or "erase" nature (Haddad 2015). While we agree with both parties on the detrimental effects of roads (Barber *et al.* 2014; Brodie *et al.* 2015), we believe that the range of specific impacts of logging roads on biodiversity is not fully addressed. Moreover, potential interactions with important global change drivers (Bailey and van de Pol 2016) are largely ignored.

With reference to Kleinschroth *et al.* (2016), we also argue that logging roads are often reused in a biodiversity friendly manner immediately after operations have ceased. The reuse occurs before any restoration procedure but nonetheless has the potential to mitigate future biodiversity loss. The users are neither loggers, nor hunters, nor conservationists; rather, they represent an integrative part of the biodiversity originally contained in tropical forests. In the case that we highlight here, the users are amphibians: more precisely, anurans that exploit artificially created habitats for reproduction. By doing so they have found a way to increase their resilience to climate-change processes that restrict the availability of reproductive habitats.

Road construction leads to severe soil disturbance and erosion. But one consequence is the formation of rills that eventually fill with water (Figure 1b). In contrast to the majority of natural aquatic habitats in pristine forest, these novel aquatic habitats (NAHs) persist for much longer time spans. They can therefore have a substantial impact on the dynamics and recovery potential of rainforest amphibians after logging disturbance, particularly under severe climatic conditions (Hölting *et al.* 2016). We investigated the frequency of NAHs in a polycyclic reduced impact logging (RIL) scheme in lowland rainforests of central Guyana to identify priority sites for biodiversity friendly, post-logging road management. We found that NAHs were not equally distributed across the road network (WebFigure 1, a and b). Particularly during extended drought phases, NAHs were extensively used as alternative reproductive sites by several frog species. However, while members of genera using NAHs increased in abundance, those that did not declined, leading to extirpations in some cases (WebFigure 1c). Over time, this outcome may result in the loss of functional diversity (Ernst *et al.* 2006). But in the short term, NAHs function as buffers that prevent further diversity loss by stabilizing populations of selected species, thereby increasing resilience and aiding post-logging faunal recovery.

The notion that artificially created habitats can foster biodiversity is not new (Meffert *et al.* 2012; Friedlander *et al.* 2014) and the intentional creation of novel habitats has even been promoted as a promising biodiversity conservation approach in the Anthropocene (Kueffer and Kaiser-Bunbury 2014). However, so far, such strategies – including the consideration and integration of novel roadside habitats in restoration schemes – have yet to gain widespread acceptance among conservation practitioners.

Road networks in the Guiana Shield are moderately developed, but not all logging roads have been adequately mapped (Figure 1a) and plans for new road infrastructure are ongoing (Verlinden *et al.* 2012). Although the forestry sector in the Guiana Shield is exerting relatively good control over logging operations and is committed to implement RIL over a large array of the managed forest estate, it is unclear whether and how these road networks will be managed to prevent further forest loss and promote diversity in already logged forests while avoiding conservation–management conflicts resulting from unexpected interactions. As RIL is commonly applied in logging rotation schemes, we advocate the recycling strategy proposed by Kleinschroth *et al.* (2016) and support the strict closure of roads to prevent unauthorized access. Moreover, we argue that forest certification and post-logging management schemes need to be critically revised to account for potential positive effects of road construction on biodiversity recovery. Hence we suggest that: (1) potential positive and/or mitigating effects should be investigated more systematically and taken into account when designing post-logging restoration measures; (2) a better understanding of the adaptive capacities of organisms is needed (Dawson *et al.* 2011) to enable conservation managers to leverage them to maximum advantage in logged forests; (3) monitoring long-term changes in (functional) composition and diversity (Ewers *et al.* 2015) should

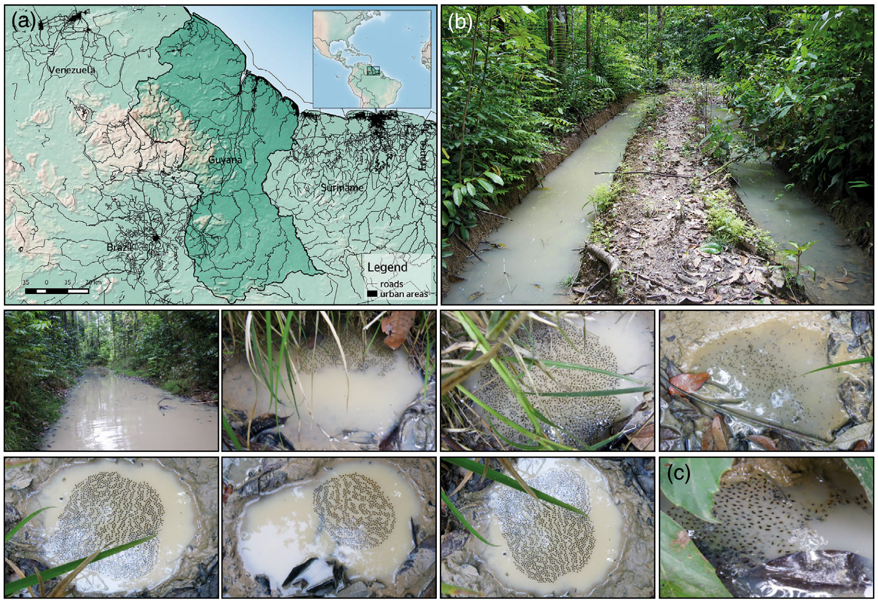

Figure 1. *Road network, artificial habitats, and organismic response in Guyanan rainforests: (a) Current status of mapped road network in Guyana, South America (source: www.openstreetmap.org). (b) Typical primary logging road through the Forest Stewardship Council (FSC 2012) certified concession in Iwokrama Forest, Guyana, with water-filled ruts. (c) Example of reproductive records along logging roads in Iwokrama Forest; here, a total of 23 giant gladiator treefrog (*Hypsiboas boans*) nests were recorded along a single water-filled primary skid road ditch measuring 100 m × 3 m.*

become an integral part of post-logging monitoring assessments; and (4) a systematic remote-sensing-based global inventory of logging roads and their surrounding matrix should be established (following Esch *et al.* [2012] for global settlement patterns).

Conserving biodiversity in logged forests through elaborate road management thus requires merging large-scale perspectives, such as the landscape-planning approach proposed by Kleinschroth *et al.* (2016), and considering small-scale biotic processes.

Raffael Ernst[1,2]*, Monique Hölting[1,2], Ken Rodney[3], Vanessa Benn[3], Raquel Thomas-Caesar[3], and Martin Wegmann[4]

[1]*Museum of Zoology, Senckenberg Natural History Collections Dresden, Dresden, Germany* **(raffael.ernst@senckenberg.de);* [2]*Department of Ecology, Technische Universität Berlin, Berlin, Germany;* [3]*Iwokrama International Centre for Rainforest Conservation and Development, Georgetown, Guyana;* [4]*Department of Remote Sensing, Institute of Geography and Geology, University of Würzburg, Würzburg, Germany*

Acknowledgements

This research is part of the BioDEC Guiana project and was supported by a grant to RE from the German Research Foundation (DFG ER 589/2–1).

Bailey LD and van de Pol M. 2016. Tackling extremes: challenges for ecological and evolutionary research on extreme climatic events. *J Anim Ecol* **85**: 85–96.

Barber CP, Cochrane MA, Souza Jr CM, *et al.* 2014. Roads, deforestation, and the mitigating effect of protected areas in the Amazon. *Biol Conserv* **177**: 203–09.

Bicknell JE, Gaveau DLA, Davies ZG, and Struebig MJ. 2015. Saving logged tropical forests: closing roads will bring immediate benefits. *Front Ecol Environ* **13**: 73–74.

Brodie JF, Giordano AJ, Zipkin EF, *et al.* 2015. Correlation and persistence of hunting and logging impacts on tropical rainforest mammals. *Conserv Biol* **29**: 110–21.

Dawson TP, Jackson ST, House JI, *et al.* 2011. Beyond predictions: biodiversity conservation in a changing climate. *Science* **332**: 53–58.

Ernst R, Linsenmair KE, and Rödel MO. 2006. Diversity erosion beyond the species level: dramatic loss of functional diversity after selective logging in two tropical amphibian communities. *Biol Conserv* **133**: 143–55.

Esch T, Taubenböck H, Roth A, *et al.* 2012. TanDEM-X mission – new perspectives for the inventory and monitoring of global settlement patterns. *J Appl Remote Sens* **6**: 061702.

Ewers RM, Boyle MJ, Gleave RA, *et al.* 2015. Logging cuts the functional importance of invertebrates in tropical rainforest. *Nat Commun* **6**: art6836.

Fimbel RA, Grajal A, and Robinson JG (Eds). 2001. The cutting edge: conserving wildlife in logged tropical forests. New York, NY: Columbia University Press.

Friedlander AM, Ballesteros E, Fay M, *et al.* 2014. Marine communities on oil platforms in Gabon, West Africa: high biodiversity oases in a low biodiversity environment. *PLoS ONE* **9**: e103709.

FSC (Forest Stewardship Council). 2012. FSC principles and criteria for forest stewardship. FSC-STD-01-001 V5-0 EN. Bonn, Germany: FSC.

Haddad NM. 2015. Corridors for people, corridors for nature. *Science* **350**: 1166–67.

Hölting M, Bovolo CI, and Ernst R. 2016. Facing complexity in tropical conservation: how reduced impact logging and climatic extremes affect beta diversity in tropical amphibian assemblages. *Biotropica* **48**: 528–36.

Kleinschroth F, Healey JR, and Gourlet-Fleury S. 2016. Sparing forests in Central Africa: re-use old logging roads to avoid creating new ones. *Front Ecol Environ* **14**: 9–10.

Kueffer C and Kaiser-Bunbury CN. 2014. Reconciling conflicting perspectives for biodiversity conservation in the Anthropocene. *Front Ecol Environ* **12**: 131–37.

Meffert PJ, Marzluff JM, and Dziock F. 2012. Unintentional habitats: value of a city for the wheatear (*Oenanthe oenanthe*). *Landscape Urban Plan* **108**: 49–56.

Meijaard E, Sheil D, Nasi R, *et al.* 2005. Life after logging: reconciling wildlife conservation and production forestry in Indonesian Borneo. Jakarta, Indonesia: CIFOR.

Verlinden ATN, Verweij PA, Plouvier D, *et al.* 2012. Living Guianas report 2012. Paramaribo, Suriname: WWF Guianas.

Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.1314/suppinfo

doi:10.1002/fee.1314

Junking tropical forests for junk food?

Over the past five decades, human diets have moved toward a greater consumption of meat and dairy products (Tilman and Clark 2014) as well as processed foods that contain a high percentage of refined sugars, fats, and oils (Kearney 2010; Monteiro *et al.* 2013). This dietary transition has been driven by a multitude of factors, including trade liberalization for transnational food corporations, income growth, expanded food retailing, and marketing, in addition to changing consumer attitudes and behavior (Kearney 2010).

This trend is increasing fastest in low and middle income countries (LMICs) such as China and India as compared with high income countries (HICs) (Stuckler *et al.* 2012; Tilman and Clark 2014). Between 1961 and 2009, the average annual growth rate of per capita caloric consumption of processed foods for China and India were 4.0% and 1.6%, respectively (WebFigure 1). Related to this rise in consumption of processed foods in LMICs are increased incidences of non-communicable diseases such as Type II diabetes, coronary heart disease, and some cancers (WHO 2011; Popkin *et al.* 2012).

"Junk food" refers to processed foods that are low in essential nutrients and high in salts, refined carbohydrates, and fats (Segen 2006). On the basis of a global systematic assessment of dietary patterns, researchers have documented an increase in junk food consumption across different countries and socioeconomic strata from 1990 to 2010 (Imamura *et al.* 2015). Market data on junk food consumption show more rapid growth in snacks, soft drinks, and processed food consumption for LMICs as compared with HICs (Stuckler *et al.* 2012).

One of the key ingredients in junk foods is vegetable oil. Globally, approximately 60% of edible vegetable oil is produced from oil palm and soybean (May-Tobin *et al.* 2012; USDA-FAS 2015). Both crops have been expanding in tropical Southeast Asia and South America, respectively, resulting in massive deforestation accompanied by declines in biodiversity and the release of sequestered carbon into the atmosphere (Morton *et al.* 2006; Wilcove and Koh 2010). To quantify the amount of vegetable oil used in junk food production, we used market data on junk food sales from Euromonitor Passport Global Market Information (Euromonitor International 2015). We collected market sales data on junk food categories such as cakes, crisps (potato chips), and chocolate confectionary, and obtained the amount of vegetable oil used as ingredients in their production. Between 2001 and 2014, global vegetable oil used in junk food production increased from ~6.5 to 9.1 million metric tons (Figure 1; WebPanel 1). We derived the mean contribution of palm oil and soybean oil to global domestic consumption of vegetable oils from 2000 to 2015 based on statistics from the US Department of Agriculture–Foreign Agricultural Service (USDA-FAS 2015). The mean contribution of palm oil and soybean oil to global vegetable oil use was 29.9% and 33.7%, respectively (WebPanel 1). Based on a range of low and high estimates of vegetable oil yields for palm oil (1.87–4.73 metric tons ha^{-1}) and soybean oil (0.29–0.54 metric tons ha^{-1}) (FAOSTAT 2015), this global demand for vegetable oil used in junk food production resulted in an expansion of oil palm plantations by ~163,500 to 413,400 ha and of soybean plantations by ~1.6 to 3.0 million ha (WebTable 2).

To estimate the volume of vegetable oil requirements in junk foods in 2050, we assumed per capita consumption of vegetable oil in junk foods increased by 0.001 kg year^{-1} for HICs and 0.029 kg year^{-1} for LMICs. These values represent the average annual increase in per capita consumption of vegetable oil in junk foods from 2001 to 2014 for HICs and LMICs, respectively (WebFigure 2). By extrapolating these values with population growth trends from the United Nations' World Population Prospects (FAOSTAT 2015; UNDP 2015), we estimate that the world will need ~17.1 million metric tons of vegetable oil for junk food production (Figure 1). Based on the mean contribution of palm and soybean oil to vegetable oil consumption, and the low and high estimates of vegetable oil yields, this equates to converting an additional ~0.5 to 1.3 million ha of land to oil palm plantations, and ~5.0 to 9.3 million ha of land to soybean plantations by 2050 (WebTable 2). Using historical trends as a guide, we believe that much of this oil palm and soybean expansion will occur at the expense of tropical rainforests, unless strict land-use regulations and market initiatives are implemented to avoid tropical deforestation (Morton *et al.* 2006; May-Tobin *et al.* 2012; Carlson *et al.* 2013).

Studies suggest that we can meet the nutritional requirements of a growing population without destroying tropical forests by closing crop yield gaps and increasing agricultural resource efficiency (Foley *et al.* 2011; West *et al.* 2014). History, however, points to continued deforestation for vegetable oils. Thus, if some tropical forests eventually become converted to cropland, it will be particularly egregious if that deforestation takes place for the sake of junk food, which has poor nutritional value for people. It is time for ecologists, nutritionists, and agronomists to work together to develop strategies to meet people's nutritional needs with healthier foods that do not entail further conversion of tropical forests (Tilman and Clark 2014; DeFries *et al.* 2015). Simply stated, there is no need to junk tropical forests for junk food.