Reforestation for Mitigation and Adaptation to Climate Change in North-Eastern Highlands of Tanzania: Beyond Carbon Sequestration

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Abstract

Reforestation has been emphasized as an authoritative intervention for climate change mitigation because of its carbon storage potential. Reforestation can also play other frequently overlooked—but important—roles in helping society and ecosystems adapt to climate variability and change. For example, reforestation can amend climate-associated impacts of altered hydrological cycles in watersheds, protect coastal areas from increased storms, and provide habitat to reduce the probability of extinction of species under a changing climate. Consequently, reforestation should be managed with both adaptation and mitigation objectives in mind, so as to maximize synergies among these diverse roles, and to avoid trade-offs in which the achievement of one goal is detrimental to another. Management of increased forest cover must also incorporate measures for reducing the direct and indirect impacts of changing climate on reforestation itself. Here, the focus is on 'climate-smart reforestation', defined as reforesting for climate change mitigation and adaptation, while ensuring that the direct and indirect impacts of climate change on reforestation are anticipated and minimized.

Keywords: *reforestation, ecosystem, climate change, carbon sequestration, Tanzania*

1. Introduction

Large areas of forests in tropical regions have historically been cleared for agriculture and reforestation. Natural regeneration, commercial and native tree plantations, as well as agro-forestry systems, are creating new opportunities and challenges in the context of climate change (Armah et al., 2016). For instance, the endorsers of the Declaration on Forests of the New York Climate Summit (September 2014) collectively agreed to restore 150m hectares globally by 2020, and 350m hectares by 2030. Another example is the Bonn Challenge (www. bonnchallenge.org), a global target to restore 150m hectares of the world's degraded and deforested lands by 2020. This is due to the fact that deforestation has been a large contributor of greenhouse gas emissions, and reverting these lands to forests has a clearly recognized potential for recovering stocks of biomass-stored carbon (Houghton, 2012; Raphael, 2018). As noted in a study by Turner et al. (2009), when comparing with other climate mitigation practices, some forest restoration options can offer a low-cost approach to reducing greenhouse gas emissions. Moreover, a similar study by Trabucco et al. (2008) observed that many global

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commitments to reforestation are motivated by climate objectives. Tree planting for mitigating climate change is still controversial, with recent debate on the cooling and warming effects of reforestation.

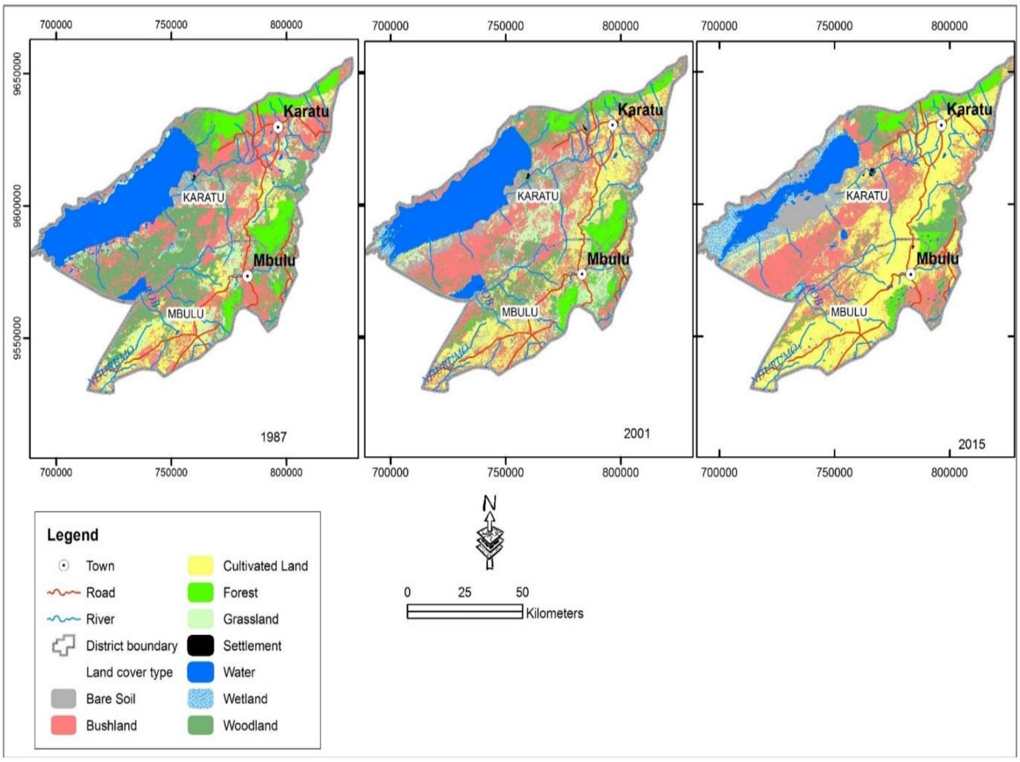
Viewing reforestation primarily as a means of mitigating climate change through carbon sequestration overlooks a suite of other roles such as regulation of land-atmosphere interactions, ecosystem services mediated by biota (e.g., pollination), and societal adaptation to climate variability and change. As noted by Harvey et al. (2014) and Paavola (2008), these roles are particularly important because development, adaptation to climate change, reduction of forest cover loss, and conservation of ecosystem services: all these present more challenges and opportunities in the tropics than elsewhere.

In this article, the argument is that carbon sequestration is only one of the multiple strategies for mitigating and adapting to climate change through reforestation. The article describes the variety of links and feedback between reforestation and climate change in tropical regions, considers their importance to decision-making, introduces a conceptual framework for climate-smart reforestation, and discusses its management implications. It considers only carbon capture and storage aspects rather than to review well-established information about carbon-focused reforestation.

2. Methodology and Study Framework

Like many desk review studies, information and data for this article was obtained through systematic review of literature and analysis of climate variables. This involved critical reading of articles, studies and reports within the field of reforestation and climate change, with particular focus on reforestation and carbon management. Academic and professional search engines—such as Google Scholar and Reference Desk—were used to obtain relevant literature on reforestation, climate change and carbon sequestration at global, regional and national levels. At the country level, various reports from the government were critically assessed and reviewed to establish elements and trends of reforestation strategies and policies towards forest management in different regions and countries across the globe. In general, the study used content and discourse analysis to uncover meanings and issues raised through published and unpublished reports; including journal papers, theses, dissertations and reports focusing on the aforementioned areas in different parts of the globe. Information obtained from this process was arranged into themes and subthemes to reflect different issues and subtitles as reflected in this article.

The evidence of vegetation land use/cover dynamics and climate change in the Northeastern Highlands of Tanzania is drawn from Mbulu and Karatu districts. The two districts are found at the edge of the eastern arm of the East-African Rift Valley in Tanzania. The study ecosystem is situated between latitudes 3°05’s and 4°15’s, and longitudes 34°45’E and 36°00’E. The area lies within an altitude ranging from 900m to 2500m above sea level, which favours a variety of tropical vegetation species (John et al., 2014). The study by Raphael (2018) in Mbulu and Karatu districts has shown that vegetation land use/cover change is real (see Map 1). Thus, there is a need for reforestation that takes into consideration the science of mitigation and adaptation to climate change so as to enhance community livelihoods and sustainable ecosystems.



Map 1: Land Use/Cover Changes in Mbulu and Karatu Districts in 1987, 2001 and 2015

Source: Landsat Imagery in 1987, 2001 and 2015

As seen in Map 1, there is decline in forest, woodland, grassland and bushland covers, while other land uses/covers have gained, such as cultivated land, wetlands, settlements and bare soil.

The article is composed of eight main sections. The first section is about the background and context to reforestation, while the second narrates the methodology and framework of the study. The third section deals with the empirical evidence of climate change in the selected study areas, while the fourth and fifth sections explain the rationale for mitigation and adaptation to climate change, respectively. The sixth section examines the climatic threats to reforestation and possible adaptation nexus. Section seven is about the synthesis of policies and management for climate-smart reforestation frameworks. The article ends with a conclusion and a set of recommendations.

3. Empirical Evidence of Climate Change in the North-eastern Highlands of Tanzania

Rainfall and temperature data is an important climate variable for studying vegetation cover dynamics in an area. The results in Figures 1 and 2 show variation in rainfall and temperature trends over 28 years in Mbulu and Karatu districts. The results indicate that in the period between 1987 and 2000, the annual average maximum and minimum temperatures were 29.6^{0}C and 11.6^{0}C, respectively; with an annual average precipitation of 534.9mm/year (Figure 1). In the period between 2001 and 2014, the area experienced an increase in annual average temperature and precipitation compared to the period between 1987 and 2000. During the period between 2001 and 2014, the annual average maximum and minimum temperatures were 29.7^{0}C and 12.2^{0}C, respectively; with the annual average of precipitation of 579.1mm/year (Figure 2). This implies that annual average precipitation increased by 44.2mm/year between the two periods. In other words, the period between 2001 and 2014 was much wetter than the period between 1987 and 2000. Börjeson (2004) indicated that the average annual rainfall in the study area ranged from 400mm in the lowlands, to 1200mm in the highlands. The availability of reliable rainfall in these areas allows the growth of natural vegetation that supports wildlife and the life of the local people.

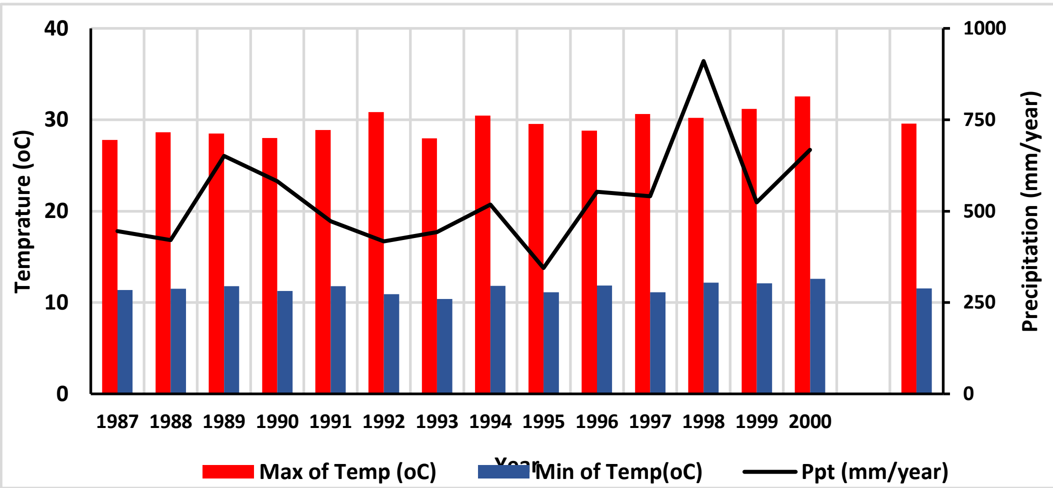


Figure 1: Annual Maximum and Minimum Rainfall in Mbulu and Karatu Districts between 1987 and 2000
Source: Raphael (2023)

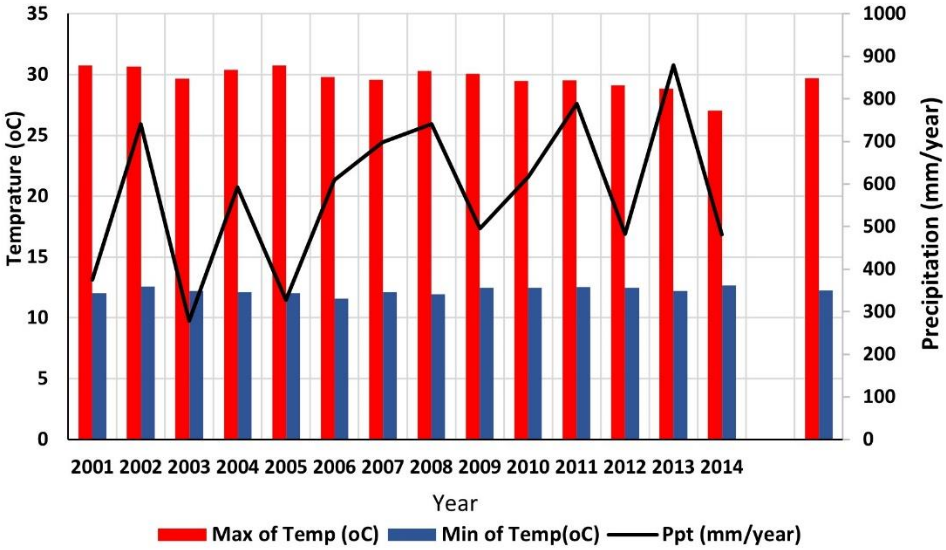


Figure 2: Annual Maximum and Minimum Rainfall in Mbulu and Karatu Districts between 2001 and 2014
Source: Raphael (2023)

The temperature data analysis showed an annual increase in maximum and minimum temperatures in the study area. For the period between 1987 and 2000, the maximum temperature increased by about 4.7^{0}C, while the minimum temperature increased by 2.2^{0}C. On the other hand, in the period between 2001 and 2014, the maximum temperature increased by 3.7^{0}C, while the minimum temperature increased by 1.1^{0}C. From this analysis, it is evident that the maximum temperature increased at a higher rate than the minimum temperature. This implies that climate change is real in the North-eastern Highlands of Tanzania in the aforementioned period of time. Studies by FAO (2010) and Panda and Sahu (2019) in India, have indicated that the increase in average annual temperature adversely affects vegetation, particularly in arid and semi-arid regions, where heat is a limiting factor in vegetation growth. Similarly, a study by Herrmann and Hutchinson (2005) in West Africa showed that increased temperature increases evapotranspiration rates of soil and water bodies, which further increases chances for drought. In the study area, like many other parts of Tanzania, temperature has increased steadily in recent years as Figures 1 and 2 indicate. The increase in temperature in the study area is also noted in a study by Raphael (2018) in Karatu and Mbulu districts, whereby the results show the drying up of streams and some rivers such as Marera, Endabash, Endagikot and Baray. Unlike the study by John et al. (2014) in Karatu District, increase in annual temperature and decline in annual rainfall have had detrimental effects on the trends of vegetation cover and growth.

The study by Raphael (2018), between 1987 and 2015, showed that vegetation covers tremendously decreased despite the increase in the amount of rainfall per year (Figures 1&2). The study also showed a decline in average annual rates of vegetation cover as described by Raphael:

> In the period between 1987 and 2015, the forest cover has declined annually by 1.36%/year, woodland by 2.5%/year, bushland by 0.12%/year, grassland by 2.68%/year and water bodies by 2.04%/year. Other land uses such as cultivated land have gained coverage by 12.09%/year, wetlands by 42.15%/year, settlements by 15. 66%/year and bare soil by 6.41%/year (Raphael, 2018: 11).

This implies that the increase in the amount of average annual rainfall in Mbulu and Karatu districts does not show any improvement in vegetation cover as expected. As noted by John et al. (2014), climate variables in the semi-arid savannah operate over relatively large areas, and cannot be invoked as an explanation for local vegetation changes. Therefore, the changes in vegetation cover in Mbulu and Karatu districts can be associated with the land use cover gained in cultivation, wetlands, settlements and bare soil. Thus, dialogue will be necessary to enable the appropriate reforestation through proper mitigation and adaptation to climate change intervention measures that are beyond carbon sequestration.

4. Reforestation for Mitigation to Climate Change

Beyond its role in mitigating climate change through carbon storage and reforestation of tropical landscapes that cause decline in vegetation cover, as mentioned earlier, any intervention on reforestation has some influence on global and regional climates through a range of mechanisms (Paavola, 2008). Reforestation has biophysical effects on the climate, which—depending on their magnitude and direction—can contribute to climate change mitigation. Globally, these effects include changes in surface albedo, surface roughness, canopy conductance, evapotranspiration and volatile organic compound emissions. The net overall result of all these changes can be either climatic warming (Kirschbaum et al., 2011) or cooling (Zhao & Jackson, 2014), depending on latitude. In boreal forests, reforestation may cause a net increase in regional temperatures through albedo effects, whereas in the tropics, the most likely net effect is cooling (Anderson et al., 2011).

Large-scale reforestation can also affect precipitation locally, regionally, and in faraway places (Swann et al., 2012). At the regional and continental scale, forests recycle rainfall and generate flows of atmospheric water vapour (Ellison et al., 2012), which may also mitigate the effects of warming in arid regions, although generalizations are difficult to make and controversies are frequent in this regard (De Groot & Van der Meer, 2010). However, further research is needed to better understand the potential for undesirable feedback such as altered precipitation in other regions, as noted in a study by Swann et al. (2012).

Furthermore, as indicated in a study by Lippke et al. (2011), reforestation can also contribute to climate change mitigation through sustainable production and use of forest products. For example, wood or biofuels from tropical plantations can be used as substitute energy or materials, which are currently responsible for large greenhouse gas emissions to the atmosphere.

5. Reforestation for Adaptation to Climate Change

Well-managed reforestation can contribute to adaptation to climate change by reducing the vulnerability of people and ecosystems to current climate hazards and future climate change as noted in a study by Doswald et al. (2014) about reforestation as a community adaptation strategy to climate change. This may occur through a variety of pathways. First, reforestation can enhance livelihood diversification, and thereby provide a safety net to increase the resilience of rural households to climate variations. For example, when agriculture is affected by drought, reforested areas can supply products such as firewood, wild fruits, mushrooms, and fodder to provide alternative sources of food, building materials, and income (Pramova et al., 2012b).

Secondly, reforestation can buffer against climate change and variability, and protect water supplies for agriculture and other human uses by stabilizing catchment hydrology, increasing base flow during drought, reducing flooding during rainfall events, and improving water quality. However, as noted in the study by Ponette-González et al. (2014), reforestation plans also need to recognize that reforestation of different types (i.e., successional stage, natural regrowth vs. plantations of native or exotic species) can lead to a variety of consequences for catchment-scale water cycles. Furthermore, Ogden et al. (2013) observed that reforestation often increases infiltration more than transpiration, increasing run-off and base flow during the dry season. On the other hand, planting fast-growing exotic species with high transpiration rates often reduces run-off, which may cause water shortages as indicated by Hodgman et al. (2012), particularly in semi-dry areas like North-eastern Tanzania. The role of reforestation in reducing storm flow is uncertain in most of the literature on extreme rainfall events. Greater understanding is needed of the effects of the type and the spatial location of reforestation on hydrological processes to enable better planning and management of local ecosystems.

Thirdly, reforestation can reduce the local impact of extreme weather events on society and ecosystems. As highlighted in the study by John et al. (2014), restoring forest cover to coastal areas and hill-slopes can stabilize land against catastrophic movements associated with wave action and intense run-off during storms and flood events. Bowler et al. (2010) noted that restoration of even a sparse tree cover can also regulate microclimatic conditions, which can limit exposure to urban populations from heat waves through shade and evaporative cooling, and protect agricultural crops by controlling temperature, humidity and exposure to winds.

Fourthly, Travis (2003) showed that some types of reforestation can contribute significantly to global biodiversity conservation by increasing resilience by species to climate change, which would otherwise magnify the decline of such species that are already occurring because of ongoing loss of forest habitat, as indicated by Raphael (2018) as well. Increasing forest cover in climate refugia, as observed by Carnus et al. (2006), can also improve long-term persistence of forest-dependent species, and improve habitat connectivity to facilitate migration of species along climatic gradients. Furthermore, Thompson et al. (2014) noted that biodiversity sustained by reforestation has the potential to improve the climate resilience of ecosystem services such as crop pollination and pest control, as well as increase future options and as-yet-unknown benefits (e.g., from drug discovery), although research into these processes has so far been largely restricted to old growth rather than restored forest.

As affirmed in the study by Kabonesa and Kindi (2013), the ability of reforestation to perform this range of climate-adaptation services will be influenced by the type of reforestation and associated level of biodiversity, as well as by forest age, although these relationships are in need of further study. For example, non-timber forest products are scarce in industrial monoculture plantations, but can be abundant in more biodiverse plantations, which also provide better habitat quality for biodiversity conservation and management.

6. Climatic Threats to Reforestation and Possible Adaptations Nexus

Climate change affects reforestation in many ways. As observed by Holmgren et al. (2013), an increased frequency of either very wet years or drought events may influence the potential for achieving long-term tree cover in areas that are marginal for forest growth. Furthermore, Anderson-Teixeira et al. (2013) noted that altered temperature and precipitation, extreme events, and increased atmospheric carbon dioxide concentrations: all will drive changes in forest structure and species composition. This is because new conditions will be physiologically unsuitable for some previously occurring species, while favouring others. Climate change may lead ecosystems to alternate stable states where forests are replaced by bushlands, and/or grasslands.

These processes, as indicated by Pawson et al. (2013), will directly affect reforestation through different ways. Climate change may increase the likelihood of outbreaks of forest pests and diseases. It could also facilitate the spread of invasive species, potentially producing both positive and negative effects, including threats to forest recovery and contributions to the rate and volume of biomass growth in the reforestation of marginal lands. Another factor, as mentioned by Lawson and Michler (2014), relates to the consequences of changes in local habitat suitability, which may require reconsidering the choice of locally appropriate species. The effects can also relate to disturbance regimes, such as the frequency or intensity of storms or fires, which may impair the success of reforestation. Indirectly, decreased suitability of some areas for agriculture may lead to the abandonment of land available for future reforestation; and increase competition between agricultural and forest land uses in areas suitable for agriculture. In other locations, as supported by Bradley et al. (2012), agricultural abandonment could lead to forest regrowth.

The emergence of forest-related policy and market instruments—such as REDD+, or adaptation plans—will also directly affect reforestation by creating incentives and influencing choices of management practices. Furthermore, policies and markets will indirectly affect reforestation through societal efforts to deal with climate change in other spheres of activity. For example, Brodie et al. (2012) noted that increasing demand for bioenergy as a mitigation option could either favour reforestation as a source of wood energy, or reduce reforestation through increased land competition from biofuel crops.

7. Synthesis of Policies and Management for Climate-smart Reforestation Framework

Given the wide range of opportunities for reforestation in contributing to both adaptation and mitigation, together with the need to identify and minimize climate-related threats to reforestation processes, there is a pressing need to adjust reforestation practices and policies to suit a changing climate. Such adjustment constitutes the strategic adoption of 'climate-smart reforestation', defined as "reforesting for climate change mitigation and adaptation," while ensuring that the direct and indirect impacts of climate change on reforestation are anticipated and minimized. As noted by Raphael (2018), given the multiple possible trade-offs, the challenge for climate-smart reforestation is to implement an effective combination of approaches to meet all three objectives: societal adaptation, climate mitigation, and ecological resilience over time and space.

The UNCCC's (2014) report revealed that existing policy gadgets address these three objectives individually, and to differing degrees. In addition, Salvini et al. (2014), found out that the role of reforestation in mitigation has been recognized by the Clean Development Mechanism (CDM) of the Kyoto Protocol, which has rewarded 55 afforestation and reforestation projects in developing countries, including Tanzania. Currently, high on the international agenda on climate change is the REDD+ initiative (Reducing Emissions from Deforestation and Forest Degradation); which includes the enhancement of forest carbon stocks. Many tropical countries—including Tanzania—have included reforestation activities in their REDD+ strategies. The place of reforestation in the adaptation policy is less developed, although several adaptation plans (such as the National Adaptation Programme of Action (NAPA), prepared by least developed countries, do consider the role of reforestation in adaptation. For example, Pramova et al. (2012a) noted that Comoros' NAPA proposes watershed rehabilitation with multiple-use plantations, restoration of degraded forests, and agroforestry to respond to the identified vulnerability of local communities to climate variations; and the shortages of water, firewood, and timber.

However, as revealed by O'Connor (2008) in one of the studies on tropical forests, most policies consider the three objectives of climate-smart reforestation separately: they often overlook possible trade-offs and synergies. For example, reforestation projects managed with a carbon purpose could have detrimental consequences on water availability in semi-arid tropics and on biodiversity. By contrast, reforestation that is explicitly climate-smart uses a multi-objective planning focus that enables different objectives to reinforce each other so that their interactions produce synergies rather than trade-offs. For example, Duguma et al. (2014) observed that tree regeneration in the Southern Highlands of Tanzania, under the Ngitili resource management system, achieves carbon storage together with improved watershed conservation and greater provision of natural resources (water, food, and fodder) for livelihoods. UNDP (2012) reported on the proposed adaptation projects in Colombia and Costa Rica that aimed to reforest using flood-resistant native tree species to reduce flood impacts on downstream communities, while also achieving carbon storage.

Likewise, FAO's (2007) report noted that, with respect to reforestation and restoration management practices, methods and guidelines have been developed with different objectives in mind. Thus, a given method may exist to: (a) enhance supporting services (e.g., improve nutrient cycling and soils by planting multiple tree species, fostering ground cover with soil fauna from natural forests); (b) conserve water (e.g., by ensuring a closed canopy or avoiding species with high water use); (c) increase biomass production (with appropriate selection of species and management intensity); and (d) ensure resilience (e.g., with diverse tree communities). Depending on the context, some of these methods could contribute to the three objectives of climate-smart reforestation; but as suggested by Simonit and Perrings (2013), trade-offs also need to be recognized and managed. For example, tree mixes can store as much carbon as mono-cultures; be more resilient and provide additional ecosystem services; and have higher rates of water use. To aid this process in the face of uncertainties, the implementation of reforestation management needs to be coupled with monitoring and adaptive management science.

The implementation of climate-smart reforestation is limited by several knowledge gaps. One example given by Hulme et al. (2001) is about the criteria that natural resources managers would use to select species for reforestation that meets multiple objectives. Many reforestation efforts in tropical regions have used a limited number of species (e.g., Eucalyptus spp. and Pinus spp. have been used in north-eastern Tanzania), in part because of limited guidance on the selection of species, and limited knowledge on other potentially productive and resilient species. The choice of exotic versus native species is an important topic, as there is an inherent tension between concerns of biodiversity and reforestation success. A good example is when native species cannot flourish in degraded sites; or when exotic species appear more adapted to the future local climate than native ones. This implies that there is limited knowledge on the response of tropical reforestation species and ecosystems to climate change, and on the ecosystem services produced by reforestation in the tropics.

Capacity building would allow managers to examine outcomes of reforestation under a range of climate scenarios; and to use improved knowledge, approaches, and tools for integrated assessment of issues such as biophysical and biogeochemical cooling; or warming effects, effects on rainfall, and contributions to societal adaptation and biodiversity conservation. These findings are also supported by Forkuo and Frimpong (2012), who noted that capacity building and tools assessment would allow farmers decide among reforestation alternatives, for example, between passive (i.e., natural regeneration) and active options.

In climate-smart reforestation, the scale of benefits is global for mitigation, but local or regional for adaptation. As beneficiaries are generally different from reforestation managers, adequate climate policy and institutional arrangements, as well as involvement of local communities, are essential to ensure that this mismatch of scales does not limit the achievement of benefits. Currently, policy instruments for climate change mitigation and adaptation provide limited incentives with often high transaction costs to reforestation managers, the Clean Development Mechanism being a clear example. Timber is often more valuable as an incentive than the value of the carbon stored. But, as informed in the study by Wertz-Kanounnikoff et al. (2011), in some cases carbon incentives can provide additional revenues that move a plantation project above a profitability threshold. In addition, the increasing recognition of the role of forests in adaptation—for instance, watershed stabilization—has raised interest in the development of economic incentives, such as payment for ecosystem services for adaptation. Even though they are currently marginal, climate change incentives can influence decision-making about management practices (Armah et al., 2016), or allow active management of spontaneous reforestation for enhancing the contribution of second growth forests to climate change adaptation and mitigation.

Also, climate-smart reforestation has reciprocal relationships with other sectors of climate change adaptation and mitigation. The relative contribution of reforestation can be minor compared with these other sectors, but it is often complementary to them. For example, coastal or watershed reforestation alone cannot guarantee complete protection from extreme events, but it is effective as part of a broader disaster risk reduction, and adaptation strategy (Armah et al., 2015). The contribution of reforestation to mitigation is also linked to other sectors—e.g., building or energy sectors—through the production of bioenergy and bio-materials. These inter-sectoral links can also lead to the development of incentives for climate-smart reforestation, such as payment for carbon and watershed protection.

8. Conclusion and Recommendations

Adaptation and mitigation are considered separately in international climate change policies, and in most national or sub-national initiatives. However, some activities can significantly contribute to both objectives in a manner that may produce either synergies or trade-offs. Reforestation is one such activity, and therefore needs to be managed with both adaptation and mitigation objectives in mind to avoid the implementation of one strategy to the detriment of the other. Furthermore, the management of increased vegetation cover needs to incorporate measures for reducing the direct and indirect impacts of climate change and variability on reforestation. Yet, the achievement of climate-smart reforestation is presently limited by a range of uncertainties and knowledge gaps. Improved knowledge will help managers make informed decisions adapted to local specificities. Finally, larger climate-smart landscape management and rural development initiatives in Tanzania—and tropical regions at large—would be strengthened by the inclusion of a component aimed at climate-smart reforestation, based on the principles reflected in this article. The Bonn Challenge and the Declaration on Forests of the New York Climate Summit are good opportunities for a global effort toward climate-smart reforestation to enhance community livelihoods and sustainable forest ecosystems.

References

Adger, W. N. (1999). Social vulnerability to climate change and extremes in coastal Vietnam. *World Development,* 27: 249–269.

Anderson, R. G., Canadell, J. G., Randerson, J. T., Jackson, Hungate, B. A., Baldocchi, D. D., Ban-Weiss, G. A., Bonan, G. B., Caldeira, K. & Cao, L. (2011). Biophysical considerations in forestry for climate protection. *Frontiers in Ecology and the Environment,* 9: 174–182.

Anderson-Teixeira, K. J., Miller, A. D., Mohan, J. E., Hudiburg, T. W., Duval, B. D. & DeLucia, E. H. (2013). Altered dynamics of forest recovery under a changing climate. *Global Change Biology,* 19: 2001–2021.

Armah, A. F., Luginaah, I., Hambati, H., Chuenpagdee, R. & Campbell, G. (2016). *Evaluating differences in barriers to climate change adaptation between the poor and non-poor in Coastal Tanzania.* Springer International Publishing Switzerland. Available at DOI 10.1007/978-3-319-25814-0_25.

Armah, A. F; Hambati, H., Luginah, I., Genesis, T. Y., Campbell, G. & Chuenpagdee, R. (2015). Monitored versus experience-based perceptions of environmental change: Evidence from Coastal Tanzania. *Journal of Integrative Environmental Sciences,* 12(2): 119–152.

Börjeson, L. (2004). *A history under siege: Intensive agriculture in the Mbulu Highlands Tanzania,* 19*th Century to the present.* Sweden: Almqvist and Wiksell.

Bowler, D. E., Buyung-Ali, L., Knight, T. M. & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning* 97: 147–155.

Bradley, B. A., Estes, L. D., Hole, D. G., Holness, S., Oppenheimer, M., Turner, W. R., Beukes, H., Schulze, R. E., Tadross, M. A. & Wilcove, D. S. (2012). Predicting how adaptation to climate change could affect ecological conservation: Secondary impacts of shifting agricultural suitability. *Diversity and Distributions,* 18: 425–437.

Brodie, J., Post, E., Laurance, W. F. (2012). Climate change and tropical biodiversity: A new focus. *Trends in Ecology & Evolution,* 27: 145–150.

Carnus, J. M., Parrotta, J., Brockerhoff, E., Arbez, M., Jactel, H., Kremer, A., Lamb, D., O'Hara, K. & Walters, B. (2006). Planted forests and biodiversity. *Journal of Forestry,* 104: 65–77.

De Groot, R. S. & Van der Meer, P. J. (2010). Quantifying and valuing goods and services provided by plantation forests. In Bauhus, J., Van der Meer, P. & Kanninen, M. (Eds). *Ecosystem goods and services from plantation forests* (pp. 16–42). Earthscan, London, United Kingdom and Washington DC.

Doswald, N., Munroe, R., Roe, D., Giuliani, A., Castelli, I., Stephens, J., Möller, I., Spencer T., Vira, B. & Reid, H. (2014). Effectiveness of ecosystem-based approaches for adaptation: Review of the evidence-base. *Climate and Development*, 6: 185–201.

Duguma, L. A., Minang, P. A. & van Noordwijk, M. (2014). Climate change mitigation and adaptation in the land use sector: From complementarity to synergy. *Environmental Management,* 54: 420–433.

Ellison, D., Futter, M. N., Bishop, K. (2012). On the forest cover - water yield debate: From demand- to supply-side thinking. *Global Change Biology,* 18: 806–820.

FAO (Food and Agricultural Organization) (2010). *Global forest resources assessment*. Main Report, Forestry Paper, Rome, Italy.

FAO (2007). *Adaptation to climate change in agriculture, forestry and fisheries: Perspective framework and priorities*. Interdepartmental. Working Group on Climate Change. Food and Agriculture Organization of the United Nations Rome, Italy.

Forkuo, E. & Frimpong, A. (2012). Analysis of forest cover change detection. *International Journal of Remote Sensing Applications,* 2(4): 82–92.

Harris, J. A., Hobbs, R. J., Higgs, E. & Aronson, J. (2006). Ecological restoration and global climate change. *Restoration Ecology,* 14: 170–176.

Harvey, C. A., Chacón, M., Donatti, C. I., Garen, E., Hannah, L., Andrade, A., Bede, L., Brown, D., Calle, A. & Chará, J. (2014). Climate-smart landscapes: Opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters,* 7: 77–90.

Herrmann, S. M. & Hutchinson, C. F. (2005). The changing contexts of the desertification debate. *Journal of Arid Environments*, 63: 538–555.

Hodgman, T., Munger, J., Hall, J. S. & Ashton, M. S. (2012). Managing afforestation and reforestation for carbon sequestration: Considerations for land managers and policy makers. In Ashton, M. S., Tyrrell, M. L., Spalding, D. & Gentry, B. (Eds). *Managing forest carbon in a changing climate* (pp. 227–255). Springer, New York, New York.

Holmgren, M., Hirota, M., van Nes, E. H. & Scheffer, M. (2013). Effects of inter-annual climate variability on tropical tree cover. *Nature Climate Change,* 3: 755–758.

Houghton, R. (2012). Carbon emissions and the drivers of deforestation and forest degradation in the tropics. *Current Opinion in Environmental Sustainability,* 4: 597–603.

Hulme, M., R. Doherty, T., Ngara, M., New, D. & Lister (2001). African climate change: 1900–2100. *Climate Research,* 17: 145–168.

John, L. R., Hambati, H. & Armah, F. A. (2014). Intensity analysis of land-use and land-cover change in Karatu District, Tanzania: Community perceptions and coping strategies. *Journal of African Geographical Review*, 33(2): 150–173.

Kabonesa, C. & Kindi, F. I. (2013). Effects of climate change and variability on pastoral communities: Coping and adaptive strategies for women and men in Uganda. In Mulinge, M. M. & Getu, M. (Eds). *Impacts of climate change and variability on pastoralist women in Sub-Saharan Africa*, OSSREA Addis Ababa, Ethiopia.

Kirschbaum, M. F., Whitehead D., Dean S. M., Beets P. N., Shepherd, J. D. & Ausseil, A. E. (2011). Implications of albedo changes following afforestation on the benefits of forests as carbon sinks. *Biogeosciences,* 8: 3687–3696.

Lawson, S. S., Michler, C. H. (2014). Afforestation, restoration and regeneration - not all trees are created equal. *Journal of Forestry Research,* 25: 3–20.

Lippke, B., Oneil, E., Harrison, R., Skog, K., Gustavsson, L. & Sathre, R. (2011). Life cycle impacts of forest management and wood utilization on carbon mitigation: Knowns and unknowns. *Carbon Management,* 2: 303–333.

O'Connor, D. (2008). Governing the global commons: Linking carbon sequestration and biodiversity conservation in tropical forests. *Global Environmental Change,* 18: 368–374.

Ogden, F. L., Crouch, T. D., Stallard, R. F. & Hall, J. S. (2013). Effect of land cover and use on dry season river runoff, runoff efficiency, and peak storm runoff in the seasonal tropics of Central Panama. *Water Resources Research,* 49: 8443–8462.

Paavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. *Environmental Science & Policy,* 11: 642–654.

Panda, A. & Sahu, N. (2019. Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmos Sci. Lett. e*932. Available at https://doi. org/10.1002/asl.932.

Pawson, S., Brin, A., Brockerhoff, E., Lamb, D., Payn, T., Paquette, A. & Parrotta, J. (2013). Plantation forests, climate change and biodiversity. *Biodiversity and Conservation,* 22: 1203–1227.

Ponette-González, A. G., MarínSpiotta, E., Brauman, K. A., Farley, K. A., Weathers, K. C. & Young, K. R. (2014). Hydrologic connectivity in the high-elevation tropics: Heterogeneous responses to land change. *Bioscience,* 64: 92–104.

Pramova, E., Locatelli, B., Brockhaus, M. & Fohlmeister, S. (2012a). Ecosystem services in the National Adaptation Programmes of Action. *Climate Policy,* 12: 393–409.

Pramova, E., Locatelli, B., Djoudi, H. & Somorin, O. A. (2012b). Forests and trees for social adaptation to climate variability and change. *Climate Change,* 3: 581–596.

Raphael, L. J. (2018). Vegetation land cover/use dynamics and their effects in Mbulu and Karatu districts in the North-eastern Highlands of Tanzania. *International Journal of Geospatial and Environmental Research,* 51: 1–23.

Raphael, L. J. (2020). The implication of vegetation land cover and use changes for policy response and community livelihoods in Tanzania. PhD thesis, University of Dar es Salaam.

Salvini, G., Herold, M., De Sy V., Kissinger, G., Brockhaus, M. & Skutsch, M. (2014). How countries link REDD+ interventions to drivers in their readiness plans: Implications for monitoring systems. *Environmental Research Letters,* 9: 074004.

Simonit, S. & Perrings, C. (2013). Bundling ecosystem services in the Panama Canal watershed. *Proceedings of the National Academy of Sciences*, 110: 9326–9331.

Swann, A. L., Fung, I. Y. & Chiang, J. C. (2012). Mid-latitude afforestation shifts general circulation and tropical precipitation. *Proceedings of the National Academy of Sciences of the United States of America,* 109: 712–716.

Thompson, I. D., Okabe, K., Parrotta, J. A., Brockerhoff, E., Jactel, H., Forrester, D. I. & Taki, H. (2014). Biodiversity and ecosystem services: Lessons from nature to improve management of planted forests for REDD-plus. *Biodiversity and Conservation,* 23: 2613–2635.

Trabucco, A., Zomer, R. J., Bossio, D. A., van Straaten, O. & Verchot, L. V. (2008). Climate change mitigation through afforestation/reforestation: A global analysis of hydrologic impacts with four case studies. *Agriculture, Ecosystems & Environment,* 126: 81–97.

Travis, J. M. J. (2003). Climate change and habitat destruction: A deadly anthropogenic cocktail. *Biological Sciences,* 270: 467–473.

Turner, W. R., Oppenheimer, M. & Wilcove, D. S. (2009). A force to fight global warming. *Nature,* 462: 278–279.

UNDP (2012). *Reducing risk and vulnerability to climate change in the region of La Depresión Momposina in Colombia (Proposal* 62507: *Project* 80029*)*. Adaptation Fund and UNDP, Washington D.C.

Wertz-Kanounnikoff, S., Locatelli, B., Wunder, S. & Brockhaus, M. (2011). Ecosystem-based adaptation to climate change: What scope for payments for environmental services? *Climate and Development,* 3: 143–158.

Zhao, K., Jackson, R. B. (2014). Biophysical forcings of land-use changes from potential forestry activities in North America. *Ecological Monographs,* 84: 329–353.