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Causal relationships between African mahoganies exports and deforestation in Ghana: policy implications

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Abstract When exploiting forest resources, the resource use must be sustainable if its use is to support its function in the natural ecosystem. The African mahogany, a prized timber species, is widely exploited, raising policy concerns about the management of forest resources to meet the social, economic, and ecological needs of present and future generations. This paper explores, for the purpose of policy implication, the relationship between the exportation and deforestation of African mahoganies. The analysis employed a Granger causality test within the error correction model to evaluate the direction of causality between African mahoganies exports and deforestation in Ghana. The results suggested that in the short run, there was significant ($P < 0.01$) unidirectional causality from African mahoganies exports to deforestation. However, there was no directional causality from deforestation to mahogany exports. Thus, mahogany extraction and logging in general are among the major factors contributing to deforestation in Ghana. The general assessment of historical trends in the extraction levels of the two main genera of African mahoganies revealed that *Entandrophragma cylindricum* and *Khaya ivorensis* have been the most exploited species over the years. Improvements in, and the enforcement of, existing forest institutions and incentives, as well as related policies, could minimise the rate of deforestation not only of the African mahogany but also in timber logging, thus stemming forest degradation and deforestation in the country.

Keywords Granger causality · Pervasive policies · Mahogany logging

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1 Introduction

In the quest to exploit forest resources for their economic value, the resource use must be sustainable if it is to support its function in the natural systems. The UNCTAD Conference in 1992 addressed the issue of sustainable forest management (SFM), defined as the management of forest resources and forestlands in a way that ensures that the goods and services derived from the forest meet the social, economic, ecological, cultural and spiritual needs of present and future generations.

The forest sector in Ghana faces several challenges, the most important being severe deforestation caused by forest logging, which is due to demographic and economic pressures, policy and institutional lapses, increased infrastructural developments and technological advances. One of the major timber species subjected to over-exploitation is the African mahogany. By the early 1990s, only about one-third of the country was still forested, and this was dominated primarily by lower commercially valued species. Consequently, the government was forced to make difficult choices between the benefits of economic exploitation and the conservation of the forests. The 1994 Forest and Wildlife Policy of Ghana is aimed at conservation and sustainable development of the nation's forest resources to maintain the environmental quality and perpetual flow of optimum benefits to all segments of society. The government currently aims to increase the sale of wood products to replace earnings from logs, the exportation of which was banned in 1989.

Ghana is recognised as one of the most advanced tropical African countries in established forest policy, legislation, forest inventory, management planning because it has national forest standards and principles along with criteria and indicators for judging the quality of forest management and usage. However, the rate of deforestation has increased in spite of these governmental efforts. It is estimated that Ghana's high forest zone (HFZ) faces a rate of deforestation of 5 and 2 % in off- and on-reserves, respectively. The off-reserves have been so severely fragmented and degraded due to illegal logging that Ghana may face future export deficits and the possible extinction of the country's forestry sector (Tamakloe 2000). The conservation status of the mahogany species in tropical Africa has recently been a subject of great concern, as natural populations are being severely depleted by deforestation mainly because of illegal logging. While pervasive logging activities are known to lead to deforestation and forest degradation, empirically, the casual relationship between logging for exports and deforestation is largely unknown. The objective of this paper is, therefore, to investigate the causal relationship between the exportation and deforestation of African mahoganies in Ghana for the purpose of impacting policy. The paper empirically tests the relationship between African mahogany logging and deforestation from the perspective that the African mahogany, a prized timber species, is widely exploited, thus raising policy concerns about the management of forest resources (off- and on-reserve) to meet the social, economic, and ecological needs of present and future generations. In addition, the paper evaluates the historical trends in the extraction levels of the African mahogany species in Ghana for policy implications.

2 Historical developments of mahogany exploitation in Ghana

African mahoganies consist of the genera *Khaya* and *Entandrophragma* (Family: Meliaceae). The species from these genera are the main sources of commercial timber in the countries where the species are found (Opuni-Frimpong et al. 2008). *Khaya* consists of four species (*ivorensis, anthotheca, grandifoliola* and *senegalensis*), and *Entandrophragma* consists of four species (*utile*, *angolense*, *cylindricum* and *candollei*). Collectively, they are known as African mahoganies. The African mahoganies are distributed in all the timber producing countries of West Africa, Central Africa and parts of Eastern Africa (Irvine 1961). The first commercial exploitation and exportation of African mahoganies from Ghana into the British timber market commenced in 1883 (Parren and de Graaf 1995), and in 1891, Ghana exported 3,000 m^3 of African mahogany (mainly *Khaya* and Entandrophragma spp.) to the United Kingdom (Taylor 1960). By 1913, with the worldwide demand for mahogany wood reaching 107,000 m^3, Ghana supplied 88,200 m^3 of the total demand (Taylor 1960). Over the years, there was a consistent increase in the extraction levels or volume of mahogany, which eventually led to over-exploitation. African mahoganies assumed great importance as a tropical hard wood when original mahoganies (*Swietenia mahagoni and Swietenia macrophylla*) were being exhausted in the Latin Americas (Parren and de Graaf 1995). As a result, the commercial exploitation of mahoganies led to the rapid depletion of the forest resource base and accelerated deforestation in Ghana. Prior to commercial logging, most of the high forest zones had been protected from threat due to their isolation. Suddenly, these previously inaccessible frontiers of pristine forest reserves became accessible, though access was difficult and there were limited settlements. Thus, the logging of African mahoganies was confined to the immediate margins of navigable rivers, and the commercial exploitation of mahoganies was, more or less, concentrated along the coasts and south western corner of the country. This state of affairs began to change with the advent of railway lines and feeder roads to the hinterlands, which paved the way for the loggers to gain access to dense virgin forests in the middle belt of the country. Naturally, mahoganies occur in small numbers and are scattered rather sparsely, even in mahogany-rich forests, often at a density of one or two per hectare (Hall et al. 2003). While selective logging methods in the tropics opened inaccessible pristine forest area to colonisation (Verissimo et al. 1995; Johns 1997; Whitmore 1999; Laurance 1999, 2001), to gain access to a single mahogany tree, loggers would often bulldoze access roads that criss-crossed the forest (Wilkie et al. 1992; Bennett 1999; Johns 1997; Stone 1998; Nepstad et al. 2001). Settlers or peasant cocoa farmers would then use the tracks constructed by the loggers to gain access to new forest frontiers and establish villages and cocoa farms (e.g. Wilkie et al. 2000; Mittelman 2001). One of the major problems associated with mahogany logging is the reduction in the canopy cover of pristine primary forest from approximately 80–43 % (Uhl and Vieira 1989). Canopy openings create opportunities for weed invasion, accompanied by a concomitant decrease in natural regeneration (Putz 1991; Sist and Brown 2004). In Ghana, at the beginning of the eighteenth century, the high forest zone where most commercial logging is conducted covered an area of approximately 8.2 million hectares. This was reduced to half in 1948, and by 1990, this zone occupied only 20 % of the original area (Dadebo and Shinohara 1999). However, there is enough empirical evidence to show that accelerated rates of deforestation in the 1980s were due to pervasive economic policies of the structural adjustment programme (SAP) imposed on the country by the World Bank and the International Monetary Fund (Kaimowitz et al. 1999; Benhin and Barbier 2004; Codjoe and Dzanku 2009). Moreover, the SAP led to a substantial increase in logging (Benhin and Barbier 2004). In fact, in the 1980s, the forestry sector was the third-largest foreign exchange earner after cacao and gold, accounting for 5–7 % of the total gross domestic product (GDP), and it employed approximately 70,000 people (IIED 1998, cited in Glastra 1999). Currently, it is estimated that the total forest cover of Ghana is approximately 4.9 million hectares (FAO 2010). However, as of 2010, the annual rate of deforestation in Ghana is approximately 135,394.86 hectares/year (FAO 2010).

3 Theoretical framework

In general, deforestation and forest degradation have been attributed to the conversion of land for agricultural purposes, the extraction of round logs for processing into wood products or local markets and/or export. However, forest degradation is mainly caused by log extraction (Ewers 2006). This paper derives its theoretical framework from dynamic models of deforestation, which is based on the concept of the optimal inter-temporal allocation of forest and forest resources (Ehui and Hertel 1989; Codjoe and Dzanku 2009; Kerr et al. 2003) and follows a modified version of framework provided by Codjoe and Dzanku (2009) and Kerr et al. (2003).

The allocation of unit area (hectare) j of forestland λ for logging mahoganies and, subsequently, for export is facing a dynamic optimisation problem. The timber firm or company decides to log the land for export leading to deforestation, or to not log the land at a particular point in time t in a bid to maximise expected streams of benefit from the hectare j of forestland λ. The optimisation problem is stated as follows (Codjoe and Dzanku 2009; Kerr et al. 2002, 2003):

$$Y = \mathrm{Max} \int_{0}^{\infty} e^{-rt} S_{jt} \mathrm{d}t + \int_{0}^{\infty} e^{-rt} \left(R_{jt}^{\lambda} - C_{jt}^{\lambda} \right) \mathrm{d}t \tag{1}$$

where Y captures the magnitude of discounted benefits; $S_{jt}$is the expected returns from forestland for the provision of ecosystem services; R_{jt}^{λ}denotes expected returns to non-forest uses; C_{jt}^{λ} is the cost involved in using the land for logging; and r denotes the prevailing interest rate. Two necessary conditions must exist for logging to occur on the forestland (λ) or the land will be converted to other profitable economic uses. Logging will only commence if it is more profitable than other land-use options, and the present discounted rents at time t from logging for exportation must be high enough to compensate for other forestland use options as well as the net cost of clearing the land. Thus, the following arbitrage conditions must exist:

$$\int_{o}^{\infty} e^{-rt} \left[\left(R_{jt}^{\lambda} - C_{jt}^{\lambda} \right) - S_{jt} \right] \mathrm{d}t > 0 \tag{2}$$

However, if the timber firm or company decides to suspend logging until time $t + 1$ to make clearing and extraction for timber more profitable, invariably the cost of extraction will go down. Thus, the following condition must also hold:

$$R_{jt}^{\lambda} - S_{jt} - rC_{jt}^{\lambda} + \frac{\mathrm{d}C_T}{\mathrm{d}t} > 0 \tag{3}$$

Conditions (3) and (4) mostly hold for the extraction of timber for exportation to be more profitable. Moreover, if the second order condition (4) holds, then either condition is sufficient for log extraction.

$$\frac{\mathrm{d}R_{jt}^{\lambda}}{\mathrm{d}t} - \frac{\mathrm{d}S_{jt}}{\mathrm{d}t} + \frac{\mathrm{d}^2}{\mathrm{d}t^2} C_{jt}^{\lambda} > 0 \tag{4}$$

From a microeconomics point of view, the ultimate aim of any timber firm engaged in extraction of mahogany species, or other timber tree species, for export is to maximise the benefit derived from the profits by converting more forestland into logging activities. However, as any renewable natural resource, the stock (F) of timber on forestland changes over time (t), leading to more clearing and deforestation, as well as forest degradation. The discounted utility maximisation problem of benefits derived from the profit over time horizon can be stated as follows:

$$Z = \underset{\Gamma_{ijt} X_{ijt}^{\lambda}}{\mathrm{Max}} PV_{q_{ijt}^{l}} = \int_{0}^{\infty} e^{-rt} \left\{ U_{ijt}^{\lambda} \left[q_{ijt}^{\lambda} \left(\Gamma_{ijt}^{\lambda}, X_{ijt}^{\lambda}, F_{ijt}^{\lambda} \right) \right] \right\} \mathrm{d}t \tag{5}$$

The discounted benefits (utility) is subject to

$$\frac{\mathrm{d}F}{\mathrm{d}t} = F_{ijt} = -D_{ijt}^{\lambda} \tag{6}$$

$$F_{ijt}, D_{ijt}^{\lambda}, X_{ijt}^{\lambda} \geq 0 \tag{7}$$

$$F(0) = F_0 \tag{8}$$

The variables in the equation are defined as follows: Z denotes the magnitude of discounted benefits (net present value) of the timber firm or company engaged in mahogany extraction from plot j at a particular location of high forest zone $\imath$ at time t. U (.) is the utility function, characteristically twice differentiable. However, the U (.) depends on the streams of benefits derived from profits generated from the logging of mahogany species. λ denotes forestland converted to timber extraction to generate the above streams of profits, and X represents inputs used, such as bulldozers, forwarders, labour, fuel, articulated trucks to extract mahoganies and value addition for export. $\Gamma_{ijt}^{\lambda}$is the deforestation rate or land cover change as result of the exploitation of timber from a unit area of forestland (λ), and F_{ijt} represents mahogany resources or stock found on the forestland on plot j at time t. Equation (6) is a constraint that depicts change in mahogany stock or other timber species in the forestland (λ) over time t, and Eq. (7) denotes the initial endowment of forestland at time t. The profit function of the logging firm for extracting from plot j at concession i in a high forest zone for forestland λ is specified as:

$$q_{ijt}^{\lambda} = P_{ijt}^{\lambda} Q_{ijt}^{\lambda} \left(X_{ijt}^{\lambda}, \Gamma_{ijt}^{\lambda}, F_{ijt} \right) - W_{ijt}^{\lambda} X_{ijt}^{\lambda} - C_{ijt}^{\lambda} \Gamma_{ijt}^{\lambda} \tag{9}$$

where $P_{ijt}^{\lambda}$is the world price (FOB) for timber (logs) and processed lumber from African mahogany species, Q_{ijt}^{λ} represents the quantity of round logs extracted and processed into other products, W_{ijt}^{λ} denotes the prices of inputs used in both the extraction of round logs and the value addition or processing of the round logs to other products and $C_{ijt}^{\lambda}$is the cost of logging. Equations (9) and (5) can be collapsed into the following equation:

$$\underset{\Gamma_{ijt}^{\lambda} X_{ijt}^{\lambda}}{\mathrm{Max}} PV_{q_{ijt}^{l}} = \int_{0}^{\infty} e^{-rt} \left\{ U_{ijt}^{\lambda} \left[P_{ijt}^{\lambda} Q_{ijt}^{\lambda} \left(\Gamma_{ijt}^{\lambda}, X_{ijt}^{\lambda}, F_{ijt}^{\lambda} \right) - W_{ijt}^{\lambda} X_{ijt}^{\lambda} - C_{ijt}^{\lambda} \Gamma_{ijt}^{\lambda} \right] \right\} \mathrm{d}t \tag{10}$$

Equation (10) is subject to Eqs. (6) and (8). In this instance, land has two optional uses: deforestation (timber extraction) or forest conservation. The optimal choice of using purchased inputs in the extraction process or the harvesting of a given mahogany stock in forestland is

$$\mathrm{Max}_{\{l\}}\, Z_{ijt}^{\lambda}$$

$$Z_{ijt}^{\lambda} = \mathrm{Max}_{[x,\Gamma,l]} = \int_{0}^{\infty} e^{-rt} q_{ijt}^{\lambda}(.)\mathrm{d}t \tag{11}$$

Equation (11) describes the dynamic model of the deforestation decision of a timber firm. Thus, the decision of the firm regarding mahogany exportation is

$$\text{Choose } \lambda_{ijt} = \text{deforest if: } Z_{ijt}^{\text{deforest}} > Z_{ijt}^{\text{forest}} \tag{12}$$

The possibility of a causal link between the firm's decision to exploit the discounted benefits arising from African mahogany for export (Eq. 3) and the dynamic deforestation decision of the timber firm (Eq. 12) can be tested. Granger causality is said to exist between two economic variables Γ_t and Λ_t if a better accuracy of predicting the current value of Λ_t is acquired by using past values of Γ_t (Granger 1969). The operational model of a casual relationship between deforestation and logging (mahogany exportation) can be specified econometrically as a simple vector autoregressive model (VAR):

$$\Lambda_t = \gamma_i \Lambda_{t-1} + \beta_i \Gamma_t + \alpha_t \tag{13}$$

where Γ_t denotes the deforestation rate or land cover change, Λ_t represents mahogany exports or logging in general, β denotes a parameter estimate and α_t is the error term. However, because data used to run equation (13) is of a time series in nature, it may be co-integrated, leading to non-stationary variables and violating assumptions under the ordinary least square (OLS). Hence, we employed the Granger causality test within an error-correction model (ECM) framework (Al-Yousif 2008) to test for short- and long-run casual relationships between mahogany export and deforestation in Ghana.

4 Research methodology

4.1 Study area description

Ghana is situated (8°00′N; 2°00′W) on the west coast of sub-Saharan Africa, a few degrees north of the Equator, and it shares common borders with Togo in the east, Burkina Faso to the north and Cöte d'Ivoire to the east. The country has 539 km of coastline bordering the Gulf of Guinea (Atlantic Ocean) in the south (Fig. 1). Ghana has a humid tropical climatic condition and experiences a bimodal rainfall pattern, with a maximum annual rainfall of approximately 2,200 mm in the moist forest to the south and a minimum rainfall amount of 1,000 mm in the savannahs to the north of the country (FAO 2002). However, the high forest zone registers two peak rainfall seasons that occur from April to July and from September to November with corresponding short, relatively dry periods.

The Harmattan season (i.e. dry and dusty West African trade winds from the Sahara into the Gulf of Guinea) is a severe but short dry season that occurs from January to February, shortly after the minor rains of the season. The diurnal average annual temperature of the country ranges between 21 and 32 °C and relative humidity of approximately 50–85 %. The country has a total land area of approximately 23.9 million hectares (Domson and Vlosky 2007), while the forest area of Ghana is estimated to be 9.17 million ha, thus approximately 40 % of the total area. Ecologically, the forest area has been separated into

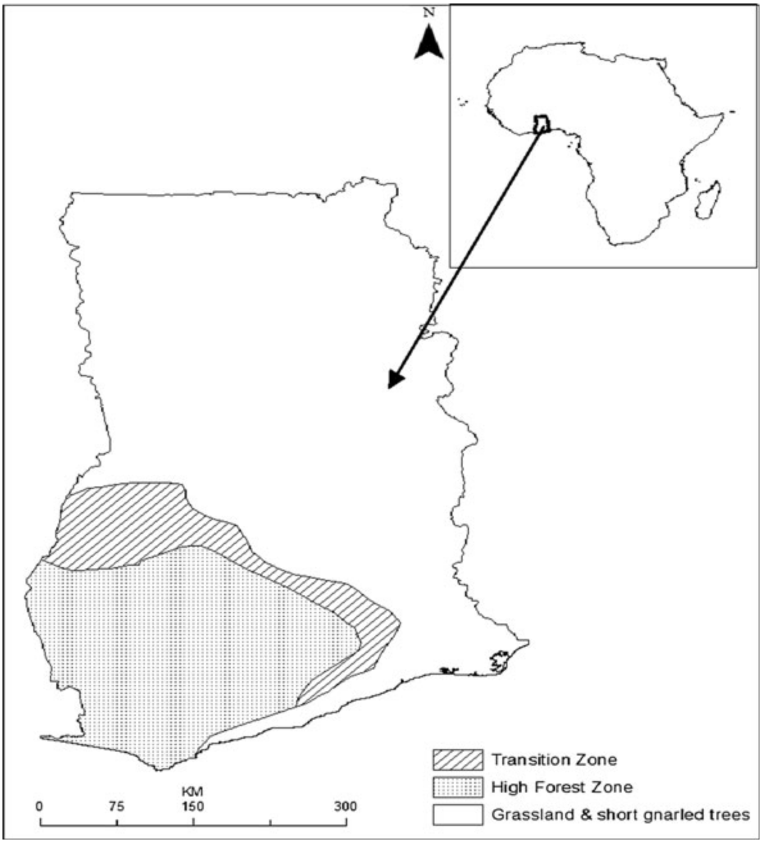

Fig. 1 The high forest zone (HFZ) and transition zone (i.e. dry semi-deciduous forest zone) where active mahogany logging is conducted in Ghana. The areas of grasslands and short gnarled trees are located on the coasts in Guinea and on the Sudan savannah. The savannah vegetation covers approximately 66 % of the total land area of Ghana

the high forest zone (8.1342 million ha) and the transitional forest one (1.036 million ha), where most commercial logging activities are conducted (Agyarko 2001). The high forest zone, also known as the closed forest zone, is further categorised into the wet evergreen, moist evergreen and moist semi-deciduous forest zones based on the precipitation gradient of the area (FAO 2002; Hall and Swaine 1976). The transitional forest formation is sometimes referred to as a dry semi-deciduous forest zone. The Guinea savannah woodland to the north of the transitional zone covers an area of approximately 14.66 million ha (Hawthorne and Abu-Juam 1995; FAO 2002), and the Guinea and Sudan savannah zones cover approximately 66 % of the total land area of the country. The high forest zone contains all the economic and commercial tree species in the country. The moist evergreen and moist semi-deciduous zones contain 27 and 17 % of the economic or commercial tree species, respectively, whereas the wet evergreen forest zone contains only 9 % of all timber species in the country (FAO 2002). Thus, land cover change data used in the empirical analysis are restricted to the high forest zone at the exclusion of other vegetation types as the distributional range of the mahogany species for commercial exploitation is confined to the high forest zone.

4.2 The economic data

The paper compiles secondary data from annual reports of Ghana's forestry commission, the FAO statistical year book (FAOSTAT statistical data base), the World Bank's data and research, and other published literature on Ghana timber exports and forest area cover changes from 1952 to 2009. Specifically, data on the annual mahogany extraction by volume and number according to species were obtained from annual reports of Ghana's forestry commission.

4.3 The model and data analysis

The study tests the direction of causation between mahoganies exports and deforestation. The test is to reject the null hypothesis that African mahoganies exports (Λ) do not Granger cause deforestation (Γ) and also that Γ does not Granger cause Λ against the alternative hypotheses of bi-directional Granger causality between these two variables. To evaluate these relationships, the paper employed a Granger causality test within an ECM framework (Bishop 1979; Granger 1969; Granger 1988; Al-Yousif 2008). A Granger causality test demands that the variables have no unit root (i.e. time stationary), which implies that the random effect of the model does not depend on time, while non-stationary time series yield spurious regressions (Granger and Newbold 1974; Phillips 1986; Darrat et al. 2005). Time series models with non-stationary variables lead to unreliable regression test statistics (Stock and Watson 1989). However, non-stationary variables in a time series model can be made stationary through appropriate differencing (Granger 1986). Subsequently, the augmented Dickey–Fuller (ADF) and the Perron–Philips (PP) tests were employed in this study to determine the appropriate order of differencing (Al-Yousif 2008; Fuller 1976; Dickey and Fuller 1981). The major constraint in the use of the differencing technique to enable variable stationarity is the loss of long-run information in the relationship of these variables. To address these, Engle and Granger (1987) and Granger (1986) suggested a system of co-integrated variables in a dynamic ECM (Al-Yousif 2008). The error correction (EC) term is incorporated into the model, along with the stationary variables, as another regressor. The EC are the lagged residuals that are obtained from the underlying co-integrating (long-run) relationship (Darrat et al. 2005). The estimated coefficient of the error-correction term captures the mechanism by which the dependent variable in the model adjusts to its long-run equilibrium (Darrat et al. 2005; Al-Yousif 2008). In other words, EC represents the long-run Granger causality. This study employed the Johansen (1988) efficient maximum-likelihood test to test for possible co-integration among the variables because Johansen's approach is considered to be better than several alternative tests (Gonzalo 1994).

To establish whether African mahoganies exports (Λ) Granger causes deforestation (Γ), the following bivariate ECM model was specified (Al-Yousif 2008):

$$\Lambda = a_o + \sum_{i=1}^{n1} a_{1i}\Lambda_{t-i} + \sum_{i=1}^{n2} a_{2i}\Delta\Gamma_{t-i} + \Psi EC_{t-i} + e_i \tag{14}$$

where Δ denotes first difference as determined by the stationarity test. Λ represents mahogany exports by volume in cubic meters, Γ denotes the deforestation rate or land cover, EC is the error correction term taken from bivariate co-integration, e is the white-noise error term, t represents time in years, and n_i is the lag of the orders of the a_i. Λ is level-stationary, while Γ is difference-stationary (Table 1). The null hypothesis that African

Table 1 Unit root test results

Variable	ADF	PP
Λ	−3.401362**	−7.67113***
Γ	−0.980335	−1.342735
$\Delta\Lambda$	−1.432507	−1.363187
$\Delta\ \Gamma$	−2.979806**	−6.940394***

ADF and PP represent the Augmented Dickey–Fuller and the Philip–Perron tests, respectively. Λ is the total annual mahogany exports in volume, Γ is the forest cover change as a proxy of deforestation, and the Δ preceding the variable is the first difference operator

*, ** and *** Rejection of the null hypothesis for non-stationarity of the time series at the 10, 5 and 1 % levels of significance, respectively

mahoganies exports do not Granger cause deforestation is rejected if the coefficient on the distributed lagged deforestation variable (a_{2i}'s) is found to be statistically significant and/or the coefficient on the EC term is found to be statistically significant (Al-Yousif 2002, 2008). The significance of a_{2i} and the coefficient Ψ indicates short- and long-run Granger causality between the two variables, respectively (Al-Yousif 2002, 2008). However, if these two variables are not co-integrated, the EC is eliminated from Eq. (14).

The test for the hypothesis of the converse direction that deforestation Granger causes African mahoganies exports was estimated with Eq. (15):

$$\Delta\Gamma_t = b_0 + \sum_{i=1}^{m1} b_{1i}\Delta\Gamma_{t-1} + \sum_{i=2}^{m2} b_{2i}\Lambda_{t-1} + \Phi EC_{t-1} + \Omega \qquad (15)$$

In this instance, African mahogany exports can be considered as a proxy for the depletion of a resource base of African mahoganies as a result of deforestation. Statistical significance of coefficients b_{2i} and Φ in model (15) indicate short- and long-run causality, respectively. Ω denotes a white-noise error term. Given the magnitudes in the land cover change variable and the mahogany export data, the data were log-transformed to minimise variance and the ensuing results from the transformation were used to run the above model. The test statistics for unit root (augmented Dickey-Fuller and the Philip Perron test statistics), co-integration (Johansen co-integration test) and Granger causality were performed in E-Views 7 of Windows (IHS Inc. 2011).

5 Results and discussion

5.1 Historical trends in mahogany extraction and deforestation

The number of recorded mahogany species extracted in Ghana from 1952 to 1991 showed fluctuation in the levels from year-to-year (Fig. 2). While the general trend consisted of relatively stable extraction levels of individual species between 1952 and 1968, there were dramatic increases with respect to the number of individual species of African mahogany harvested between 1970 and 1980, and the early 1970s were characterised by a sharp increase in the number of African mahoganies extracted. However, there was a dramatic decline with respect to the number of individual species of African mahoganies harvested between the late 1970s and 1980 (Fig. 2), as the period 1970 to 1980 was characterised by a general decline in the forestry sector of the Ghanaian economy (Owusu 2008). According

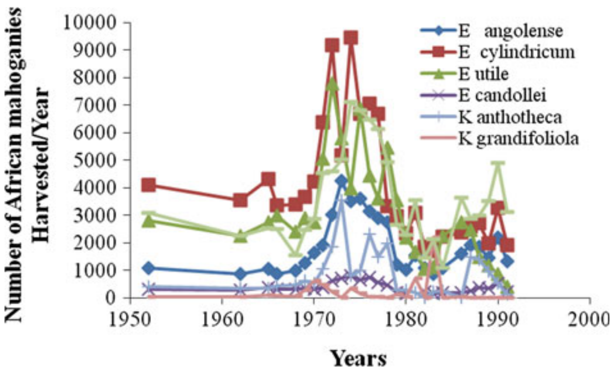

Fig. 2 Annual numbers of individual African mahogany species (*Khaya* and *Entandrophragma*) extracted between 1952 and 1991(data source: annual reports of Ghana Forestry Commission)

to Owusu (2008), from the late 1970s to 1983, there was a decline in wood supply to the international market. However, relatively large numbers of mahogany species were extracted during this same time period. For example, over 50 % of the total timber harvest in Ghana was illegally logged and occurred in off-reserve forests, placing pressure on officials to ensure SFM in Ghana. The implication was that there was an oversupply of mahogany and other timber species in the domestic market (Owusu 2008). In addition, there was concomitant deterioration in the basic infrastructure as a result of long periods of neglect, coupled with limited investments in fusion or capital inflows into the forestry sector by successive governments (Owusu 2008; World Bank 1989; Huq 1989).

However, after 1983, during the period coinciding with the Economic Recovery Programme (ERP) and SAP, which was initiated by the PNDC government with assistance from the IMF and the World Bank, the number of mahoganies being extracted began to increase. At an individual species level, trends in the extraction of mahoganies among the genus *Entandrophragma* were considerably high (high numbers of *Entandrophragma cylindricum* and *Entandrophragma utile* were extracted between 1952 and 1991). Similarly, during the same period, *Khaya ivorensis* was the most extracted species in the genus *Khaya*, followed by *Khaya anthotheca*. Based on these trends, it is not surprising that the IUCN has reported that the population of *Entandrophragma cylindricum* is threatened in most countries in West Africa, including Ghana (Hawthorne 1998). Moreover, Danquah et al. (2011) reported relatively low numbers of *Entandrophragma cylindricum* compared to other species of African mahogany in four forest reserves in the country. Nevertheless, with the implementation of the ERP in 1983 to address years of economic stagnation and through prescribed measures from the World Bank and the IMF, there was a dramatic turnaround in the forestry industry. As a result, from 1983 to 1990 and beyond, the volume of mahogany exports increased with a corresponding decrease in forest cover in the HFZ (Figs. 3, 4). The SAP focused more on enhancing the production capacity of export commodities. The two primary commodities, apart from cocoa, came from the extractive industries of timber exportation and mining. However, these two extractive activities have been implicated as major contributors to deforestation and forest degradation (Angelsen and Kaimowitz 1999; Ewers 2006; Benhin and Barbier 2004).

In fact, the SAP has been criticised for contributing to deforestation and forest degradation in Ghana (Codjoe and Dzanku 2009; Kaimowitz et al. 1999; Hansen-Kuhn 1993; Reed 1992). Deforestation was more rapid between 1983 and 2009 (Fig. 3). However,

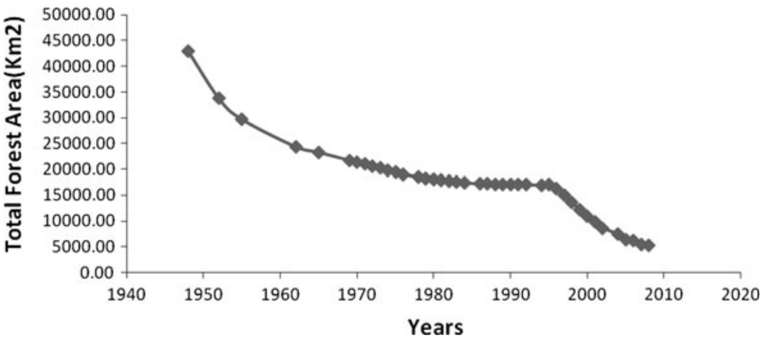

Fig. 3 Trend in area changes of forest cover in the high forest zone (HFZ) of Ghana. Data source: annual reports (1948–2009) of Ghana Forestry Commission

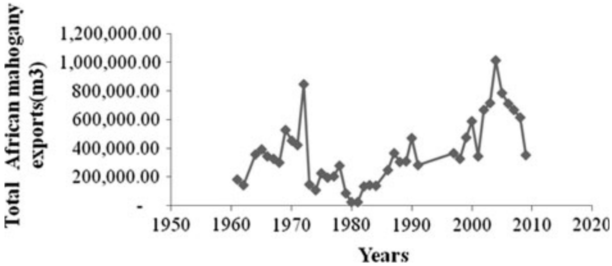

Fig. 4 Total African mahoganies exported from Ghana, 1961–2009

Hall (1987) estimated that between 1955 and 1972, 30 % of the forests in the HFZ disappeared. In a related study, Dadebo and Shinohara (1999) maintained that from 1948 to 1990 forest cover was lost at an annual rate of 0.58 %, mostly due to cocoa expansion and other agricultural activities. According to current FAO (2010) statistics, between 1990 and 2009, forest cover was lost at a rate of 135 394.86 ha per annum.

5.2 Unit root and co-integration test results

The unit root test statistics from the ADF and PP indicate that Λ is level-stationary while Γ is not (Table 1). However, the Γ time series achieved a state of difference-stationary after being differenced once. Moreover, the Λ time series loses its stationary characteristics upon differencing once (Table 1). Thus, it is theoretically plausible to incorporate Λ level-stationary and $D\Gamma$ difference-stationary variables into Eqs. (1) and (2) to establish Granger-causal relationships between the African mahoganies exportation and deforestation variables. This approach is in keeping with the fact that the Granger causality test requires that variables in the model specification be stationary (Phillips 1986; Granger 1986; Wolde-Rufael 2001).

Furthermore, the Granger causality test aims to avoid unreliable estimation (Stock and Watson 1989). However, while the results from co-integration indicated that there is no long-run relationship between Λ and Γ (Table 2), in the short run, these two variables are co-integrated. In analysing equations (14) and (15), the results indicate that African mahogany exports (Λ) cause deforestation (Γ) in Ghana (Table 3). The results also indicate

Table 2 Co-integration test results

	Max. eigenvalues	5 % Critical value	Prob.	Trace statistics	5 % Critical value	Prob.
None	0.247074	14.26460	0.0696	13.91079	15.49471	0.0854
At most one	0.012112	3.841466	0.4492	0.572762	3.841466	0.4492

A trace test indicated no co-integration at the 0.05 level. The max-eigenvalues test indicates no co-integration at the 0.05 level. H_0: EC has no co-integration; H_1: EC has co-integration

Table 3 Granger causality test statistics

Granger causality test statistics

Lags	(1) Λ does not Granger-cause Γ			(2) Γ does not Granger-cause Λ		
	Obs.	*F* stats	*P* value	Obs.	*F* stats	*P* value
1	48	6.86908	0.0119*	48	3.26421	0.0775*
2	47	3.32116	0.0458**	47	1.55690	0.2227
3	46	5.42123	0.0032***	46	2.06048	0.1212
4	45	3.98833	0.0089***	45	1.66561	0.1783
5	44	3.34223	0.0150**	44	1.79220	0.1417

Lagged values of Λ significantly influence current values of Γ; hence, a rejection of the null hypothesis in (1)

*, ** and *** Statistical significance of the lagged values at 10, 5 and 1 % levels, respectively

that, in the short run, there is a statistically significant causality between Λ and Γ at the 1 % level. Moreover, this significant causality is unidirectional from Λ to Γ in the short run (Table 3). However, there is no significant causality from Γ to Λ, thus suggesting that one of the main driving forces of deforestation in Ghana is the exportation of mahoganies. Mahogany exports, in this instance, can thus be considered as a proxy to capture general logging activities (on- and off-reserve, legal and illegal) in the country. These empirical results are consistent with the general assertion that the extraction and logging of mahoganies have contributed to deforestation in Ghana (Codjoe and Dzanku 2009; Owusu 2008; Boni 2006, IUCN 2006, Benhin and Barbier 2004; Schartzman and Kingston 1997).

6 Policy implications and conclusions

The empirical results demonstrate that mahoganies export (a proxy for general logging activities on- and off-reserve, legal and illegal) in the country is one of the contributing factors to deforestation in Ghana. Thus, there are two questions. How can the illegal logging, which is a major problem for the forestry sector and an accelerator in the logging–deforestation nexus, be addressed? Further, what can be done to enhance the sustainable management and extraction of timber species such as mahogany? The key is to strengthen the institutional policies in the forestry sector and develop new and innovative incentive structures in the sector that ensure the full participation of forest-fringed communities in sustaining and supporting forest management. Forest management schemes require compliance with relevant forest legislation at the harvesting stage and the assurance that logging on the specified forest is legal. The legality assurance involves checks to confirm compliance with forest management prescriptions at the stand levels, processing facilities, field inspections and reviews of documentation at all levels in the supply chain. Therefore, the Forestry Commission of Ghana (FC), as an institution, must be more responsive to the needs of the local communities in terms of transparency and efficiency, and the commission must create and strengthen its enforcement capabilities through enhanced incentives for its field operatives.

Another major constraint to forest tree protection is the land and tree tenure policy instrument that envisages that all economic timber tree species on individual lands, whether they are state lands acquired through designated forest reserves or private lands, are vested in the state and held in trust by the FC. In principle, what this forest policy means is that all economic forest trees in the country belong to the state. This approach is a deviation from traditionally held beliefs that landownership includes all resources within and above it. However, 50 % of the revenue accruing from stumpage fees, for example, mahoganies extraction and other economic timber tree species, is paid as a royalty to the local communities through the Office of Administration of Stool Lands for disbursement to traditional authorities and district assemblies. In truth, these monies fail to reach the families and local communities from whose lands the timber extraction was conducted. This is a major disincentive for local communities to tend and protect young tree saplings to facilitate natural regeneration in logged forest areas or to plant trees on or near their farms. Therefore, in the absence of well-defined property right regimes, illegal logging is promoted. Consistent with EU's action plan on Forest law Enforcement, Governance and Trade (FLEGT) and through bilateral voluntary agreements (VPs) with Ghana, issues concerning property rights and land tenure should be given impetus. FLEGT and VPs are bound to fail if emphasis is placed only on legality of timber harvesting, systems of verifications of legality, licensing systems and independent monitoring mechanisms to the detriment of the local communities whose livelihood directly depends on the forest. In addition, securing legal assurance for timber exports and related processed wood products under FLEGT and VPs without checking deforestation created by an underdevelopment and unstructured domestic market is not beneficial. Further consideration should be given to issues of governance in relationship to benefit sharing and the enforcement of existing laws and policies. There should be decentralisation of the forestry sector that promotes local communities and stakeholders involvement in policy formulation with respect to the efficient public forest management in the country. In effect, this will give more voice to the local communities, thus allowing them to be a part of the whole process of forest management. The promotion of joint community-based forest resource management programs will enhance conservation and the management of mahogany species while reducing deforestation in the country.

Revisions in pervasive economic incentive instruments such as a low income tax policy regime that promotes excessive logging are suggested. While the current tax decree establishes 35 % as the corporate tax for limited liability companies in other sectors of the economy, the tax is only 8 % for companies engaged in timber processing for export. As this low tax rate is quite attractive to many investors in the forestry sector, the number of timber companies increases and thus places pressure on the existing forestry resource base. However, the existing policy is silent on promoting investment in forestry tree plantations, in that investments in other tree crop plantations, notably rubber, shea and coconut, have a 10-year tax holiday from the first day of harvest. To reduce deforestation and forest degradation, this policy should also be applicable to forest tree plantations of mahoganies and other timber tree species. These aforementioned dynamics existing in the forestry sector where investments are not made in forest tree plantation exerts undue pressure on the natural forest as the demand for installed milling capacity exceeds the supply of timber from the natural forest. In conclusion, the consuming countries of mahogany and other timber tree species, consistent with the ITTO declaration, the EU action plan on FLEGT and VPs should source all export timber products of mahogany and other economic tree species from sustainably managed forests.

There is also the need to promote research-based and technology-led forestry that reduces the impact on the immediate environment subsequently reducing deforestation and degradation and facilitating the natural regeneration of mahogany species. A technology-led forestry sector should focus on the use of mixed species and substitution through efficient value-adding and the reduction of waste generation during processing rather than solely relying on traditional species such as mahoganies.

It is also ecologically sound to ensure that once logging is completed, the area should be placed under long-term protective status to facilitate natural regeneration, and accordingly, the policy directives that compel timber companies and concessionaires to plant trees after harvesting should be strictly enforced. Currently, there is no policy that requires loggers and timber companies to limit the impact of their activities or operations. Consistent with the national forest policy, loggers should be required to comply with and accept harvest schedules and levels of extraction that will be sustainable.

The economic cost of punishment for offenders of illegal timber extraction should be strict to serve as a disincentive for illegal logging. However, alternative livelihoods should be provided in the local community to prevent conflicts emanating from the use of forestry-related resources. Overall, for the successful implementation of sustainable forestry management policies and enforcement of the laws, capacity building should be strengthened. Furthermore, the forestry commission must increase its capacity to monitor logging and ensure that individual concessionaires comply with their obligations under the concession.

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