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IS STUMP HARVESTING A REMEDY FOR THE CLIMATE CRISIS OR A CURSE FOR BIODIVERSITY? AN INTERDISCIPLINARY STUDY OF CONFLICTING GOALS.

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Abstract

Dead wood is recognized as being one of the most important factors for forest biodiversity for many organism groups. One of the Swedish official environmental objectives is therefore to increase dead wood volume. However, reducing climate impact through increased use of forest biofuels is likely to work against this objective. The analysis is based on a regional economic forest sector model, focusing on northern Sweden, that includes suppliers and major users of roundwood and ecological results of stump harvest on forest biodiversity.

The parameters of the model are estimated with a data set spanning 28 years. We simulate the effects of an increased demand for wood fuels in northern Sweden, with or without stump harvest. The two scenarios have different effects on all major roundwood markets in the region, as well as on biodiversity. More specifically, in our model, the scenario with stump harvest implies a 0.3 percent decrease in the emissions of greenhouse gases and a 4.12 percent reduction in overall population density of saproxylic beetles on each years future clear cuts. Thus, a clear goal conflict exists.

1. **Introduction**
2. **The economic model**
3. **Estimation of the economic model**
4. **The ecological model**
5. **Simulation**
6. **Discussion**

1. Introduction

The main objective with this study is to analyze the potential goal conflict between two Swedish environmental objectives, *Reduced Climate Impact* and *A Rich Diversity of Plant and Animal Life*[1], as well as analyze how a policy aiming towards these targets will affect the forestry sector. The reason for studying this issue is that the potential presence of goal conflicts has implications for both target setting of the goals and the measures taken to fulfill the objectives. A standard cost-benefit analysis, disregarding the effects of one goal on the other, will thus be biased.

Apart from the traditional use of forest resources as an economical input to the forest industry, the forest and its resources serve as an important source for both energy and biodiversity. Forest has become a key factor as a renewable energy resource in Swedish energy and climate policy. The importance of forest will be further strengthened, not the least as a result of the newly decided EU targets concerning green house gas emissions reduction, and renewable energy. At the same time, national as well as EU concerns concerning biodiversity have become increasingly important and resulted in policy actions at both the national and EU level.

Forest land plays a crucial role for biodiversity and is particularly important for Sweden, with forests covering 68 % of the land area. However, intense forestry has resulted in an increasing number of threatened forest species. In Sweden approximately 50% or 2131 of the red listed species are considered forest dwelling (Gärdenfors, 2010). One of the most important factors for sustaining a rich biodiversity in the boreal forest landscape is the presence of dead wood (e.g., Berg et al. 1994, Jonsell et al. 1998, Siitonen, 2001). A large proportion of the species in boreal forests depend directly or indirectly on dead wood (Hanski and Hammond 1995, Siitonen, 2001, Speight, 1989). About 90% of the Swedish red-listed dead wood dependent species are confined to coarse woody debris (CWD, defined as dead wood with a diameter larger than 10 cm). Forest management in Fennoscandia has decreased the volume of CWD to 2 - 30% (normally less than 10%) of the normal quantity, which is presently found in small remaining patches of old-growth boreal forests (Fridman and Walheim 2000, Siitonen 2001, Stenbacka et al. 2010). Consequently, the efforts to enhance the conditions for these species have focused on preserving and creating CWD in the forest landscape (Dahlberg and Stokland 2004, Gibb et al. 2006, Hjältén et al. 2007). The importance of CWD for *A Rich Diversity of Plant and Animal Life* is recognized through a sub-goal, which is to increase dead wood volume.[1] A large scale introduction of stumps harvest is likely to counteract these efforts and have negative effects for biodiversity as stumps seem to be and important substrate for wood living species (Hjältén et al. 2010).

In June 2009 the Swedish parliament decided on a new climate policy action plan.[2] The new target is to reduce the greenhouse gas emissions from activities not included in the EU Emissions Trading Scheme with 40%, (notably transportation and buildings) between 1990 and 2020. Furthermore, this target is part of an action plan, which includes the goal to use 50% renewable energy sources by 2020 in Sweden. Sweden's new climate policy conforms with the EU climate and energy package, which mandates a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels, to increase the fraction of renewable energy with 20 %, and to reduce the primary energy use compared with projected levels with 20%. All three goals are to be reached by 2020.[3] Presumably, this will boost demand for renewable energy, including bioenergy from forestry, even further.

Power and district heating plants with good substitution possibilities and fuel selection, have largely abandoned fossil fuels in favor of renewable energy sources. In 1980, the use of biofuels, waste, peat, etc., accounted for less than 7% of the primary energy input for district heating. Twenty-seven years later, the corresponding share had increased by almost ten times to approximately 69%. A large part of the shift from fossil fuels to renewable fuels can be traced back to the increased use of forest fuels. In total, the use of forest fuels only accounted for 0.3 TWh, or less than one percent of total input, in year 1980 - rising to 21 TWh, or almost 40 percent of the total energy input by 2007 (Swedish Energy Agency 2008). Based on available

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[1] A description of the Swedish environmental targets can be found on the Swedish Environmental Objectives Portal <http://www.miljomal.nu/Environmental-Objectives-Portal/>

[2] For details see http://www.swedishepa.com/en/In-English/Menu/Climate-change/Climate-policy/Swedens-climate-policy/.

[3] For details concerning the EU package, see <http://ec.europa.eu/clima/policies/brief/eu/package_en.htm>.

forecasts and scenarios (e.g. Swedish Energy Agency 2007) it is clear that the demand for biofuels, especially forest fuels, can be expected to increase even further in the future.

However, as shown in Ankarhem et al. (1999), Ankarhem (2004), and Geijer et al. (2011) the Swedish market for forest fuels is closely interlinked with the markets for other wood assortments. This implies that as demand for biofuels increases the competition for raw material might pick up. To escape this dilemma, and still increase the supply of raw material for forest fuel, tree stump harvesting has been suggested (e.g. the Swedish Government Bill 2007/08:108, and Swedish Forest Agency, 2009a).[4] The main inspiration for stump harvesting in Sweden comes from Finland. Currently stump harvesting in Sweden is conducted at a rather small scale. The area that was subject to stump harvest in Sweden was, 10, 500, 1100 and 1400 hectares respectively in the years 2005-2008 but is expected to increase to 10 000-20 000 hectare in the near future (Swedish Forest Agency, 2009b). As previously mentioned, trying to reduce the impact from global warming through increased use of tree stumps is likely to work against the objective *A Rich Diversity of Plant and Animal Life*. This is an example of how different - each worthwhile - environmental objectives can come into conflict.

The problem is analyzed and illustrated through an empirical analysis based on a forest sector model for northern Sweden. The model includes the market behavior of suppliers and major users of roundwood as well as an ecological module that is linked to the utilization of the forest resources. The economic model is a regional version of the model presented in Geijer *et.al*. (2011). It has been regionalized to focus specifically on northern Sweden. This model includes demand and supply of the major wood assortments, implying that most market interactions within the forestry sector is taken into account. The model is then used to assess effects on the whole forest sector from an increase in the demand for forest fuel.

[4] An alternative that have been discussed lately is intensive forest management, which for example could mean increased fertilization of forest land, an increased share of fast growing species (See Brännlund et.al. 2009)

The main reason for focusing on northern Sweden is the existence of an empirical data set on biodiversity in tree stumps and other dead wood substrates in northern Sweden (Gibb et al. 2006, Johansson et al. 2007, Stenbacka et al. 2010, Hjältén et al. 2007). This data set provides the possibilities to make quantitative estimates regarding the consequences of increased forest fuel harvesting on population densities and possible effects on species level on organisms which are dependent on dead wood.

The rest of the paper is structured as follows. In section 2 we introduce our regional economic model of the Swedish forestry sector and in section 3 we present the parameter estimates of the model. The ecological model is described and estimated in section 4. In section 5, we join the economic and ecological model to simulate the effect of large scale stump harvest as well as an increase in the demand for forest fuel. Finally, in section 6, the paper ends with a discussion of the results.

2. The economic model

The model used to analyse the potential goal conflict basically consists of two parts; a model describing the interlinkages between the different parts of the forest sector, and a second model describing the relation between stump harvesting and biodiversity via the changes in dead wood. Finally, we introduced the supply of stumps, acquired from Athanassiadis et al. (2009).

The forest sector model is a modified version of the model used in Ankarhem et al. (1999). The model differs from Ankarhem et al. (1999) in the sense that we allow for technological progress, and that we allow for lags in the adjustment to changes of the explanatory variables. This means that if a price (or any other explanatory variable) changes, demand and supply does not necessarily adjust completely within one period. This also means that we can estimate both short run (within one year) and intermediate run effects.

The forest sector model consists of four actors. The first actor is the forest owners who supply three types of raw forest material to the market: pulpwood, sawtimber and forest fuels. The forest owners are assumed to choose the quantities of different assortments that maximize profits at given prices. This is made conditional on the cutting costs and the standing stock of timber. The remaining actors in the model are the ones using raw materials from the forest as an input in their production process; the pulp industry, sawmills and the heating industry.

Sawmills make use of labour, energy and capital to convert saw timber into sawn goods and sawmill chips. The heating industry is also assumed to use labour and capital to transform different kind of fuels (e.g. forest fuel) to heating. Finally, the pulp industry use labour, energy and capital to transform pulpwood and woodchips into pulp[5]. In all three industries capital is considered fixed in the short run, while the other input factors are flexible. The sawmill- and heating industry are assumed to operate under an environment of perfect competition. The pulp mills are, on the contrary, assumed to have significant market power with respect to purchase of pulp wood (Bergman & Löfgren, 1988. Bergman & Brännlund, 1995). There is however a "backstop market" in the international market for pulpwood. For that reason, the pulp industry will use their oligopsony power to buy a certain amount of domestically supplied pulpwood, and then buy pulpwood on the international market until marginal revenue is equal to marginal cost. Therefore, the pulp mills profit will depend on the domestic price as well as the import price of pulpwood, but the cost at the margin, and therefore also the production decision, will only depend on the marginal, or import, price.

The region under study is called "logging area one" – an administrative district roughly corresponding to the four northernmost counties in Sweden, Norrbotten, Västerbotten, Västernorrland and most of Jämtland. The motive for choosing this specific logging area is the fact that the ecological data is mainly relevant for this region.

To parameterize the model we assume that the technology in each industry can be represented by a restricted Generalized Leontief (GL) profit function, which is a flexible form profit function (see Diewert, 1973). We then apply Hotelling´s lemma to acquire the corresponding demand and supply equations. In addition to the flexible factors of production, we assume a fixed capital stock, a linear technological progress term (time) and allow for lags in the adjustment to a price change in all of the wood

[5] The sawmill chips can also be used as an energy input.

using industries. The supply of the forest owners is assumed to adjust instantaneously in response to a price changes.

The model to be estimated can be summarized as follows:

Forest owners supply of sawtimber (*st*), pulpwood (*pw*) and forest fuel (*ff*):

$$y^s_{i(t)} = \sum_j \alpha_{ij} \left(p_{j(t)} / p_{i(t)} \right)^{\frac{1}{2}} + a_{iK} K_{F(t)}, \quad i = st, pw, ff \quad j = st, pw, ff, cut \tag{1}$$

Where the subscript *cut* stand for the cutting cost and *t* denotes time.

Sawmills supply of sawn goods (*sg*) and sawmill chips (*sc*), and demand for sawtimber (*st*):

$$y^s_{i(t)} = \sum_j \beta_{sj} \left(p_{j(t)} / p_{i(t)} \right)^{\frac{1}{2}} + \beta_{ik} K_{S(t)} + \beta_{it} t + \delta_i y^s_{i(t-1)}, \quad i = sg, sc; j = sg, sc, st, sl, se \tag{2}$$

$$y^d_{st(t)} = -\left\{ \sum_i \beta_{sti} \left(p_{i(t)} / p_{st(t)} \right)^{\frac{1}{2}} + \beta_{stk} K_{S(t)} + \beta_{stt} t + \delta_{st} y^d_{st(t-1)} \right\}, \quad i = sg, sc, st, sl, se \tag{3}$$

The subscripts *sl* and *se* refer to labour and energy used by sawmills, and the variable K_S stands for the sawmills capital stock. This specification deviates from a standard GL specification by the inclusion of a linear technological progress term (*t*), and a partial adjustment term ($y_{x(t-1)}$). In the following equations, (4) - (7), the subscripts *pl, pe, hl* and *he* refer to labour and energy in the pulp and heating industry respectively. Likewise, K_P and K_H is the capital stock in respective industry. Technological progress and the adjustment process will also be included in the same fashion.

Pulp industries supply of pulp (*p*), demand for sawmill chips (*sc*) and pulpwood (*pw*) are:

$$y^s_{p(t)} = \sum_j \beta_{pj} (p_{j(t)} / p_{p(t)})^{\frac{1}{2}} + \beta_{pk} K_{P(t)} + \beta_{pt} t + \delta_p y^s_{p(t-1)}, \quad j = p, sc, imp, pl, pe \tag{4}$$

$$y^d_i = -\left\{ \sum_j \beta_{ij} \left(p_{j(t)} / p_{i(t)} \right)^{\frac{1}{2}} + \beta_{ik} K_{P(t)} + \beta_{it} t + \delta_i y^d_{i(t-1)} \right\} \tag{5}$$

$i = sc, pw; \; j = p, sc, imp, pl, pe$

The subscript *imp* stand for the import price of pulpwood.

Correspondingly, the heating industry's demand for forest fuel (*ff*) is:

$$y^{d}_{ff(t)} = -\left\{\sum_{j} \beta_{ffj} \left(p_{j(t)} / p_{ff(t)} \right)^{\frac{1}{2}} + \beta_{ffk} K_{H(t)} + \beta_{fft} t + \delta_{ff} y^{d}_{ff(t-1)} \right\}, \quad i = h, ff, hl.he \tag{6}$$

Finally we assume that the markets for all roundwood assortments, i.e., sawtimber, pulpwood and forest fuel, as well as the market for sawmill chips, are in equilibrium in each time period.

$$y^{s}_{i(t)} = y^{d}_{i(t)}, \quad i = st, pw, ff, sc \tag{7}$$

The data we use for the forest sector model is time series data covering the period 1970 – 2006. An exception though is data on the import price of pulpwood for which data is missing for the period 1995 – 2001. For this reason we will omit these seven observations from the estimation. Descriptive statistics of the data used is shown in Table 1. Data was gathered from Statistics Sweden, the Swedish Forest Agency, the Swedish Energy Agency, the Swedish University of Agricultural Sciences and SDC (the Swedish sawmills IT-company).

Table 1: Descriptive statistics, years 1979-1994 and 2002-2006.

Sector		Unit*	Mean	St. Dev	Min	Max
Forestry						
Sawtimber	y_{ST}	1000 m^3	7138	1825	5118	10289
Pulpwood	y_{PW}	1000 m^3	8007	472	6710	8741
Forest fuel	y_{FF}	1000 m^3	723	280	340	1180
Sawtimber price	p_{ST}	SEK/m^3	433	68	340	507
Pulpwood price	p_{PW}	SEK/m^3	217	50	105	297
Forest fuel price	p_{FF}	SEK/m^3	338	98	198	458
Cutting cost	p_{CUT}	SEK/m^3	140	39	80	187
Timber stock	K_F	million m^3	557	47	514	661
Sawmills						
Sawn softwood	y_{SG}	1000 m^3	3301	841	2000	4693
Sawmill chips	Y_{SC}	1000 m^3	2347	537	1733	3326
Sawn softwood price	p_{SG}	SEK/m^3	1916	240	1522	2401
Energy price	P_{SE}	SEK/MWh	40	8.2	24	53
Labor price	p_{SL}	SEK/hour	100	7.4	89	116
Capital	K_S	million SEK	23385	3162	20203	29K
Pulp industry						
Pulp	y_P	1000 ton	3236	300	2587	3628
Pulp price	p_P	SEK/ton	4109	878	2882	5455
Pulpwood import price	p_{IMP}	SEK/m^3	308	53	168	377
Energy price	p_{PE}	SEK/MWh	28	4.4	20	39
Labour price	p_{PL}	SEK/hour	122	7.2	110	133
Capital	K_P	million SEK	45450	2652	39K	49K
Heating industry						
Heat	y_H	1000 MWh	8730	1279	6540	10440
Heat price	p_H	SEK/MWh	374	48	270	449
Fossil fuel price	p_{HE}	SEK/MWh	130	43	83	212
Labour price	p_{HL}	SEK/hour	122	12	108	145
Capital	K_H	million SEK	37662	6148	27K	46K

*All m^3 units are excluding bark.

Note: The supplied quantities and output prices in the forest sector, as well as the quantity of sawmill chips, are also included as demanded quantities and input prices for respective demand side industry. All prices are expressed at the 2000 level and all wood quantities are excluding bark.

The amount of saw timber and pulpwood used by the industries located within logging area one is used as equilibrium quantities of these assortments. In absence of regional data concerning the quantities of forest fuel, we approximated the regional supply based on numbers for domestic supply of primary forest fuel. Likewise, the corresponding prices for saw timber and pulpwood are the average regional prices for northern Sweden, while the nationwide average price for sawmill chips is used as a proxy for the price of forest fuel. The import price of pulpwood is the total imported quantity of pulpwood divided by its total cost. Since the heating industries can, and to some extent do, use sawmill chips instead of wood chips directly from the forest, we believe that there is substantial correlation between these two prices. The same price is of course also used as the price of sawmill chips. The quantity of sawmill chips is the quantity supplied by regional industries in northern Sweden.

The price for both energy and labour in wood industries is calculated implicitly from domestic industry-specific cost and quantities, except for the last years where data concerning wages within different occupations have been used to approximate the wage rate. In forestry, the cutting cost is the total cost of different thinning and regeneration cuttings divided by the amount of extracted wood.

Export prices for (sawn and planed) softwood and wood pulp (sulphate - unbleached) are used as output prices for sawmills and the pulp industry. Their corresponding quantities are the ones supplied by sawmills and pulp industries located in northern Sweden. For the energy industry we have used an implicit domestic output price defined as the ratio between the total revenue from delivered heating and the delivered quantities. The amount of capital is once again nationwide domestic quantities, and consists of the value of the machines and buildings, which we assume to vary in the same way as the regional counterparts.

3. Estimation of the economic model

The parameters of the equation system for the forest sector model (equation (1) – (7)) are estimated with three stage least square (3SLS), which essentially is separate equation by equation 2SLS estimation followed by a GLS estimation which is similar to the seemingly unrelated regression (SUR) model. The variables that are treated as endogenous variables in the estimation, i.e. replaced by instrumental variables, are the price of saw timber, pulpwood, forest fuel (and sawmill chips).

Prior to estimating the system, we include a quadratic time trend in the supply of forest fuel because of technological progress. Also, we impose symmetry in the supply functions of forestry products by requiring that $\alpha_{ij} = \alpha_{ji}$, $i, j = st, pw, ff$. Symmetry is also introduced in the equations describing the sawmills behaviour by setting $\beta_{ij} = \beta_{ji}$, $i, j = sg, sc, st$,$\beta_{ij} = \beta_{ji} \;\; i, j = sg, sc, st$ and in the pulp industries by letting $\beta_{ij} = \beta_{ji}$, $i, j = p, sc, pw$$\beta_{ij} = \beta_{ji} \;\; i, j = p, sc, pw$. Finally, we introduce two dummy variables to account for the missing observations. The first dummy exist to target possible technological development/structural changes in the years for the missing observations. This dummy variable (β_{i2002}, $i = sg, sc, st, p, pw, ff$) equals zero for t less than 2003, and one for t equal or greater than 2003. A second dummy variable (β_{iD}, $i = sg, sc, st, p, pw, ff$) is introduced because of the adjustment term and takes the value zero every year except 2002 where it equals one.

The details of the results are presented in appendix A. The results show that around sixty percent (51/86) of the parameters are significantly different from zero at the five percent level. The supply of all wood assortments also increases with the standing stock of timber. The parameters concerning the effect of capital on supply or demand in the wood using industries are only significantly different from zero in one out of seven instances – indicating that our proxy variables, i.e. nationwide changes in the same variables, might be inadequate to some degree. However, we decided to keep them in the model in order to prevent the possible effect of omitted variable bias rather than dropping them altogether. Since the model specification does not really allow for any easy interpretation of the size of the parameters alone, we will instead turn to a presentation of the short and long run elasticities.

In Table 4 the short and long run elasticities are calculated at the mean level of all prices and quantities (see table 1). The elasticities were also evaluated using more recent values, i.e. the average prices and quantities for the years 2000 – 2004, but with little change in magnitudes. Since the partial adjustment term is not significantly different from zero in the equations that describe the supply of sawmill chips and pulp, and the demand for forest fuel, we conclude that the long and short term elasticities does not differ in these cases.

Table 2: Short and long run elasticities. All elasticities are evaluated at the mean prices and quantities.

Forestry owners

	P_{ST}	P_{PW}	P_{FF}	P_{CUT}
S Saw timber	**0.47**	**-0.23**	**- 0.12**	-0.13
S Pulpwood	**-0.29**	**0.28**	-0.01	0.02
S Forest fuel	**-1.51**	-0.13	0.11	**1.52**

Sawmills

	P_{SG}		P_{SC}		P_{ST}		P_{SL}		P_{SE}	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
S Sawn gods	**0.17**	**0.33**	**0.08**	**0.16**	**-0.19**	**-0.37**	0.02	0.04	-0.09	-0.18
S Chips	**0.65**	**0.65**	**0.34**	**0.34**	**-0.72**	**-0.72**	-0.02	-0.02	-0.25	-0.25
D Saw timber	**0.38**	**0.63**	**0.18**	**0.30**	**-0.57**	**-0.94**	**0.19**	**0.32**	**-0.18**	**-0.30**

Pulp Industry

	P_{P}		P_{SC}		P_{IMP}		P_{PL}		P_{PE}	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
S Pulp	**0.33**	**0.33**	-0.01	-0.01	**-0.05**	**-0.05**	**-0.31**	**-0.31**	0.03	0.03
D Chips	0.12	0.19	**-0.18**	**-0.28**	**0.39**	**0.61**	-0.14	-0.22	**-0.20**	**-0.31**
D Pulpwood	**0.18**	**0.22**	**0.09**	**0.11**	**-0.13**	**-0.16**	**-0.23**	**-0.28**	**0.09**	**0.11**

Heating Ind.

	P_{H}		P_{FF}		P_{HL}		P_{HE}	
	SR	LR	SR	LR	SR	LR	SR	LR
D Forest fuel	**0.40**	**0.40**	**-0.26**	**-0.26**	**-0.11**	**-0.11**	-0.03	-0.03

Note: S = Supply, D = Demand. **Bold** numbers denote significance at the five percent level.

Most of the elasticities have the expected sign, e.g. the supply of a specific product is increasing, and the demand is decreasing with respect to its own price. Furthermore, all of the forest products are substitutes to one another. This result is consistent with results from previous research of the aggregated Swedish wood market, e.g Ankarhem et al. (1999) and Geijer et al. (2011).

The supply of sawn good/sawmill chips also increase with the price of both sawmill chips and sawn goods, which is reasonable considering the joint production process. In the pulp industries, sawmill chips is to some extent a substitute for pulpwood, and the demand for pulpwood/sawmill chips do accordingly increase with the price of their respective substitute. In the heating industry, forest fuel is a substitute for other energy sources and, as a result, the demand for forest fuel increases with the price of energy.

Two of the elasticities that are significantly different from zero have unexpected signs. First of all, it is unlikely that the demand of saw timber would increase with the price of labour. It is also not theoretically motivated that the supply of forest fuel should increase with the cost of logging. This estimate is especially troublesome since it would cause serious problems (i.e. unlikely outcomes) in the simulation. This unintuitive result has also showed up in previous empirical studies of the Swedish forest sector (e.g. Ankarhem et al. (1999)). However, during a shorter time period (from 1989 and onward) the logging cost has been divided into "regeneration cutting cost" and "thinning cost". An estimation where these variables replace the previously used cutting cost give the result that the supply of all wood assortments decrease with the cost of regeneration cutting but increase with the cost of thinning (creating an overall decrease in supply if both types of cost increase by a similar proportion). In light of these mixed results, we will simply set the influence of cutting cost to zero in the simulation – and thereby removing its effect from the supply of forest fuel, even though its significantly different from zero. The remaining variables and parameters will be used whether they are statistically significant or not.

4. The ecological model

The ecological model originates from an experiment conducted at ten clear-felled forest stands situated in the administrative counties of Västerbotten and Västernorrland within the northern-boreal and middle-boreal vegetation zones of Sweden (Ahti et al., 1968). The localities were between the latitudes 63.6208 N and 64.2858 N and longitudes 16.8898 E and 20.1328 E, and ranged from an altitude of 100 to 550 m above sea level (for further information, see Gibb et al., 2005). At each locality low stumps were sampled for wood living beetles from May to September in 2007. All collected beetles were counted and identified to species level. Dead wood of Norwegian spruce (*Picea abies,* L.) was assessed in each of the 10 sites. The volume of logs and snags was calculated using the conic parabolic function introduced by Fraver et al. (2007). For stumps, two different ways to calculate the volume was used. One calculation for the volume corresponding to the part of the stump sampled during the dead wood survey ($V_{sampled}$) and a separate to calculate the total volume of the stump (V_{total}). The latter was done because of two reasons: firstly it was interesting to know the proportion of the stump used for insect sampling, and secondly this step was crucial for further calculations on annual stump harvesting area in the specified region. $V_{sampled}$ was calculated using the function for cylinder. To get V_{total} we started with calculating the biomass for spruce using the formula for biomass of spruce stumps including roots following biomass functions for pine, spruce and birch in Sweden (Marklund, 1988). The dead wood volume considered available for saproxylics on a stump and the volume sampled ($V_{sampled}$), was only about 15% of the total stump volume, V_{total} (see Table 3). This is a conservative estimate because above- and below ground roots and parts of the stump were excluded. Despite this, the volume of stumps considered available for saproxylics ($V_{sampled}$) were much higher than the volume of other dead wood substrate types found on the examined clear-cuts (see Table 3).

Table 3. A summary of results from the dead wood inventory. V_{total}, $V_{sampled}$, m_{bio} and number of stumps concerns only stumps. All numbers concerns dead wood from spruce on the inventoried sites (500 m^2).

	Mean	Median	Std. Error	Min	Max
V_{total} (m^3)	2.74	2.84	0.34	1.27	4.24
$V_{sampled}$ (m^3)	0.43	0.45	0.05	0.21	0.72
m_{bio} (Kg)	1122.63	1162.50	138.32	534.20	1739.84
Number of stumps	26.10	24.50	2.07	20.00	39.00
V_{logs} (m^3)	0.11	0.12	0.03	0.00	0.25
V_{snags} (m^3)	0.02	0.00	0.02	0.00	0.16

To make predictions of the effects from stump harvesting on population densities of saproxylic beetles extrapolations of both the availability of dead wood, in the form of stumps, and the abundance of saproxylic beetles had to be made. Extrapolation of data is always associated with strong uncertainty of extrapolated values, especially when the extrapolation exceeds far outside the known range of the data (Crawley, 2007). To make the extrapolation, a model was made to explain the relationship. We assumed that the relation between abundance of saproxylic beetles per hectare (BIO) and increasing volume of available substrate, in this case in the form of single low stumps (V_{total}), is linear.

$$BIO_i = \alpha + \beta * V_{total,i} \qquad (9)$$

A linear relation between increasing area or volume and abundance has proven to be valid for many different organisms (Bowers and Matter, 1997; Bender et al., 1998). Therefore the data was fitted to a linear model. The intercept and the predicted value and their standard errors was extracted from the linear model and used to extrapolate the abundance (Table 4). All calculations were made in the open source program R 2.8.1 for statistical computing (R Development Core Team, 2008).

Table 4. Parameter estimates of the linear ecological model.

	Estimate	**Std. Error**	**t-value**	***p*-value**
$\boldsymbol{\alpha}$	-46.87	9.88	-4.74	< 0.001
$\boldsymbol{\beta}$	110.25	2.85	38.77	< 0.001
Adj. R^2	0.97			
Model *p*-value	< 0.001			

During the period 2005-2009, the average final harvesting area (*AFHA*) in the Swedish counties Jämtland, Västernorrland, Västerbotten and Norrbotten was 96826 ha (Source: Swedish National Forest Inventory. 2010). This means that on an average year 5.3 million m^3 dead wood in the forms of stumps is left on clear cuts.[6] Subsequently, the AFHA becomes the habitat of approximately 580 million saproxylic beetles.[7]

The effect of stump harvesting on biodiversity (*BIO*), i.e. total abundance of saproxylic beetles on clear cuts, is calculated by removing the amount of supplied stumps (y_{STUMP}^{S}) from the total volume of stumps (y_{STUMP}^{Total}) on the clear cuts. Since we have a linear model, the distribution between sites does not matter. Thus, we aggregate the supply of stumps from, and effect on biodiversity on, individual hectares (equation 9) to:

$$BIO = \sum_{i=1}^{AFHA} BIO_i = \sum_{i=1}^{AFHA} (\alpha + \beta * (V_{total,i} - V_{\text{supply},i})) = \alpha * AFHA + \beta * (y_{STUMP}^{Total} - y_{STUMP}^{s}) \quad (10)$$

6 $AFHA * \overline{V}_{total} = y_{STUMP}^{Total} = 5.3\ million$, where $\overline{V}_{total}$ stands for the mean amount of dead wood per hectare. Also, note that the mean amount of dead wood reported in table 3 is per 500 m^2 , which imply that the mean amount per hectare is 20 times larger (i.e. $\overline{V}_{total}$ =54.8)

7 $AFHA(\alpha * + \beta * \overline{V}_{total})$ = 580 million

5. Simulations

The purpose of this section is to illustrate the effects on the forest sector and biodiversity (population densities of saproxylics) as a result of a non-marginal increase of demand for forest fuel, and the possibility of stump harvest. The scenarios are supposed to reflect the ambitions to reach the greenhouse gas and renewable energy targets.

Before we present the scenarios we will append a stump supply equation to the model, since this will provide the link to the ecological effects from changes in demand for biomass. As mentioned, stump harvesting has only recently begun in Sweden, even though it is quite common in e.g. Finland. For this reason, it is still impossible to empirically estimate the supply function of forest fuel from stumps. However, the domestic marginal cost (i.e. supply under the assumption of perfect competition) has been calculated from technological data by Athanassiadis et al. (2009). The calculation has been done under the assumption that the final ecological and technical/economical restrictions, among other things, will demand that 20 percent of branches, treetops and stumps will have to be left in the forest after a clear-cut. Their results imply that, over the range that is under consideration in this study (prices for forest fuel between 750 and 950 SEK/ton), the supply of stumps (in 1000 m3fub) can be approximated by the following quadratic function[8]:

$$y^{S}_{STUMP} = 9279 - 93.7 * p_{FF} + 0.236 * p^{2}_{FF} \qquad (11)$$

The price of forest fuel (p_{FF}) in (11) refer to our proxy prize for forest fuel in SEK/m3fub, which is linked by a conversion factor to the prices used in Athanassiadis et al. (2009).

There exist many estimates and forecasts concerning the heating plants future demand for bio fuels in general and forest fuel in particular (e.g. Svebio, 2008). In the simulations we will assume that the demand for forest fuel, originating from heating

[8] Only three of the reported price/output combinations are used for the calculation of the stump supply function. The one associated with the present prize level (850 SEK/ton) and the ones one step above and below. An OLS estimation of a cubic supply function, using all eight observations, would give similar values over the range that we are interested in.

plants within cutting area one, will increase by 30 percent (equivalent to approximately 350 000 m3fub or an energy input of 0.6 TWh/year). In the simulations, this will translate to a 350 000 m3fub exogenous increase in the demand for primary forest fuel at every price level. In the first simulation we assume that there will be no supply of stumps, whereas in the second scenario, we allow for supply of tree stumps by making use of equation (11) and (12).

The two scenarios that will be considered are then one with, and one without, supply of stumps, but with an exogenous increase in demand for forest fuels.

(1) Exogenous increase in demand for forest fuel by 350 000 m^3fub, compared to the current level, without a supply of stumps. In the scenario the demand for forest fuel is then defined as.

$$y_{FF}^{d}(1) = f(\mathbf{p}^{0}, \mathbf{x}^{0}) + 350$$

Given this exogenous shift in demand, the equilibrium condition in (7) is used to solve for the new equilibrium prices and quantities given equation for all endogenous variables.

(2) Exogenous increase in demand for forest fuel by 350 000 m3fub, compared to the current level, but with possible supply of stumps. To allow for supply of stumps we make use of equation (11) to define a new forest fuel equation.

$$y_{FF}^{s}(2) = y_{BRAT}^{s} + y_{STUMP}^{s} \qquad (12)$$

Given this new supply function (12) and the new forest fuel demand function defined in scenario (1), new equilibrium prices and quantities are solved using the equilibrium condition.

This second scenario will be done in two steps. This allows us to separate the effect of the introduction of large scale stump harvesting (without any changes in demand) from the effect of the exogenous demand increase. More specifically the two steps are:

(a) Allowing large scale stump harvesting using equation (11), but no change in exogenous demand for forest fuels.

(b) An exogenous increase in demand for forest fuels.

(c) Allowing large scale stump harvesting while simultaneously increasing the demand. The results in scenario (c) is equivalent to summing the absolute effects of scenario (a) and (b)

The second simulation is done with short and long run parameter estimates. The results from the simulations are presented in table 5.

Table 5: Changes in the endogenous variables (Δy(%) in percent, Δy in thousands of m^3fub), due to a 350 000 m3 exogenous change in the demand for wood fuel.

Simulation	**1:SR**	**2a:SR**	**2b:SR**	**2c:SR**	**2a:LR**	**2b:LR**	**2c:LR**
ΔF(%)	0.24	0.15	1.21	1.35	0.15	1.22	1.35
ΔF(K.m3)	48	30	243	272	30	245	275
ΔBIO(%)	**-**	**-0.63**	**-4.12**	**-4.75**	**-0.65**	**-4.06**	**-4.71**
Δy_{ST}(%)	-0.94	0.03	-0.33	-0.30	0.10	-0.42	-0.33
Δy_{ST}(K.m3)	-97	3	-33	-30	10	-43	-33
Δy_{PW}(%)	-1.49	0.11	-0.51	-0.39	0.09	-0.38	-0.29
Δy_{PW}(K.m3)	-130	10	-45	-35		-33	-25
Δy_{FF}(%)	**23.18**	**0.68**	**27.03**	**27.80**	**0.59**	**27.07**	**27.88**
Δy_{FF}(K.m3)	274.	8	321	328	7	321	329
Δy_{BRAT}(%)	(23.18)	-2.20	9.01	6.61	-2.29	9.35	6.86
Δy_{BRAT}(K.m3)	(274)	-26	104	78	-27	108	81
Δy_{STUMP}(%)*	-	∞	649	∞	∞	622	∞
Δy_{STUMP}(K.m3)	-	33	217	250	34	214	248
Δp_{FF}	28.88	-2.24	9.60	7.15	-2.21	9.45	7.03
Δp_{ST}	4.35	-0.36	1.48	1.12	-0.25	1.02	0.77
Δy_{CHIP}	-0.66	0.03	-0.23	-0.19	0.03	-0.22	-0.19
Δp_{CHIP}	7.98	-0.65	2.71	2.04	-0.39	1.63	1.23
Δy_S	-0.17	0.02	-0.06	-0.04	0.02	-0.10	-0.08
Δy_P	-0.04	0.00	-0.02	-0.01	0.00	-0.01	-0.01

SR=short run, LR = Long run, F= total biomass supply from the forest, BIO= mean reduction in population densities of saproxylics in the total area of new clear cuts. *In some of the scenarios, the amount of harvested stumps goes from zero to a positive amount. The percentage change is thus infinite (or undefined).

Simulation 1 and 2b is comparable in the sense that they both show the market response to a similar increase in the demand, with or without stump harvest (even though their starting position is somewhat different). 1 and 2c is comparable in the sense that they both show a potential future state where the demand for forest fuel has increased, and we have or have not introduced large scale stump harvesting. Scenario 2a simply shows the expected effect of allowing large scale stump harvesting at current conditions.

In the first simulation (1 in table 5), the increased demand for forest fuel translates into a relatively small net increase in the biomass supply from the forest. Instead, more than 80 percent of the increased supply of forest fuel is achieved through a similar reduction in the supply of saw timber and pulpwood – accompanied by relatively large increases in the endogenous prices. When the supply of stumps is introduced (2a), there is a small decrease in prices and the supplied/demanded quantities of all wood assortments increase. However, given our model, the introduction of stump harvest alone (ceteris paribus) will only induce marginal changes. Finally, when the demand for forest fuel increase under a regime that includes a supply of stumps (2b), only 25 percent of the increased supply of forest fuel is achieved at the expense of delivered quantities of saw timber and pulpwood. Thus, if Sweden allows large scale stump harvest, it might have a small effect in the present but will greatly mitigate the increased competition for wood resources as the demand for forest fuel increases.

The estimated size of the goal conflict between *Reduced Climate Impact* and *A Rich Diversity of Plant and Animal Life* can be seen through inspection of the changes in the two variables forest fuel ($\boldsymbol{y_{FF}}$) and overall population density of saproxylics (BIO). Without a supply of stumps, the exogenous increase in demand for forest fuel results in a 274 000 m3 increased use of forest fuel. With a supply of stumps, the use of forest fuel increase by another 47 000 m3, but is doing so at a cost in terms of a reduction of populations densities. If the additional 47 000 m3 wood fuel is used as a substitute for oil, the emissions of CO2 decrease by 27 000 metric ton[9] which amount to approximately 0.3 percent of the greenhouse gas that is emitted from "logging area one". Thus, the goal conflict, within logging area one, amounts to a tradeoff in this region between a 0.3 percent decrease in emissions of greenhouse gases and a 4.12 percent reduction in overall population density of saproxylic beetles on each year's future clear cuts.

[9] Assumptions: 0.42 metric ton solid matter per m^3 wood, 5 Mwh energy per metric ton solid wood, 0.264 metric ton carbon emissions per Mwh energy from crude oil (IPCC 2006, Table 2.2) and, most importantly, that carbon emissions from forest fuel can be seen as carbon neutral.

6. Discussion

Political goals are all too often formulated without regard for the possibility of goal conflicts. Essentially, it is a question of whether two, each worthwhile, goals jointly lie within the production possibility set. This paper has analyzed the potential goal conflict between the Swedish environmental objectives *A Rich Diversity of Plant and Animal Life* and *Reduced Climate Impact*. Our scenario resulted in a 0.3 percent decrease in emissions of greenhouse gases and a 4.12 percent reduction in overall population density of saproxylic beetles on future clear cuts. This should be compared to the interim targets in Swedish environmental goals which is to lower greenhouse gases by at least 4% from1990 to 2008-2012 and with 40% by 2020 (http://www.miljomal.se/Environmental-Objectives-Portal/Generation-goal/). Thus, in our model stump harvest contribute with 7.5% and 0.75 % to the target for 2008-2012 and 2020, respectively.

For dead wood the interim targets of the Swedish environmental goals is to increase dead wood availablity by 40% by 2010. This goal has been met but it is very much questioned if this is sufficient to maintain saproxylic diversity (Bernes 2011). Thus, although stump harvest could reduce climate impact by providing bioenergy, recent studies suggest that low stumps provides an important substrate for saproxylic organisms and suggestingthat stump harvest could have negative effect on biodiversity (Caruso and Rudolphi 2009, Hjältén et al. 2010). As table 3 shows, low stumps are the dominating substrate found on clear-cuts. Furthermore, the age distribution of the Swedish forest is strongly skewed towards younger stands, e.g. 22.5% is younger than 21 years (SLU 2010), which means that a large part of the forest land is former clear cuts with associated stumps. According to Carusso and Rudolphi (2009) stumps left after logging can remain up to 18 years before they are completely degraded. This, in relation to the results from the current study, indicates that low stumps might constitute a considerable part of the dead wood substrate available in the Swedish forest landscape. Due to the fact that transport costs are increasing rapidly with the distance from the production site and the bio fuel plant (Athanassiadis et al. 2009) it is reasonable to believe that stump harvesting will be non-uniformly dispersed in the landscape, with some geographical areas, close to power plants heavily harvested and other areas left un-harvested. In such areas compensation measures like creation of dead wood during final harvesting might be needed.

Our estimations of population effects should be considered as conservative due to the unknown impact at species level such as changes in metapopulation dynamics in the remaining forest patches (Harrison and Bruna 1999) and isolation effects (Rukke 2000). We know that there is a clear succession of saproxylic beetle species on spruce stumps, e.g. species occurring on fresh substrates the first years after clear-felling does not appear after a number of years and species utilizing dead wood in later decay stages are absent during the first years (Boulanger and Sirois 2007; Ulyshen and Hanula 2010). It is therefore important to remember that our data is limited to one year and hence excludes all beetle species potentially occurring both before and after this period in the succession and consequently the abundance. If about the same number of species are occurring on stumps from when they are created until they are completely decayed, which might be up to 18 years (Caruso and Rudolphi 2009) the total effects of stump harvesting on the abundance of saproxylic beetles might reach over 100 000 individuals per hectare. Furthermore, we have seen indications that some groups of beetles seem to be negatively influenced by stump harvesting even after long periods of time. These groups include mostly mycetophagous species, which even after 20 years did have lover abundances in the previously harvested sites then in the control sites (Andersson et al. in press).

Also, it should be noted that compared to Sweden as a whole, “logging area one” have a relatively high share of forest as well as energy consumption (and greenhouse gas emissions) per capita. To the extent our results can be extrapolated to other Swedish regions, the high share of forest (and thus clear cuts) imply that it is possible to extract a lot of stump per capita at a relatively low cost in terms of percentage changes in the availability of dead wood in the forest (and thus changes in biodiversity). On the other hand, the high energy consumption per capita imply that a given absolute change in emissions translate into a smaller percentage change.

No nonmarket value of potential biodiversity impact has been estimated in this paper. However our simulations imply that evaluation of stump harvest benefits should consider the goal conflict with biodiversity protection.

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Appendix A. Econometric results

Table A1: Three stage least squares parameter estimates (in thousands) of the Swedish forest sector model.

Forestry								
S. Saw timber			S. Pulpwood			S. Forest fuel		
Par.	Est.	s.e.	Par.	Est.	s.e	Par.	Est.	s.e.
α_{SS}	-1.65	4.4	α_{PP}	7.0	1.5*	α_{FF}	581	384
α_{SP}	-3.9	1.9*	α_{PS}	-3.9	1.9*	a_{Fcut}	-1.9	0.5*
α_{SF}	-1.9	0.5*	α_{PF}	-0.2	0.6	a_{FP}	-0.2	0.6
α_{SCut}	-3.3	4.1	α_{PCut}	0.5	2.0	a_{FL}	3.4	0.6*
α_{SK}	0.03	4E-3*	α_{PK}	0.01	3E-3*	α_{FK}	1E-3	1E-3
						a_{Ft}	-5.9	4.0
						α_{Ft^2}	2E-3	1E-3
Sawmills								
S. Sawn goods			S. Sawmill chips			D. Saw timber		
Par.	Est.	s.e.	Par.	Est.	s.e	Par.	Est.	s.e.
β_{GG}	-127	36,9*	β_{CC}	-88.6	45.4*	β_{SS}	166	60.2*
β_{GC}	1.3	0.2*	β_{CG}	1.3	0.2*	β_{SG}	-2.6	0.6*
β_{GS}	-2.6	0.6*	β_{CS}	-2.9	0.5*	β_{SC}	-2.9	0.5*
β_{GL}	1.7	3.0	β_{CL}	-0.1	1.8	β_{SL}	-5.4	2.2*
β_{GE}	-4.1	4.1	β_{CE}	-3.4	2.4	β_{SE}	8.7	2.8*
β_{GK}	1E-4	6E-5	β_{CK}	6E-5	4E-5	β_{SK}	3E-5	1E-4
β_{Gt}	0.07	0.02*	β_{Ct}	0.05	0.02*	β_{St}	-0.08	0.03*
β_{G-1}	5E-4	6E-5*	β_{C-1}	-3E-4	2E-4	β_{S-1}	-4E-4	6E-5*
β_{G2002}	0.8	0.3*	β_{C2002}	0.6	0.3*	β_{S2002}	0.8	0.5
β_{GD}	0.5	0.1*	β_{CD}	-0.3	0.1*	β_{SD}	0.9	0.2*
Pulp industry								
S. Pulp			D. Sawmill chips			D. Pulp wood		
Par.	Est.	s.e.	Par.	Est.	s.e	Par.	Est.	s.e.
β_{pp}	-169	23.5*	β_{CC}	94.4	33.8*	B_{PP}	220	60*
β_{pP}	-0.9	0.2*	β_{Cp}	-0.2	0.1	β_{Pp}	-0.9	0.2*
β_{pI}	-0.2	0.1	β_{CI}	-1.6	0.7*	β_{PI}	-1.6	0.7*
β_{pL}	-11.3	1.5*	β_{CL}	1.1	0.7	β_{PL}	6.6	1.4*
β_{pE}	2.7	2.5	β_{CE}	3.2	0.9*	β_{PE}	-5.4	1.6*
β_{pK}	-2E-5	0.1E-5	β_{CK}	2E-5	2E-5	β_{PK}	1E-4	5E-5*
β_{pt}	0.1	0.01*	β_{Ct}	-0.04	0.02*	β_{Pt}	-0.1	0.03*
β_{p-1}	-3E-5	1E-4	β_{C-1}	-4E-4	2E-4*	β_{P-1}	2E-4	6E-5*
β_{p2002}	-0.3	0.1*	β_{C2002}	0.4	0.3	β_{P2002}	0.4	0.2
β_{pD}	0.2	0.05*	β_{CD}	0.1	0.1	β_{PD}	0.2	0.1*
Heating industry								
D. Forest fuel								
Par.	Est.	s.e.	Par.	Est.	s.e.			
B_{FF}	-29	19	β_{Ft}	0.01	0.01			
β_{FH}	-0.5	0.2*	β_{F-1}	-3E-4	2E-4			
B_{FL}	0.3	0.1	β_{F2002}	0.2	0.1*			
B_{FE}	0.1	0.2	β_{FD}	-0.1	0.1			
B_{FK}	2E-5	1E-5						

Note: * denote significance at the five percent level. For all subscripts of parameters: S=saw timber, P=pulp wood, F=forest fuel, C=sawmill chips, I=import price of pulpwood, G=sawn good, p=pulp H=heat and K, L, E is the specific capital, labour and energy costs of the respective industry.