Raport final
***privind implementarea proiectului*:**

„Mobilizarea și monitorizarea efortului cu impact climatic pozitiv din sectorul forestier”

***(cod ERA-FACCE ERA-GAS* FORCLIMIT)**
Contract 82/2017

Perioada de implementare: 01.09.2017-31.05.2020

Bucuresti 2020

Denumire proiect: Mobilizarea și monitorizarea efortului cu impact climatic pozitiv din sectorul forestier (titlul original: *Mobilizing and Monitoring Climate Positive Efforts in Forests and Forestry*)

Cod proiect: ERA- FACCE ERA-GAS FORCLIMIT, Contract 82/2017 UEFISCDI/MEC Romania

Lista partenerilor

Partner Role	Partner organisation name	Country
Coordinator (Partner 1)	Norwegian University of Life Sciences, **NMBU (P1)**	Norway (NO)
Partner 2	Wageningen University, **WU (P2)**	Netherlands (NL)
Partner 3	U.S. Forest Service, **USFS (P3)**	U.S.A.
Partner 4	Swedish University of Agricultural Sciences, **SLU (P4)**	Sweden (SE)
Partner 5	Finnish Meteorological Institute, **FMI (P5)**	Finland (FI)
Partner 6	Faculty of Silviculture and Forest Engeneering, Transylvania University of Brasov, **BRV (P6)**	Romania (RO)

Colectivul proiectului din partea partenerului **Universitatea Transilvania din Brașov/ Facultatea de Silvicultură și Exploatări Forestiere** a fost:
V.N.B. Blujdea (responsabil contract)
I. Dutcă
C. Petrițan
M. Miclăuș

Valoarea totală a contractului: 801 mii lei/178 mii Euro

Perioada de implementare: Septembrie 2017 – Mai 2020

Data elaborării raportului final: Mai 2020

Despre programul de finanțare: FACCE ERA-GAS este acțiunea ERA-NET Cofund pentru stimulatrea cunoașterii privind monitorizarea și reducerea emisiilor de gaze cu efect de seră (GES) din agricultură și silvicultură. FACCE ERA-GAS a fost inițiată în cadrul *Inițiativei comune de programare pentru agricultură, securitatea alimentară și schimbare climatică (FACCE-JPI)*. Scopul acestei acțiuni ERA-NET Cofund este de a consolida coordonarea transnațională a programelor de cercetare și de a oferi o valoare adăugată cercetării și inovării privind reducerea emisiilor de gaze cu efect de seră în Spațiul European de Cercetare și Noua Zeelandă.

Consorțiul FACCE ERA-GAS este format din 19 organizații partenere din 13 țări: Danemarca, Finlanda, Franța, Germania, Irlanda, Letonia, Olanda, Norvegia, Polonia, România, Suedia, Turcia și Regatul Unit. Noua Zeelandă contribuie, de asemenea, la apelul comun cofinanțat ca agenție de finanțare non-parteneră. Teagasc, Autoritatea pentru Agricultură și Dezvoltare Alimentară din Irlanda, coordonează ERA-NET. FACCE ERA-GAS funcționează din mai 2016 până în aprilie 2021.

1 Cuprins

2 Introducere. Context științific.

Consorțiul FORCLIMIT susține că potențialul de reducere de emisii asociat gospodăririi pădurilor din Europa este semnificativ de ridicat, cu toate acestea, este insuficient stimulat în cadrul politicilor UE privind reducerile de emisii, și dăm ca exemplu Regulamentul LULUCF (Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (Text with EEA relevance). Luând notă de insuficiența efortului global de reduceri de emisii de gaze cu efect de seră, Parlamentul European recomanda printr-o rezoluție din Noiembrie 2018 ca UE sa devină neutrală climatic la jumătatea acestui secol, ceea ce justifică și mai mult nevoia de clarificare a contribuției pădurii și sectorului folosinței terenului la acest efort.

Până în prezent, resursele forestiere și sectorul forestier european au compensat aproximativ 13% din emisiile cauzate de utilizarea combustibililor fosili în Europa, reprezentând aproximativ 569 Mt CO_2/an (Nabuurs et al., 2015), rezultate din sechestrarea carbonului în păduri și din activități de reducere a emisiilor in sectorul forestier. În această proiect, efortul s-a concentrat în mod special pe înțelegerea provocărilor legate de potențialul de reducere de emisii al pădurilor și al resurselor forestiere (o parte semnificativă a așa - numitului sector LULUCF ce include folosința terenurilor) în cadrul mai larg al sectorului AFOLU (IPCC, 2006), care include și sectorul Agricultură pe lângă LULUCF. Potențialul suplimentar de reducere de emisii asociat sectorului forestier (ex. in păduri, soluri forestiere) este ridicat, însă acest potențial este incert, pe de o parte, din cauza lipsei de stimulente din partea politicilor existente si lipsa instrumentelor de reducere de emisii și, pe de altă parte, din cauza incertitudinii privind aplicarea și efectele activităților desfășurate în acest sens de proprietarii de păduri și utilizatorii resursei lemnoase. Noi abordăm aceste două aspecte împreună, deoarece numai astfel pot fi făcute progrese evidente.

FORCLIMIT a avut trei obiective principale:

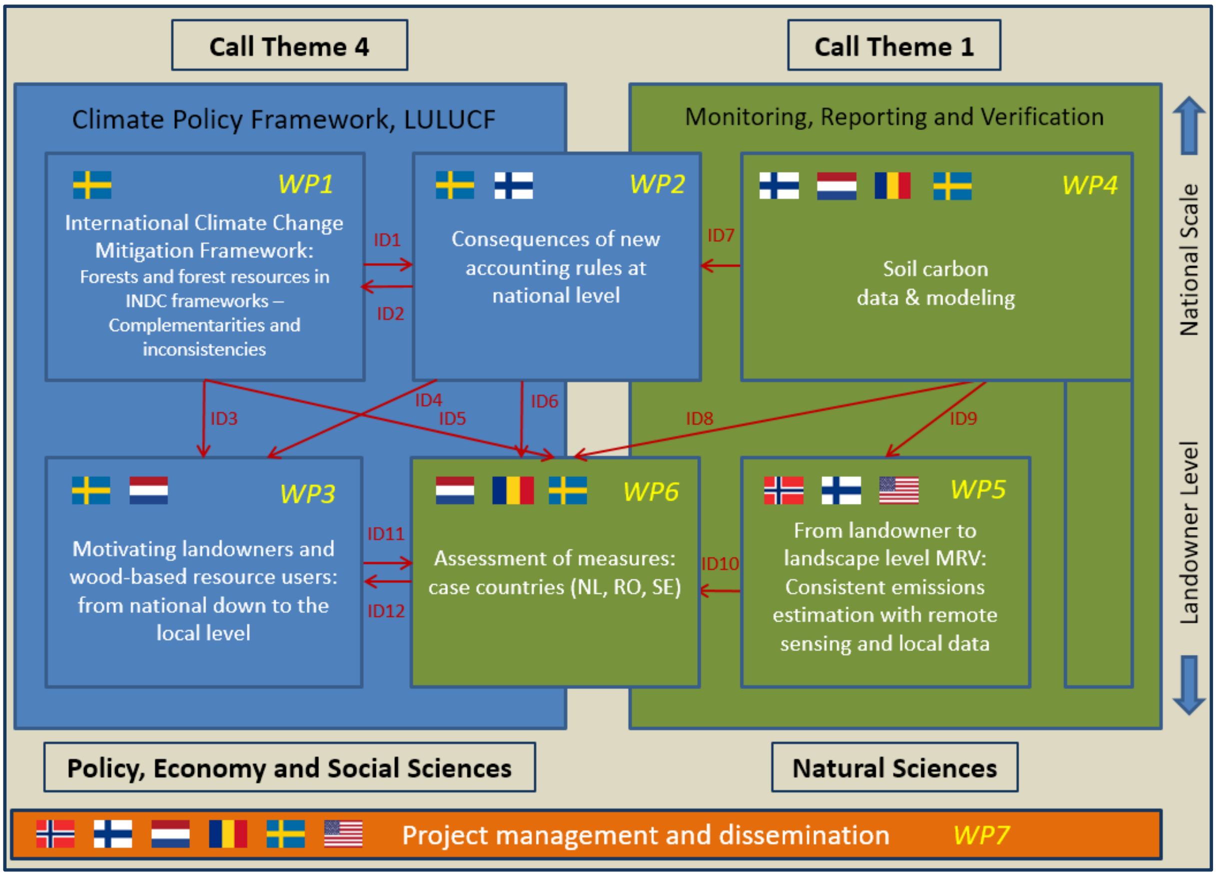
(1) să analizeze și să propună îmbunătățiri ale cadrului de contabilizare a reducerilor de emisii într-un cadru de politici si instrumente cu abordare unitară internațional, care să faciliteze o contabilizare consistentă a emisiilor din păduri din diferite țări;

(2) să analizeze strategiile economice și ale politicilor existente în motivarea proprietarilor de terenuri forestiere ca aceștia să depună efort pentru a realiza reducerii de emisii de gaze cu efect de seră din gospodărirea pădurilor și de-a lungul lanțului de custodie al lemnului;

(3) să îmbunătățească sistemul de monitorizare, raportare si verificare (MRV) actual, care vizează doar estimarea națională a emisiilor de GES, cu posibilitatea de estimare la scară locală (ex. arboret, unitate de administrare, proprietate), precum și evaluarea măsurilor economice și a politicilor existente. Acest lucru este demonstrat prin trei studii de caz în trei țări diferite: Olanda, Romania si Suedia.

3 Obiective și activități

In figura următoare tematica pachetelor de lucru (WP-uri), modul în care WP sunt interconectate (reperele intermediare și rezultatele interne dintre WP reprezenate prin săgeți numerotate) reflect scara spațială a diferitelor activități și abordarea interdisciplinară a cercetării. Steagurile indică națiunile (partenerii) implicați în fiecare WP. Primul steag într-un WP este liderul acelui WP. Denumirea pachetelor este confrorm textului propunerii.



***Pachetele de lucru si sarcinile din proiect unde Unitbv a avut reponsabilitati prin contract*:**

Sarcina 4.1: *Compilarea datelor locale relevante pentru sol (inclusiv climă) din suprafețele de testare ale proiectului (NL, RO, SE) și includerea acestor date în baza de date Yasso*. În detaliu, de exemplu, partenerul **BRV** va obține date locale cu modele de biomasă pentru speciile de arbori din bazele de date naționale și internaționale existente. Estimările vor fi validate cu valorile naționale ale BEF-urile pe categorii de diametre pentru arborete și specii de arbori. Datele climatice (respectiv precipitațiile și temperatura lunară, și amplitudinea anuală a temperaturii) vor fi obținute de la stațiile meteorologice locale sau de la www.worldclim.org și atribuite suprafețelor de eșantionaj ale IFN pentru a lua în considerare gradienții naturali. Acolo unde degradarea locală a pădurii este relevantă, parametrii relevanți vor fi definiți și cuantificați (adică: închiderea suboptimală coronamentului, perioada îndelungată cu teren neacoperit de vegetație, schimbarea compoziției către specii de lemn care nu sunt valoroase din punct de vedere economic). Pentru calibrarea și validarea rezultatelor simulărilor cu Yasso15, datele existente vor fi armonizate și compilate (de exemplu, cantitatea de C organic în solurile minerale și cantitatea de lemn mort din suprafețele de eșantionaj IFN; datele privind conținutul de humus și litieră din baza de date FMP).

Sarcina 4.2: Calcularea estimărilor pentru punctele de eșantionaj locale utilizând Yasso15 și analizarea valabilității acestor estimări față de măsurătorile locale.

Sarcina 4.3: Planificarea îmbunătățirilor aplicațiilor locale ale Yasso15 potrivit necesităților. De exemplu, legate de studiul de caz RO, există activități experimentale și de eșantionare pentru parametrizarea locală care includ; a) realizarea unui experiment de descompunere “litter bag” pentru principalele tipuri de păduri locale pe un gradient vertical (de către un doctorand înscris în programul de doctorat al BRV) și b) dezvoltarea unor parametri empirici locali pentru componentele biomasei bazate pe datele IFN din două măsurători succesive. Protocoalele experimentale vor fi elaborate pe baza referințelor publicate și a experienței anterioare. Pregătirea scripturilor pentru prelucrarea datelor și datelor de input în Yasso15.

Sarcina 4.4: Recalibrarea sau implementarea altor modificări în Yasso15 pentru a-l face adecvat condițiilor locale.

Sarcina 4.5: Efectuarea simulărilor pentru cazurile test folosind Yasso15 testat local. În plus, definitivarea contribuției cu elemente specifice solului pentru **WP2 (ID7)**.

Sarcina 4.6: Diseminarea metodologiei Yasso15 testate la nivel local. **BRV** va asigura legătura cu IFN pentru a pune în aplicare metodologia în politica națională de raportare, contabilizare și reduceri de emisii de GES.

Sarcina 4.7: Furnizarea Yasso15 testat la nivel local pentru cazurile și modelele **WP5-6 (ID8-9).** Limitele parametrilor derivați vor fi furnizate în mod explicit și utilizate pentru parametrizare, pentru fiecare studiu de caz.

Sarcina 6.1: În acest caz, partenerul **WU** va extinde modelul regional al bilanțului carbonului din păduri (EFISCEN-space) cu o rutină economică și va inițializa informațiile despre resursele forestiere și proprietarii de păduri în cele trei țări implicate. Modelul îmbunătățit va utiliza factorii de emisie îmbunătățiți pentru solurile forestiere din **WP4 (ID8)** și va utiliza factorii de emisie pentru managementul pădurilor și biomasei pentru nivelul proprietarilor de teren din **WP5 (ID10)**. În plus, aceste analize se vor baza pe **WP3** (motivația proprietarilor de terenuri, **ID11**) și **WP1** (reguli contabile **ID5**). EFISCEN-space este un model dependent de desimea arboretului, de climat, de distribuția diametrului și de creșterea pădurilor, adecvat atât rulării pe date IFN cât și pe date FMP. Versiunile anterioare ale EFISCEN au fost aplicate la realizarea proiecțiilor privind bilanțul carbonului la nivelul statelor membre ale UE, determinând nivelul de referință al pădurilor pentru aceste state membre. Este suficient de robust pentru a acoperi regiuni mari, cum ar fi țările, și suficient de detaliat pentru a include măsuri specifice de gestionare pe tipuri de proprietar și pe anumite tipuri de păduri. Rezoluția a rezultatului este de 1 x 1 km.

Sarcina 6.2: Pe baza rezultatelor elaborate in **WP3 (ID11)**, **WU** va identifica, în colaborare cu proprietarii de cazurile de studiu regionale (**SLU, BRV, WU**), măsurile economice regionale specifice și stimulentele politice care ar putea fi utilizate pentru a elimina barierele și care pot genera efecte semnificative de reduceri de emisii în sectorul forestier. Stimulentele identificate (**ID6** din **WP2**) vor fi adaptate la circumstanțele naționale, în consultare cu părțile interesate (a se vedea sarcina 6.3).

Sarcina 6.3: Evaluarea curbelor de răspuns ale proprietarilor de teren la stimulentele economice și politicilor bazate pe **WP3 (ID11).** În SIC, foarte semnificative sunt circumstanțele locale ele reprezintând de fapt oportunitate de a realiza reducerile de emisii (de exemplu, așteptările proprietarilor). Aceste cazuri sunt:

a) Suedia: un mare proprietar industrial și proprietari privați relativ mari și silvicultură industrială. Poate adaptarea la schimbările climatice să genereze o reducere de emisii susținută și durabilă, este recoltarea o presiune prea mare la nivel local? Stimulentele acordă o atenție suficientă solurilor drenate și de ex. biodiversității?

b) Olanda: organizație de conservare a naturii și proprietarii privați mici. Stoc de C pe picior relativ mare, compromisuri cu alte funcții ale pădurilor, zone sensibile la doborâturi de vânt. Cum adaptarea și optimizarea lanțului lemnului poate să producă beneficii climatice sporite?
c) România: zonă de studiu care acoperă pădurile private, inclusiv comunități. Un eșantion de peisaje rurale în cadrul unor procese durabile de restituire a pădurilor în perioada post-1990, sub presiunea concurenței locale pentru lemn și preocupărilor societății privind continuitatea pădurii. Peisajul este un mozaic de păduri normale și degradate din cauze antropice. Vom defini și testa soluții de gopodărire inteligentă climatic a terenurilor forestiere, inclusiv refacerea pădurilor degradate. Două ocoale silvice au convenit, în principiu, să găzduiască acest exercițiu. Pe baza literaturii existente și a cunoștințelor locale privind răspunsul la prețuri al proprietarilor, evaluarea răspunsului proprietarului va fi făcută prin chestionare și interviuri, bazându-se și pe **WP3 (ID11)**.

Sarcina 6.4: În cadrul acestei sarcini, **WU** (în colaborare **SLU, BRV, WU**) evaluează prin simularea de scenarii cu EFISCEN-space, potențialul realist de reducere de emisii în cele trei regiuni, bazat pe măsuri economice și politice. Vor fi organizate implicarea părților interesate punând în aplicare cele mai bune practici de consultare și va fi creat transferul de cunoștințe.

Sarcina 6.5: Cuantificarea contribuției relative a diferitelor surse de incertitudine la emisiile de carbon și proiecțiile de sechestrare la scară local. Studiul de caz RO include validarea proiecțiilor prin modelarea paralelă cu un alt model empiric Carbon Budget Model (CBM-CFS) și comparații cu EFISCEN-space. Exercițiul are valoare deoarece cele două modele sunt conceptual diferite în funcționarea depozitelor de carbon (rularea la nivel de arbore de EFISCEN-space, arboret de CBM-CFS). O comparabilitate deplină va fi realizată prin armonizarea datelor de intrare privind inventarul forestier și degradarea materiei organice moarte de la **WP4 (ID8)**.

Activități aditionale la care Unitbv a contribuit direct (fiind legate implicit de activitățile asumate) sau a contribuit la elaborarea articolelor științifice, fie ca autor fie ca revizor inainte d epublicare:

Sarcina 4.7: Furnizarea Yasso15 testat la nivel local pentru cazurile și modelele **WP5-6 (ID8-9)**. Limitele parametrilor derivați vor fi furnizate în mod explicit și utilizate pentru parametrizare, pentru fiecare studiu de caz.

Sarcina 1.4: Evaluarea strategiei UE privind LULUCF și analiza compatibilității cu strategiile abordate în cadrul internațional emergent, precum și cu obiectivele și interesele la nivelul statelor membre.

Sarcina 5.1: Vom valorifica patru seturi de date existente și unice deja disponibile (sau care urmează să fie finalizate în 2017) la nivel local (arboret și proprietate) și la nivel de peisaj. Datele cuprind date ALS "wall-to-wall" (înălțime și densime a pădurii în mod tipic pe 100m^2) multi-temporale (10-15 ani) și observații detaliate privind proprietățile biofizice la numeroase scări ale loturilor de eșantionare (de la ~ 200 m^2 până la ~ 2-3 ha). Vom cuantifica contribuția relativă a diferitelor surse de incertitudine (modelul alometric, modelul de carbon al solului, eșantionarea, modelul auxiliar de date) pe estimările emisiilor utilizând estimatori și simulări bazate pe model (Monte-Carlo și simulare de eșantionare). Se va utiliza un model îmbunătățit Yasso15 de carbon antamat în **WP4 (ID9)**. **USFS**, cu o experiență remarcabilă în inferența bazată pe modele, se va implica activ în acestă cercetare. **FMI** va asista cu inițializarea modelului Yasso15 (a se vedea **WP4**).

Sarcina 5.2: Estimatorii biomasei bazate pe modele și asistate de modele, raportate în literatura științifică, vor fi aplicați pentru estimarea modificărilor diferitelor depozite de carbon, la diferite niveluri geografice. Vom aborda problemele de erori sistematice (bias) cu date empirice. La nivel local (arboret/parcelă, proprietate), pentru care sunt disponibile puține date sau deloc, vom folosi estimatori simulați de modele și vom valida empiric precizia. Erorile sistematice vor fi evaluate cu date empirice ale arboretului local. Pentru scări mai mari (peisaj), estimatorii asistați de model vor fi utilizați și în cazul în care dimensiunile eșantioanelor permit inferența bazată pe designul de eșantionare. Tendințele regionale (erorile sistematice) în estimatorii la scară peisajului vor fi identificate și cuantificate utilizând modele externe regiunii/peisajului în cauză. Astfel, vom beneficia de colecția unică a celor patru seturi de date regionale folosind modele dezvoltate într-o regiune și aplicate într-o regiune diferită. Corecția pentru erorile sistematice de tip Horvitz-Thompson în estimatorul asistat de model va fi o indicație a problemelor de părtinire. Această analiză va informa viitoarele decizii de proiectare ale inventarierii prin sondaje pentru estimarea schimbării stocului de carbon, adică măsura în care MRV la nivel de arboret, la nivel de proprietate și la nivel de peisaj ar trebui să se bazeze pe eforturi local de eșantionare sau pot fi asistate datele IFN. Rezultatele acestor analize vor oferi, de asemenea, îndrumare privind alegerea unor estimatori foarte potriviți la nivel local, unde mulți dintre estimatorii de variație existenți tind să subestimeze varianța. Această sarcină se va baza pe rezultatele din **WP4** (Yassso15; **ID9**) și va furniza factori de emisie (**ID10**) pentru **WU** sub **WP6**. Expertiza statistică și experiența în estimarea bazată pe model și asistată de model posedată de **USFS** este esențială pentru această activitate.

4 Metode și rezultate

Rezultatele finale ale cercetărilor sunt enumerate la titlurile 4.1- 4.19 din sectiunea "Metode si rezultate". Realizările sunt prezentate pe secțiuni corespunzătoare pachetelor angajate prin contract. Fiecare secțiune prezintă stadiul la data finalizării proiectului (31 Mai 2020) pe intreaga durată a proiectului de 32 de luni, astfel:

a) *articolele publicate* - abstractul și link-ul la publicație;
b) *articolele transmise* sau în curs de transmitere pentru publicare sunt incluse in extenso in anexe individualizate, fiecare având însă o secțiune în textul principal (e.g. abstractul).
c) *rezultatele* proiectului care nu sunt in *format de publicare* vor fi prezentate in secțiuni scurte cu material în extenso în anexă care să reflecte stadiul actual. Acestea nu sunt finalizate din cauze evidente legate de durata experimentelor sau faptului ca unii partenerii externi au contracte ce durează pana la 31 decembrie 2020 si incă lucrează la componetele lor sa comune.

4.1 Evaluarea curbelor de răspuns ale proprietarilor de teren la stimulentele economice și politicilor in domeniul schimbarilor climatice (V. Blujdea, I. Dutcă)

Chestionarul distribuit asociațiilor de proprietari si administratori de padure este prezentat in Anexa 1a, iar Anexa 1b prezinta varianta curenta a articolului. Acesta reprezintă contribuție la realizarea **sarcinilor D6.1 si D6.3** (prelucrarea este in curs de catre WUR).

4.2 Armonizarea, calibrarea și validarea stocurilor de C din materia organică moartă cu CBM-CFS3 si Yasso15 (V. Blujdea)

Parametrizarea implicită a modelelor CBM si Yasso15 nu oferă estimări adecvate ale stocurilor de C din sol la scară locală / regională, deși în intervalul de variație de 1 STD față de valoarea medie determinată pe baza de date din IFN. Simulările rezultate de ambele modele demonstrează că depozitul de materie organică moartă asociat solurilor minerale se comportă ca un absorbant de CO2 din atmosferă pe termen lung. Simulările efectuate cu ambele modele arată un puternic efect de „pornire" asupra schimbării stocului C care se manisfetsă pe durata si putin după primul deceniu simulat, urmat de o stabilizare. Sistematic, Yasso15 simulează valori mai mici decât CBM. Încercarea de a calibra procesele de descompunere prin modificarea parametrizării CBM a dus la o îmbunătățire a rezultatelor in raport cu măsurătorile din IFN.

Manuscrisul in forma avansată este prezentat in **Anexa 2b**, in timp ce **Anexa 2a** conține elemente de parametrizare a modelului CBM-CFSv3 (calibrate pe România care au fost inițial dezvoltate pentru simulările asociate articolului din **Anexa 4**).

Acesta reprezintă contibuție la **sarcina 4.7** din contract.

4.3 Strategii la nivel național și ale Uniunii Europene pentru promovarea acțiunilor de protecția climei bazate pe resurse forestiere si sectorul forestier - motivarea proprietarilor, a consumatorilor și a actorilor din sectorul public de nivel local (V. Blujdea)

Utilizarea pădurilor și a resurselor bazate pe păduri în cadrul Uniunii Europene (UE) și în cadrul politicilor climatice ale statelor membre rămâne controversată. Evitarea mobilizării depline a potențialului resurselor bazate pe păduri și sector forestier a dus la un cadru de politică LULUCF la nivelul UE care este simultan expansiv și restrictiv, ce constă în integrarea mai bună și creșterea rolului pădurii și sectorului forestier în politica climatică, dar și stabilind în același timp limite precise în deplina mobilizare. Chiar și cu cea mai recentă revizuire a politicii UE, Regulamentul LULUCF (UE 2018/841) în cadrul Acordului de la Paris, acțiunile de reducere de emisii asociate resursei și sectorului forestier rămân circumscrise unei rețele extrem de complexă și greoaie de reguli (adică FRL, cap, HWP, neutralitate de carbon, bioenergie, AL / DL (ARD), etc.). Pentru a motiva sectorul și actorii conexi să adopte acțiuni mai favorabile reducerilor de emisii, UE a încurajat statele membre să furnizeze informații în virtutea așa-numitului Art. 10 privind măsurile luate. Astfel, pentru a evalua dacă cea mai recentă revizuire a politicii LULUCF din 2018 poate motiva cu success participarea diversilor actori interesati la actiuni de reduceri de emisii, efectuăm următorul exercițiu. Pe baza celor mai recente date disponibile, evaluăm obiectivele viitoare legate de LULUCF ale anumitor state membre ale UE pornind de la performanța lor în cadrul celei de-a doua perioade de angajament a Protocolului d ela Kyoto (CP2: 2013-2020). Întrucât modificările introduse în cadrul politicilor UE între perioadele a 2-a și a 3-a de angajament de reduceri de emisii (CP3: 2021-2030) sunt relativ minore, cu excepția reformelor politice suplimentare, performanța actuală oferă un indicator adecvat al rezultatelor așteptate. Am constatat că din cauza gradului de inadecvare a măsurilor comune instituite la nivelul UE, proprietarii, consumatorii și sectorul public la scară locală, statele membre in general, chiar și statele membre bine intenționate se confruntă cu destimulente puternice care previn acțiunea, atât la nivel național, cât și local. Cu toate acestea, cu modificări relativ minore, cadrul de politici si legislatie al UE și național ar putea propulsa contributia in mod semnificativ.

Manuscrisul este depus la Environmental Science and Policy si este prezentat in **Anexa 3**.

Acesta reprezintă contibuție in cadrul la **sarcina 1.4,** din propunerea de proiect.

4.4 Două abordări privind modelarea scenariilor privind pădurea pentru raportarea sechestrării de CO2: comparare pe baza datelor inventarului forestier național din România (V. Blujdea, I. Dutca)

Această lucrare prezintă o comparație cantitativă a dinamicii pădurilor, a stocurilor de carbon și a fluxurilor de carbon până în 2060, așa cum este simulată de CBM-CFS3 și EFISCEN. Scopul este de a compara rezultatele simulării cu aceste două modele și de a identifica cauzele oricăror diferențe.

Ambele modele necesită ca date de intrare date derivate din inventarul forestier. EFISCEN a fost inițial dezvoltat pentru modelarea resurselor forestiere, iar CBM a fost dezvoltat încă de la început ca model de simulare a stocurilor de carbon.

Intrările de date au fost armonizate pentru ambele modele pe baza datelelor din inventarul forestier național din România (NFI-1, NFI-2) privind suprafata de pădure disponibilă pentru aprovizionarea cu lemn (FAWS) care a acoperit 6,1 milioane ha și furnizează date pe suprafață, clasă de vârstă, specii de arbori, regiunea administrativă și proprietatea asupra terenurilor. Pentru comparație, în modele au fost simulate identic aceleași practici de gestionare și date climatice.

Acesta reprezintă contibuție la **sarcina 6.1 si 6.5** din propunerea de proiect.

Manuscrisul este depus la Carbon Balance and Management si este prezentat in **Anexa 4**.

4.5 Estimarea dinamicii stocului de carbon folosind modelul Yasso 15, simulare și parametrizare locală în condiții de schimbare a folosinței terenului la/de la pădure (M. Miclaus)

Pentru a înțelege contribuția schimbării folosinței terenului la bilanțul emisiilor gazelor cu efect de seră (GES) – în special a dioxidului de carbon (CO_2), asociate conversiilor simetrice *la* și *de la* terenurile forestiere de la și la alte folosințe, este necesară implementarea unor metode robuste care să surprindă, pe de o parte, absorbția de CO_2 extrem de lentă în cazul conversiilor de la alte folosințe la pădure (e.g. împăduriri) și pe de altă parte, emisiile accelerate de CO_2 aferente conversiilor de la pădure la alte folosințe (ex: despăduriri).
Cea mai nouă versiune a modelului Yasso, Yasso 15, care descrie ciclul C organic în sol (Järvenpää et al 2015), reprezintă o îmbunătățire a unei versiuni anterioare Yasso07 (Liski et al. 2005, Tuomi și al. 2009, Tuomi et al. 2011b). Acesta in plus cuantifică și respirația heterotrofică a solului. Aplicațiile sale se extend la simularea dinamicii stocurilor de C din schimbarea folosinței terenului, gestionarea ecosistemelor, și analiza impactului schimbării climatice. Sintaxa modelui Yasso15 este relativ simplă, datele de intrare necesită doar informații cu privire la cantitatea de C plus parametrii climatici (temperatură și precipitatii). Versiunea curenta Yasso15 utilizează un set de date mai diversificate, punându-se mai mult accent pe ipotezele de modelare și unele detalii matematice care au condus la o calitate mai bună a modelarii, respectiv o mai bună reprezentare a metodelor și proceselor ecologice fundamentale. În plus, estimările de incertitudine sunt parte importantă a acestei versiuni, facilitând și simulări ce implică modelarea carbonului organic între diferite tipuri de folosințe ale terenului.
Definiții: în acest experiment s-au ales trei suprafețe de probă (SP) care să reflecte secvența conversiei de la pajiște la pădure.
Design experimental: conform planului amenajistic SP-urile se poziționează în raza us. 7A din Ocolului Pădurile Șincii (vezi figura următoare cu locația suprafețelor de probă).

Distribuția altitudinală: cele trei suprafețe de probă corespunzând altitudinii de 600-700 m Specificații ale conversiei: forma finală așteptată în urma conversiei este reprezentată de pădure cu compoziția fag și carpen (cu vârsta arboretului de 80 ani), forma tranzitorie între pajiște și pădure în vârsta cca. 20 de ani reprezentată de un amestec fag și carpen, și forma de folosință inițială înainte de conversie (pajiște).
Recoltare probe sol și pre-procesare: Pentru recoltarea probelor de sol din fiecare secvență s-a folosit o sondă tip Edelman și Riverside/ Eijelkamp (vezi figura), s-au efectuat câte 5 repetiții din 10 în 10 cm, din care s-au prelevat probe până la adâncimea de aproximativ 1m. Locația fiecărei probă de sol fiind înregistrată în GPS. Numarul total de probe a fost fiind de 82.

Ulterior au fost aduse în laborator în pungi de plastic etichetate corespunzător, urmând a fi procesate pentru determinarea conținutului de C organic, azot total, analiza granuloetrică/textura și densitatea aparentă.

Acesta reprezintă activitate la **sarcina 4.7** din propunerea de proiect.

Metodologia pentru recoltarea biomasei erbacee din pajiști este prezentată in **Anexa 5.**

4.6 Analiza incertitudinii metodelor utilizate pentru detectarea schimbării folosinței terenului prin metode diferite (M. Miclăuș, V. Blujdea)

Îmbunătățirea metodelor de estimare a schimbării stocului de carbon odată cu schimbarea folosinței terenurilor este una din marile provocări legate de implementarea inventarelor de gaze cu efect de seră și a reducerilor de emisii asociate obligațiilor internaționale (Protocolul de la Kyoto, Acordul de la Pari/legislația Uniunii Europene). Activitatea face parte din cadrul WP5.

Estimarea cu acuratețe ridicată a emisiilor din sectorul LULUCF poate aduce îmbunătățiri inventarelor naționale ale emisiilor de gaze cu efect de seră (INEGES). În acest studiu, investigăm dinamica stocului de carbon din solurile terenurilor aflate în conversie, de la pădure la alte folosințe și de la alte folosințe la pădure (e.g. împăduriri, despăduriri). Au fost aplicate metode pentru estimarea incertitudinii care ar putea avea un impact important, în trei sondaje, prin analiza diferitelor tipuri de simulare, aceasta implică observația transferurilor de C organic între diferite tipuri de orizonturi de sol ale diferitelor folosințe ale terenului. Studiul a fost realizat prin intermediul modelului Yasso 15, aplicat în sondaje forestiere, sondaje în tranziție și sondaje în pășune din care au fost colectate și măsurate date conform metodologiilor de eșantionare, și simulează condițiile zona Estul Țării Făgărașului, apoi au fost comparate cu baza globală de date pe care modelul le dispune. Pentru a compara modificările stocurilor C din diferite orizonturi de sol, urmează validarea modelului verificând dacă se suprapune cu măsurătorile și condițiile locale. Mai mult, aceste validări ale modelului Yasso în diferite tipuri de folosințe a terenului și măsurători repetate pe termen lung pot aduce o contribuție valoroasă în domeniu.

Acest manuscris este in lucru (colectivul este format din: Miclăuș Mihaela, Abrudan Ioan Vasile, Blujdea Viorel, Ellison David, Grafström Anton, Nilsson Björn, Nilsson Mats, Petersson Hans, Strimbu Victor, Wallerman Jörgen) si urmează a fi trimis spre publicare la revista European Journal of Soil Science.

Acest studiu reprezintă contribuție la **sarcina 5.1**.

Compararea a trei metode utilizate in diverse sisteme de raportare este descrisa in versiunea avansata de articol inclusa in **Anexa 6.**

4.7 Studiu privind efectul grupării observațiilor asupra modelelor alometrice (Site-effects on biomass allometric models for early growth plantations of Norway spruce (Picea abies (L.) Karst.)) (I. Dutca, V. Blujdea)

Este general recunoscut ca modelele alometrice necesare pentru estimarea biomasei in păduri sunt specifice zonei din care au fost eșantionați arborii. Asta pentru ca forma arborilor este influențată de genotip dar si de factorii de mediu cum ar fi solul, clima dar si competiția dintre arbori. Plecând de la premisa că aceste caracteristici au o variabilitate spațială, concluzionam că și alometria arborilor are o variabilitate spațială. Folosind modele ierarhice cu interceptul variabil, am putut arata cât de mult sunt afectate aceste modele de variabilitatea spațială. Coeficientul de corelație intraclasa este des folosit în sociologie pentru a arata proporția varianței modelului, cauzată de diferențele dintre grupuri. În mod similar, noi am arătat că diferențele dintre plantațiile tinere de molid (Picea abies) în România produc proporții foarte mari din varianța totală a modelului alometric. Această proporție a variat între 33 si 86% din varianța totală a modelului, în funcție de variabila independenta folosita și componenta arborilor estimată. Am mai arătat că, folosind diametrul de bază ca variabilă independenta în model, efectele produse de gruparea arborilor eșantionați în plantații este mai mic decât atunci când folosim înălțimea arborilor. Atunci când sunt folosite ambele variabile (diametrul și înălțimea) este mai bine sa fie folosită o variabila combinata (D^2H) deoarece efectul plantației asupra modelului este mai mic. Dintre componentele arborilor, biomasa fusului are o specificitate mai mare decât biomasa frunzelor sau ramurilor.

Rezultatele obținute precum și metodologia prezentată în această lucrare sunt foarte importante pentru domeniul estimării privind carbonul în păduri, deoarece folosind coeficientul de corelație intra-clasă se poate decide dacă modelele alometrice elaborate pentru un arboret pot fi folosite și în alte arborete. Deși se vorbește foarte des despre specificitatea modelelor alometrice, acest studiu este primul studiu care arata într-un mod cantitativ că specificitatea modelelor alometrice este una foarte ridicată.

Acest studiu, cu titlul "Site-effects on biomass allometric models for early growth plantations of Norway spruce (Picea abies (L.) Karst.)" a fost publicat în revista Biomass & Bioenergy nr. 116 din Septembrie 2018.

Varianta publicata a articolului este disponibila la:

https://www.sciencedirect.com/science/article/pii/S0961953418301259?via%3Dihub sau https://doi.org/10.1016/j.biombioe.2018.05.013.

Activitatea face parte din cadrul **sarcinilor 4.1 si 5.2**.

4.8 Studiu privind efectul metodelor de ajustare a observațiilor în modelele alometrice neliniare pentru corectarea heteroscedasticității (A comparison of weighting approaches in nonlinear allometric models and their effects on large-area biomass prediction) (I. Dutca, V. Blujdea).

Modelele alometrice folosite pentru estimarea biomasei/volumului arborilor individuali sunt modele de regresie neliniară în care varianța crește odată cu creșterea variabilei independente. De aceea atunci când aceste modele sunt estimate folosind metoda neliniară, observațiile trebuie ajustate cu ajutorul unei funcții care de regulă descrie inversa varianței valorilor reziduale. In literatură au fost sugerate numeroase modalități prin care se pot ajusta observațiile. In acest studiu am comparat nouă modalități de corectare a heteroscedasticității si am investigat efectul pe care aceste modalități diferite de corectare îl au asupra produsului final și anume în estimările de biomasa pe suprafețe întinse. Rezultatele preliminare au arătat ca modalitatea de corectare a heteroscedasticitatii poate avea efecte nedorite si anume de creștere a incertitudinii estimărilor de biomasa cu pana la 10%, așa că o atenție sporită trebuie dată acestui aspect.

Activitatea face parte din cadrul **sarcinilor 4.1 si 5.2**.

O varianta de lucru a acestui articol este prezentata in **Anexa 7**.

4.9 Elaborarea unei masuri practice pentru evaluarea oportunității combinării variabilelor diametrul de baza (D) si înălțime (H) in D^2H (A practical measure for determining if diameter (D) and height (H) should be combined into D^2H in allometric biomass models) (I. Dutca, V Blujdea)

Modele alometrice folosesc variabile ușor de măsurat (e.g. diametrul D si/sau înălțimea H) pentru a estima caracteristici greu de măsurat ale arborilor (e.g. biomasa). Însă diametrul si înălțimea arborilor sunt variabile care sunt corelate, deoarece arborii cu diametrul mai mare au de regula si o înălțime mai mare. Pentru a limita efectele nedorite ale coliniarității dintre variabile se folosește adesea o variabila combinata D^2H, plecând de la premisa ca biomasa supraterana este proporțională cu volumul unui cilindru cu diametrul=D si înălțimea=H. Însă variabila combinata constrânge modelul sa producă un raport fix al parametrilor pentru D si H, respectiv 2.0. Așadar, ipoteza studiului este ca pierderea de acuratețe a modelului este în funcție de raportul Q (raportul dintre parametrul lui D si parametrul lui H). Cu cat raportul Q este mai diferit de 2.0 cu atât pierderea de acuratețe atunci când folosesc D^2H este mai mare. Folosind cinci seturi de date cu observații de biomasa am demonstrat că folosirea variabilei combinate produce o pierdere a acurateței care depinde de raportul Q. Pentru aceste seturi de date, pierderile de acuratețe ale estimărilor au fost de pana la 12% în ceea ce privește media relativa absoluta a valorilor reziduale si de pana la 18% în ceea ce privește suma pătratelor raportului de acuratețe (i.e. un indicator al acurateței).

In acest studiu, pentru elaborarea modelelor alometrice am folosit atât procedeul transformării logaritmice cat si modelul neliniar cu ajustarea observațiilor. Am arătat că atâta timp cat ajustarea observațiilor pentru a compensa heteroscedasticitatea este făcută corect, modelul neliniar produce parametri foarte apropiați de cei rezultați din transformarea logaritmică.

Rezultatele studiului sunt extrem de importante pentru creșterea acurateței estimărilor de biomasă cu repercusiuni în creșterea relevantei participării sectorului forestier în reducerile de emisii.

Studiul a fost publicat in revista Forestry, numărul 92 din Octombrie 2019, paginile 627–634.

Varianta publicată a articolului este disponibilă la: https://doi.org/10.1093/forestry/cpz041

Acest studiu răspunde obligațiilor asociate **sarcinii 5.2** din propunerea de proiect si a fost elaborat si publicat împreună cu Ronald McRoberts (partenerul de la US Forest Service) si Erik Naesset (coordonatorul proiectului, de la NMBU).

4.10 Studiu privind variabilitatea explicată de diferențele dintre specii si diferențele dintre locații în modelele alometrice ("The Variation Driven by Differences between Species and between Sites in Allometric Biomass Models") (I. Dutca)

Modele alometrice sunt instrumente vitale pentru estimările de biomasă și pentru buna implementare a programelor de reduceri de emisii din păduri. Aceste modele folosesc variabile independente ușor de măsurat (e.g. diametrul de baza, înălțimea arborilor) pentru a estima biomasa arborilor în picioare. Însă ele au doua mari limitări: (1) faptul ca modele sunt specifice speciei si locației si (2) faptul ca măsurătorile de biomasă pentru elaborarea de noi modele sunt dificile si implica logistica si costuri mari. Cunoașterea nivelului de specificitate în raport cu specia și în raport cu locația a acestor modele nu este bine cunoscuta. De aceea scopul acestui studiu a fost de a arata gradul de specificitate al modelelor in raport cu specia si locația, folosind doua seturi de date din Eurasia si Canada. Aplicând un model ierarhic ANOVA valorilor reziduale ale modelelor alometrice, am separat varianța totală în (i) varianța explicată de diferențele dintre specii, (ii) varianța explicată de diferențele dintre locații și (ii) varianța reziduală. Mai departe, am folosit proporția varianței explicată de fiecare din cele doua nivele (specie și locație) pentru a evalua cât de specifice sunt modele alometrice speciei respectiv locației. Pentru determinarea erorilor standard ale acestor proporții am aplicat o analiza Bootstrap. Rezultatele au arătat ca specia explică o proporție a varianței totale mult mai mare decât explică locația. Proporția varianței explicate de diferențele dintre specii a fost de 42.56% (SE = 6.10%) pentru Eurasia și 47.54% (SE=6.07%) pentru Canada, pe când proporția explicată de diferențele dintre locații a fost de 20.08% (SE=3.35%) pentru Eurasia si 8.27% (SE=1.38%) pentru Canada. Așadar diferențele dintre specii generează o variabilitate mult mai mare în modele alometrice în comparație cu diferențele dintre locații. Folosind diametrul si înălțimea arborilor ca variabile independente în modelul apometric (comparativ cu situația în care doar diametrul este folosit ca variabilă independentă), a condus la o scădere a proporției varianței explicată de diferențele dintre locații de cca. 24-44%, pe când proporția varianței explicată de diferențele dintre specii a rămas neschimbată. In plus, am arătat cum sunt grupate speciile în funcție de alometria lor (i.e. relația dintre biomasa si variabilele independente).

Aceste informații sunt foarte de valoroase deoarece ele arată cât de mari pot fi diferențele dintre modelele alometrice ale diferitelor specii, precum și cât de mari pot fi diferențele între modelele alometrice specifice locațiilor. De asemenea, mai indică riscul de erori sistematice atunci când modele specifice unei specii sunt folosite pentru o altă specie și cât de mari sunt riscurile atunci când un model dezvoltat pentru o locație este folosit într-o altă locație. Deoarece proporția varianței explicată de diferențele dintre specii a fost mai mare decât cea explicată de diferențele dintre locații, riscul de erori sistematice este mai mare când modele sunt mutate de la o specie la alta decât atunci când ele sunt mutate de la o locație la alta. De asemenea, am arătat că, deoarece variația condițiilor climatice este mai mare în setul de date din Eurasia, proporția variantei explicată de diferențele dintre locații este mai mare decât pentru setul de date din Canada.

Studiul a fost publicat in revista Forests 2019, 10(11), 976;
https://doi.org/10.3390/f10110976

Acest studiu răspunde obligațiilor asociate **sarcinii 5.2** din propunerea de proiect.

4.11 Studiu privind impactul caracteristicelor eșantionului în modelele alometrice asupra acurateței și preciziei estimărilor de biomasă ("Sampling trees to develop allometric biomass models: How does tree selection affect model prediction accuracy and precision?") (I. Dutca)

Este bine știut ca acuratețea si precizia estimărilor de biomasa depind într-o oarecare măsură de modelele alometrice pentru estimarea biomasei la nivel de individ. Deși este cunoscut faptul ca variabilitatea intrinseca a relației intre biomasa si predictor(i) precum si mărimea eșantionului (numărul de observații) influențează acuratețea si precizia (acuratețea a fost definita ca diferență dintre valoarea estimata si valoarea reala), acest studiu aduce in discuție si alte caracteristici ale eșantionului cum ar fi mărimea intervalului de diametre al eșantionului, poziția acestui interval (data de valoarea de start a intervalului) si distribuția diametrelor in eșantion. Folosind simulări Monte-Carlo am generat seturi de date cu diferite caracteristici. Mai departe, cu aceste date am elaborat modele alometrice care au fost folosite pentru a estima biomasa unei suprafețe de proba. Concluziile studiului au fost:

- Variabilitatea relației Biomasa-Diametru a fost cel mai important factor care influențează acuratețea si precizia estimărilor de biomasa;
- Mărimea eșantionului (numărul de observații) deși a influențat semnificativ acuratețea estimării a avut un efect nesemnificativ asupra preciziei estimării;
- Distribuția diametrelor in eșantion a avut un efect similar mărimii eșantionului; a influențat semnificativ acuratețea estimării, însă nesemnificativ precizia estimării;
- Am demonstrat ca arborii mici aduc o cantitate mai mare de informație in modelul alometric, deci modelele alometrice care includ arbori mici vor avea o ajustare mai buna (o valoare a coeficientului de determinare R^2 mai mare) si valori mai mici ale erorilor standard ale parametrilor. Acest lucru este datorita faptului ca varianta in modele alometrice (care sunt neliniare) nu este constanta si creste cu diameterul (=heteroscedasticitate). Însă în modele alometrice heteroscedasticitatea este controlată prin ajustarea observațiilor cu un factor care se calculează ca inversa variantei. Cum varianta este mica la arborii mici, acest factor este mai mare la arborii mici, deci cantitatea de informație (sau importanța) arborilor mici în model este mai mare. Cu toate acestea, deși modelul in care sunt incluși arborii mici este mai bun (din punct de vedere al coeficientului de determinare), impactul asupra acurateței si preciziei estimărilor de biomasa este nesemnificativ.
- Am arătat ca eșantionând un număr constant de arbori pentru fiecare categorie de diametre rezulta modele care produc estimări cu acuratețe si precizie mai ridicata.
- De asemenea, deși R^2 este frecvent folosit pentru alegerea modelelor (sub ipoteza ca un model cu R^2 mai mare este mai bun) am arătat ca R^2 este dependent de mărimea intervalului de diametre folosit pentru elaborarea modelului iar acuratețea si precizia modelelor nu depind de intervalul de diametre folosit. Așadar, ca precizia si acuratețea estimărilor de biomasa nu depind de valoarea R^2 a modelului.

Articolul a fost acceptat spre publicare la revista *Ecological Indicators* in data de 18 mai 2020.

Varianta acceptata a articolului este prezentat în **Anexa 8**.

Acest studiu răspunde obligațiilor asociate **sarcinii 5.2** din propunerea de proiect.

4.12 Calibrarea modelului PREBAS cu datele tip-IFN (I. Dutca, V. Blujdea)

Modelul PREBAS este un model care simulează dinamica pădurii la nivel de arboret (sau strat din arboret) si a luat naștere prin combinarea modelelor CROBAS si PRELES. CROBAS este un model pentru estimarea creșterii individuale a arborilor. Creșterea se bazează pe acumularea si alocarea carbonului, așadar creșterea este egală cu producția netă. PRELES este un model folosit pentru estimarea capacitații de fotosinteză a unei păduri, input care este esențial in CROBAS. Fotosinteza brută este calculată ca produs între masa frunzelor și rata specifică a fotosintezei.

Pentru calibrarea modelului PREBAS am folosit datele IFN referitoare la caracteristicile arborilor măsurați, dar și o serie de date climatice specifice fiecărei suprafețe de probă IFN.

```
nYears = 100
siteInfo <- read.csv("inputs/siteInfo.csv",header = T)
thinning <- read.csv("inputs/Thinning.csv",header = T)
initVar <- read.csv("inputs/initVar.csv",header = T, row.names = 1)
obsData <- read.csv("inputs/obsData.csv",header = T)

weather <- read.csv("inputs/weather.csv",header = T)
PAR = c(weather$PAR,weather$PAR,weather$PAR)
TAir = c(weather$TAir,weather$TAir,weather$TAir)
Precip = c(weather$Precip,weather$Precip,weather$Precip)
VPD = c(weather$VPD,weather$VPD,weather$VPD)
CO2 = c(weather$CO2,weather$CO2,weather$CO2)
DOY = c(weather$DOY,weather$DOY,weather$DOY)

PREBASout <- prebas(
                   nYears=nYears,
                   pCROBAS = pCROB,
                   pPRELES = pPREL,
                   siteInfo = siteInfo,
                   thinning = thinning,
                   PAR=PAR,TAir=TAir,VPD=VPD,Precip=Precip,CO2=CO2,
                   P0=NA,
                   initVar = as.matrix(initVar),
                   defaultThin = 0.,
                   ClCut = 1.,
                   inDclct = NA,
                   inAclct = NA)
```

Figura 1. Un exemplu din scriptul R al modelului PREBAS, cu funcția „prebas”.

Au fost elaborate următoarele baze de date specifice modelului PREBAS:

- **Inventarul caracteristicilor dendrometrice ale suprafețelor IFN**. Informațiile de tip IFN simulând fiecare suprafață din IFN au fost stratificate în funcție de specie. Fișierul conține informații referitoare la vârsta medie pe strat, înălțimea medie a arborilor din strat, dimetrul mediu al arborilor din strat, suprafața de baza a stratului, numărul de arbori din strat, înălțimea medie a bazei coroanei a arborilor din start, lungimea medie a coroanei arborilor din strat, volumul arborilor din strat si biomasa fiecărei componente a arborilor din strat (biomasa ramurilor, frunzelor fusului, rădăcinilor fine si a celor grosiere). In total, pentru datele IFN, au fost identificate 13772 straturi.

- **Caracteristicile plotului IFN** (pentru 2982 locații) in care au fost incluse coordonatele, tipul de sol, profunzimea solului, capacitatea de apa in câmp si clasa de producție.
- **Datele climatice**. Pentru fiecare plot au fost create serii de timp cu date climatice din 1970 până in 2010, ce conțin temperatura medie zilnica, precipitațiile medii zilnice, concentrația zilnica de CO_2 si radiația activa fotosintetizanta.

Toate aceste baze de date au fost folosite pentru simularea unor caracteristici cum ar fi diametrul de bază, înălțimea, suprafața de bază, biomasa trunchiului, producția primară netă, creșterea trunchiului, pe o perioadă de 40 de ani (Fig. 2).

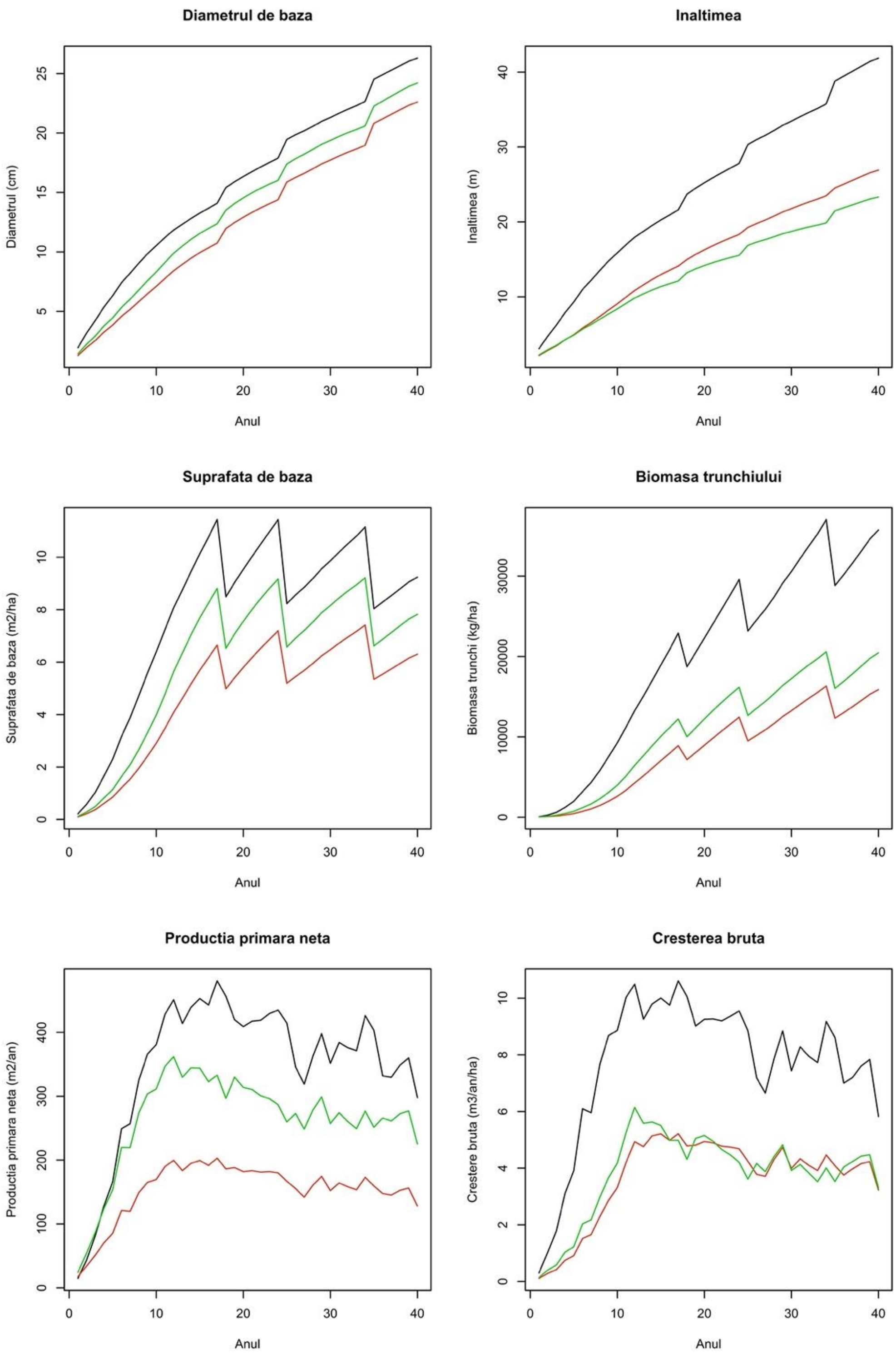


Figura 2. Un exemplu de rezultat obținut pentru o perioadă de simulare de 40 de ani

Mai multe detalii despre calibrarea modelului PREBAS, in **Anexa 9.**

Acest studiu răspunde obligațiilor asociate **sarcinii 4.3** din propunerea de proiect.

4.13 Rezultate curente privind experimentul de “cuantificarea descompunerii litierei prin metoda litter bag" (C. Petritan, M. Miclaus, I. Dutca, V. Blujdea)

Rezultatele cumulate obținute de la inceputul priectului sunt prezentate in Anexa 10b. Metodologia initiala a fost descrisa in Anexa 10a, aici fiind repetată pentru transparență si continuitate cu ajustări minime de atunci în urma aplicării in teren. Experimentul asociat a constat în amplasarea a 640 plicuri cu litieră și a 448 plicuri cu lemn mort în 4 tipuri de pădure de pe raza O.S. Pădurile Șincii (jud. Brașov). Experimentul va fi urmărit pentru o perioadă de 3 ani prin prelevare de probe potrivit calendarului din metodologie.

În anul 2019 au fost prelevate câte 5 plicuri de litieră în lunile Aprilie, Iunie, Iulie și Septembrie conform agendei prestabilite in anul 2017 și modificată în 2018. În anul 2020 se vor efectua ultimele 2 recoltări în Mai și Septembrie. De asemenea în lunile Aprilie, Iulie și Octombrie 2019 au fost recoltate câte 6 probe pentru fiecare variantă de studiu în cazul experimentului de descompunere a lemnului de mici dimensiuni (sub 5.6 cm diametru). Și în acest caz am redus de la 8 la 6 numărul de probe pentru fiecare recoltare ceea ce ne oferă avantajul unei prelevări suplimentare dedicată anului 4 (2021) și anului 5 (2022).

Probele au fost recoltate și transportate în laborator unde după câteva zile de uscare la temperatura camerei au fost scoase din plicuri, curățate de orice impuritate externă și uscate 5 zile la 80 grade în etuvă. În urma recântăririi după uscare, am putut determina care a fost procentul de pierdere în biomasă prin raportarea la masa inițială (masa avută la momentul instalării în teren).

În figura 1 (**anexa 10b**) este redată dinamica descompunerii frunzelor și acelor în primele 24 luni ale experimentului pentru toate cele 8 variante de studiu, cu punerea accentului pe scoaterea în evidență a variabilității în cadrul fiecărei etape de recoltare. În figura 2 și tabelul 1 din anexa 9 sunt redate modelele și coeficienții aferenți acestora, modele ce descriu relația dintre cantitățile de masă rămasă exprimate ca și procent din masa inițială și timpul de descompunere (exprimat în luni). Cele mai mari rate de descompunere, dar și cele mai mari valori ale coeficienților de determinare ale modelelor au fost înregistrate la specia brad, cu o ușoară tendință de superioritate pentru arboretul virgin comparativ cu cel parcurs cu lucrări. Contrar așteptărilor, fagul, singura specie de foioase din cele trei studiate, prezintă ratele de descompunere cele mai mici, având de asemenea și cele mai mici valori ale coeficientului de determinare pentru modelul exponențial negativ folosit la ajustarea dinamicii descompunerii. Molidul prezintă valori intermediare celorlalte două specii. La speciile de rășinoase, descompunerea în pădurea virgină a fost mai intensă comparativ cu pădurea parcursă, în timp ce la fag a fost depistat un comportament contrar.

Așa cum se poate vedea din Figura 3 a anexei 9b, la categoria de lemn foarte subțire (d=0.1-2cm) cea mai mare rată de descompunere s-a înregistrat la specia bradul din pădurea virgină (pierdere în biomasă de 20% în Iulie și 25% în Octombrie), urmată îndeaproape de fagul din arboretul pur (21% Iulie și 23 % Octombrie). La polul opus, cea mai mică rată a fost semnalată la molidișul pur (aproximativ 5% în Iulie 13% în Octombrie). În cadrul clasei de mărime lemn mijlociu (d=2.1-4.0) (figura 3 b), fagul a prezentat cele mai ridicate rate de descompunere, în timp ce molidul cele mai mici. Ratele de descompunere ale lemnului de la cea mai mare categorie de grosime (d=4.1-5.6 cm) (figura 3 c) au fost similare pentru toate cele 8 variante structurate (cu variații între 5 și 10%). În ceea ce privește influența managementului asupra gradelor de descompunere, prin comparația ratelor de descompunere a celor 3 specii din pădurea parcursă cu intervenții silviculturale cu ratele înregistrate în pădurea virgină, s-au găsit diferențe semnificative doar la specia brad și clasa de lemn foarte subțire (o rată mai mare în pădurea neparcursă). Din punct de vedere al influenței amestecului asupra descompunerii, fagul a prezentat în arboretul pur rate de descompunere aproape duble comparativ cu pădurea de amestec atât pentru clasa de diametre mici, precum și pentru clasa de dimensiuni mijlocii.

Conform modelului carbonului din sol și de descompunere a litierei (Yasso15) litiera se descompune în 4 grupuri de componente, așa-numitul AWEN(A-substanțe hidrosolubile în acid, W-substanțe solubile în apă, E-solvenți (ex. etanol sau diclorometan), W-substanțe care nu sunt nici solubile nici hidrosolubile). Am proiectat ca un total de 144 de probe (3 specii x 2 tipuri de material –litieră și lemn de dimensiuni mici x 3 perioade de recoltare – la început de experiment –Noiembrie 207, la mijloc de experiment Noiembrie 2018 si la sfârșit de proiect Noiembrie 2019 x 8 replicații) să fie trimise în Finlanda, la partenerul finlandez, care pe baza protocolului aferent să fie determinate aceste 4 grupuri de componente. Au fost obținute rezultatele analizelor primului set de date și se află în lucru în laboratorul finlandez setul al doilea corespunzător momentului 2 (noiembrie 2018), urmând ca în cel mai scurt timp să fie trimisă și a treia rundă de probe la doi ani după începerea experimentului.

Conform acestor prime analize obținute, componenta A (substanțe hidrosolubile în acid) este semnificativ mai mare la lemnul de fag comparativ cu cel de brad și molid, în timp ce componentele E și N sunt semnificativ mai mici la lemnul de fag comparativ cu cel de molid și brad (între conifere neexistând diferențe semnificative). Componenta W deși este mai redusă în lemnul de fag decât în lemnul rășinoaselor, diferențele între cele trei specii nu sunt semnificative (Anexa 10b, figura 4). În ceea ce privește procentul de participare al fiecărei componente AWEN în cazul descompunerii frunzelor/acelor (Anexa 9, figura 5), se poate observa cum componentele N și A, la frunzele de fag sunt semnificativ mai mari decât cele ale rășinoaselor, în timp ce componenta W prezintă un comportament opus (valoarea minimă fiind întâlnită la fag). Referitor la componenta E, bradul prezintă valoarea cea mai indicată și molidul pe cea mai scăzută, fagul posedând o valoare intermediară (totuși cu diferențe semnificative între toate cele 3 specii).

În ceea ce privește relația dintre componentele lemnului de mici dimensiuni și diametrul pieselor eșantionate putem concluziona următoarele:

-la specia fag nu a existat nici o legătură semnificativă între variația diametrului și cele 4 componente structurale.

-la ambele specii de rășinoase s-a identificat o corelație pozitivă între componenta A și diametru (crește procentul componentei A cu creșterea diametrului), precum și o corelație negativă între componenta W și diametru (pe măsură ce crește diametrul scade proporția componentei W în compoziția /structura lemnului de brad și molid).

În plus, la mijlocul anului 2019 au fost descărcate informațiile înregistrate în ultimele 12 lunii către senzorii de temperatură din aer și din sol, în figura 6 din Anexa 9b I fiind redate spre exemplificare locația de molidiș pur parcurs cu lucrări silvotehnice. Aceste date climatice vor fi folosite în final la parametrizarea și validarea modelului Yasso 15 pentru zonele test ale proiectului.

Rezultatele detaliate sunt prezentate in **Anexa 10**.

Aceasta corespunde sarcinilor din **pachetele de lucru 4 si 6**.

4.14 Efectele în cascadă asociate cu mortalitatea rășinoaselor indusă de schimbările climatice în păduri temperate montane asupra intensificării emisiilor de CO2 din sol (I. C. Petrițan)

Mortalitatea arborilor indusă de schimbările climatice se produce la nivel global, la scări din ce în ce mai mari și cu o creștere a frecvenței de apariție. Însă rămâne încă puțin cunoscut în ce măsură mortalitatea arborilor provocată de schimbările climatice afectează ecologia și capacitatea de reducere a carbonului din soluri. În acest studiu am investigat, la un nivel regional, mortalitatea arborilor cauzată de fenomenele de secetă, pe baza evenimentelor care au apărut după un foarte secetos an 2012 în zona montană a Carpaților, fenomen ce a condus la apariția și manifestarea proceselor de uscare în cadrul a trei specii de rășinoase (bradul, pinul silvestru și pinul negru). Fenomenul de uscare a influențat semnificativ emisiile de CO_2 din soluri, acestea fiind cuantificate prin intermediul respirației solului. La o distanță de cinci ani după producerea principalului fenomen de secetă din 2012, emisiile de CO_2 din solul aflat în imediata apropiere a arborilor uscați (cuantificate prin respirația solului) au fost cu până la 21% (cu o variație de 18-35%) mai mari comparativ cu măsurătorile realizate sub arborii vii. Emisiile de CO_2 din sol cuantificate prin respirația totală și respirația heterotrofă a solului au fost puternic corelate cu schimbările produse în mediul solului ca o consecință a mortalității arborilor (de exemplu, modificările produse în cantitatea și calitatea materiei organice a solului, în alterarea microclimatului, a pH sau a demografiei rădăcinilor fine). Mai mult, mortalitatea masivă asociată secetei din 2012 a condus la o mai accentuată prezență a succesiunii de vegetație (regenerarea puieților de foioase, a arbuștilor și a speciilor ierboase), succesiune ce poate controla factorii de mediu care la rândul lor, fie direct fie indirect, pot afecta fluxurile biotice ale solului (respirația heterotrofă și respirația totală a solului). Pe lângă foarte cunoscutele efecte directe ale schimbărilor climatice asupra emisiilor de CO_2 din soluri, efectele în cascadă produse de mortalitatea arborilor ca efect al schimbărilor climatice poate exercita un puternic impact indirect asupra emisiilor de CO_2 din soluri. În concluzie, mortalitatea arborilor indusă de schimbările climatice alterează magnitudinea acțiunii factorilor de mediu asupra respirației solului și deci determină cum bugetul de carbon din ecosistem răspunde la schimbările climatice.

Acest studiu a fost publicat în revista Soil Biology and Biochemistry nr 133 din 2019, iar varianta publicată se poate găsi la linkul:

https://www.sciencedirect.com/science/article/abs/pii/S0038071719300574

Acesta corespunde **sarcinii 6.4**.

4.15 Încălzirea climatică predispune la mortalitatea arborilor indusă de secetă, indiferent de starea de conservare a pădurilor de gorun (I.C. Petritan)

Declinul pădurilor este unul dintre cele mai importante răspunsuri la schimbările climatice globale. Stresul la secetă legat de încălzirea climatică și interacțiunea cu managementul din trecut al pădurilor temperate nu au fost evaluate pe deplin încă. Deși ambii factori influențează funcționarea ecosistemului forestier, nu se știe prea multe despre modul în care măsurile de gestionare a pădurilor modulează reacțiile de creștere a arborilor în timpul recentelor episoade de declin ale pădurilor de gorun din Europa. În acest studiu, am examinat rolul jucat de managementul aplicat în trecut - păduri neparcurse cu lucrări silviculturale și păduri naturale - în fenomenele recente de mortalitate a arborilor care au avut loc începând cu anul 2000 în pădurile de gorun din vestul României. Am analizat modul în care structura arboretului (vârsta, dimensiunea arborilor, competiția) și factorii climatici (indicele de secetă, temperatura și precipitațiile) determină modelele de creștere radială a arborilor din imediata vecinătate a arborilor morți aflați în picioare și a arborilor vii. Astfel, am analizat creșterile suprafeței de bază (BAI), impactul măsurilor silviculturale întreprinse în trecut și relațiile dintre creșterea arborilor și factorii climatici pe parcursul secolului XX, pentru a distinge rolurile și interacțiunile pe care le-a cauzat încălzirea recentă. Am găsit că creșterea temperaturii și modificările cererii de apă atmosferică în sezonul de creștere conduc la o accentuare a stresului la secetă începând cu sfârșitul secolului XX, accentuare ce se manifestă în mod similar atât în pădurile gospodărite și cât și în cele neparcurse. Arborii morți aflați în picioare din pădurile naturale, precum și cei din pădurile parcurse au arătat o creștere mai mică decât arborii vii, pe parcursul de la două până la cinci decenii înainte de apariția uscării. În ambele tipuri de păduri, arborii morți și arborii vii au prezentat modele de creștere divergente după mijlocul anilor '80, ceea ce indică faptul că reducerea în creștere a fost declanșată de condiții severe de secetă. Arborii uscați din arboretele parcurse cu lucrări silvotehnice au înregistrat reduceri mai puternice de creștere după anii 1980, deși au prezentat o un grad de concurență mai redus, comparativ cu arborii uscați din pădurile naturale. Densitatea ridicată a arboretelor a determinat negativ creșterea radială și a indus o sensibilitatea climatică sporită în ploturile amplasate în pădurea naturală. Concurența a acționat sinergic cu încălzirea climatică și seceta provocând mortalitatea arborilor, indiferent de starea de conservare a pădurilor de gorun. Evaluarea noastră retrospectivă a ratelor de creștere în legătură cu schimbările climatice și structurale oferă informații valoroase pentru deciziile de conservare și gestionare a pădurilor de gorun. Aceste constatări evidențiază importanța măsurilor de management anterioare care au condus la declinul recent a pădurilor de cvercinee din zona temperată, ceea ce le face mai vulnerabile în condițiile de secetă prognozată.

Acest articol este scris in colectiv cu A.M. Petritan, I.C. Petritan et al. a fost trimis la revista Agriculture and Forest Meteorology 2020 și se găsește under review (elemente suplimentare se pot solicita autorilor).

Acesta corespunde **sarcinii 6.4**.

4.16 Variabilitatea spațială a respirației solului și a factorilor de mediu ce o controlează sunt supuse unei sezonalități puternice într-un arboret de fag echien (I.C.Petritan)

Incertitudinile datorate unei heterogenități spațiale a respirației solului, până acum slab explicată, rămân destul de ridicate. Acest lucru se datorează în parte faptului că există o înțelegere limitată asupra modului în care factorii de mediu controlează variabilitatea spațială a respirației solului (de exemplu, temperatura solului, umiditatea sau activitatea plantelor) și modul în care acești factori variază sezonier. De asemenea, efortul de eșantionare necesar obținerii unor estimări robuste din punct de vedere statistic ale respirației solului s-ar putea schimba dramatic datorită modificărilor sezoniere ale rolului diferiților factorii de mediu. Acest studiu a fost conceput pentru a aprofunda complexitatea heterogenității spațio-temporale a respirației solului într-un arboret echien de fag de 4,0 ha (85 de ani), acoperind perioade fenologice și climatice contrastante ale anului (primăvara, vara, toamna, iarna). Chiar și în acest arboret relativ omogen, am găsit o mare variabilitate spațială a respirației solului (CV> 30%) și un puternic impact al sezonalității asupra magnitudinii acesteia, dar și asupra relațiilor cauză-efect dintre mediu și această heterogenitate spațială, fapt care s-a reflectat și în efortul de eșantionare necesar obțineți unei estimări sigure a respirației solului (> 800 probe în timpul verii, față de <69 eșantioane în timpul iernii). Variabilitatea spațială găsită în acest arbor echien de fag sugerează că chiar și în structurile forestiere „mai simple” există o mare cantitate de heterogenitate care ar trebui luată în considerare obligatoriu. Aici postulăm că sezonalitatea privind magnitudinea și complexitatea spațială a respirației solului a fost determinată de schimbările sezoniere ale constrângerilor micrometeorologice ale respirației solului: în timpul iernii, temperaturile reci limitează activitatea metabolică a plantelor și a solului și, prin urmare, reduc heterogenitatea respirației solului, în timp ce în timpul verii, cererile mari de apă de vegetație și modificări ale disponibilității apei datorită complexității topografice a terenului constrânge respirația solului și creează o variabilitate spațială ridicată a acesteia. În acest studiu, oferim un cadru util pentru a înțelege potențialii factori și amploarea variabilității spațiale a respirației solului de la nivel de arboret la scară sezonieră, ca mijloc de îmbunătățire a strategiilor de eșantionare în studiile viitoare.

Acest articol eset scris in colectiv (J. Curiel Yuste, ... I. C. Petritan.) a fost trimis spre publicare la revista European Journal of Soil Science.

Acesta corespunde **sarcinii 6.4**.

4.17 Estimarea dinamicii stocului de carbon folosind modelul Yasso 15, simulare și parametrizare locală în condiții de schimbare a folosinței terenului la/de la pădure (M. Miclăuș)

Recoltare probe în teren: In această etapă finală s-au recoltat cu ajutorul sondelor 90 de probe (30+30+30) sol din fiecare tip de sondaj (pădure, tranziție, pajiste) pentru determinarea densității aparente (DA), fiecare probă fiind transferată fāra a se pierde din cantitate, într-o pungă de plastic și etichetată corespunzător.

Densitatea aparentă (DA), sau greutatea volumetrică reprezintă greutatea unității de volum de sol absolute uscat în așezare naturală. Acest parametru caracterizează gradul de împachetare, de afânare a particulelor elementare de sol și/sau a agretelor structurale (Florea & Rizea 2008, ISO11272). DA are un rol important în evidențierea migrației materiei organice între compartimentele solului cât și între diferitele tipuri de folosință a terenului.

Formula DA, D = M/Vs unde, D – densitatea (g/cm3), M – masa solului uscat (g), Vs – Volumul particulelor solide ale solului (cm3).

Procesare în laborator: Fiecare probă este cantărită la o balanță analitică, cu precizie de 0,0001g, pentru a stabili umiditatea initială.

Cantitatea de sol din pungă va fi trecută printr-o sită metalică cu dimensiunea porilor de 20 mm pentru a separa fracțiunile solide de mari dimensiuni (radăcini, pietriș). Această fractiune se va scădea din volumul inițial prin măsurarea volumului dislocat într-un cilindru cu apă.

Cantitatea de sol separată va fi uscata la etuvă la 105^0 timp de 48 de ore, se va cântări ulterior, datele se vor introduce în formulă.

Metodologia recoltării a biomasei ierboase este prezentată în **Anexa 5**.

Aceasta corespunde **sarcinii 43 și 4.4**.

4.18 Carotele de creștere ale inventarului forestier național din România (G. Marin)

Datele dendrocronologice furnizează o mai bună înțelegere a procesului de dezvoltare a arborelui și, folosite coroborat cu datele inventarului forestier, pot livra date de intrare pentru modelarea creșterii pădurii. Totuși, măsurători acurate și precise ale unui număr mare de carote de creștere necesită resurse semnificative. O posibilă sursă de date despre inelul anual o constituie inventarul forestier național (IFN), care procesează în fiecare an o cantitate mare de date despre păduri. Un IFN care a făcut un efort semnificativ pentru colectarea de date dendrocronologice este IFN din România, care până în prezent a colectat, măsurat și interdatat mai mult de 50.000 de carote de creștere. Această cantitate de carote de creștere face ca IFN din România să fie deținătorul celei mai mari colecții de date dendrocronologice.

Acest articol prezintă metoda de procesare a carotelor de creștere și pune la dispoziția entităților interesate datele inelelor anuale pentru cele mai importante trei specii forestiere din România și anume fagul, molidul și gorunul. Pentru a fi utile, seturile de date se referă la arborete pure (o specie) și echiene (diferențe de vârsă sub 5 ani) în care nu s-au făcut intervenții silviculturale (fără management activ). Datele sunt stocate într-un fișier ASCII care conține șase câmpuri: ecoregiunea, specia, anul, vârsta, lățimea medie a inelului anual și varianța. Pentru a asigura confidențialitatea informațiilor, a fost estimată media lățimii inelelor anuale pe cinci ani, pentru care a fost calculată și varianța.

Acesta activitate este realizata in cadrul **sarcinii 4.1**.

Articolul este disponibil la HTTP://MCFNS.COM

4.19 Variabilitatea regională a creșterii la principalele specii forestiere din România folosind carotele de creștere colectate de Inventarul forestier national (G. Marin)

În multe țări, datele din Inventarul Forestier Național (IFN) sunt folosite pentru a estima variabilitatea creșterii pădurii la nivelul țării. Identificarea zonelor cu creșteri similare constituie fundamentul pentru dezvoltarea de modele regionale. Obiectivul acestui studiu este identificarea zonelor cu creșteri similare ale diametrului de bază (diametrul la 1,3 m de la nivelul solului) și ale suprafeței de bază folosind carotele de creștere recoltate și pregătite de Inventarul forestier național pentru principalele trei specii forestiere din România: fagul (Fagus sylvatica L.), molidul (Picea abies L. Karst) și gorunul (Quercus petraea (Matt.) Liebl.). Am folosit 6.536 carote de creștere cu vârsta mai mică de 100 de ani, cu un total de 427,635 inele anuale. Au fost delimitate 21 de ecoregiuni, ale căror limite nu se suprapun, pe baza criteriilor de geomorfologie, sol, geologie și continuitate spațială.

Am folosit analiza modelelor mixte și analiza multivariată pentru a estima diferențele de creștere ale diametrului de bază și ale suprafeței de bază dintre regiuni. Indiferent de specie, analiza modelelor mixte a arătat că există diferențe de creștere semnificative între ecoregiuni. Totuși, unele ecoregiuni au fost similare din punct de vedere al creșterii și pot fi unite. Rezultatele analizei multivariată au întărit constatarea că există diferențe de creștere între ecoregiuni și au arătat că, în cazul fagului și molidul, acestea nu se pot grupa temporal. Creșterea gorunului a fost diferită nu numai pe ecoregiuni, dar și în timp, deoarece unele ecoregiuni sunt mai expuse la secetă. Studiul a arătat că în România pot exista diferențe spațiale semnificative ale creșterii la speciile de arbori analizate. De aceea, modelele de creștere dezvoltate la scara întregii țări încorporează prea multă variabilitate pentru a fi considerate fezabile operațional. Mai mult, este dificil de justificat folosirea unor astfel de modele de creștere ca instrumente legale de planificare.

Acesta activitate este realizata in cadrul **sarcinii 4.1**.

Articolul este disponibil la https://www.mdpi.com/1999-4907/11/4/409.

5 Administrarea bazei de date generată pe durata proiectului

- procesarea statistică s-a făcut cu prioritate în R (open source): https://cran.r-project.org/bin/windows/base/;
- modul de stocare și actualizare a bazelor de date pentru fiecare dintre modelele utilizate: fișiere Microsoft Excel pentru EFISCEN, PREBAS (excel si procesare in R) si Microsoft Acces pentru CBM-CFS. Bazele de date sunt deplin interschimbabile prin scripturi R sau aplicațiile incorporate in softurile în cauză;
- bazele de date si foile de calcul implementeează reguli de controlul și asigurarea calității (ex. chei de verificare);
- scripturile statistice realizate in R sunt in îngrijirea membrilor echipei și autorilor de articole care le-au realizat si pot sprijini la procesarea altor seturi de date identice sau similare, fie in scop de implementare a politicilor sau stiintific.

6 Sprijin activități incluse in alte pachete de lucru din proiect

- informare continuă cu privire la regulile de contabilizare a reducerilor de emisii din sectorul folosinței terenurilor incluse în Pachetul energie clima 2030 (https://ec.europa.eu/clima/policies/strategies/2030_en), in sprijinul Pachetelor de lucru 1, 2 si 5 ale FORCLIMIT (unde Unitbv nu a avut responsabilitate asumate direct);
- participarea la discuțiile științifice pe durata intâlnirilor fizice si online;
- revizuirea unor materiale ale altor grupe de lucru (ex. articole in variante de pre-publicare);

7 Managementul și comunicarea în cadrul proiectului

Membrii echipei au colaborat individual și direct cu partenerii externi (filierele pot fi deduse din componenta echipelor de autori ai articolelor).

Responsabilul de proiect a asigurat: a) controlul și asigurarea calității la pregătirea și procesarea bazelor de date (ex. chei de control in foile de calul, verificări ale datelor sau rezultatelor față de surse terțe); b) controlul și asigurarea calității materialelor produse (inclusiv prin solicitarea opiniilor unor experți din afara proiectului inainte de depunerea articolelor pentru publicare) și c) procesarea probelor biochimice de către partenerii externi (ex. compozitia biochimică a litierei de către partenerul FMI).

Calendarul de colectare probe de sol și biomasă (pentru validarea modelelor) și descompunere litieră a fost menținut cu strictețe si va continua și după finalizarea proiectului (ultima probă va fi recoltată in Septembrie 2020), în așa fel încât trei sezoane de vegetație complete sunt incluse în experiment.

În afara discuțiilor punctuale legate de fiecare activitate a fiecărui membru al echipei de lucru care s-au desfășurat cel mult la câteva zile, au fost organizate întâlniri periodice ale echipei naționale de proiect pentru o zi de lucru in comun cel mult odată la 3 săptamâni pentru a evalua progresul individual si comun. Cu partenerii externi au fost realizate videoconferinte cu participarea intregului consortiu odată la două – trei luni, în timp ce au fost schimbate sute de emailuri si organizate nenumarate videoconferinte spontane la alegerea echipelor.

Referitor la comunicarea excelentă avută cu partenerii europeni implicați în proiect:

- întâlnirea avută între toate instituțiile partenere la Brasov, în perioada 17-20 Septembrie 2018;
- prezența membrilor la câteva întâlniri privind LULUCF (raportarea inventarului gazelor cu efect de seră pentru folosinta terenului in cadrul UNFCCC) in vederea actualizării informațiilor și practicilor emergente (organizate de EC si UNFCCC);
- deplasarea la WUR a doi membrii ai echipei de proiect , V. Blujdea si I. Dutca pentru armonizarea bazelor de date in vederea rularii CBM-CFS si EFISCEN;
- prezenta unui expert WUR (Dr. R. Sikkema) la Brasov in perioada 10-15 Septembrie 2018 pentru validari rezulate modele CBM si EFISCEN;
- prezenta membru echipa de proiect M. Miclaus la Upsala in 25.11-01.12. 2018 pentru redactarea unui articol in vederea publicarii privind metodele de estimare a marimii suprafețelor in conversie și incertutudinile asociate;
- prezenta lui Gh. Mairn la Oregon State University din Corvallis pentru a realiza curbele de crestere si de productie care reprezintă elementele de baza in realizarea scenariilor de reduceri de emisii de gaze cu efect de sera asociate gospodăririi pădurii prin utilizare de modele empirice prevăzuta in pachetele de lucru 4 si 6 din proiect;
- prezenta a trei membri ai echipei, V. Blujdea, I. Petritan si M. Miclaus la FMI in August 2019 pentru a avansa capacitatea de modelarea pe soluri forestiere.

Transfeul de cunoaștere cu membrii echipei inventarului forestier national care au participat la pregatirea bazelor de date (alegerea modelelor asociate curbelor cresterii si stocului de biomasă), parametrizatrea modelelor pentru inițializarea și simularea stocurilor și schimbării stocurilor materiei organice moarte/ carbon din sol (Yasso15 si CBM) și mai ales calibrarea modelelor si validarea simularii stocurilor de C din solul mineal la scara regională. Acest transfer s-a realizat în maniera continuă pe durata proiectului, inclusiv prin elaborarea de publicații in comun.

8 Vizibilitate nationala si internatională a proiectului

Activitățile de asigurare a vizibilității au constat in:

- actualizarea continuă a site-ului asociat al proiectului (http://www.forestinventory.no/forclimit/)
- organizarea de workshop-uri privind evoluția proiectului, adresate personalului didactic, studentilor si factorilor de decizie locali in 8 martie 2018 si 14 Decembrie 2018 la Facultatea de silvicultura din Brasov;
- prezenta în perioada 24-25 Septembrie 2018 a lui V. Blujdea in calitate de key speaker în Belgia, la Brussels, la întâlnirea "LULUCF: practical consequences for the forest-based sector, Joint workshop on the practical consequences of the introduction of the Regulation for the inclusion of Land Use, Land Use Change and Forestry (LULUCF) within the 2030 EU Climate and Energy framework", organizată de EUSTAFOR și Biroul Regiunii Toscana din Brussels (https://eustafor.eu/lulucf-practical-consequences-for-the-forest-based-sector/);
- intalnirea publică finală a proiectului a fost amânată, dar va fi organizată în lunile următoare odată cu ușurarea riscurilor legate de pandemia de COVID19.

Brașov, 25.05.2020 **Dr. ing. Viorel Blujdea**

9 Anexe

Anexa 1a. Chestionar

Părerea dvs. despre gospodarirea pădurilor și măsuri de gospodarire inteligentă climatic

Universitatea Transilvania din Brașov

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Potrivit legislației recente UE (ex. Regulamentul (EU)2018/841), sectorului folosinței terenului, care include pe cel forestier, îi revine obligația de a nu fi sursă netă de emisii de gaze cu efect de seră pe durata 2021-2030. O asemenea obligație este definită pentru fiecare stat membru al UE. Pentru a se conforma, guvernele încearcă să înțeleagă cum sectorul forestier poate contribui, cum poate fi mobilizat și ce resurse sunt necesare. De menționat că în politica climatică, gospodarirea pădurii și productia de produse de lemn cu durata lunga de utilizare sunt reunite intr-un domeniu unic. Pentru a îndeplini această nouă sarcină a sectorului este promovat un concept denumit "gosopodărire inteligentă climatic" care nuanțează activitatea de gospodărire a pădurii cu elemente ce contribuie la diminuarea emisiilor de gaze cu efect de seră.

Important este ca acest chestionar se adresează viziunii și experienței personale a administratorului sau proprietarului de pădure, nu trebuie să reflecte o poziție oficială.

Totodata, chestionarul poate constitui o sursă de informare pentru dvs. în ce privește măsurile de "gosopodărire inteligentă climatic", acest chestionar fiind construit pe baza experienței deja anatamate în alte țări din UE.

Va rugam completați sau colorați (sau marcați cum doriți dvs.) varianta aleasă.

Toate răspunsurile sunt anonime, iar analiza va fi realizată la nivel național.

I. Descrierea proprietarului/administratorului de pădure și a așteptărilor sale din perspectiva schimbării climatice

1. În care regiune(i) din România dețineți pădure?
Alegeți: Oltenia, Muntenia, Banat, Crișana, Maramureș, Bucovina, Moldova, Dobrogea, Transilvania

2. Ce suprafața totală de pădure cu rol preponderent de producție (adică pe care sunt aplicate măsuri active de gospodărire) dețineți …………..ha, sau administrați ………. ha? (rotunjiți la întreg. În cazul în care ambele sunt valabile, "administrarea" este prioritară)

3. Ce pondere din venitul dvs. anual provine din silvicultură? Ex. pentru administratori poate fi de 100%.
10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

4. Aveți informații, sau credeți, că pădurea dvs. este supusă efectelor schimbări climatice?
DA/NU

Dacă DA, vă rugăm să selectați intre evenimentele care au afectat pădurea: incendii /seceta / temperatura aerului /vânt de mare intensitate /insecte /căderi de precipitații abundente/altele.......

5. Dacă este cazul, ce specii forestiere sunt cele mai afectate de perturbări naturale, de schimbarea condițiilor de creștere sau de alte pericole (naturale)?

□ *Quercus sp.* □ *Fagus sp* □ *Poplar sp* □ *Alnus sp.* □ *Robinia sp.* □ alte foioase: .....
□ *Pinus sp.* □ *Picea sp.* □ *Abies sp* □ *Douglas sp.* □ *Larix sp.* □ alte rasinoase: .....

6. Ce fel pădure aveti in proprietate sau administrati?
□ privată individuală
□ publică a statului
□ privată a statului
□ publică a comunitatiilor
□ organizație neguvernamentală
□ alt tip de proprietate (vă rugăm să specificați): ....

II. Măsuri de gospodărire inteligentă climatic - situația actuală (si anterioară anului 2020)

Pentru a facilita acest sondaj, am definit câteva modalități generale de gospodărire a pădurilor, care pot fi valabile pentru terenurile forestiere productive și terenurile forestiere neproductive, alegeți pe cele mai potrivite.

7. Vă rugăm să specificați principalele funcții ale pădurii din proprietate sau administrare, si distribuția acestuia pe funcții?

Funcțiile pădurii	Distribuția în suprafață (având în suprafață raportată la întrebarea
Gospodărire prioritar orientată spre conservarea biodiversității Scop: promovarea prioritară a conservarii biodiversității	.... ha
Gospodărire orientată prioritar spre producția de lemn Scop: promovarea prioritară a producției de lemn	..... ha
Gospodărirea multifuncțională a pădurilor Scop: întărirea capacității multifuncționale a pădurilor, inclusiv a producției de lemn	...... ha
Teren neacoperit cu pădure	..... ha
Total suprafața de pădure in administrare/proprietate	**...ha**

8. Vă rugăm să indicați cât din creșterea curenta anuală în volum este recoltată (în medie, începand cu 2015)?
<25% 25%-50% 50%-75% 75%-100% 100%-125% > 125%

9. Vă rugăm să evaluați nivelul dvs. de acord / dezacord cu aplicarea măsurilor de sprijin a gospodăririi pădurilor cu impact climatic, în România (va rugam alegeți o opțiune pentru fiecare măsură – prin colorare sau îngroșare).

Măsuri generale de sprijin pentru gospodărirea pădurilor	*Nu sunt sigur că se aplică în cazul meu*	*Nu se poate aplica*	*Se aplică în prezent (până în 2020*	*Se poate aplica în viitorul apropiat (până în 2030)*	*Mai degrabă se poate aplica după 203*
Ați participat la cursuri de educație suplimentară privind efectele schimbărilor climatice	1	2	3	4	5
Aflați mai multe despre gospodărirea pădurilor citind, ascultând sau vorbind cu alții	1	2	3	4	5
Ați participat la cursuri sau pregătire formală, cu durata de cel puțin o zi	1	2	3	4	5
Va asigurați sprijinul și asistența în luarea deciziilor cu consilierii proprii sau consultanții proprii (inclusiv prin utilizarea sistemelor de asistență decizională)	1	2	3	4	5
Ați aflat mai multe informații prin acțiunile sistematice de popularizarea informațiilor despre schimbarea climatică și efectele asupra pădurilor și gospodăririi pădurilor	1	2	3	4	5
Ați aflat mai multe prin acțiunile de popularizarea informațiilor despre amenajarea pădurilor	1	2	3	4	5
Ați aflat mai multe prin acțiunile de popularizarea informațiilor despre tehnicile de recoltare a lemnului din păduri	1	2	3	4	5

10. Comentarii intermediare: Aveți vreun comentariu suplimentar cu privire la situația actuală a gospodăririi pădurilor sau la alte măsuri de gospodărire inteligentă climatic pentru pădurile in proprietate/administrare?

....

III. Noi opțiuni privind măsuri de gospodărire inteligentă climatic pentru viitorul apropiat (2020 - 2030)

Prin acest sondaj am dori să evaluăm răspunsul dvs. la noile inițiative de realizare a reducerilor de emisii sau adaptare prin gospodărirea pădurii în Romania.

11. Doriți să introduceți noi măsuri de gospodărire inteligentă climatic după 2020? (o listă de masuri este în întrebarea 14, vă rugăm să alegeți un răspuns)
□ Da □ Nu □ Poate □ Nu știu

12. Când ar trebui să înceapă aplicarea acestor măsuri de gospodărire inteligentă climatic?
□ 2020 și după □ 2025 și după □ 2030 și după

13. Dacă ar fi posibilă o compensație pentru a introduce măsuri adiționale de gospodărire inteligentă climatic ce stimulent ați prefera (alegeți doar varianta care v-ar conveni cel mai mult)?
□ Rambursarea cheltuielilor de gospodărire prin subvenții
□ Reducerea taxelor fiscale ale proprietarului
□ Vânzarea reducerilor de emisii pe piața libera

□ Nu știu / niciuna dintre ele

14. Ce măsuri ați prefera să implementați pentru pădurea in administrare / proprietate? Pentru a facilita acest sondaj, am elaborat patru scenarii fictive de gospodărire a pădurilor, cu măsuri relevante de gospodărire inteligentă climatic. In elaborarea răspunsurilor va rugam să faceți abstracție de costurile pe care schimbarea tipului de gospodărire le-ar implica. Vă rugăm alegeți o singura opțiune (prin colorare sau îngroșare).

Lista de măsuri de gospodărire inteligente climatic	Aș prefera această măsură	Nu aș prefera această măsură	Măsura nu este aplicabilă în cazul meu	Nu știu este ca
A. Creșterea stocului de carbon in componentele ecosistemului forestier Scopul: menținerea sau creșterea cantității de carbon în arbori și în solul forestier.				
Prelungirea ciclului de producție a pădurii astfel încât să beneficieze de creșterea medie anuala in totalitate (ex. la stejar, 140 ani în loc de 120 de ani)?	1	2	3	4
Stimularea creșterii prin fertilizare cu îngrășăminte chimice?	1	2	3	4
Regularizarea regimului hidrologic al solurilor cu exces de apă pentru a maximiza creșterea arborilor?	1	2	3	4
Aplicarea de intervenții reduse cantitativ în arboret orientate spre conservarea stocului pe picior și în consecință extrageri mai reduse de lemn?	1	2	3	4
Optați pentru introducerea de specii repede crescătoare în locul celor încet crescătoare?	1	2	3	4
Optați pentru introducerea de specii cu densitate a lemnului mai ridicata în locul speciilor cu densitate scăzută a lemnului?	1	2	3	4
Optați pentru crearea de arborete mixte în locul celor pure?	1	2	3	4
B. Gospodărirea pădurilor orientată spre reducerea riscurilor cauzate de schimbarea climatică Scopul: adaptarea la perturbări naturale, cum ar fi seceta, atacuri de ciuperci sau insecte, doborâturi de vânt				
Optați pentru introducerea de proveniențe genetice îmbunătățite și selecționate genetic în locul regenerării naturale?	1	2	3	4
Optați pentru păstrarea speciilor de arbori cu creștere mai mare în volum dar cu densitate mai redusă a lemnului mai degrabă decât pentru specii cu creștere în volum mai redusă dar cu densitate a lemnului mai ridicată?	1	2	3	4
Optați pentru păstrarea speciilor indigene chiar dacă au o creștere mai redusă și lemn fără valoare economică însemnată?	1	2	3	4
Optați pentru introducerea imediată de specii mai tolerante la fenomenele asociate schimbării climatice (la secetă, insecte, furtuni)?	1	2	3	4
Optați pentru introducerea imediată de specii mai tolerante (la secetă, insecte, furtuni) după următoarea tăiere finală?				
Optați pentru intervenții de igiena mai frecvente pentru a evita incendiile și răspândirea insectelor sau a altor boli?	1	2	3	4
Optați pentru extragerea activă a arborilor morți pentru a evita răspândirea insectelor sau a altor boli?				
Optați pentru întreținerea adecvata a drenajelor din pădure, pentru a adapta pădurea la evenimentele extreme combinate (ex. secetă îndelungata urmata de precipitații abundente)	1	2	3	4
Optați pentru diversificarea compoziției și structurii pădurii în locul arboretelor actuale bazate pe o singură specie pentru o productivitate mai mare?	1	2	3	4

✚ Optați pentru trecerea la sisteme de gospodărire ”cu acoperire continua” în locul metodei actuale ce include cicluri de producție cu lungime definită si tăieri rase?	1	2	3	4
C. Gospodărirea pădurilor în scopul producției suplimentare de biomasă Scop: să sprijine producția și utilizarea lemnului de calitate scăzută, intervențiile silvice neprofitabile, recoltarea resturilor de exploatare				
✚ Optați pentru scurtarea ciclului de producție a pădurii astfel încât sa beneficieze doar de maximul creșterii curente anuale (ex. in loc de 120 de ani la stejar la 80 de ani)?	1	2	3	4
✚ Optați pentru intensificarea intervențiilor în arborete si extragerea întregii biomase lemnoase disponibile (arbori de mici dimensiuni, semen de lâncezire) pentru a extrage cat mai mult lemn?	1	2	3	4
✚ Optați pentru colectarea întregii biomase rezultate din intervenții silviculturale (totuși luând în considerare orice restricție privind conservarea biodiversității din legislația forestieră)?	1	2	3	4
✚ Optați pentru colectarea cioatelor după tăierea definitivă (având în vedere restricțiile din legislația forestieră)?	1	2	3	4
✚ Optați pentru recoltarea integrala a arborilor si lemnului mort din pădure în vederea utilizării ca lemn de foc sau tocatura pentru uz industria lemnului?	1	2	3	4
D. Gospodărirea pădurilor pentru creșterea calității lemnului pe picior, pentru a asigura mai mult carbon depozitat pe termen lung în produse din lemn Scop: sprijinirea creșterii proporției lemnului de înaltă calitate si stocarea pe termen lung a carbonului în produse din lemn				
✚ Optați pentru practicarea elagajului artificial?	1	2	3	4
✚ Optați pentru identificarea, selecția timpurie si promovarea arborilor de calitate superioară în arborete?	1	2	3	4

15. Care dintre pachetele de mai jos vi se pare mai atractiv (colorați sau îngroșati)?

A. Practica curenta
Scop: nici o schimbare în modul actual de gospodărire

B. Creșterea stocului de carbon în componentele ecosistemului forestier
Scop: menținerea sau creșterea cantității de carbon în pădure și în solul forestier.

C. Gospodărirea pădurilor orientată spre reducerea riscurilor cauzate de schimbarea climatică
Scopul: adaptarea la perturbări naturale, cum ar fi seceta, atacuri de ciuperci sau insecte, doborâturi de vânt

D. Gospodărirea pădurilor în scopul producției suplimentare de biomasă
Scop: să sprijine utilizarea lemnului de calitate scăzută, intervențiile neprofitabile, recoltarea resturilor de exploatare pentru producția de bioenergie

E. Gospodărirea pădurilor pentru creșterea calității lemnului pe picior, pentru a asigura mai mult carbon depozitat pe termen lung în produse din lemn
Scop: să sprijine creșterea proporției lemnului de înaltă calitate si stocarea pe termen lung de carbon în produse din lemn

16. Pe baza preferințelor de mai sus (întrebarea 15), ce proporție din suprafața de pădure în proprietate/administrare ați dori să o faceți obiectul acestui scenariu?
10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

17. Dacă este cazul, la ce nivel din creșterea curenta ați fi de acord să vă măriți recolta în viitorul apropiat (2025-2030), în comparație cu intensitatea actuală a recoltei (a se vedea întrebarea 8)?

<25%   25%-50%   50%-75%   75%-100%   100%-125%   > 125%

OBSERVAȚII FINALE: Aveți alte subiecte sau comentarii pentru noi cu privire la alte măsuri ce pot fi aplicate? Sau ați sugera alte pachete pentru viitorul apropiat până în 2030?
……………………………………………………………………………………………………

Sunteți gata! Vă rugăm să returnați acest sondaj prin e-mail la:
viorel.blujdea@unitbv.ro și ***idutca@unitbv.ro***

Pentru intrebari lamuritoare: V. Blujdea (0739 523 219) *sau* ***I. Dutca (0744 662 749)***

MULȚUMIM PENTRU TIMPUL ACORDAT!

Anexa 1b. Appendix A Forclimit - Forest owner responses curves (FORC) & CSF measures

Coordinator: Richard Sikkema, Assistance for survey distribution to be provided by Hans Petersson (SLU Uppsala) and Viorel Blujdea (Brasov University). A sample survey (in English) will soon be internally discussed, completed & distributed within Forclimit.

Optional expert advice: see suggestions below.
Draft Planning 29 October 2019 – August 2020 for Deliverable 6.3 ("Forest climate mitigation potential in the three case countries based on economic and policy measures/scenarios until 2050")

 Check enquiry with WUR's Forest Policy department (FNP): week 39-40 (autumn 2019)
 Check enquiry within FORCLIMIT consortium: week 41
 Check enquiry with WUR's Statistical department: week 42
 Optional expert check of methods within SLU (e.g. Prof Francisco Aguilar): week 42
 Sending out the enquiry to a panel of experts (test responses): October 2019
 Sending out the enquiry to about 300 forest owners in Romania, Sweden and the Netherlands: Nov 2019. Responses back before the end of 2019.
 Approach and possible draft results presented at conference "Governing and managing forests for multiple ecosystem services across the globe. 26-28 February 2020, Bonn, Germany.
 Analysed results February- March 2020. Expected output: 2 graphs, 1 table (see expected results)
 EFISCEN space runs April – Jun 2020. This output is related to FORCLIMIT Deliverable 6.3:
 Draft Manuscript (Scientific Paper) with graphs, table & EFISCEN runs as key results: Summer 2020
In cooperation with FORCLIMIT partners (.....) and also with WUR's FNP department (...)

Introduction
We will have a step-based approach (one by one extracted below from FORCLIMIT project)
 Analysis of mitigation (and adaptation) incentives, in consultation with forest owners, to identify CSF strategies based on local/regional needs, forestry technicalities, national policy requirements & local societal challenges. * red text: revisions of FORCLIMIT's original Project proposal

 By means of appropriate method, compile forest owners response curves (FORC's) to test economic & policy incentives for climate smart forestry (CSF). Three countries: Netherlands, Romania & Sweden;

 FORCLIMIT partners will run scenario model to assess regionally specific measures & policy incentives (new "EFISCEN Space"). To remove barriers & most likely to yield largest climate mitigation effort across forest wood-chain.

 At the end, we test the effects on forest management until 2050, based on three elements of sustainable forest management:

 maximization of carbon stocks1 and

 wood harvest diversification for solid products and bioenergy, remaining below net annual increment2

1 Original FORCLIMIT project proposal states "maximisation of wood products". WUR thinks it is more appropriate to use "maximisation of carbon stocks".
2 Original FORCLIMIT project proposal refers to "options for achieving the maximum of availability of biomass for bioenergy". Instead WUR proposes "wood harvest diversification for solid products and bioenergy, ...".

Method
Mail survey to three times 100 forest owners (linked to NFI plots) in Netherlands, Romania and Sweden. We recommend to have the survey checked by a WUR and, or SLU statistical experts, after which the survey can be send out as follows.
2020 business as usual
First we will equally divide the forest owners in five types of forest owners (see Method), based on an representative area. Thus relatively more forest owners with smaller forest areas than larger forest owners to be selected. As such we can describe the future Forest management & needed activities in 2020-2050:
Regular forest management, to promote biodiversity and elements other than wood production. For example, in the Netherlands this is split in dry forests (in dunes and other dry forests with species like Pinus sp., Fagus sp. or Quercus sp.) and wet forests (along river and brooks, on peatlands and other wet forests types with species like Carpinus sp. or Fraxinus sp.).
Additional management for dry and wet forests with production function, to enhance the regeneration in forests with a production function, e.g. in the Netherlands those productive forests comprise again dry and wet forests.
Those types are actually based on the current Dutch forest types eligible for SNP subsidies (Bij12, 2019) and can be changed into Swedish respective Romanian forest types currently eligible for subsidies or subject to carbon tax advantages. The 2020 situation is considered as "zero measurement"
2050 future choices & climate forest measures
Second , we have elaborated four new future packages, each consisting of individual climate smart forest measures.
A. Carbon management, to maintain or enhance the carbon uptake in the forest and forest soil.
B. Climate management, to mitigate or adapt to increasing natural disturbances from climate change, like drought, insect attacks, wind throw. The current packages offer some kind of sanitary cleaning, but this could be further intensified.
C. Biomass management, to support the use of low-quality wood, unprofitable thinnings, harvesting residues for bioenergy

D. Wood quality management, to support the growth of high-quality wood. I.e. in the Netherlands we have now test with QD tree treatment system (special type of pruning), to support the growth of future trees with larger dimension (sawlogs).
The choice-based query is needed to compile forest owners response curves (FORC's), this approach is adapted from Aguilar et al (2014) for compiling forest owner's willingness to harvest (WTH).
The choice-based query is needed to compile forest owners response curves (FORC's), this approach is adapted from Aguilar et al (2014) for compiling forest owner's willingness to harvest (WTH).
Landowner demographic profile (age only), parcel size, attitudes to policy measure (CSF subsidies) and economic measures (tax advantages) are used to predict whether forest owners are aiming to manage their forest in a more or less active way. The preliminary hypothesis is that CSF measures with existing subsidies have a slightly larger positive impact on large forest owners, i.e. the number of large forest owners have applied relatively more (in %) to packages with less or more active forest management measures in 2020. Small forest owners are little sensitive to the impact of carbon tax & indirect competitive advantages and shall adapt less or more active forest management in 2050.
For this purpose, a (polytomous) logit model shall analyse the impacts in terms of forest owner numbers and the size of their forest land. The collected response is needed to run the EFISCEN Space model. Please have a look at Table A (page 5) for the proposed near future set of CSF packages, the related CSF measures and the expected response by number of forest owner for five owner types.

- WUR will randomly select 100 to 150 forest owners out of Cadastre with forest land, split into 5 owner type: (State forest; other public forest; NGOs; industrial private forest; non-industrial private forest)
- SLU will randomly select 100 to 150 forest owners out of Cadastre (same or similar area division)
- BRV will randomly select 100 to 150 forest owners out of Cadastre (same or similar area division)

Expected example results for scientific paper (graphical outcome)

Figure 1 Division of forest owner responses in 2020 based on existing packages and subsidies. Fictive situation in the Netherlands

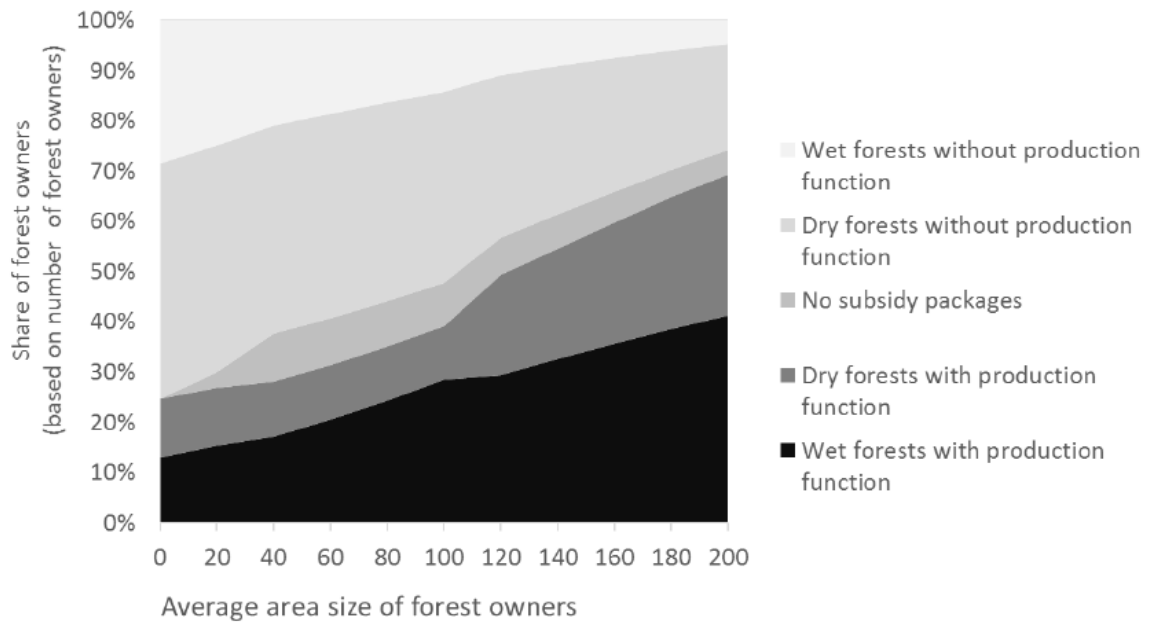

Figure 2 Predicted division of forest owner responses in 2050 to new CSF packages (supported by carbon tax advantages or extra subsidies). Fictive situation in the Netherlands.

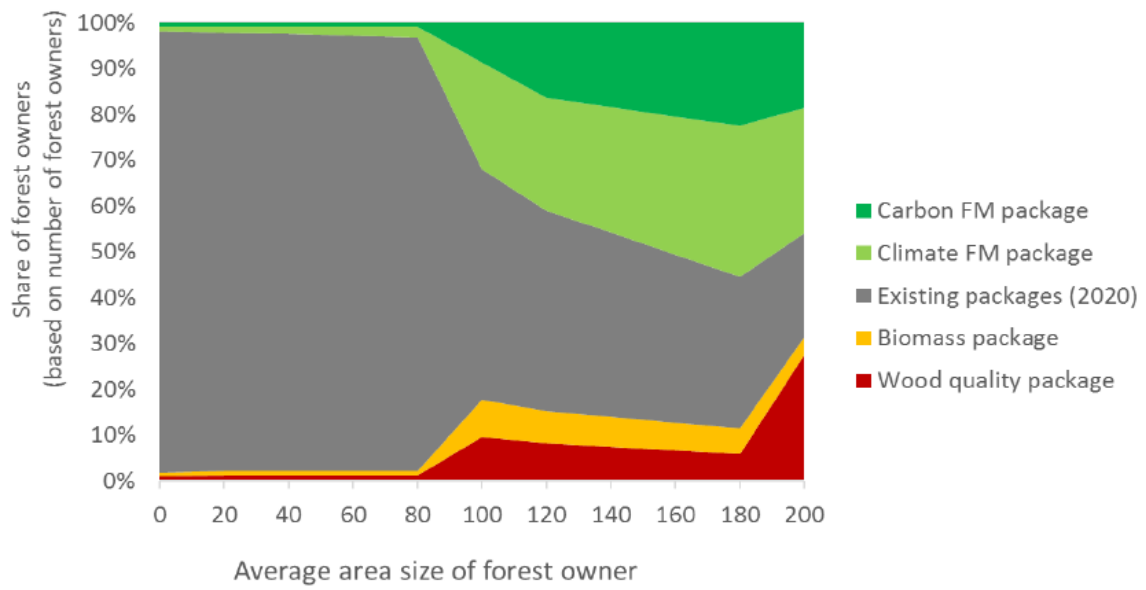

Table 1. ***Example of what results might look like.*** *Arc elasticities per type of forest owner (number of owners in %) for different themes or scenarios, either effected by subsidies or by carbon tax advantages*   Note: fictive (positive) elasticities; e.g. < 1, inelastic effects; > 1 elastic effects).*

Arc elasticities in:	I. national public forest owners (state forest services)	II. Provincial or community forest owners	III. Non-governmental forest owners (eNGO's)	IV. Industrial private forest owners	V. Non industrial private forest owner
Sweden					
- 2020 situation (subsidies/carbon taxes)					
- 2050 situation (four new packages)					
The Netherlands					
- 2020 situation (subsidies taxes)	2.1	0.7	1.2	2.5	0.3
- 2050 situation (four new packages)	2.5	0.2	0.2	3.2	0.1
Romania					
- 2020 situation (subsidies/carbon taxes)					
- 2050 situation (four new packages)					

* advantages of imposed carbon tax on fossil alternatives, for energy substitution or material substitution, or as tax benefit for the additional carbon sink in the standing volume of the forest. To be recalculated to € per ha.

List of References; consulted for possible methods of forest owner response curves (FORC's)

A. Aguilar et al 2014. Non industrial forest owner's willingness to harvest: how high timber prices influence woody biomass supply. In Biomass & Bioenergy 71: 202-215.

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C. Bij 12, 2019. SN Regeling: natuurtypen en beheertypen. Accessed on: 14 October 2019. https://www.bij12.nl/onderwerpen/natuur-en-landschap/index-natuur-en-landschap/natuurtypen/

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F. Paquel K, Bowyer C, Allen B, Nesbit M, Martineau H, Lesscher JP, Arets E, 2017. Analysis of LULUCF actions in EU Member States as reported under Art. 10 of the LULUCF Decision. Institute for Environmental European Policy (IEEP), 24 November 2017. London, United Kingdom.

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Anexa 2. Informatii suplimentare privind armonizarea bazelor de date in vederea validarii reciproce a medelelor CBM-CFS si EFISCEN

Anexa 2a. Criteriile de clasificare si parametrii agregați regional pentru baza de date națională din Inventarul Forestier National

Criterii	Specificatii
Tip de padure/ specii	Rasinoase (OC), Molid (PA), Brad (AA), Predom rasinoase (PredCon), Amestecuri (ConBroad), Predom foioase (PredCon), Foioase (OB), Fag (FS), Cvercinee (QR), Salcam (RP) – pentru tipurile de padure ingrosate parametrii modelului sunt actualizati prin ajustare la nivel de regional (clima si regiune)
Clase de varsta	1-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 91-100, 101-110, 111-120, 121-130, 131-140, 141-150, 151-160, >160, Unevenaged
Regiuni administrative (NUTS-2)	RO11, RO12, RO21, RO22, RO31, RO32, RO41, RO42
Volum pe picior	Volume annual, m3 y-1
Recolta de masa lemnoasa	Volume annual, m3 y-1
Suprafata	Area, ha
Creserea neta anuala	Net annual growth, m3 y-1 ha-1
Eroarea de eșantionare (in %) pentru toți parametrii de mai sus	Estimation error, %

Parametrii ecuatiilor utilizati la modelare

$$\mathbf{V=a*e^{(-b*A)}*(1-e^{(-b*A)})^{\wedge(c-1)}}, \textit{ unde}$$

V- volumul comercial,
A – clasa de varsta de 10 ani,
a,b,c – parametrii ecuatiei specifici ficarei tip de padure

Parametrii ecuatiei pentru estimarea volumului lemnului comercial pe picior

Tip de padure	ConBroad	AA	FS	OB	OC	PA	PredBroad	PredCon	QR	RP
a	2291.41	136381.7553	2019.821	976.8087	3787.497176	2777.876	3696.275	2841.894	1607.577	3541.647
b	0.009851	3.81253E-05	0.005134	0.006911	0.015951353	0.016171	0.01238	0.008661	0.011314	0.002407
c	2.598057	1.949198118	2.137377	2.012281	4.180130563	3.50011	3.635651	2.89859	2.956918	2.413442

Parameteii ecuatiei pentru estimarea cresterii curente cumulate a volumului lemnului comercial pe picior

Tip de padure	ConBroad	AA	FS	OB	OC	PA	PredBroad	PredCon	QR	RP
a	46.67395443	30.53049718	44.82908538	12.60159597	44.91925629	32.29905709	16.71558839	25.99785093	18.19606152	32.28165566
b	0.014718484	0.003007487	3.28696E-05	0.003763308	0.018643759	0.010442337	0.00294835	0.005746935	0.010859768	0.044339613
c	2.33569566	1.542279681	1.349733947	1.264787544	2.574587006	2.109134766	1.388390928	1.474466432	1.659962736	2.806735827

Parametrii ecutiei Boudewyn privind modelarea alocarii de biomasa in compartimetele arborelui functie de volumul lemnului comercial. *P* reprezinta proportia componentei de biomasa din biomasa supraterana integrala (potrivit Boudewyn, P., Song, X., Magnussen, S., Gillis, M.D., 2007. Model-based, Volume-to-Biomass Conversion for Forested and Vegetated Land in Canada. Canadian Forest Service, Victoria, Canada (Inf. Rep. BC-X-411).).

$$(4) \quad p_{stemwood} = \frac{1}{1 + e^{a1+a2\times vol+a3\times lvol} + e^{b1+b2\times vol+b3\times lvol} + e^{c1+c2\times vol+c3\times lvol}}$$

$$(5) \quad p_{bark} = \frac{e^{a1+a2\times vol+a3\times lvol}}{1 + e^{a1+a2\times vol+a3\times lvol} + e^{b1+b2\times vol+b3\times lvol} + e^{c1+c2\times vol+c3\times lvol}}$$

$$(6) \quad p_{branches} = \frac{e^{b1+b2\times vol+b3\times lvol}}{1 + e^{a1+a2\times vol+a3\times lvol} + e^{b1+b2\times vol+b3\times lvol} + e^{c1+c2\times vol+c3\times lvol}}$$

$$(7) \quad p_{foliage} = \frac{e^{c1+c2\times vol+c3\times lvol}}{1 + e^{a1+a2\times vol+a3\times lvol} + e^{b1+b2\times vol+b3\times lvol} + e^{c1+c2\times vol+c3\times lvol}}$$

Valorile parametrilor pentru cele zece tipuri de padure

Tip de padure	a1	a2	a3	b1	b2	b3	c1	c2	c3
ROU_PC	-1.573653143	-0.001653423	0.043681989	-1.917251538	-0.001318462	0.067893453	-0.753406708	0.005322017	-0.854548877
ROU_CB	-1.688343	0.001696	-0.255443	-2.022535	-0.001800	0.128927	-0.722283	0.005140	-1.059489

ROU_AA	-1.426523	-0.000687	-0.083774	-1.822640	-0.000141	-0.056877	-0.522418	-0.000518	-0.500000
ROU_OC	-1.195958	-0.000340	0.044504	-1.588882	-0.002690	-0.172668	-0.888850	-0.004805	-0.407255
ROU_PA	-1.573125306	-0.000498028	-0.022566376	-1.926269813	-0.00016829	-0.011293606	-0.870537754	-0.002046936	-0.443987026
ROU_FS	-1.675509	0.000425	-0.153451	-1.988408	-0.001124	0.070280	-0.796988	0.005713	-1.132685
ROU_PB	-1.716351128	0.000573495	-0.139975714	-2.052043708	-0.001049959	0.055252471	-0.95141123	0.003589983	-0.968666404
ROU_OB	-1.677640	0.000431	-0.104280	-1.990934	-0.002655	0.119850	-0.890889	0.008447	-1.127068
ROU_QR	-1.578718567	-0.002813506	-0.057617124	-1.918073416	-0.001676584	-0.076810471	-0.756820282	-0.008479747	-0.862874224
ROU_RP	-1.631169997	-0.00824022	0.295419876	-1.940141497	-0.015736249	0.303245098	-1.1000358	0.018019029	-0.720251145

Parametrii pentru conversia volmului comercial in biomasa lemnoasa supraterana

Ecuatia $B=A*Vol^{B}$, unde Vol – volumul comercial pe picior

Tip de padure	A	B
ROU_PC	0.453425409	1.002847289
ROU_CB	0.488376	1.011117
ROU_AA	0.401728	0.997698
ROU_OC	0.414060	0.995031
ROU_PA	0.364690872	1.016230027
ROU_FS	0.649242	0.997663
ROU_PB	0.567652516	1.00460649
ROU_OB	0.638217	0.989001
ROU_QR	0.708919191	0.982355399
ROU_RP	0.605874314	1.014093923

Anexa 2b. ***Simulation of soils and dead organic matter decomposition by CBM-CFS v3 and Yasso15 – harmonization, calibration and verification***

V. Blujdea (Unitbv), Lisa Kumala (FMI), J. Lyski (FMI), ...

Abstract

Default parametrization does not provide accurate results of C stocks at local/regional scale. Simulation by both models demonstrate that dead organic matter pool is a small sink on long term. Simulations by both models show a strong "start-up" effect over the C stock change the first decade with stabilization after two decades expected due to similar inputs along the simulated period. Systematically, Yasso15 simulates smaller values than CBM. Attempt to calibrate the decomposition in CBM parametrization resulted in an improved fit.

Introduction

Mimic both CBM initialization and running simulations by Yasso15. Running different models provide info on trends and research needs, as well as

Both models provide tools valid for projections of C stock cna d changes in forest mineral soils: „upland sites" (Kurz et. al., 2009) or non-peat ()...., while authors recognise their models resuting in large uncertainty on poorly drained soils.

Paralel simulations may allow better dynamic of various C sub-pools. Both models run versions with annual time step (Table 1).

Under reproting pressure form the climate change convention, CBM-CFS3 provides a resolution at the level of 11 dead organic matter and mineral soil pools which alows working out estimates that match the five pools defined by IPCC (2006), while allows for enhanced representation of key ecological processes, e.g. biomass to soils, and comparison of projections with field measurements (Kurz et. al., 2009).

Method

We endeavour a „local" calibration of the dead organic matter stocks simulated by the two models. „Local" needs to be understdood as a sub-national scale, from the perspective of climate and forest type intersection. Such a spatial scale is appropiate for simulation given high variability of C content in dead organic matter pools.

In fact, this exercise regards harmonization, initialization, calibration and validation.

Despite different inputs required by each model, the *harmonization* targets three elements:

a) ***climate and forest data***. How climate influences the decomposition is described for CBM (Kurz et al., 2009) and for Yasso15 (Järvenpää, M., Repo, A., Akujärvi, A., Kaasalainen, M. & Liski, J. Soil carbon model Yasso15 - *Bayesian calibration using worldwide litter decomposition and carbon stock data*, https://en.ilmatieteenlaitos.fi/yasso-description).

Table 1. Climate description for each climate unit (CLU) and relevance of data for our simulation by CBM and Yasso15 (from coldest to hottest)

CLU code/model	Tma	Tmaxa	Tmina	Tamp	Precipitation
CBM, Yasso15	CBM, Yasso15	Yasso15	Yasso15	Yasso15	CBM*, Yasso15*
44	4.7	19.3	-9.6	28.9	886.3
35	6.7	22.0	-8.4	30.4	823.1
34	8.3	24.2	-7.4	31.6	751.7
26	9.8	26.2	-5.7	31.9	748.7
25	11.0	27.7	-4.6	32.3	678.2
* data actually, not used by the model, but required as input					

b) ***parametrization of the decomposition process***. Decomposition follows different concepts. ***CBM*** tracks nine dead organic matter subpools which strive to describe the complexity of the decomposition process relative to a) type of biomass input (which reffers to particles of different dimensions), b) forest species grouping (only for snags in hardwood and softwood), c) positioning of decomposition above or belowground soil surface, and d) relative decay rate for each sub-pool according to four degrees (very fast, fast, medium and slow). The decay is modeled applying two relative factors to the base decay rate (for the reference mean annual average temperature of 10^{o}C), such as: i) temperature-dependent decay modifier (which usually reduces the decomosition rate) and ii) an open-canopy effect decay multiplier reflecting the stand characteristics (which usually enhances the decomposition rate). Overall, some 83% of the C lost by a subpool is converted to CO2 emitted to atmosphaere in one time step. Phisical transfers among certain sub-pools apply to each time step, e.g. from coarse to intermediary medium or fast, or from aboveground to belowground subpools. Specifically, CBM version used allows one unique set of decomposition factors for all forest types and climates.
Yasso15 is based on decomposition of four chemical fractions in the organic matter input into the soil (AWEN).

c) ***biomass amounts input into the soils*** e.g. types and quantities, with an annual time step is extracted from CBM. Forests area is stratified on ten forest types across five climates. CBM implements forest growth based on volume increment and conversion of volume to biomass growth. On one side, in order to derive the *natural transfers* from living biomass to DOM (e.g. in stands without interventions), CBM incorporates a turnover based solution to estimate the annual mortality and litter transfer rates. Transfers occur to five dead organic matter pools (according to the dimensions: from stemwood, otherwood, foliage, fine and course roots) through specific transfer rates (user-defined/adjustable). All in all, the biomass types simulated by CBM used for input in Yasso are: merch (i.e. stemwood with bark), other wood (i.e. aboveground stumps and branches with bark), foliage, fine and coarse roots (diameter < 5mm and > 5 respectively) according to Kurz et al., 2009). On the other size, the residues amount resulted from *harvesting operations* transfers to soils are based on merchantability criteria (e.g. share of tops and stumps left as residues) and disturbance matrix defined for each type of disturbance. All scenarious exclude natural disturbances.

Biomass input to the soils and dead organic matter decomposition are tracked on the spatial intersection of the ten forest types over five climates.

Table 2 – Correspondence between pools in the Carbon Budget Model of the Canadian Forest Sector 3—version 1.1 (CBM-CFS3) and recommended pools by the Intergovernmental Panel on Climate Change Good Practice Guidance (GPG) (IPCC, 2003). SW = softwood, HW = hardwood, DOM = dead organic matter.

CBM-CFS3 pool	Description	GPG pool
Merchantable + bark (SW or HW)	Live stemwood of merchantable size[a] plus bark	Aboveground biomass
Other wood + bark (SW or HW)	Live branches, stumps and small trees including bark	Aboveground biomass
Foliage (SW or HW)	Live foliage	Aboveground biomass
Fine roots (SW or HW)	Live roots, approximately <5 mm diameter	Belowground biomass
Coarse roots (SW or HW)	Live roots, approximately ≥5 mm diameter	Belowground biomass
Snag stems DOM (SW or HW)	Dead standing stemwood of merchantable size including bark	Dead wood
Snag branches DOM (SW or HW)	Dead branches, stumps and small trees including bark	Dead wood
Medium DOM	Coarse woody debris on the ground	Dead wood
Aboveground fast DOM	Fine and small woody debris plus dead coarse roots in the forest floor, approximately ≥5 and <75 mm diameter	Litter
Aboveground very fast DOM	The L horizon[b] comprised of foliar litter plus dead fine roots, approximately <5 mm diameter	Litter
Aboveground slow DOM	F, H and O horizons[b]	Litter
Belowground fast DOM	Dead coarse roots in the mineral soil, approximately ≥5 diameter	Dead wood
Belowground very fast DOM	Dead fine roots in the mineral soil, approximately <5 mm diameter	Soil organic matter
Belowground slow DOM	Humified organic matter in the mineral soil	Soil organic matter

Both models simulate with annual time steps, i.e. one complete vegetatation season.

Initialization is achieved by each model according to own procedure, but using the same biomass to soils input as extracted from CBM. Input is derived for a period of 50 years (generated from aboveground standing stock dynamics). Input is organized at very detailed spatial scale, while also implicitley accounting for age structure dinamic. CBM assumes a non-equilibrium approach where initial C stock on DOM is under the influence of historical natural disturbance (e.g. fire) and the most recent intervention before the initial moment of simulation. Yasso assumes equlibrium approach where initial C stock in the four biochemical fractions saturates without tacking into account any disturbance.

Calibration would be achieved individually for each model based on initialized total amount of carbon and trends in the first part of the simulated period. Default parametrization of each model is used as a start. Calibration is targeted for major subpools as measured by NFI (i.e. litter, dead wood and organic mater in mineral soils) for the selectyed climate & forest types. This is driven by observations density at regional and national scale (the smallest). In CBM calibration is performed by iterative changes of the decomposition parameteres targeting simultaneoulsy match of measured data.

Validation against total soil C stock measured by NFI in 2013 (i.e. 5000 soils samples).

A *comparative sensitivity* analysis involves two scenarious additional to the business as usual (BAU) scenario where the annual harvest reaches some 60% of the volume increment: a) no harvest scenario which maximizes the biomass accumulation as a standing stock and mortality ("noDist") and b) maximize the input into the soils through management interventions leading to a harvest volume equal to annual biomass growth ("maxH").

Comparation of three scenarios *with regard to the initialization* of the total C stocks, SOM and LT, DW (in the initial year of the simulation).

Comparation of three scenarios over the *simulation period*:

a) total annual biomass inputs to the soil vs. total soils C stock for CBM and Yasso15;
b) total annual biomass inputs to the soil vs. annual C stock change for CBM and Yasso15;
c) trends of each sub-pool for the three scenarios by CBM, i.e. IPCC pools
d) trends of each sub-pool for the three scenarios by Yasso15, i.e. AWEN

Comparison of the two models' temperature and amount of biomass input senzitivity:

e) Sensitivity of initial C stock each model to average temperature on forest types
f) Sensitivity of initial C stock change each model to average temperature on forest types

Comparison on forest types:

a) trends of each sub-pool for the three scenarios by CBM, i.e. IPCC pools

Data processing implies basic statistical processing. Data is derived from NFI1 and NFI2 (http://roifn.ro/site/despre-ifn/).

Results

Initialization of total C stock in the soil. CBM outputs from running 50 years is used as input for Yasso's spin-off. One particularity is that Yasso15 does not apply any particular disturbance over the initialization, while CBM incorporates repeated "total biomass burning" until saturation of C stock in the soils and also applies a correction to ensure the DOM impact of the latest management disturbance before initialization. Indeed, initialized amount of total SOC by CBM and Yasso15 are compared to IFN measured values (Figure 1).

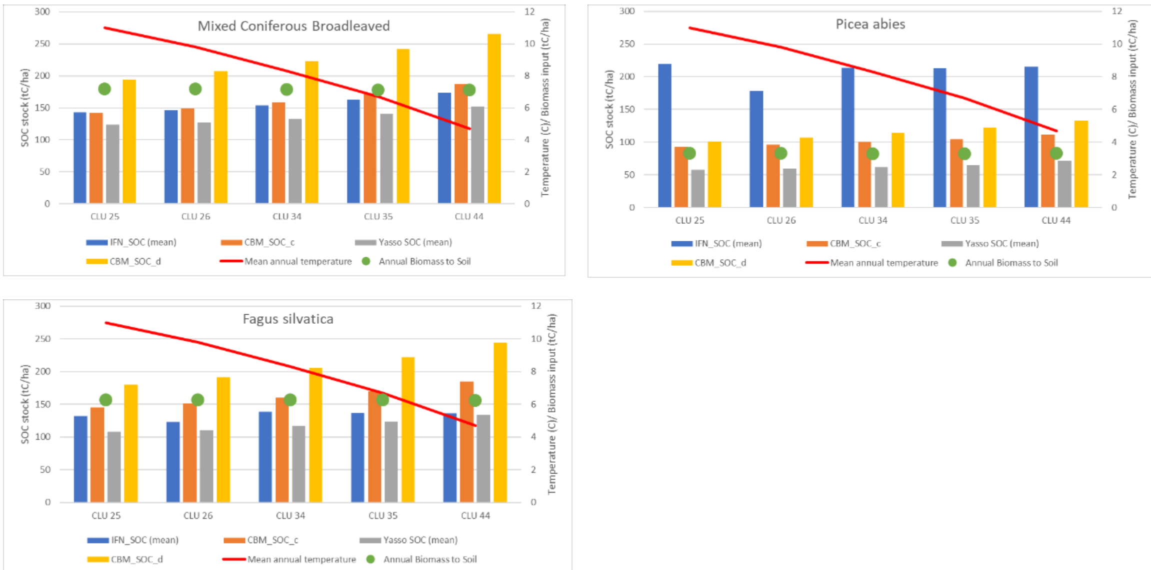


Figure 1. Initialized amount vs. NFI measured total soils C stock. Red line represents the mean annual temperature across the climatic units (CLU). Green dots represent total amount of biomass inpuit into the soils across the three climatic units for each forest type. CDM_d and CBM_c stands for default, respectively for calibrated parametrization of the decomposition by CBM.

There is a generally negative low correlation of SOC stock with the mean annual temperature and biomass amount input to soil (in practice there is an increasing altitude from CLU 24 to CLU 44, Figure 1).

Compared to measured SOC as reference for the year 2010, CBM with default parametrization tends to overestimate the initial SOC stock (see Mixed Con Broad and Fagus silvatica), while Yasso15 tends to slightly underestimate it. Attempt to calibrate CBM parametrization resulted in better fit of resulted in comparable total SOC to measured data. On the other side, systematically Yasso15 simulates smaller values than CBM.

Initialization of SOC's slow decomposing fraction of C by CBM. SOM represents the C pool with the slowest turnover (of some 500 or more years) while it also represents the largest share in the total C pools in the soil. Share of SOM stock of C in total SOC ranges 63-89% by CBM and 96-98% for IFN measured data. Further on, CBM systematically overestimate the allocation in dead wood and litter by some 250% in case of default parametrization and by some orders of magnitude compared to IFN measured data.

Dynamic of total C stock in soils. BAU and maxH scenarios both associates to a decrease of biomass input into the soils, unlike noDist (Figure 2). noDist scenarios provides an input into the soils which is initially smaller than for BAU, while then is higher. Strong drop of inputs associates to SOC decrease under maxH, with default calibration being more affected.

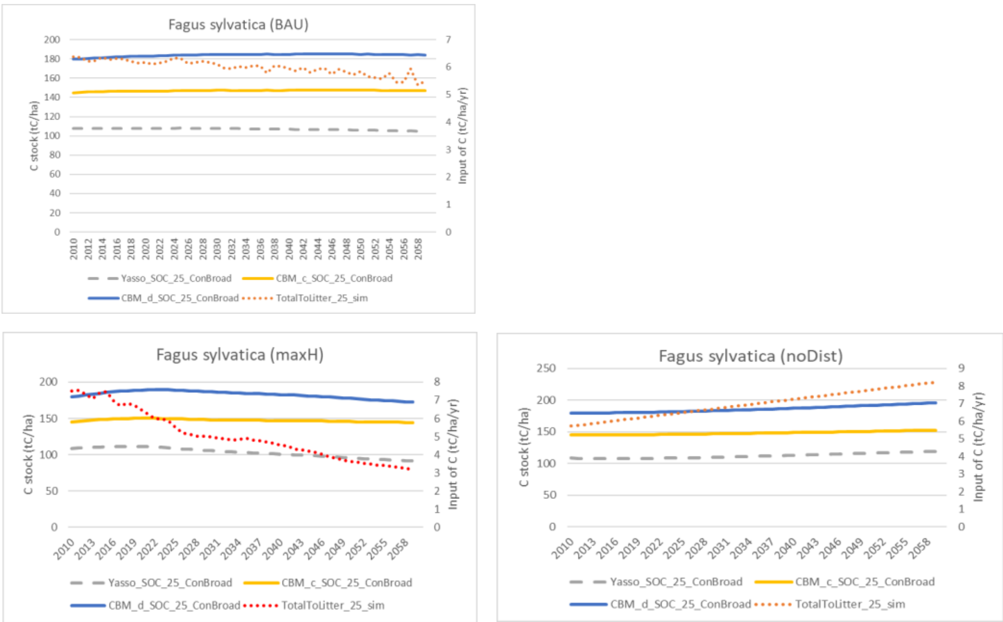


Figure 2. Simulated amounts by CBM (continuous lines) and Yasso15 (dashed line) for one climatic region (CLU25). Dotted line represents biomass input to the soil. CDM_d and CBM_c stands for default, respectively for calibrated parametrization of the decomposition by CBM.

Dynamic of C stock change in soils. Toward the end of the 50 years of simulations both models stabilize for all three scenarios (Figure 3). Specifically, both models show losses from soils, compared to noDist that shows an increase. Moreover, there is startup effect for all cases, i.e. over the first 10-15 years of the simulations. Moreover, for all scenarios, modelled CSC values mirrors each other with higher estimates reported by CBM (Figure 3). On long term there is also a trend toward decreasing the differences.

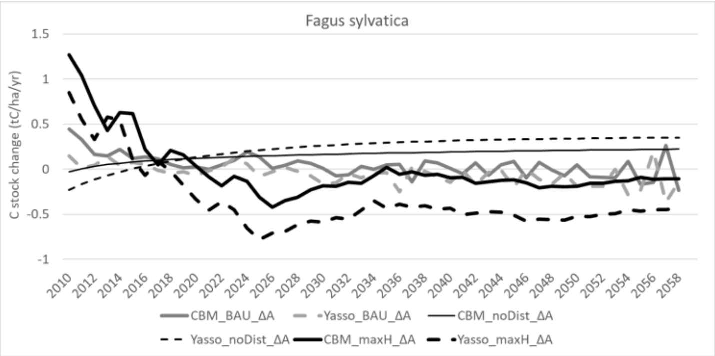


Figure 3. Simulated annual C stock change by CBM_c (continuous lines) and Yasso15 (dashed line) for one climatic region (CLU25) corresponding to there scenarios (BAU, noDist, maxH).

Discussion

[Initialization] Matching the *input biomass into the models was the only partially achievable harmonization of the inputs*. The maximum harmonization achieved could be that the amounts corresponding to biomass turnovers simulated by CBM as age-dependent yield standing forests were used assumed as harmonized inputs in both DOM models.

Further on, decomposition parameters between two models could not be harmonized as one runs the decomposition of physical C pools, the other runs decomposition on chemical compounds. CBM perform initialization into the own metabolism and returns the initialized values. Yasso uses average value for the biomass inputs in this simulation, as part of the its equilibrium approach.

CBM approaches a non-equilibrium soil condition in the initial year, unlike Yasso. Stabilization of CSC, e.g. close to zero values, in some 50 years for all scenarios by both models (Figure 3) suggests that level of the initialized SOC does not depend on the input amounts as it mostly depends on decomposition.

Biomass input to soils in Picea abies is less than half of the amount compared to other forest types (Figure 1), so failure of simulation of reasonable SOC stock by both models is most likely linked to living biomass compartmentation and turnover values applied as part of biomass to soil inputs for this forest type.

CBM default parametrization does not provide robust results with regard to initial data.

Model parametrization with local data remains another major challenging part of SOC simulation. Poor local data and especially definition of available data is usually a strong barrier in suing local data. No matter that, CBM construction has relevant impact on initialization and simulations of SOC, namely the fact that the version we were running was implementing an unique set of decomposition parameters across all strata (e.g. climate units, or forest types). That makes it less powerful in simulating SOC across large territories with large combinations of climates.

CBM and Yasso have different initialization procedure. CBM applies burning of living biomass as the solution to saturate the soils C, this means the litter and dead wood are fully burned every few decades to hundred years (Kurz et all, 2009) under specific parametrization of stand-replacing fires. So, for CBM this procedure gives a significant weight to SOM as long term in C pool in the initialization (litter and dead wood are ephemerous with their half-life more 10 smaller than SOM). Comparatively, Yasso15 applies similar initialization for total C stock (incl. Lt and Dead wood), which means it may be influenced by the inputs as well (e.g. from forest management). Thus, a difference tolerance of 1.00% is more effective under CBM which only checks SOM which is indeed less prone to short term impacts like disturbances.

IFN reports higher contribution of SOM than litter stock in total soils C stock. Actual parameters involved in decomposition equations and transfers between pools may not fully reflect the climates in Romania. Total SOC is not expected to be underestimated given the actual method implemented in sampling all C pool on the ground by NFI. Despite clear definition and understanding of this pool, it remains very complicated parametrization and validation against sampled values, while avoid double-counting with litter or losses which lead to underestimation of its amount.

Mismatch of initialized SOC with IFN can be also explained by significant change in mngm over last 50 years.

Biomass inputs into the soil takes into consideration a forest status from latest NFI which reflects the status over last decade, while in fact the history of the forestry was more intense for at least 4 decades during the communism time before 1990.

Matching the dead organic matter sub-pools. Yasso reports total C stock and the soil on subpools (e.g. IPCC pools) is not possible without making additional assumptions and simplifications on the results. This is nevertheless a difficult task as measured data is very much different by default assumptions (i.e. measured data reports < 1 % litter while measured results in some 3%).

Both models seem stable in terms of CSC under short term change of the inputs, see maxH scenarios which shows a dramatic drop of inputs.

Running strata includes all age-classes which makes the approach less sensitive to such variation.

[Simulation step] Total annual biomass inputs to the soil vs. total soils C stock for CBM and for Yasso15. With 1 year time step there decomposition fallows an average pattern, e.g. lows and heights over the year are not reflected. The impact of average temperature on annual time step changes needs to be understood, as DOM is very sensitive to temperature change with seasonality.

A constant input of C in the soils occurs with BAU scenario, while maximum harvest leads to a steady decrease of inputs in time and no disturbance leads to a slight increase of the inputs in the soils. These have insignificant impact on C stock in the soils

The three dead organic matter fractions change significantly under the influence of the biomass input, with dead wood pool following forestry operations. Biomass input drives the shape of total SOC (Figure 4). No matter if default or calibrated parametrization of CBM.

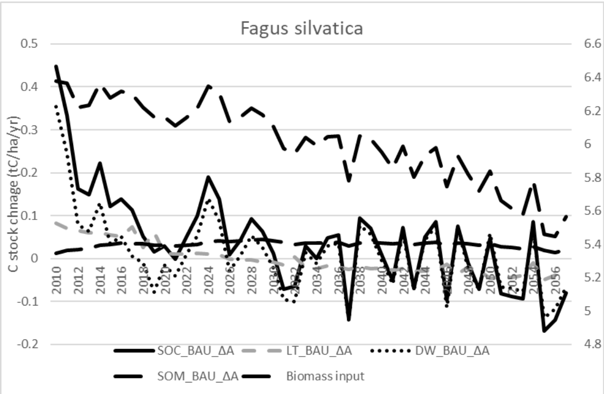
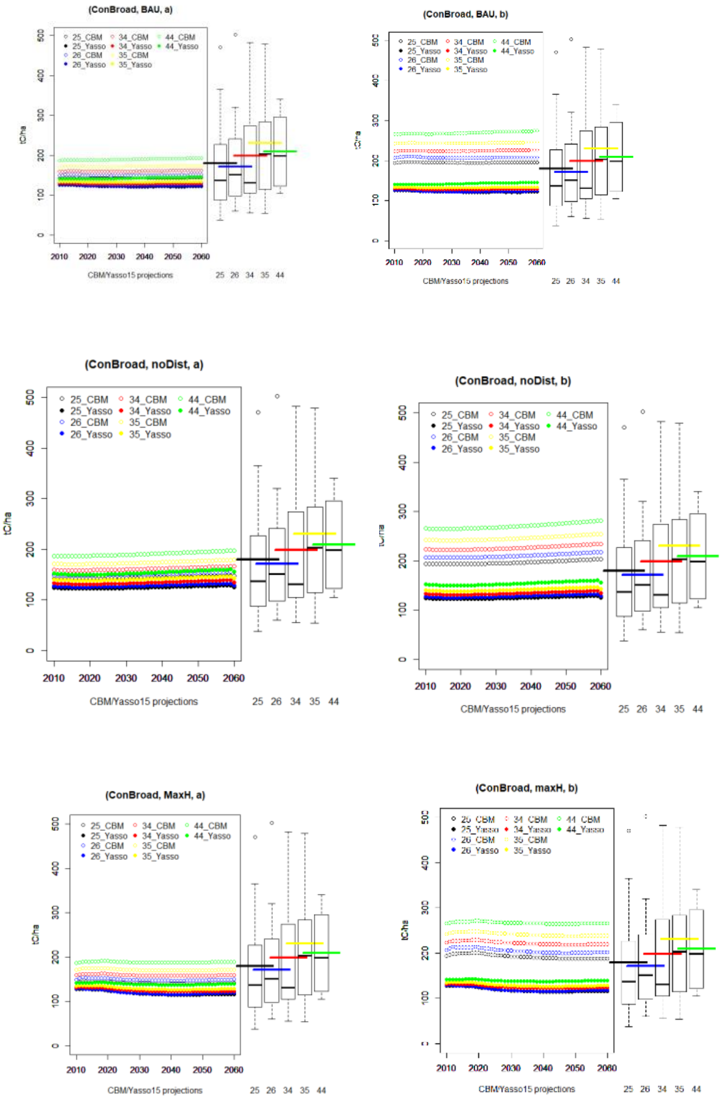


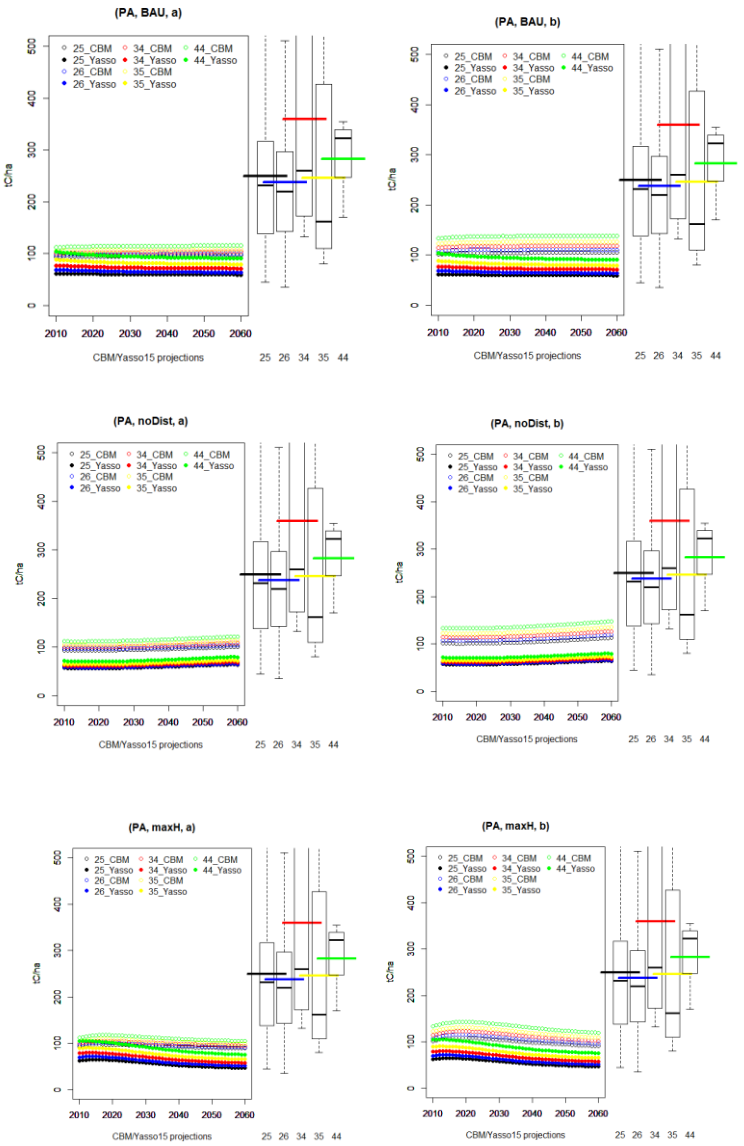
Figure 4. Simulated annual C stock changes in total SOC, soil organic matter, dead wood and litter.

Detailed results by CBM showing performance of the two models fo the initialization and dynamic of CBM (option a) calibrated, b) default parametrization) and Yasso15 under the three scenarios (BAU, noDist, maxH).

ConBroad forests for CLU 25 (a) calibrated parameters (b) default parameters



Picea abies (a) calibrated parameters (b) default parameters



Anexa 3. EU and National Level Strategies for Promoting Climate-Friendly, Forest and Forest Resource-Based Action – Motivating Forest Owners, Consumers and Lower-Level Public Sector Actors

By David Ellison, Hans Petersson, Viorel Blujdea and Richard Sikkema

Abstract

The use of forests and forest-based resources in European Union (EU) and Member state climate policy frameworks remains controversial. Hesitation to fully mobilize forest and forest-based resources has resulted in an EU-level LULUCF policy framework that is simultaneously expansive and restrictive, both integrating and increasing the forest and forest-based role in climate policy, while simultaneously setting precise limits on its full-scale mobilization. Even with the most recent EU LULUCF policy revision (EU 2018/841) under the framework of the Paris Agreement, forest and forest resource-based mitigation actions remain circumscribed by a complex and confusing web of rules (i.e. the FRL, cap, HWP carbon pool, carbon neutrality, bioenergy, AL/DL (ARD), etc.). In order to open up pathways for motivating the LULUCF sector and related actors to adopt more climate-friendly actions, the EU has encouraged Member states to elaborate so-called *Art. 10-related measures*. Thus, in order to assess whether the most recent LULUCF policy revision is likely to motivate more successful climate change mitigation, we undertake the following exercise. Based on the most recent available data, we assess the future LULUCF related goals of select EU Member states based on their performance under the 2nd Commitment Period (CP2: 2013-2020). Since the changes introduced in the EU policy framework between the 2nd and 3rd Commitment (CP3: 2021-2030) periods are relatively minor, barring additional policy reforms, current performance provides a good indicator of the type of outcomes the new policy framework is likely to encourage. Our findings indicate that, because of the revealed degree of mismatch across EU, national and forest owner (as well as consumer and lower level public sector) interests, even well-intentioned Member states face powerful disincentives to act both at the national and the local, landowner level. Nonetheless, with comparatively minor tweaks, the EU and national-level frameworks could potentially propel significantly more dynamic climate change mitigation (and adaptation).

Keywords: LULUCF, Forest, Mitigation, Adaptation, FRL, HWP, Afforestation, EU, UNFCCC

Introduction

Accelerating the use of forests and forest-based resources in national and international climate policy frameworks could potentially go a long way to further supporting the effort to reduce global atmospheric concentrations of CO2 and planetary warming potential.[1–5] In the European Union, Member states are increasingly encouraged to make better and more climate-friendly use of their forests. The EU's new LULUCF (Land Use, Land-Use Change and Forestry) regulation (Regulation EU/2018/841) has more firmly integrated Member state forests and forest-based resources into national and EU-level climate policy frameworks and some elements of the new EU LULUCF regulation expand the forest role. At the same time, however, the regulation places ever more precise limits on the climate-friendly use of the forest resource. Specific elements of the new strategy, e.g. the perpetuation of the cap and the limited flexibility in offsetting emissions from other sectors via net LULUCF-sector removals, underpin limitations on the broader mobilization of the forest resource. Thus, the developing mix of EU and national-level strategies for mobilizing forests and forest-based resources for the purposes of climate change mitigation (and adaptation) remains incomplete.

Over time, EU governance has introduced powerful incentives to take advantage of Europe's bioenergy resources (carbon neutrality principle)[6] and has increasingly opened the door to strategies based on increased use of long-lived harvested wood products (HWPs). First included in the Kyoto Protocol's 2nd commitment period (CP2), the cap on HWP carbon pool credits has been removed from accounting under CP3 (3rd Commitment Period). This will favor additional the substitution of energy-intensive products (i.e. cement, steel and some plastics) with wood products, serving to mobilize additional carbon sequestration in the long-lived HWP carbon pool. Nonetheless, the EU strictly limits the forest and forest resource-based role in supporting carbon sequestration in standing forests beyond the cap and under-stimulates potential forest use for compensating emission reductions in other sectors through a broad and confusing web of regulatory restrictions. These include the FMRL (the Forest Management Reference Level, now the Forest Reference Level, FRL, in the new EU-regulation), the cap, limitations on flexibility, and strict LULUCF exclusion from any EU ETS (Emission Trading Scheme) role.

The EU has further called upon Member states to undertake an assessment of the potential additional carbon sequestration and net climate change mitigation from forests and forest-based resources. So-called *Article 10* reporting, introduced in EU LULUCF Decision 529/2013, thus calls upon Member states to highlight their potential for increased LULUCF-based climate change mitigation, and, eventually, to detail any measures taken to achieve these goals. To-date, remarkably little research attention has been paid to how to motivate national and local level forest owners and consumers of forest-based resources to mobilize these resources for the goals of national-level climate change mitigation and adaptation. Art. 10 represents a tacit recognition that one of the currently most under-researched and seemingly neglected questions is essentially how to mobilize action on the ground. However, given that the EU offers no additional resources for Art. 10 measures, it likewise represents a tacit recognition that Member states must come up with the necessary resources on their own.

Two principal levels of governance in the EU can be mobilized in order to encourage more climate-friendly actions on the part of forest owners, consumers and other lower-level actors (e.g. the public sector): the European level of governance and national, Member state-level governments. Our principal goal is to better understand how the interlocking policy features at the EU and Member state level are likely to interact and thus motivate forest owners, consumers and other lower-level actors to undertake climate-friendly actions. Ellison et al[7] highlight that land and forest owners on the one hand and national governments on the other face very different sets of incentives when it comes to the LULUCF policy framework. Thus, even if EU and national-level governments establish specific climate-related goals, forest owners and other lower level actors may not be motivated by the same interests, and thus may not follow national or EU-level climate-friendly objectives. Thus, despite the fact that some incentives may facilitate Member states' promoting greater use of the forest resource climate goals, in order for this to happen effectively, EU, national and forest owner interests must be adequately aligned.

We divide the discussion of the potential for mobilizing land and forest owners and consumers to undertake climate-friendly actions into four parts. First, we address the EU-level role in motivating climate friendly forest actions. Second, we investigate the nature and structure of the perceived interests' different actors face. Third, we analyze national level efforts motivated, in particular, by the Art. 10 exercise. Fourth, we take a look at what is actually happening on the ground in individual Member states (MS) to assess potential outcomes based from the current set of EU incentives and MS-level attempts to pursue specific forest resource-based climate change mitigation agendas. We conclude with a discussion of our findings across the wider set of EU Member states and highlight weaknesses and strengths in current EU and national level policy frameworks.

LULUCF in the EU Climate Policy Framework

In order to fully understand both what leeway and what incentives Member states face to encourage land and forest owners to undertake climate friendly actions, it is necessary to fully understand the EU LULUCF climate policy framework and how it both affects and interacts with other levels of governance. Table I provides a detailed overview of the evolution in the LULUCF policy frameworks across all three Commitment periods. The EU policy framework essentially sets the frame (and limits) within which Member states are likely to choose national level policy measures in an attempt to drive lower level actors to undertake relevant action.

Accounting Rules		Kyoto Rules (CP1: 2008-2012)	Durban Rules (CP2: 2013-2020)	EU Rules (CP3: 2021-2030)
Reported/Accounted Activities	**AL/DL, MFL, MC, MG (ARD, FM, CM, GM), MW (WDR) and all additional lands not included in activities**	ARD mandatory, FM voluntary	ARD and FM mandatory (WDR optional)	AL, DL, MFL, MC, MG mandatory (MW mandatory from 2026, AL becomes MFL after 20 years, converted land can exit accounting)
Reference Level/ (Accounting Method)	**AL/DL (ARD)**	reference level = "0" (gross-net)	reference level = "0" (gross-net)	reference level = "0" (gross-net)
	MFL (FM) - (incl. HWP)	reference level = "0" (gross-net)	projected, historical or reference level (including bioenergy use) = "0" (net-net) FMRL	average reference level based on 2000-2009 = "0" (net-net) FRL
	MC, MG (CM, GM), MW (WDR)	reference level 1990 (net-net)	reference level 1990 (net-net)	Average reference level based on 2005-2009 = "0" (net-net) (MW mandatory from 2026)
Accounting Restrictions	**"*cap*" on MFL (FM) carbon credits**	3% of 1990 emissions, 15% of actual net removals (whichever smaller, or negotiated)	3.5% of 1990 emissions (only after fulfilling FMRL)	3.5% of 1990 emissions (only after fulfilling FRL)
	Carbon Pools under MFL (FM) – HWP, deadwood, soil organic carbon, litter	HWP omitted	HWP included, limited by "cap"	HWP included (no cap limitations, paper excluded), Deadwood included (no cap limitations), (caps remain for soil, litter pools)
	Net Removals up to FRL (FMRL)	not relevant	not accounted (but can be debited)	not accounted (but can be debited)
	Offsetting of net AL/DL (ARD) and other land use emissions with net removals in other LULUCF activities	permitted, from FM to ARD (compensation rule)	not permitted	Permitted for all Land Uses (after fulfilling reference level)
Flexibility Mechanisms	**ETS System**	not permitted in EU (but permitted in some other regions and countries)	not permitted in EU (but permitted in some other regions and countries)	not permitted in EU (but permitted in some other regions and countries)
	LULUCF => ESR (ESD)	not permitted	not permitted	280 MtCO2e
	ESR (ESD) => LULUCF	not permitted	not permitted	permitted (not limited)

Table I: Accounting Rules for EU Members States, as Defined by the Current and Previous Policy Frameworks

Note I: For CP1 and CP2, the EU legislative framework mirrors the Kyoto (CP1) and Durban (CP2) frameworks. The only difference is the exclusion of forests from the EU and international Emission Trading Schemes (ETS). The EU has consistently excluded the forest-based sector from the ETS. Changes in carbon pools, living biomass, dead wood, litter, soil organic carbon and HWP are reported for all activities. Accounted debits/credits are based on changes in these pools.

Note II: There has been a lot of change in the naming and acronyms of different activities in the LULUCF sector, as well as on what is included under each (e.g. ARD is cimmulated in time since 1990, AL would only include last 20 years). Detailed information can be found in the Kyoto Protocol and in Regulation EU/2018/841. Previous forest activity designations are included in parentheses in the table above and all acronyms are defined as follows:
AL (afforested land), DL (deforested land), previously ARD (Afforestation-Reforestation-Deforestation),
MFL (managed forest land), previously FM (Forest Management)
MC (managed croplands), previously CM (cropland management)
MG (managed grazing land), previously GM (grazing land management)
MW (managed wetlands), previously WDR (wetland, drainage, re-wetting)

ESR (effort sharing regulation), previously ESD (effort sharing decision)

Under the 2015 Paris Agreement, the terms of the 2011 Durban LULUCF Agreement became moribund and Parties are now free to pursue their own strategies. Many other Parties have abandoned the Durban model and opted for more flexible arrangements.[8] The EU, however, has chosen to further revise and embed the basic elements of the Durban framework in its climate policy framework. Over the short historical period during which forests and forest-based resources have been increasingly regulated by the UNFCCC framework and the corresponding policies that embed this framework in EU climate policy, the role of forests has been simultaneously expanded and further circumscribed. The segments of the forest resource that have most effectively been mobilized for climate change mitigation include Art. 3.3 afforestation-reforestation and deforestation (ARD), biomass for bioenergy (climate neutrality), and, more recently, the harvested wood product (HWP) carbon pool. Further, marginal increases in the “cap”, the share of accountable carbon credits under Forest Management (FM), were introduced between the 1st and 2nd Commitment Periods.

While the 2011 Durban LULUCF Agreement (FCCC/KP/CMP/2011/10/Add.1.; Decision 2/CMP.7) expanded the potential role of forests in some areas, it clamped down in others. For one, the agreement required that all countries report annual fluxes in carbon stocks under forest management (Art. 3.4 under the Kyoto Protocol, KP). Previously, Parties could voluntarily report FM, thereby making it possible for individual countries to exclude their forestry sectors from any potential UNFCCC policy intervention. For another, the Durban Agreement witnessed the introduction of the Forest Management Reference Level (FMRL). The FMRL was originally intended; 1) to limit the potential impact of “historical growth” through the projection of forest management activities under business as usual (i.e. harvest and age-structure) in the commitment framework, and 2) to reduce the granting of ‘free credits’.[7] Since historical growth was typically greater than the cap, countries could typically gain credits without undertaking additional actions. However, the FMRL likewise has had the seemingly unintended effect of imposing a new, additional emission reduction commitment on Member states. By requiring increased carbon sequestration (net removals) in standing forests up to the FMRL, the FMRL has essentially operated as an additional commitment above and beyond country and Party emission reduction commitments.[4,7] Because this LULUCF sector “commitment” is accounted independently from country-level emission reduction commitments, the Durban FMRL essentially has had the effect of increasing climate ambition.

Falling short of the FMRL (or the FRL in CP3) in the EU framework results in Member states are being held responsible for debits under the CP2 and CP3 accounting frameworks. Moreover, success in meeting the FMRL/FRL is not accounted as a benefit (i.e. carbon credits), despite the positive impact of additional net removals in standing forests on the global carbon budget.[7] Further, in order to meet the conditions of the new cap and become eligible to claim carbon credits for net removals in standing forests, countries are now first required to meet their FMRL commitments. Under CP1, the right to generate carbon credits under FM was more heavily “capped” (see the first addendum to the KP published in 2005 (decision 16/CMP.1).[9] However, there was no requirement to fulfill a minimum amount of additional forest growth before becoming eligible to receive these credits. As these regulations were revised for CP2 and CP3, the cap has effectively been increased in size, but has simultaneously been made dependent upon the fulfillment of the FMRL/FRL. While this means for many countries that credits are no longer ‘given away for free’, since most countries could fulfill their caps under CP1 without changing their behavior, this new, unrewarded contribution to the global carbon budget is certainly curious.

Caps on the right to claim forest-based carbon credits for removals in standing forests, were originally introduced in CP1 in order to limit the potential impact of the forest sector on country level emission reduction commitments. Calculated in CP1 as 3% of 1990 emissions and then revised to 3.5 % of total national emissions (incl. agriculture, but excl. LULUCF) in the base year (for most countries, 1990), the cap has never been strictly based on the forest sector, but rather on emissions in other sectors. The result, however, has been that Member states with higher levels of forest cover face highly restrictive caps, while Member states with comparatively small shares of forest cover face excessively liberal caps (see Figure I).[7] Thus, for countries with greater shares of forest cover, the caps are so small, they render the incentive framework virtually unusable and cannot even be targeted effectively. In part as a result of this fact, most of these Member states have ended up with relatively large amounts of “unaccounted” net removals over CP2, elsewhere labeled the “incentive gap”.[3] While caps may effectively provide some Member states with a pathway for improving their overall climate policy performance, the entire logic of imposing a cap is at best questionable. Moreover, for Member states cannot really benefit from the cap, such strict limits are likely to diminish incentives to invest in additional net removals in standing forests (and thereby additional forest growth).

The new, EU LULUCF legislative framework (Regulation EU/2018/841) for CP3 (2021-2030) consists of a similar set of simultaneously expansionary and increasingly restrictive regulations. LULUCF has now been formally set apart in a separate, conceptually isolated “pillar” and the range of “activities” covered has been expanded to include all relevant land types and carbon pools (cropland and grazing land management, wetlands and deadwood), as well as the traditional elements already included under previous agreements (managed forest lands and afforestation, reforestation and deforestation on unmanaged lands and HWP). The EU’s CP3 2030 target, like the Paris Agreement itself, requires that LULUCF should not be a net source of emissions. However, since clause is not supported by any sanctions or penalties, it remains unclear what the relative weight of this statement will be. The degree of compartmentalization of LULUCF created by its division into multiple “activities”, however, unnecessarily complicates the accounting of frameworks and reference levels (e.g. net-net and gross-net). Thus, despite considerable movement toward all-inclusive land-based accounting framework (most carbon pools have now been effectively included in LULUCF), accounting remains heavily divided and compartmentalized.

Significantly greater flexibility has, however, entered the LULUCF accounting framework in other ways. It is now possible, for example, to use carbon credits stemming from net removals in standing forests in other pillars (see Table 1). However, the regulation imposes precise limits on flexibility from the LULUCF sector. Thus, Member states can now formally compensate emission reduction shortfalls in the non-ETS, “effort sharing” sector (CP3 ESR) with LULUCF surpluses up to an EU-wide total of 280 MtCO2e (minus 18 MtCO2e after Brexit). Likewise, shortfalls in the LULUCF sector, i.e. debits, can be compensated in the reverse direction (from the ESR) over the period 2021-2030 (Regulation EU/2018/842: Art. 12, para 1). This essentially makes it possible for individual Member states to go beyond reference management practices (e.g. harvest more), but still make up for this by further reducing emissions in the non-ETS sector (i.e. housing, commercial buildings, transport, non-ETS industry, agriculture and waste). The non-ETS sector has, however, long been one of the more difficult sectors in which to make significant progress on emission reductions.[10] Thus, this clause could potentially motivate EU Member states to get more serious about the non-ETS sector where, as repeatedly demonstrated, there is significant emission reduction potential. Alternatively, reverse flexibility may encourage some Members states to do more with forests.

The LULUCF agreement has likewise increased flexibility within the LULUCF pillar. Though the Durban ruling eliminated the so-called “*compensation rule*” under which many countries had previously been permitted to offset net emissions from ARD activities with surplus credits from forest management activities. The compensation of net ARD emissions was quite common during CP1. Were it not for the compensation rule, the total EU ARD segment would have resulted in net emissions during CP1.[7,11] Moreover, FM-based ARD compensation accounted for about 86% of total net removals across the EU as a whole for the period 2008-2012.[11] Since ARD was initially the LULUCF activity expected to generate the greatest potential for achieving additional forest growth, this finding deserves more attention. The inability of re- and afforestation to keep pace with deforestation across the EU as a whole raises important questions about the effectiveness of the ARD strategy for promoting carbon sequestration. The CP3 ruling, however, has now opened this up again and allowed for the transfer of surplus net removals across different activities in the LULUCF pillar.

The CP3 LULUCF regulation has further removed previous limitations on the mobilization of the harvested wood product (HWP) carbon pool. Under the new ruling, the cap no longer applies to the HWP carbon pool (as was the case in CP2). Next to bioenergy, which has always been strongly favored due to its carbon neutral status, HWPs have previously only been partially supported due to the increasing costs of steel and cement production imposed by the gradually expanding impact of the ETS system. As costs gradually rise for fossil fuel-based industries like steel, cement and plastic production, the incentive to use HWP resources directly for bioenergy gradually diminishes. But the lack of full accounting for the HWP carbon pool portion meant that bioenergy continued to have an advantage over accounting for HWP resources.[3] Thus, the removal of the cap on HWP carbon pool accounting may further open up interesting pathways for individual Member states to harness the substitutive potential of HWPs and thereby favor the long-term use of HWP for construction and other uses (e.g. furniture). Further, the ruling on dead wood, likewise no longer capped under CP3, now permits countries claim net removals for all deadwood remaining on managed forest lands. To the extent deadwood can be mobilized, it may act as an additional incentive for improving forest biodiversity.

The expansive elements of the revised EU-level policy framework provide some important opportunities for exchange between the various segments of the climate policy framework. Increases in the cap, the role of the FMRL/FRL in their impact on commitments, and the shift to uncapped accounting of HWP carbon removals create opportunities for an increased forest role. However, the number of imposed constraints, in particular the cap and the FMRL/FRL, continue to create important disincentives. Moreover, in a somewhat peculiar twist of fate, CP3 has created additional disincentives to invest in ARD (now AL/DL) by requiring that all afforested lands (AL) be moved to managed forest land (MFL) after a period of twenty years. Since the annual additional net carbon sequestration from such standing forests thereby becomes subject to the cap and thus would no longer be fully accountable (assuming of course that the cap remains in place and is not modified significantly), this is likely to further slow the rate of investment in lands not under forest management.

Not surprisingly perhaps, the FMRL and cap frameworks, in particular, have been the subject of frequent debate.[3,4,7,12] And the occasionally shifting FMRL and cap framework has been subject to a number of occasionally important “technical corrections” (we treat this at greater length in the supplementary material). The forestry sector, broadly speaking, as well as several Member state governments, have remained suspicious of the EU legislative framework and have tended to see the FMRL (and the FRL for CP3), in particular, as a potential limitation on their right to mobilize the bioeconomy in favor of climate change mitigation. Thus for CP3, both Finland and Sweden, for example, (much like Japan for CP2[7]), effectively requested FRLs equivalent to “0”, in apparent attempts to shield the forest sector from the EU regulatory framework.[13,14]

Moreover, the placement of constraints on how additional annual growth in European forests can be used further has unseemly and presumably unintended impacts.[4,7,12] For one, since forest owners invest resources in productive forests, imposing limits on the use of these productive resources (through the imposition of reference levels) is likely to create real disincentives to future forest investment. For another, additional forest and forest resource use may in fact provide significant marginal returns to national, and thus EU and global carbon budgets.[15] Further, as demonstrated by Solberg et al[12], the FRL may have important impacts on the leakage of harvest (and thus potentially also deforestation) to other parts of the world.

As argued elsewhere,[7,16] many of these potential problems could be more effectively addressed in different ways that would not have the more direct effect of politicizing felling rates in individual Member states. One way , i.e. to consider for post-2030, of doing this is to eliminate the FRL altogether, and instead impose a separate, additional, *floating emission reduction commitment* on Member states, roughly equivalent, for example, to the current contribution from forest-based net removals, that could then be met by through any available surplus (ETS, non-ETS and/or LULUCF). Moreover, such a strategy would presumably sit well with those forest owners who continue to resist increased impositions on their right to make sovereign forest-related decisions.[17] Finally, a floating emission reduction commitment could further help resolve the perplexing problems arising from the accounting of harvest emissions in the LULUCF sector and the compensation for bioenergy use accounted in the energy sector. Note that such a strategy is not significantly different from one of increased or absolute "flexibility" but would have the added benefit of depoliticizing pressures arising from the imposition of the FRL on managed forest lands (MFL). Moreover, such a strategy would not have any negative impacts on other Member states but could potentially help contribute to accelerated emission reductions.

What is missed in the EU level framework, on the other hand, is the fact that land- and forest owners may not respond in the same way as governments to the incentives created by the EU LULUF policy framework. This is because the incentives created by the EU LULUCF regulations and UNFCCC emission reduction commitments affect governments and other actors in different ways. Likewise, governments themselves may fail to undertake or support more climate-friendly actions where these are not adequately mobilized in the EU-level framework. We describe and discuss these potential interactions across EU-, national- and local-level actors and policy frameworks in detail in the following section.

Climate-Friendly Forest and Forest Resource-based Measures

One of the more perplexing problems to emerge in the context of the forest role under the Paris Agreement is how and to what extent Member states and lower level actors such as consumers and forest owners are motivated to undertake climate friendly actions? The benefits for the EU and Member state governments under the new EU climate policy framework are not necessarily implicitely and immediately benefits for forest owners, consumers and other lower-level actors such as the public sector and local level governments, at least not without effort. Thus, motivating more climate friendly action at lower levels may potentially require some kind of incentive framework.

Motivating primarily economically motivated actors, for example, to undertake more climate-friendly forest and forest resource-based action may potentially require shifting incentives from more economic toward climate-oriented goals. However, getting consumers, forest owners and other lower level actors to change their forest and forest resource-based behavior may be more difficult than many assume. For the most part, the EU has opted not to provide additional EU-level mechanisms to spur such action forward, leaving this primarily up to Member states. And the apparent suggestion from Art. 10 of EU LULUCF Decision 529/2013, again appears to be that Member states should ultimately undertake such actions on their own (including by using various EU funding). In keeping with the general spirit of the EU climate policy framework and the 2015 Paris Agreement on climate action, Member states should see fit to undertake actions of their own accord, without the benefit of incentives created from above.

What then motivates actors to undertake positive climate-friendly action with respect to forests and forest-based resources in the first place? Generally speaking, as Parties to the Paris Agreement, Member states are first and foremost motivated to undertake actions that will help them meet their commitments under UNFCCC agreements (i.e. the Kyoto Protocols and the Paris Agreement). Moreover, Member states presumably have an interest in being able to demonstrate the impact of the efforts undertaken. This second point, however, introduces important limits: if such efforts are not "*accountable"* within the context of the carbon budget Parties submit to the both the EU and the UNFCCC, Member states will face reduced incentives to undertake related actions. In this regard, only "*accountable* and *reportable"* actions within the existing climate policy framework will likely appear attractive.

Forest owners, on the other hand, respond to a different set of interests. Altruistically and of their own accord, forest owners are less likely to choose actions that solely benefit the climate. Though some may opt to do this, the principal factor motivating forest owner actions has long been economic gain.[18–20] Forest owners in fact remain highly protective their decision-making rights over private lands.[17] Thus, even though forest owners exhibit increasing awareness of climate change, climate-related actions are more likely to involve strategies that preserve the potential economic gain from the forest resource. Precisely because of this economic imperative, it took many decades to convert the struggle over "*multi-purpose forestry*" into the public and private management regime governing today's forests.[21] To make matters even more complex, the *climate agenda* has, in a sense, been superimposed over the more or less stable institutional multi-purpose forestry framework, catching forest owners somewhat by surprise.

A common definition of the circumstances requiring government intervention is when the market is either unable or unwilling to deliver optimal outcomes on its own. Since the incentives faced by national governments and by individual actors (land and forest owners, consumers and lower-level actors) differ (see Table II), and since governments ideally want these actors to respond to climate concerns over and above economic interests/concerns, some form of government intervention is presumably required to shift behavior in the appropriate direction. Thus, creating an incentive framework that will encourage land and forest owners to adopt the goals of pursuing climate-friendly actions and introducing the ideals and potential models of *climate smart forestry*,[4,22] presumably requires some degree of public intervention.

The incentive framework land and forest owners face ultimately depends on whether or not national and/or EU level governments create policy frameworks that translate the incentives they face through their UNFCCC emission reduction commitments, into similar incentive frameworks that adequately align the interests of all participants (this is the concept of "pass-through" highlighted in columns 6 and 7 in Table II). Unlike national governments, land and forest owners first and foremost are motivated by the possibility of making an income from their available land resources. Productive forests represent one of many possible income-generating choices open to land and forest owners. Agriculture, or the division of land into residential development plots represent additional choices.

Presumably, the coopting of forest and forest-based resources for the purposes of climate change mitigation (and adaptation) requires an income-generating and/or regulatory component in order to compete with alternative land use options in order for rational land and forest owners to respond. And in some countries, land and forest owners are even protected from the imposition of regulations that could potentially reduce forest owner incomes from the forest resource. Due to the basic requirement of stakeholder support, top-down strategies are seldom the best choice for public policy. Thus, the necessity of some kind of incentive framework capable of stimulating forest owners to respond to incentives commensurate with the goals of climate change mitigation (and adaptation) is what structures the logic of the Incentives depicted in Table II.

EU Managed Forest Land Framework			Party/Government perspective		Landowner perspective			
Scenario	Net Removals (From–To)	Accounting Options	Paris Agreement and NDC-based Incentives (1)	Promote Growth (G)/ Harvest (H)? (2)	Economic Drivers (3)	With Government Intervention & Incentives (4)	Logic (5)	Possible Mechanisms (6)
(1)	**0 - FRL**	Debits Only (Target/Commitment)	Harvest for bioenergy, HWP not significantly different from Standing Forest	G/H	HWP, Bioenergy	Standing Forests, HWP and Bioenergy	fully incentivized G/H	Carbon Price (Tax/ETS), carbon neutrality, CS Standing Forest Payments, HWP Carbon Pool incentives
(2)	**FRL - cap**	Credits Only	Harvest for bioenergy, HWP not significantly different from Standing Forest	G/H	HWP, Bioenergy	Standing Forests, HWP and Bioenergy	fully incentivized G/H	
(3)	**Surplus beyond cap to Flexibility Limit**	Credits can be transferred to LULUCF activities & ESR	Harvest for bioenergy, HWP not significantly different from Standing Forest	G/H	HWP, Bioenergy	Standing Forests, HWP and Bioenergy	fully incentivized G/H	
(4)	**Flexibility Limt - Total MFL removal**	Credits for HWP removals (only)	Harvest for HWP and Bioenergy (with cascading, preference for HWP)	H	HWP, Bioenergy	Harvest for HWP and Bioenergy (with cascading, preference for HWP)	Standing forests not incentivized H	+ Legislate Cascading

Table II: The Incentives Faced by Forest Owners and National Governments (Parties) under the New EU LULUCF Policy Framework for Commitment Period 3 (2021-2030)

Source: updated and revised from Ellison et al (2014). The current version of the Incentive Table reflects the future situation as determined by the new EU LULUCF regulation (EU/2018/841) for the next commitment period - CP3.

Note: There are three principal changes in this Incentive Table originally introduced in Ellison et al (2014). The first two changes concern the EU's new CP3 LULUCF regulation. First, HWP removals are no longer capped in the CP3 framework. Thus, HWP appears more frequently in the table as a more or less fully incentivized outcome. This was not the case under CP2. Second, some flexibilities have been added, making it possible to transfer credits from the LULUCF sector to the ESR sector (Scenario 3). Third, prices for HWP have changed. We assume throughout that prices for the various components along the forest value chain (HWP, biomass for bioenergy, or standing forest), are the principal factor driving action on the part of land and forest owners. Though prices for bioenergy were previously higher than for HWP resources (Ellison et al., 2014), recent market developments have led to the inverse relationship (waste incineration is currently cheaper than biomass for bioenergy use). Thus, herein we assume that prices for HWP resources are highest (sawn wood > round wood for pulp > bioenergy), while those for bioenergy resources come in second. Standing forests are valuable to forest owners only in so far as they sequester additional net amounts of carbon (net removals) that can be monetized in some way (4). Barring some kind of government intervention (4), forest owners have stronger incentives to care about economic drivers (3). Member state governments, on the other hand, are motivated by the terms of political agreements and/or by any potential sanctions they might face for non-fulfillment (e.g. debits for the failure to achieve the FRL). Land and forest owners, however, are only likely to recognize the value of carbon sequestered in standing forests once it is compensated in some way through the climate policy framework. Thus, the structure of incentives forest owners face will differ depending on the set of national-level LULUCF and climate policy regulations individual Member states introduce through legislation.

The interest frameworks highlighted in Table I highlight an awkward structure of divided and potentially misaligned incentives across governments, on the one hand, and forest and landowners on the other. Depending on the types of motivations and incentives each set of actors faces, the incentive structure may or may not result in actions being undertaken that match EU and National level Government attempts to favor the climate. For one, no policy framework currently exists for providing direct incentives to forest owners for net removals in standing forests (green shaded area, Table II). Thus, unless land and forest owners are entirely altruistic and primarily concerned about the climate, forest owners are not likely to increase the total amount of standing forest and are more likely to respond to economic drivers. Moreover, though our focus here is primarily on land and forests owners, a similar interest mismatch is likely to occur across national governments on the one hand, and consumers and other lower-level actors (e.g. the public sector) on the other.

Under CP2 and CP3, in Scenario I (Table II), the FMRL/FRL in effect sets targets for net removals in standing forests and Parties or Member state governments likely feel an obligation to achieve these targets. However, land- and forest owners are far more likely to respond to economic incentives and sell harvest-ready biomass to the highest bidder. Given current price dynamics in the harvested wood product (HWP) and bioenergy sectors, harvesting forest resources for HWP represents the most attractive option for land and forest owners. Selling tree biomass for bioenergy production takes a close second (depending on price fluctuations in these markets). The extent to which the HWP and bioenergy markets compete with each other depends primarily on the prices for bioenergy resources, as well as the extent to which countries are willing to use solid biomass, as opposed to harvesting residues, for bioenergy production. In some countries, forest residues (tops and branches) are primarily used for bioenergy while stems are sold for sawnwood, pulp and some bioenergy. There is generally no competition between these market segments. However, depending on prices, there may be some competition over how much of an individual tree is sold to each segment (e.g. over the relative shares of tops and stems). Finally, there can also be competition with other market segments (e.g. cellulosic fibers and chemicals). But to-date these have not been significant.

Even from the moment an individual country has fulfilled its FRL and becomes eligible to claim credits under the cap (scenario 2), nothing really changes. Without a mechanism for passing the benefits of claimed credits on to land and forest owners, these actors continue to face competing incentives. In most cases, forest owners ideally prefer to maximize their incomes. They are therefore far more likely to act with respect to the benefits (prices) offered by the harvested wood products and perhaps the bioenergy sector (depending on price fluctuations). However, as highlighted in the green columns, with the introduction of strategically designed incentive systems at the national level, forest owners can be encouraged to respond to other strategic goals.

One interesting difference, however, in scenario 2 relative to the first scenario is that Parties, not forest owners, are eligible to claim carbon credits. Thus, under scenario 2 it should become easier for Parties to legislate policy frameworks that pass these benefits on to land and forest owners. Moreover, in lieu of this, forest owners face different incentives than Parties and will be less likely to pursue more explicitly climate-related behavior and the goals created by the cap. Under scenario I, however, Parties are not eligible for carbon credits up to the FRL and creating benefits for land and forest owners by passing a regulation that encourages compliance comes at a greater cost: up to the

FRL, no credits can be sold on the open market to compensate Parties. On the other hand, since Parties are subject to debits when they fall short of the FMRL/FRL, they also face powerful incentives to introduce mechanisms that can ensure the achievement of the FMRL/FRL. Though we are not aware of any current strategies being introduced, the question remains whether this will lead to greater centralized control over, and the potential imposition of penalties for noncompliance with, national felling rates.[7,12] Under scenario 2, where Parties, and potentially also land and forest owners if appropriately legislated, could be eligible to claim benefits, the choice of outcomes is potentially more meaningfully aligned across actors and options. Scenario 3 poses essentially the same set of conditions on the various actors. Thus, in order for Parties to mobilize this incentive, they must find ways to mobilize forest owners.

Finally, once there are no more options to claim carbon credits and there is no commitment to achieve additional net removals in standing forests (scenario 4), all incentives to improve net removals in standing forests, and thereby to promote additional forest growth (G) are significantly reduced or eliminated (and are only motivated by any national-level forestry regulations and guidelines). On the other hand, both national governments and forest owners, assuming "*pass-through*" mechanisms that offer up incentives to the next level, are incentivized to take advantage of the harvested wood product market (depending of course on market conditions and price fluctuations). Further, if the goal of "cascading" (a policy to ensure wood is first used for HWPs and is only turned into bioenergy at the end of its product lifecycle) has been fully implemented into the national policy framework, and assuming incentives have been granted to forest owners, HWP should ultimately be favored over harvesting for bioenergy.

According to the potential strategies outlined in Table I, in order to raise the relative share of carbon sequestered in standing forests and thus promote increased forest growth, the only relevant strategy for improving land and forest owner behavior vis-à-vis the range of choices they face, is to introduce some kind of *pass-through* strategy which transfers benefits for additional climate-friendly behavior/interventions to land and forest owners, whether through direct monetary benefits or some other strategy. Thus, one possibility for promoting additional forest growth might be to provide direct payments to forest owners for overall increases in carbon sequestration in standing forests (e.g. re-planting and improved forest treatments). On the other hand, ensuring that forest owners alone have the right to decide how to use their forest resources may also provide additional investment incentives. The FRL, however, may create important disincentives in this regard.[7,12,17]

Adding the advantage of accounting the HWP carbon pool next to the substitution-driven trend in prices further strengthens the benefits of promoting HWPs. However, consumers face a similar dilemma to that faced by forest owners. If the climate advantage posed by opting for long-lived wood products is not evident to consumers through signals like price advantages, consumers may be likely to choose other options. Thus, without some form of pass-through mechanism, as in the case above with forest owners, the advantages of long-lived wood products may not be as self-evident to consumers as is potentially necessary in order to get them to shift their purchasing behavior. On the other hand, if governments are able to pass these benefits on to consumers, this may favor higher rates of substitution and "cascading", by encouraging the greater use of biomass for long-lived HWPs (ideally, HWPs should only enter the bioenergy resource stream at the end of their product life cycle, or adequate sorting of wood quality).

Governments, on the other hand, only face incentives to introduce strategies for improving climate-friendly actions on the part of land and forest owners, consumers and lower level actors and levels of governance (e.g. the public sector), in situations where such actions will benefit that countries total accountable carbon budget. If parts of this carbon budget are excluded from accounting, governments face no incentive to pursue improvements. This phenomenon is what some authors have called the "incentive gap".[3] As under CP2, this gap persists in the current accounting framework. All net removals in standing forests that surpass the range of accountable net removals (FLR + cap) essentially lie 'outside the range of meaningful opportunities' for government action. Since investments in net removals and carbon sequestration in standing forests are potentially costly, and since this range cannot be meaningfully accounted, governments are unlikely to create policy frameworks and provide incentives for actions that will have no impact on their accountable carbon budget. This means there will be little support for increased forest growth beyond the FLR+cap margin. Under these circumstances, both land and forest owners are likely to favor maximizing available harvest.

Land and forest owners presumably face strong incentives to undertake investments in the future forest resource. Thus, some might argue responsibility for the future forest resource can in fact be delegated to them, since economic incentives encourage them to ensure its increase and longevity. However, the tendency to embed forestry in political arguments and debates around the FRL suggests there is considerable future uncertainty over how the forest resource may be managed. The more the FRL is used to cordon off ever greater shares of forest land from harvest, the more forest owners face diminished incentives to invest in additional forest growth. *The FRL is therefore politically problematic*. This uncertainty the incentives investments private forest owners face to invest in the future forest resource, since decisions about it are beyond their control. In fact, most of the initial decisions related to the cap and the FMRL were made in top-down UNFCCC negotiations, without real negotiation with the forestry sector.

Finally, more attention should likewise be paid to HWPs and their potential to contribute to the HWP carbon pool. Although forest owners face clear price incentives to harvest biomass and sell it for HWPs, this alone will have no specific impact on shifting the use of biomass for more long-lived HWPs. Forest owners are only likely to respond to the prices for long-lived HWPs where these are higher than prices for other HWP uses. To-date, the principal price signal for long-lived HWPs has been likely to arise from higher prices for comparable goods used, in particular, in construction (i.e. those for energy-intensive products like steel and concrete). However, the comparable price of the net removals entering the HWP carbon pool has not currently been translated into either the prices of HWPs, or, in particular, those of products like furniture and other long-lived wood-based products. Thus, in order to promote consumer behavior that aligns with the goals of climate change mitigation, it will likely be necessary for Parties to find better strategies to encourage consumer-related behavior as well.

National-Level Member State Forest and Forest-Resource-based Action Plans – The Response to Art. 10 of 529/2013

Barring any effort from the European Union, national Member state governments have, for the most part, been left to their own devices. The incentive structure highlighted in Table I above indicates that Parties to the Paris Agreement who set their national contributions and make commitments to reduce emissions by specific amounts face one set of incentives, while land and forest owners face potentially competing incentives. Thus, both the European Union and Member states have committed to reducing emissions by 40% by the year 2030 (relative to 1990). Likewise, Member states, in negotiation with the European Commission, are setting FRLs for this period. No parallel or similar commitments, however, are made by land and forest owners (or by consumers). In this sense, local-level actors, forest owners, consumers and even local level governments face more strictly economic incentives.

The Art. 10 exercise

Despite the lack of strong incentives from the EU side, the European Commission has nonetheless required Member states to inform them about any such actions they undertake on their own. Art. 10 of the EU LULUCF ruling (Decision 529/2013) requests that Member states, “draw up and transmit to the Commission information on their current and future LULUCF actions to limit or reduce emissions and maintain or increase removals”. Thus, although the LULUCF climate policy framework essentially leaves Member states to their own devices with regard to mobilizing forest and forest resource-based climate-friendly action, the Commission nonetheless requires Member states to report both on possible measures, as well as to provide a precise list of the “most appropriate measures”, taking into account national circumstances and based on the set of categories listed in the ruling.

For the forest and forest-resource based sector, these involve measures related to re- and afforestation, conservation of existing carbon sinks, enhancing production (presumably with the intent of raising available amounts of biomass material), enhancing the HWP (carbon) pool, improving forest management, preventing deforestation, as well as measures related to reducing natural disturbances and substituting fossil fuel-based materials with HWP resources. Moreover, Member states are expected to report on the relative GHG potentials for each of these measures.

The Art. 10 exercise represents something of a moving target, since, to this day, Member states are still considering and implementing the outcomes of this effort. Thus, the Art. 10 exercise may initiate processes whose outcomes will only become fully apparent in coming years. The strategy of pushing Member states to highlight the potential range of additional forest measures appears to have had the impact of at least encouraging Member states to think more carefully through the range of possible LULUCF-related actions available to them. Thus, even if Member states are not clearly incentivized to undertake additional action due to the disincentives built into the EU climate policy framework, some Member states have at least made significant efforts to undertake real analyses of potential measures. The Institute for European Environmental Policy (IEEP) has undertaken a preliminary analysis of the Art. 10 reports submitted to the EU in 2015 and 2016.[23]

EU Member states were not required to submit all requested information and many Members states did not submit information on things like what measures they actually intended to implement, as well as how those strategies might be implemented or how much individual countries might be willing to spend on individual measures. Thus, the outcome of this exercise yields an overview of possible measures, without providing a lot of information on what Member states actually intend to do, or how they might achieve their goals. IEEP authors even speculate about why Member states do not have "dedicated LULUCF strategies" and point out that this may be the result of the "non-mandatory nature of mitigation in this sector".[23]

(MtCO2e) Measures	IEEP by 2030	Nabuurs et al 2017 by 2050
Organic Soils	-30	
Mineral Soils	-50	
FM	-148	-172
Afforestation	-1.58	-64
Preventing D	-3	
Energy Substitution		-141
Forest Reserves		-64
Totals:	**-233**	**-441**

	Bastin et al 2019 (Mha)
Finland	4.5
Germany	3.2
Netherlands	0.2
Romania	0.9
Sweden	5.7
UK	4.7
EU Total	**38 (Mha)**

Table III: Estimations of Additional Unused Mitigation Potential in Europe.

Note: avoided emissions resulting from Energy substitution are measured in the ETS sector and are not assessed in the LULUCF sector.

The IEEP report provides estimates for how much additional potential climate change mitigation could be achieved by the year 2030 if Member states were more inclined to undertake significant mitigation actions (Table III). The principal potentials lie in the re-wetting of organic soils in order to reduce emissions, and in forest management, though improvements in carbon sequestration in mineral soils are also frequently mentioned. The mitigation potential in the forest management sector is several orders of magnitude greater than that in the other sectors. Moreover, many of the Member states suggest the mitigation potential from the re-wetting of wetlands is uncertain.

For comparison, Table III also highlights findings from Nabuurs et al,[4] who assess additional unused mitigation potential up through the year 2050. These results differ from those of the IEEP review of national level assessments on a few important counts. For one, Nabuurs et al highlight the fact that an additional -141 $MtCO2e^{-1}$ could still come out of the bioenergy sector (despite the fact that emission reductions resulting from avoided emissions are only accounted in the energy sector). While bioenergy potential is also noted in the IEEP report, and while Figure 8 highlights the countries that mention pursuing this potential, no additional data is provided on actual mitigation potential because Member states themselves do not report this data. Nabuurs et al likewise suggest there is significantly greater potential than currently exploited in both the establishment of forest reserves (land set-asides), and in afforestation, amounting to -128 MtCO2e by 2050. For additional Member state-level comparison purposes, we have included data on afforestation potential from the Crowther Report, by Bastin et al.[1] It is worth nothing that estimates on potential returns from stronger encouragement of, and substitution using, harvested wood products are generally missing from studies like those cited above, despite often considerable potential.

A Preliminary Assessment of Member State LULUCF Performance

Since the Paris Agreement highlights that Parties to the agreement should attempt to, "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (Art. 4.1), and since the European Union's LULUCF legislation requires the identification of measures for encouraging climate friendly actions on the part of forest and forest-based resources, we investigate a range of possible national-level measures for their potential to have a positive impact on climate change mitigation, either through carbon sequestration and net removals in standing forests, or through the mechanism of fossil fuel substitution.

Bearing in mind the general incentive framework defined above, we investigate current policies and actions emerging from the national level governance and their potential to encourage actions likely to benefit the climate on the part of land, forest owners, as well as consumers. For individual Member states, the potential measures do not look significantly different. For the countries we have chosen to look at (Sweden, the Netherlands and Romania, along with an assortment of additional EU Member states that vary on the basis of their allotted "caps" and on the basis of their initial amount of forest cover), we find that most have made similar observations about the advantages of wetlands re-wetting and forest management (FM). Few additional measures are highlighted.

The selection of national level programs intended to support these programs is strongly differentiated. In the Swedish case, for example, while a greater number of ***potential*** measures are highlighted, most of these measures have no implementing, incentive-based programs to support them. And when they do, most of these programs have already been in place over an extended period of time. In fact, in the Swedish case, most of the measures aimed at bioenergy, material substitution and increasing the HWP carbon pool seem primarily to rely on the potential for existing market-based mechanisms to propel them forward. Thus far, only measures intended to facilitate and improve regeneration, cleaning and stand treatments, as well managing damages from wild animals are currently supported. In addition to this, measures to support biodiversity, including land set-asides in protected areas, are likewise being supported. The Swedish government thus plans to set aside an additional 1,142,000 ha's of land between the years 2012-2020, of which 350,000 ha's is forest land.

Other Member states, however, have somewhat more ambitious plans to increase forest cover. In this sense, land set-asides differ significantly from re- and afforestation projects, because they are less likely to result in *additional* contributions to the national (and thereby global) climate budget, though they may have significant positive benefits in terms of their contributions to increased biodiversity. Countries that are planning significant re- and afforestation projects are the UK, the Netherlands and to some extent Germany. We have used the country-level Art. 10 reports and other official forest-related planning documents as the official source documentation for each of the three EU Member states discussed below.[24–29]

The Netherlands

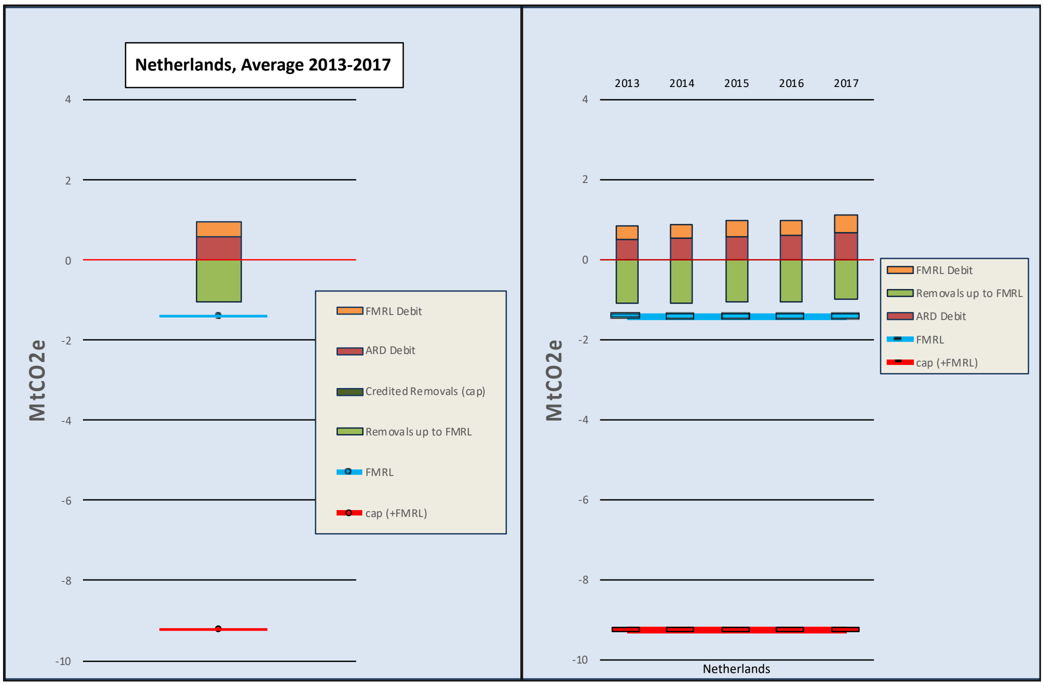


Figure I: Dutch Net Average and Annual Accounted LULUCF Impact – CP2 Rules: 2013-2017

The Netherlands has the obvious advantage that it has a very large "cap" relative to its future forest potential, and thus has significant room for making real improvements in the relative contribution forests and forest-based resources can make to the overall Dutch commitment. In 2017, Dutch emissions in other sectors were 193.26 MtCO2e. As illustrated in Figure I, removals from the forestry sector over the period 2013-2017 average approximately -1.045 MtCO2e annually, just shy of the FMRL (-1.425 MtCO2e), and yielding a small debit (+.38 MtCO2e, indicated in orange at the top of the bar).

The "cap" in the Netherlands is quite large, -7.8 MtCO2e (distance between the blue FMRL and the red cap+FMRL lines) relative to total Dutch FM sector forest growth potential, the largest in fact in the EU. Moreover, to-date, the cap remains unused. Thus, considerable room remains for the Netherlands to take advantage of this potential under FM, where the cap applies. Moreover, the national government was concerned about the eventuality there will be significant shortfalls in the available amounts of biomass material for bioenergy. The principal strategy for promoting additional growth in the forest sector under FM in the Netherlands is a subsidy program (Nature and Landscape Subsidy System, or SNL) that provides monetary rewards directly to farmers who plant forests on their land. The national government has thus far committed to increasing the national forest area by 100,000 ha's within the next several years.

The Netherlands has also recently published its *National Forest Strategy*,[30] to which it has dedicated some 51 million Euros, as well as additional measures to slow and/or compensate deforestation in Natura 2000 areas and to develop other government-owned lands. The Netherlands is committed to increasing the total amount of forested land by approximately 10% by 2030 (an amount equivalent to approximately 37,000 ha's.), increasing the amount of wood available for annual harvest, and simultaneously limiting the relative size of any single clear cut (to 0.5 ha, though larger clear cut areas are permitted in the case of disturbances and disease). The government seems committed to making up for the backlog in deforestation since 2017, resulting from the expansion of Natura 2000 regions that returned some lands to natural heather.

Likewise, given the total amount of emissions in the ARD sector (i.e. from lands not under forest management) in the Netherlands, it is perhaps no surprise significant attention will be paid to emissions from peatlands. For this reason, the national government has committed to spending 176 million Euros up to 2030 and hopes to achieve a 1 MtCO2e reduction in peat meadow areas and related emissions. Due to the extensive use of some of these peatlands for grazing cattle in the dairy sector, there are limits to the degree to which many of the former peatland areas can be fully re-wetted. However, a technology has been developed to allow at least partial re-wetting involving a partial raising of the water table that is expected to bring improvements.

Across these two LULUCF segments, the Netherlands envisions an increased mitigation potential of between -1.4 and -1.8 MtCO2e (-1 MtCO2e in peatlands and between -0.4 and -0.8 across the so-called National Nature Network, which targets an expansion of approximately 46 kha, and an additional 100,000 ha increase in forest land). Though this may seem like a relatively small potential increase in forested lands, Bastin et al[1] envision a total potential increase in forest cover in the Netherlands of approximately 189 kha. If Bastin et al. are correct, then only another 43 kha of land is potentially available for re- and afforestation efforts. Given the Netherlands large cap, the Dutch, at least potentially, could both undertake *and benefit from* significantly greater actions in the LULUCF sector. The limiting factor, however, may be the available land resources.

The Nature and Landscape Subsidy SNL system for encouraging additional forest growth in the Netherlands is potentially slanted toward promoting less intensive forest use. Approximately 80% of the Dutch forested area falls under the SNL system and is broken up into two subcategories. 60% of this subsidized forested area qualifies as forests with a "production function", while 40% are subsidized as natural forests and the annual harvest is limited to only 20% of the annual increment on 80% of the forested area. More can be harvested on the remaining 20% of forested area. Forests receiving SNL nature subsidies are subject to the requirement that the subsidized forest land must be open to the public. Subsidy amounts vary significantly depending on whether they support dry or wet forest, and nature forest management of wood production (Table IV).

(Euro/ha)	**Wet Forests**	**Dry Forests**
Biodiversity-oriented FM	17.08	92.10
Monitoring	19.57	7.65
Production-oriented FM	45.15	25.64
Monitoring	5.13	5.13

Table IV: Dutch Subsidies for Biodiversity- and Production-Oriented Forest Management, Wet and Dry Forests

Note: the category names have changed for the current period and were previously labeled “Nature Forest Management” and “Wood Production Management”, respectively. Monitoring is frequently carried out by the Bosgroep association. Private forest owners, on the other hand, receive the basic subsidy.

The Dutch government seems torn on the question of how to handle the demand for wood-based bioenergy resources. In the second Art. 10 report and the National Forest Accounting Plan (2018), the national government suggests that all large-scale, wood-based bioenergy resources will most likely be imported. At the same time, the national government is willing to consider alternatives for more intensive use of Dutch forests, in particular should the supply of biomass resources become constrained. In the *Forest Strategy* report, the government makes clear commitments to prioritizing biomass resources for harvested wood products (HWPs) and foresees the diminishing of the relative share of wood resources going immediately to bioenergy production.

Romania

Some confusion awaits current representation of forest-related accounting regarding total net removals in forest management in Romania. As highlighted in Figure II, the data reported in 2018 and 2019 does not match up. The submitted data for 2019 suggests there are significantly higher amounts of net removals in standing forests (by extension, significantly lower harvests) than represented in the 2018 submitted data. The reasons for these discrepancies remain obscure. Different Romanian governments reportedly rely on different background datasets for their estimations of reported data (i.e. the National Forest Inventory and data from the National Statistical Office). While technical corrections have been the norm for most Member states (see related discussion in the Supplement), Romania is still improving the reliability of its reported GHG inventory data. These problems with the forestry data further diminish confidence in the official Romanian GHG estimates.

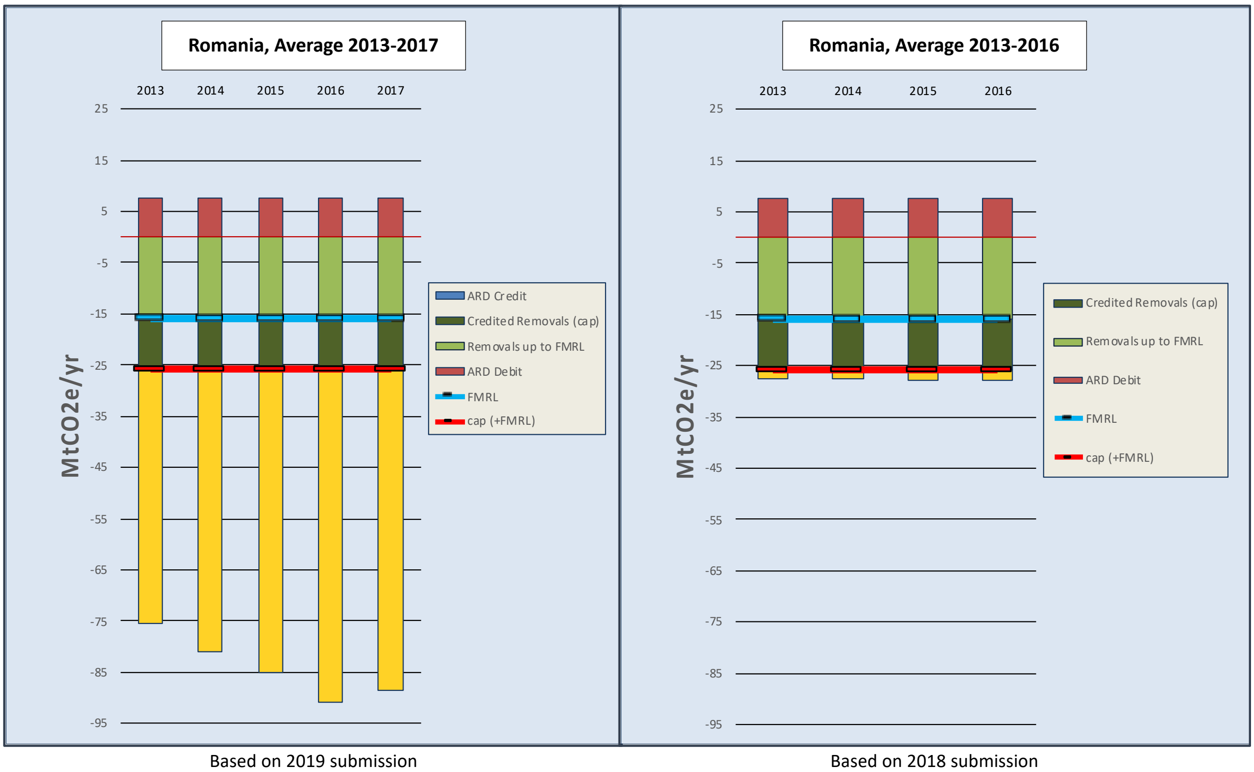


Figure II: Romanian Net Annual Accounted LULUCF Impact – CP2 Rules: 2013-2017

Note: based on Official Submission Data for 2019 and 2018, respectively.

For the period 2013-2017, Romania exhibits a comparatively high level of LULUCF emissions resulting from ongoing net deforestation in the ARD segment. With total GHG emissions in non-LULUCF sectors of approximately 113.79 MtCO2e in 2017, net deforestation rates constitute approximately 7% of annual emissions (or approximately 7.55 MtCO2e per year). On the other hand, the reported data suggests there is no additional crediting potential under forest management, since the entire cap potential of 9.89 MtCO2e is fully exploited and the FMRL has been consistently fulfilled.

Thus, the forest management sector has generally failed to encourage additional measures on the side of the Romanian government. Based on personal communications, Romanian government officials have not been strongly motivated by the possibility of claiming carbon credits under forest management, despite the fact that large and medium-sized forest owners reportedly have some interest in such a mechanism. There has been discussion about setting up a possible mechanism for transferring carbon credits to landowners. However, the national government reportedly lacks the will to achieve this goal. Representatives state that the EU LULUCF regulation 'fails to stimulate any land-based mitigation activities.' The lack of incentives to invest in forest-based mitigation on managed forest lands is not surprising given that comparatively large shares of net removals simply go unaccounted in the Romanian case. Depending on which submission should be trusted, these unaccounted emissions range anywhere from approximately 2 MtCO2e, to as much as 58.5 MtCO2e based on the 2019 submission data.

The Romanian government however does list a number of potential strategies for achieving additional climate change mitigation in the ARD segment of the LULUCF framework on both agricultural and non-agricultural lands. The most significant effort is clearly the focus on the considerable afforestation potential available on degraded and abandoned lands. Romania's Art. 10 report notes that the Ministry of Agriculture and Rural Development (MARD) is creating an inventory of degraded lands. Of the 836.5 kha of degraded land, after completion of less than half of available counties in Romania some 115.1 kha of land are reportedly suitable for afforestation. According to this report, many former agricultural lands dispersed throughout the country are available. Bastin et al[1] , on the other hand, see reforestation potential on the order of approximately 870 Kha, somewhat greater than the amount of available land noted in the Art. 10 report. Additional assessments, however, are still underway.

Attempts to raise the share of afforestation should ultimately go a long way to reducing and possibly reversing net deforestation in Romania, and thus reducing ARD debits (increasing net removals). Moreover, attempts to increase the overall size and cover of the forest resource in Romania are likely to have positive feedbacks in terms of Romania's ability to benefit from the economic returns attached to a sizeable forest resource, since, based on the new EU LULUCF regulation, afforestation on ARD lands must later be transferred to the managed forest land sector after 20 years.

Based on personal communications, the principal focus of such efforts is on future economic returns. The government has dedicated 15 million Euros in funding to incentivize forest expansion between 2014-2020.[31] On average, direct payments to landowners can amount on average to a total support of approximately 8889 EUR/ha over a period of about 12 years. The payments are intended to cover afforestation on both agricultural and non-agricultural lands and include payments for afforestation, compensation for arable land loss, maintaining and treating new forest plantations, as well as approximately 75% of the initial set-up costs.

The goal is to achieve approximately 1.6 kha/year in forest expansion over the next decade.

In the long run, however, one clearly neglected segment of the LULUCF policy framework in Romania is the potential role long-lived HWPs could play in further improving net carbon sequestration in the HWP carbon pool. The potentially large share of unaccounted net removals in standing forests does represent a potential wood resource that could be mobilized for other, potentially more meaningful climate-friendly efforts. However, Member states in general have not really made any significant attempts to move in this direction.

Sweden

In comparison to most of the other EU Member states, Sweden (much like Finland) has received a very small cap, in particular relative to its forest potential. Sweden's cap represents approximately 2% of the annual harvest (the actual size of the harvest is not depicted in Figure III) and, as such, is very difficult to target in any meaningful way. However, as long as Sweden overshoots the total amount of net removals in standing forests, there is little doubt it will be able to take advantage of the full cap permitted under the current EU rules. This has indeed been the case ever since the Durban LULUCF framework first went into effect in 2013, and annual Swedish net removals in standing forests have not varied dramatically since 1990, despite regular year-to-year fluctuations.

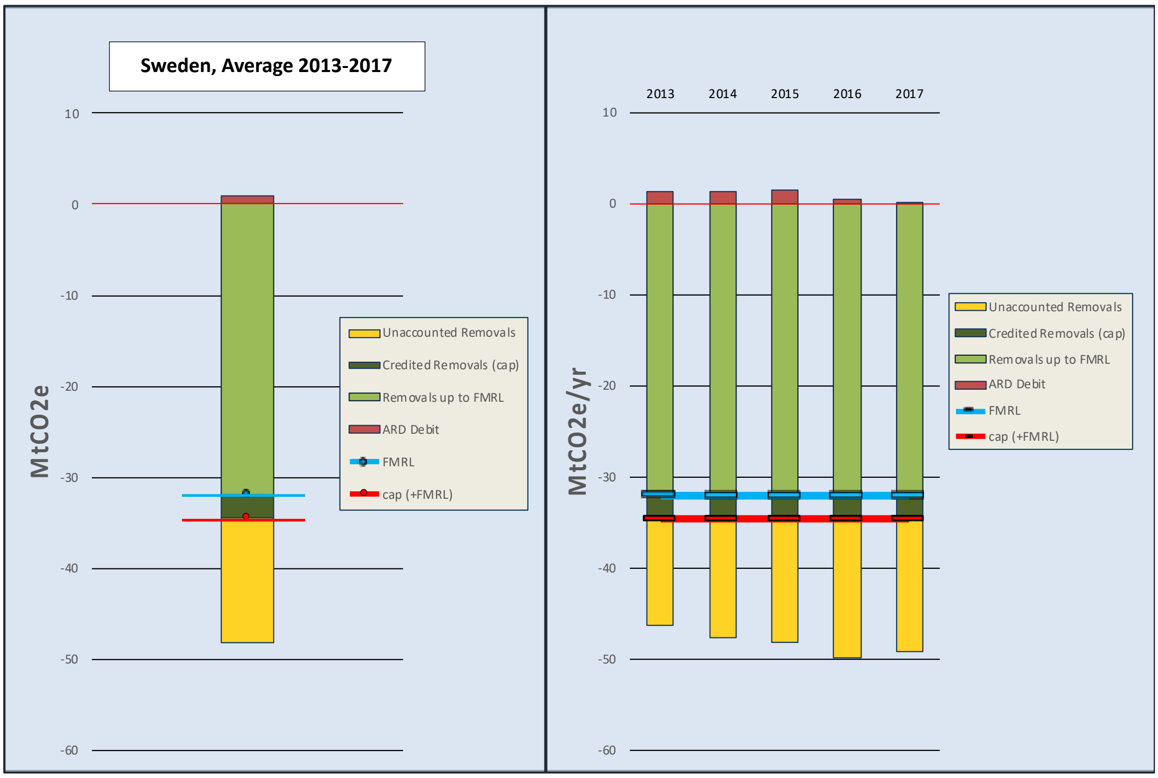


Figure III: Swedish Net Average and Annual Accounted LULUCF Impact – CP2 Rules: 2013-2017

On the other hand, the cap in Sweden is not likely to have much of an impact on incentives to increase net removals in standing forests. Since the cap is almost impossible to target, and since Sweden has had no trouble achieving the full cap in past years, it is unlikely Sweden would not be able to garner the full share of cap credit available to it in future years. On the other hand, it is always possible increasing demand for bioenergy resources will gradually bring about some change in this regard. The Swedish government and the forestry sector seem intent on ensuring it can use all available forestry resources and has been somewhat defiant regarding current attempts to set the FRL for the next commitment period from 2021-2030.

Though the Swedish Art. 10 reports highlight several possible strategies for increasing carbon sequestration or improving the amount of material and fossil fuel substitution, surprisingly few implementation measures have thus far taken root. The measures that will be funded with EU Rural Development funds, for example, are primarily focused on informational campaigns directed at forest owners. But few or no resources will be paid directly to forest owners in order to motivate real change in forest potential. As indicated several times throughout the Art. 10 reports, most of the incentives are expected to come from rising carbon prices and through the resulting pressures on fossil fuel use. Sweden's introduction of a carbon tax in 1991 has reportedly had a decisive impact on the shift from fossil fuel use in the energy sector, toward a gradual uptake of bioenergy resources. Doubling in importance between 1990 and 2012, bioenergy accounted for 30% of total energy consumption in 2012 and continues to rise. Moreover, at the time of the second Art. 10

report's publication, Sweden's carbon tax was at 1080 SEK/tCO2 (or approximately 100 EUR/tCO2). And Sweden has likewise provided other market-based supports.

The second factor that is thought to drive progress in the forest and forest resource-based sector without significant intervention from the government is the fact that forestry has long been a profitable enterprise in Sweden, forest owners themselves are strongly motivated by market forces to undertake actions to "maintain or enhance the production of valuable wood beyond what is required in the forest law" (2nd Art. 10 report, 2016). In fact, Swedish forest stocks continue to increase at a rate of approximately 3-7 Mton C/year and have essentially doubled over the latter part of the 20th century.

Thus, for the most part, and despite the fact that the second Art. 10 report, in particular, highlights the potential for growth in Swedish forests to increase by as much as 15% with increased fertilization, or by 2-3% with higher reforestation ambitions, little is being done to motivate such changes from the government side. On the other hand, the Swedish report laments the fact there are specific limitations imposed on the use of EU funds for promoting the conversion of farmland to forest land. Since Common Agricultural Policy (CAP) direct payments are essentially based on the requirement that farmland not have more than 60 trees per hectare, this sets significant limits on the potential for Swedish farmers to convert more farms to forest land.

One area where significant efforts have been promised is related to land set-asides for biodiversity and ecosystem service protections. In this area, the Swedish government has committed to increasing the amount of protected area to 1.142 million ha's by the year 2020. And this will include some 350,000 ha's of forest land. However, it should be noted that this has been an ongoing program in Sweden since 2012, and much of this land is already forested. Thus, while its status will change, annual carbon fluxes and permanent stocks will not change significantly as a result.

Perhaps more stunning is the fact that a relatively large share of net removals in standing forests cannot be accounted in Swedish reporting either to the EU, or to the UNFCCC, because these removals far surpass the limits set by the current EU "cap" framework, and thus do not "*qualify*" under any of the existing accounting frameworks. The likely incentive arising out of this framework is that Sweden will eventually see fit to use ever greater amounts of its annual net harvest potential. However, to-date, Sweden has not successfully managed to do this, and currently at least waste incineration has taken up for some of the available forest potential.

Thus, while Sweden sees great potential in the forest and forest resource-based sector, it is actually doing very little to provide additional incentives above and beyond what the existing market-based systems already provide. This is true as well for the great potential in building sector use of long-lived HWPs. Though the Swedish government has encouraged the building sector to emphasize and improve HWP use, current efforts exclusively involve informational campaigns.

Discussion & Conclusions

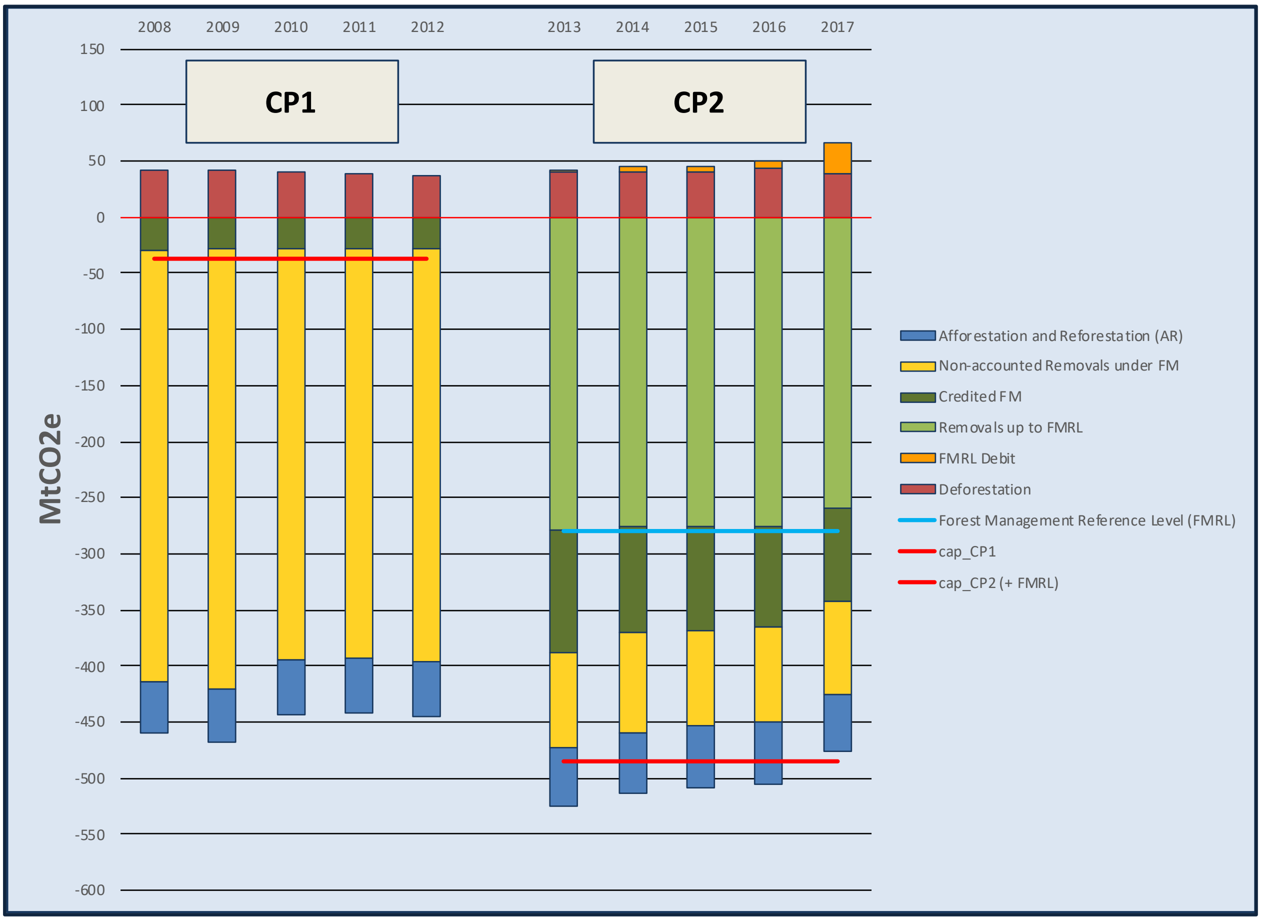


Figure IV: EU Net Annual Accounted LULUCF Impact – CP1 (2008-2012) & CP2 (2013-2017)

Note: The principal differences between CP1 and CP2 are the result of; 1) changes in the accounting rules (adoption of the FMRL and the revised cap methodology), and 2) the shift from voluntary to mandatory reporting and accounting under FM.

All in all, EU Member states generally seem to be fulfilling their LULUCF goals. However, the data for 2017 does indicate a larger shortfall than in previous years (Figure IV). Moreover, the overall trend in carbon sequestration across CP2 appears to be moving in the wrong direction. Still, no single EU Member state has dramatically under-performed, though a few Member states have experienced significant difficulties in more recent years (see Supplement, in particular Denmark, Portugal and Slovakia). Many of the earlier technical corrections were made to adjust the LULUCF framework to Member state conditions and to create a setting that might create incentives for future additional carbon sequestration in standing forests. On the other hand, many of the more forest rich states gain few incentives from this framework and continue to exhibit somewhat substantial unaccounted net removals in standing forests. This evidence suggests important “incentive gaps” continue to plague the current system and discourage future forest growth potential.

Many MS could presumably benefit from a more promising balance in the ARD segment between deforestation, and re- and afforestation. It remains unclear what the specific barriers might be.

While land competition between managed and unmanaged forest may explain some of this difficulty, many MS with lower levels of forest cover could presumably tolerate significant increases. Moreover, this segment is currently rewarded with the right to claim carbon credits. However, as with the failure to pass incentives on to forest owners and consumers, some misalignment between the national/federal ability to account carbon credits and the failure to pass these benefits on to lower level public sector actors and institutions may potentially obstruct more active mobilization under the current framework.

In the long run, strategies for mobilizing the HWP carbon pool are surprisingly absent from many or most of the Member state policy frameworks. At least one possible reason for this may be due to the difficulties associated with calculating what the exact return on investment in this particular segment. On the other hand, as many authors have attempted to illustrate in the past,[15,32] there are presumably handsome potential returns to the further mobilization of action in this segment. To the extent this is true, it begs the question why national Member state governments have not more effectively dedicated themselves to finding effective mobilization strategies for promoting greater use of long-lived HWPs.

Even this limited number of illustrations of three Member state cases effectively highlights that Member states are far more likely to consider mobilizing LULUCF activities that will benefit their reportable carbon accounting and are likely to ignore or disregard other aspects. This suggests first and foremost that the EU LULUCF policy framework must be considered the first tier in mobilizing states to undertake specific actions to motivate climate friendly forest actions. This fact, for example, explains well why the Netherlands seems keen on increasing forest cover on managed forest lands, while both Sweden and Romania have not taken up this opportunity. Likewise, Romania has clearly elected to focus on improving conditions in its ARD segment and Sweden, apart from the current land set-asides, is not undertaking additional actions in ARD or on managed forest lands.

Whether or not land and forest owners will respond to some of the incentives introduced at the national level remains uncertain. Romania is an interesting case in point, since it seems difficult to persuade farmers to give up CAP income, despite the fact that the incentives offered for afforestation are generous and cover both potential lost agricultural income for almost 15 years, and likewise cover what farmers would otherwise receive in direct single area payments. While the Romanian government might potentially have more luck encouraging forest owners to undertake additional efforts on managed forest lands, these would generally not be recognized within the current LULUCF carbon accounting framework.

One additional area that has been consistently neglected by all countries is the increased incentive to mobilize forest resources for long-lived harvested wood products and the HWP carbon pool. Since there are no longer any caps on the role this pool plays in the carbon accounting framework, Member states should be more strongly incentivized to develop framework and strategies for mobilizing this sector. To-date, however, we find little or no evidence that this is actually happening on the ground. Though Sweden, for example, has promoted making information about the advantages of wood products public through government-related websites, thus far there has been no consideration of more intensive efforts in this direction. Likewise, both Romania and the

Netherlands could also benefit from mobilizing long-lived HWP products and supporting related substitution.

Generally speaking, there is still considerable room for improvement in the EU and national level forest and forest-resource related climate policy frameworks. Finding strategies that are truly likely to mobilize action on the part of national governments, forest owners and other actors (e.g. consumers and the public sector) remains the principal objective and should concern policymakers, stakeholders and researchers for several years to come. We highlight, in particular, the restrictions imposed by the FMRL/FRL, the cap, and the apparent misalignment of incentives between actors across the various levels of governance (EU, national and down to the local level). The impact these factors are likely to have on the behavior of forest- and landowners, consumers and lower level public sector actors requires greater attention. This begins with the EU level LULUCF policy framework and continues on down through the Member states policy frameworks.

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Anexa 4. Two large-scale forest scenario modelling approaches for reporting CO_2 removal: comparison using Romanian national forest inventory data

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Abstract (max 350 words)

Background: This paper presents a quantitative comparison of forest dynamics, carbon stocks and fluxes for up to 2060, as simulated by CBM-CFS3 and EFISCEN. The aim is to compare simulation results from these two modelling approaches and identify the causes of any differences. Both these carbon bookkeeping models require forest inventory data as input. EFISCEN was originally developed to model forest resources, but CBM was developed as a carbon bookkeeping model from the outset.

Harmonized inputs of both models were based on data from Romanian national forest inventory (NFI-1, NFI-2), on Forest Available for Wood Supply (FAWS) which covered 6.1 million ha and provides data by area, age class, tree species, administrative region and land ownership. For the comparison, the models were input with identical management practices and climate data. No natural disturbances were assumed.

Results: Even though their inputs were based on the same data, the models behaved differently. EFISCEN started from a +1.5% deviation from the initial merchantable stock only estimate, but CBM deviated by +6%. In the CBM simulations, over time the forest aged more and the remaining stock of broadleaved species was larger than EFISCEN, due to different harvest applications per forest type. When enlarged with a smaller share of non-merchantable wood components, the ultimate carbon stock (2060) of total living biomass was 14% lower in EFISCEN than in CBM. In average over the simulated period, CBM distributes that difference 66% in merchantable and 34 % in non-merchantable compared to EFISCEN. Ultimately, the carbon sink of living biomass in CBM was 22% higher than in EFISCEN. The 22% difference is attributable to a counteracting mathematical effect arising when the accumulation of different percentages of bio-compartments, different trends in growing of the standing stocks in broadleaved and coniferous and divergent NAI are applied to the relatively low initial stock in EFISCEN and to the relatively higher initial stock in CBM. Soil accumulation was also diametrically different, tending to move away from equilibrium in EFISCEN but towards equilibrium in CBM.

Conclusions: The models showed a difference in output and need further improvements before they might serve in a global stocktake. A key point for attention in future updates is the average sink compilation: although national forest inventories are carried out in cycles of 5 – 10 years, CBM reports annual estimates, whereas EFISCEN simulates in 5-year time steps.

Keywords: CBM-CFS3, EFISCEN 4.2, CO_2 sink, Paris Climate Agreement, NFI, Romania, Managed Forest land, global stocktake.

Background

Forests play a very important role in the global climate, both through their biophysical influence on the climate and through their influence on the carbon cycle (IPCC SRCCL 2019). In the Paris Agreement (UNFCCC 2015), forests were recognized as an option to mitigate GHG (greenhouse gases) emissions at country level. Reliable monitoring of carbon flows is therefore essential when forest-related measures are adopted under the Paris Agreement and when the next global stocktakes take place in 2023 and 2028. This (under Article 14 of the Paris Agreement) is a process for taking stock of collective progress toward achieving the purpose of the Agreement and its long-term goals (UNFCCC 2015; Craft and Fisher 2018). If the baseline assessment of a forest carbon balance is not regarded as credible, the mitigation impact of measures will not be accepted (Grassi et al, 2018; Nabuurs et al, 2018a).

Since 2010, several forest model simulators have been developed. They range from forest decision support systems like MELA and Heureka (Redsven et al 2013; Wikström et al 2011), to continental land-use or global vegetation models like GLOBIOM, Orchidee or Lund–Potsdam–Jena model (Havlik et al 2011; Yue et al 2018; Smith et al 2001). The disadvantage of the decision support systems is that they differ considerably from real forest management practices in their timing, underlying methodology and scenarios. The disadvantage of the continental models is that forest cover is represented less precisely and often forest management is only marginally represented. The model used most frequently by the European Commission and various European countries is either the European Forest Information Scenario Model (EFISCEN), originally set up for forest resources management and wood availability in European countries, or the Carbon Budget Model (CBM), originally set up for monitoring forest carbon flows in Canada.

Both latter models can use datasets from national forest inventories (NFIs) or regional ones (Nabuurs et al, 2000, 2007, Schelhaas et al, 2017; Kurz et al, 2009; Stinson et al, 2011). Both models are important tools for delivering robust estimates for the reporting and accounting of carbon balances and demonstrating the effects of measures to mitigate climate change (Grassi et al, 2017, 2018; Nabuurs et al 2018b). Both EFISCEN and CBM can provide ex-ante estimates of carbon balances needed for carbon accounting, such as the Forest Management Reference Level and the Forest Reference Level (European Commission 2018).

In a review of forest carbon models that use growth & yield curves (Kim et al 2015), CBM and EFISCEN were analysed qualitatively. CBM-CFS3 is a carbon bookkeeping model for forest carbon, with inputs per compartment in terms of living biomass and of dead organic matter (NRCan 2019). The model investigates C dynamics in relation to natural and human-induced disturbances including land-use changes and a wide range of forest management options, in both small-scale and large-scale forests. EFISCEN is a carbon bookkeeping model geared to the European situation and built up from all compartments in biomass and dead organic matter pools. It projects forest carbon dynamics in combination with diverse scenarios and describes matrix structure large-scale forest ecosystem processes efficiently. In a more quantitative paper (Jonsson et al 2017), the maximum wood supply (MWS) in the EU was estimated using CBM and compared with that obtained earlier by Verkerk et al (2011) using EFISCEN: on average, CBM estimates of potential woody biomass were 20% higher than EFISCEN estimates, due to non-harmonized input data and the different forest management regimes in the EU Member States.

Even though both models rely on forest inventory data, uncertainties occur when the standard projections require specific pre-processing of yield and increment, additional parameters like biomass expansion factors, large variety of forest management approaches and parametrization processes affecting dead organic matter and soils decomposition.

To ascertain the reliability of EFISCEN, a run over a long time span was done, using historical forest inventory data from Finland and Switzerland, and after an additional uncertainty analysis for both countries, the EFISCEN model was refined (Nabuurs et al 2002, Thürig & Schelhaas, 2006), subjected to a model quality assessment and made available as open access software. Previous research has also been done on the reliability of CBM: an uncertainty assessment was executed first for the dead organic matter (DOM) pool in Canada's managed forests (White et al 2008) and later, Shaw et al (2014) examined the accuracy of CBM by comparing it with independent estimates for NFI ground plots across Canada. Metsaranta et al (2017) have calculated the precision of CBM by using Monte Carlo simulation approaches to propagate errors in model parameters and other variables in order to obtain confidence intervals for carbon stocks and fluxes.

Aim

Another way of assessing the reliability of EFISCEN and CBM is by comparing the results of simulations using harmonized inputs and assumptions derived from the same underlying data. This study set out to quantitatively compare the forest dynamics and carbon parameters for Romanian FAWS (forests available for wood supply) as modelled in EFISCEN (version 4.2) and CBM-CFS3 (version 1.2) and to identify and explain any differences originating from the two modelling approaches. Romanian forest was chosen for the case study because of its variety of forest types and forest management regimes.

Methods

The overall approach was to have harmonized inputs in CBM and EFISCEN. The specific inputs for each model were built from data regarding FAWS available from Romanian NFI: area aggregated by age classes for ten forest types, age-classes dependent standing stock volume and its net annual increment, annual harvested volumes (e.g. on thinning and final felling) as well as the mortality rate. These were further subdivided on administrative regions, ownership (e.g. public, private) and climatic conditions (e.g. as drivers for the dead organic matter decomposition). The results of a 50-year projection were then compared and causes of any differences analysed.

Although we tried to harmonize as much as possible, there remain some explicit differences between both models. After conversion to carbon figures, CBM-CFS applies carbon-based growth functions. EFISCEN has stem volume-based growth functions instead, and the conversion to carbon is done later in the simulation. Another difference between both models is that CBM runs a 1-year time step, whereas EFISCEN is based on 5-year time steps.

Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)

The CBM model was originally created to be applied to the Canadian forest inventory and aims to inventory carbon stocks and changes in managed and non-managed forests, with an adequate capacity to represent natural disturbances (e.g. forest fires, windthrow, tree diseases, etc.) in addition to regular human-driven disturbances such as harvesting. The CBM-CFS3 is actually an inventory-based, yield- and growth-data driven model for even-aged stands that simulates the carbon dynamics of above- and belowground biomass, litter, deadwood and soil pools at regional or landscape level. European applications include simulations of uneven-aged stands and coppices (Pilli et al 2013). The model identifies 5 biomass pools, 9 DOM C sub-pools, C related emissions from fires and a transfer to a wood products pool (Kurz et al. 2009). Carbon stocks and fluxes to the atmosphere are simulated with 1-year time steps, following the UNFCCC reporting requirements (IPCC, 2003, 2006) for national GHG inventories.

During the model run, a library of tables of the standing stock volume and its net increment (see Appendix A) define the biomass production by age class and forest type. The model performs a soil initialization process through multiple iterations until the slowly decaying carbon in DOM pools at the end of two successive rotations meets a tolerated difference of 1%. Once this steady state has been reached by soil-specific pools, the model grows each stand to the current age defined by its deviser, by applying the corresponding yield table. During the model run, the biomass growth of three aboveground and two belowground sub-compartments is allocated as a function of the age-class-dependent merchantable volume increment curves. The simulator transfers carbon to and among DOM pools and their emissions to the atmosphere; the proportion of carbon transferred depends on the composition of the sub-pool. Any type of anthropogenic intervention (i.e. thinning, clearcutting, salvage logging) or natural disturbance (e.g. fire, windstorm) can be applied by CBM, thereby defining a set of eligibility criteria and the specific impact on each carbon pool (Kull et al., 2016). There are currently some 300 types of natural disturbances available as a default in the CBM database (AIDB). The model has been applied to 26 EU countries, using NFIs' input data, in order to estimate the EU forest carbon dynamics from 2000 to 2012 and until 2030 under different harvest scenarios, including the effect of natural disturbances and land-use change (Pilli et al, 2013, 2016a, 2016b). Other countries are using it for scientific exploration or operational purposes (e.g. Kim et al 2015; Zamolodchikov et al 2013).

European Forest Information Scenario Model (EFISCEN 4.2.0)

EFISCEN is a detailed forest resource model (wood stocks, increment, harvests) based on about 5000 forest types for Europe. It depicts forest areas at regional (NUTS-2) scale in terms of age classes, growing stocks and increment, using data obtained from the latest available national forest inventory data (Nabuurs et al 1997, 2000, 2007, Karjalainen et al. 2001, Schelhaas 2007; Verkerk et al 2017). Based on this information, the model can project the forest development for different scenarios of wood demand, forest growth under climate change and various forest management regimes. These scenarios are mainly determined by management actions, but the model can also take account of changes in forest area (e.g. deforestation), in species composition and in growth (e.g. due to climate change). It has been used to investigate the impacts of forest management changes, biomass availability and carbon balances (Nabuurs et al. 2007). It has also been applied to set the forest reference level (FRL) of EU forests under the Kyoto Protocol's second commitment period (Böttcher et al. 2012) and to establish appropriate harvesting levels given the forest management reference level (FMRL) after 2020 (Nabuurs et al 2018b).

EFISCEN simulates stem volume and change over time. It is a matrix model in which the state of the forest is represented in matrices as an area distribution over age and volume classes (Salnäss 1990). Ageing is simulated as the area transferred to higher age classes, while growth is simulated as the area transferred to higher volume classes. The core of the model simulates stem growth. Stem volume is then scaled up to whole-tree biomass by applying age-dependent biomass expansion factors (personal communication 2018) for branches, roots and foliage (needles or leaves). The model incorporates an earlier version of the Yasso soil model (Liski et al 2005). Litter and dead wood are added from their various sources and divided into litter quality classes; these decays and are transferred to five soil pools driven by climate sensitive functions.

There are two ways of initializing soil carbon stocks in EFISCEN. One is to define the stocks for all litter compartments (as total carbon in the forest type, Gg C); the other is to run a spin-up in which the litter input of the first time step is used as input to Yasso, and then Yasso is run repeatedly until the stocks are in balance. The spin-up will run automatically if the initial stocks are set to zero. For the comparison we used the second method, i.e. to run a spin-up, as we did not have data on carbon stock values for Romanian litter compartments and tree species.

The factor driving forest management in the EFISCEN model is the harvesting regime. Harvest regimes are specified at two levels in the model. First, a basic management regime per forest type and country defines the age range during which thinnings can take place and a minimum age for final fellings. These regimes can be regarded as constraints on the total harvest level. Multiplying the area available for thinnings and final fellings by the corresponding wood harvest gives the volume of wood that is theoretically available for harvesting. In the second step, the actual demand for wood is specified for thinnings and for final felling separately at the national level. The model calculates the volumes of the available potential that needs to be harvested to satisfy demand and implements this calculated intensity in the simulation. Thinning is simulated by transferring area to a lower volume class, while the difference in volume is assumed to be the volume that has been removed by the thinning. Final felling is simulated by moving the area back to the first volume and age class of the matrix, from where it can start growing again. The difference in volume is assumed to be the volume removed by final cut (Verkerk et al 2017). The model can be used for upscaling the effects of natural disturbances and adaptive management (Schelhaas et al 2015) and trade-offs with biodiversity and deadwood (Verkerk 2015).

Approach, parameterization and input data

The input parameters for CBM and EFISCEN are described in Appendix A. Our analysis is based on one reference scenario only, business as usual (BAU). We did not include natural disturbances in our comparison. DOM pools were simulated with default model parametrization. As we did not include any recovery of tops and branches, all slash remains in the forest after felling. In order to ensure comparability with EFISCEN results, CBM results were converted back to volume using the inverse of volume-to-biomass equations.

CBM-CFS3 and EFISCEN-4.2's input parameters are also given in Appendix A. Conceptually the models do not differ very much in that both represent the forest–soil–wood harvest carbon cycle.

The main parameters determine land use (and land use change), forest growth, forest management, non-merchantable wood percentages and the options to include carbon in forest soil and harvested wood products (HWP). However, the underlying data are processed in slightly different ways: in EFISCEN the biomass compartments are age-class dependent. CBM applies equations for the weight of other biomass compartments, starting from the standing volume.

FAWS input data from Romanian National Forest Inventory

Data representing the state of the forest in 2010, the mid-year of the national forest inventory (NFI1: www.roifn.ro), was used as input into the models. We used the available data for “forests available for wood supply” (FAWS) for comparison of CBM with EFISCEN. The FAWS (6.07 million ha) are about 88% of the total forest area of the NFI1 (6.90 million ha). The remaining 12% is protected, not accessible, not managed or otherwise not available for wood supply. Ten major forest types are defined in the NFI (Appendix B). The defined forest type strata are distributed across seven NUTS-2 administrative units (regions), two types of forest owners (public, private). Forest state parameters are available for age classes of 10 years (e.g. age class 1 includes stands 0 to 9 years old, age class 2 is stands 10 to 19 years old, etc.). We assumed one general site class index for the forest growth conditions.

To convert from standing merchantable wood volumes (in m^3) to biomass (in tonnes) we used available Romanian tree wood densities (Mos 1985) as well as the proportion of bark and branches (Giurgiu et al 1972). The BEFs were estimated as one percentage per forest type and per age classes of 10 years for EFISCEN. For CBM, the values of the four biomass sub-pools (stemwood, bark, branches, foliage) on age-class were simultaneously fit as function of the merchantable volume by a model mimicking Boudewyn approach (Boudewyn et al., 2007). For all biomass compartments, we assumed 50% carbon per kg dry matter (Table 1).

Table 1 Percentage share of various components of the C stock in the total living biomass pool. In order to make them comparable, the varying CBM and EFISCEN biomass types have been allocated over four compartments and aggregated for all species*

Model	Time step	Merchantable stem**,*** (%)	Foliage (%)	Other wood (i.e. tops, stumps) **,*** (%)	Coarse roots*** (%)	Fine roots (%)
CBM	2010	66	2	16	14	2
	2060	64	2	20	13	2
EFISCEN	2010	70	3	9	16	2
	2060	71	2	9	16	2

* in % of total tree carbon from simulations outputs as C content. Carbon content & mass density are assumed to be the same for all bio-compartments per forest type;

** CBM “merchantable” includes stemwood overbark (up to threshold diameter). Tops and aboveground stumps with their bark is included under “Other wood”.

*** EFISCEN reports stemwood overbark and tops, stumps are included in the coarse roots.

In addition, the mortality rate and the standing deadwood fall rate were first harmonized for CBM, based on the NFI-1 and NFI-2 outcomes for the annual change in mortality volume between 2010 and 2015 (0.96 m^3 ha^{-1} yr^{-1}) and the standing deadwood volume in 2010 (NFI-1: 8.8 m^3 ha^{-1}) (see Appendix C). The deadwood fall rate defines the proportion of the standing deadwood pool that is transferred as lying deadwood to the litter and mineral soil pool. EFISCEN used the input parameters calibrated by CBM for annual mortality (0.3% of standing merchantable wood stock) and annual fall rate of deadwood (8.8% of standing deadwood stock) over 50 years. In addition to harmonizing the merchantable volume, we harmonized the turnover of the other biomass compartments to the litter and mineral soil pool. For example, a 2% turnover of living coarse roots to the litter layer was applied each year (Appendix C). Decomposition was based on default parametrization specific to each model.

Finally, the turnover within the litter and mineral soil compartments is relevant for the carbon stock and carbon flux in the forest soil. This turnover differs between the CBM and EFISCEN processes: in CBM it is modelled by an integrated DOM soil module (Kurz et al., 2009), whereas in EFISCEN it is modelled by the Yasso07 soil module (Liski et al, 2005). In order to compile the biomass turnovers and soil decomposition rates, the CBM soil module distinguished 8 climatic regions by means of historic rainfall and temperature data. The EFISCEN soil module also uses region-specific climate parameters (Schelhaas et al 2004): degree days (temperature in growing season) and the drought index (difference between rainfall and evaporation). Those parameters are based on the historical weather patterns (1979-2017) in the ECA&D database (Klein Tank et al 2002, Haylok et al 2008).

Results

Forest dynamics

In Figure 1, the CBM and EFISCEN estimates of the forest area by age class at the end of simulation period are compared with the NFI estimates at the beginning of simulation period. For the purposes of the comparison, we aggregated EFISCEN's 10-year age classes into 20-year classes, to match the selected CBM output. Both models show an ageing forest resource towards 2060, developing from a relatively young Romanian forest resource with most of its areas in youngest age class. At the end of the simulation period (2060), CBM shows a strong ageing of forest whereas EFISCEN's forest remains younger: it has a larger area of age classes below 80 years. For example, EFISCEN has four times larger area in the youngest age class below 20 years, whereas CBM has a 55% larger area in the oldest age class above 140 years. The FAWS area is currently consisting of 17% coniferous, 63% broadleaved based forests and 25% mixed forests (NFI-1). In both models, the area division of forest types which remains stable over time, except for some negligible area changes due to deforestation.

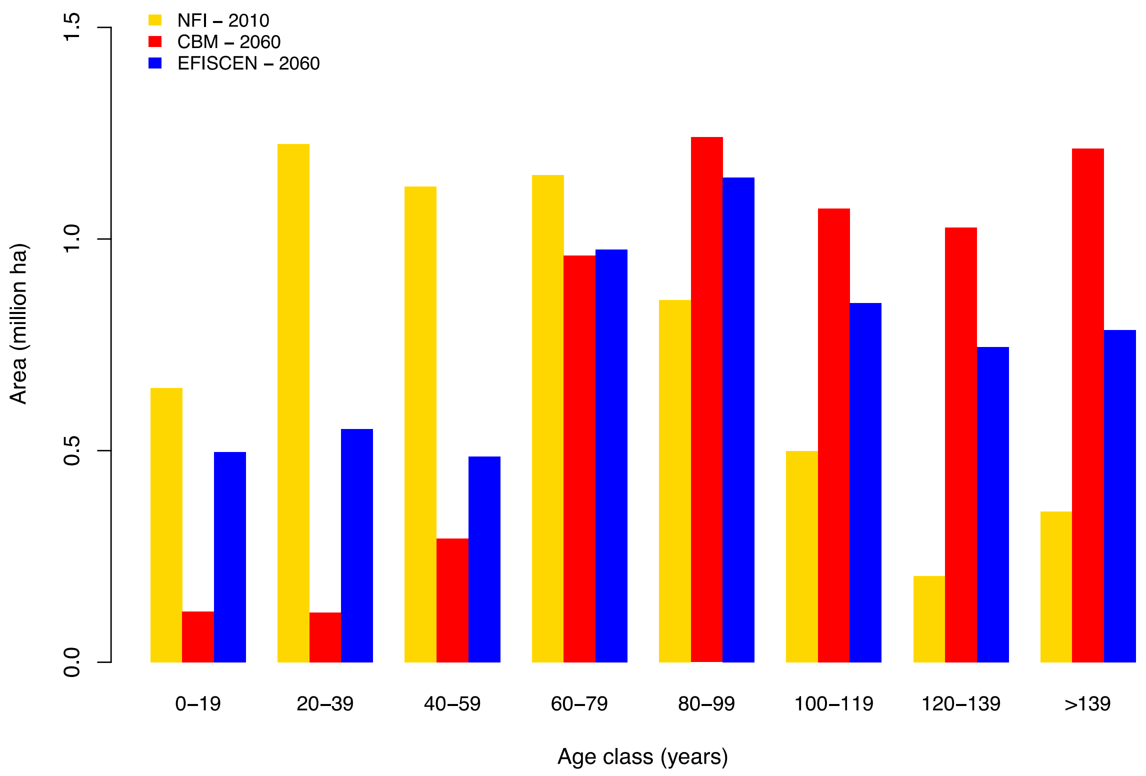

Figure 1. Age class distribution (area in million ha) in 2010 (NFI-1) and 2060 (simulated by EFISCEN & CBM)

In Figure 2, we compare the initial standing growing stock as simulated by the models with NFI data and show the development over time. Whereas EFISCEN starts close (+1.5%) to the initial data from the Romanian NFI or FAWS, which is 247 m^3 ha^{-1}, CBM gives a growing stock that is 6% higher than the NFI figure. At the end of the modelling period, the growing stock of EFISCEN has increased less than that of CBM and is below 360 m^3 ha^{-1}, whereas CBM ends up below 390 m^3 ha^{-1}. In EFISCEN, the proportion of coniferous (in % merchantable stock) increases from 32% to 33% and the broadleaved species decrease from 68% to 67% in 2010-2060. In CBM, the proportion of broadleaved forests increases by 59%, mix forests by 40% while coniferous decreases by 5%. The opposing species trends are attributable to a difference in the models' harvest applications (see Discussion section).

In the period 2010-2060, the volume of merchantable tree stock increases by 1.4 m^3 ha^{-1} in CBM and by 1.6 m^3 ha^{-1} in EFISCEN (Figure 2), reflecting the differences between NAI and felled tree volumes simulated. For comparison, we added the Forest Europe (2015) figures for FAWS (merchantable tree stock[1] starting at 1.1 billion m^3) and the original NFI estimates for the total Romanian forest in 2010 (tree stock[1] starting at 2.0 billion m^3). Due to a different definition of "forest", Forest Europe (2015) has a much smaller FAWS area and related smaller standing stock volumes. The trends shown in Figure 2 by the 2010 and 2015 dots for Forest Europe and those for the original NFI data correspond to less realistic increases in tree stock: 13.6 m^3 ha^{-1} yr^{-1} for Forest Europe and 3.2 m^3 ha^{-1} yr^{-1} for NFI.

[1] In the State of Europe's forest (Forest Europe 2015), "growing stock" refers to the volume of tree stem, whereas original NFI stock data refer to total tree including branches. We excluded the branches by assuming 9% branches in total tree volume in 2010-2015 (Table 1).

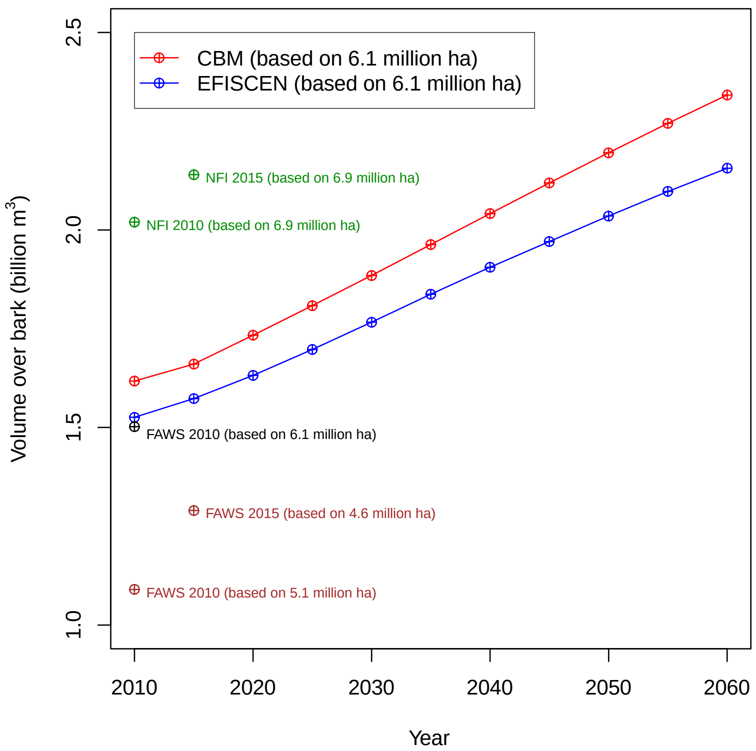

Figure 2. Volume of total standing merchantable stock (billion m^3, overbark) simulated by CBM and EFISCEN.

Legend:

The merchantable stock volume for FAWS in 2010 as estimated from NFI-1 (black dot). For comparison we added the total aboveground volume for national forests from NFI 2010 and 2015 (green dots, top left) and for FAWS in 2010 and 2015 according to Forests Europa (2015) (brown dots, bottom left).

The projected actual increment (Figure 3) yielded by the models differs by 1% to 9%. In both models, the NAI first increases until 2035. The somewhat larger increasing trend in EFISCEN may be caused by a pre-specified function (boost factor) that determines regrowth after thinning interventions (Appendix A). The growth curves in both EFISCEN and CBM then decline somewhat due to the growing proportion of old stands (Figure 1). But one might expect a larger NAI in EFISCEN than in CBM, because of the stronger ageing of forest stands in CBM, although larger area of very young stands in EFISCEN seems to affect more the annual increment. For comparison, the outcomes of both models are within the range for the rough estimate of NAI by Forests Europe (2015) and the annual increment data from the NFI-1 and NFI-2.

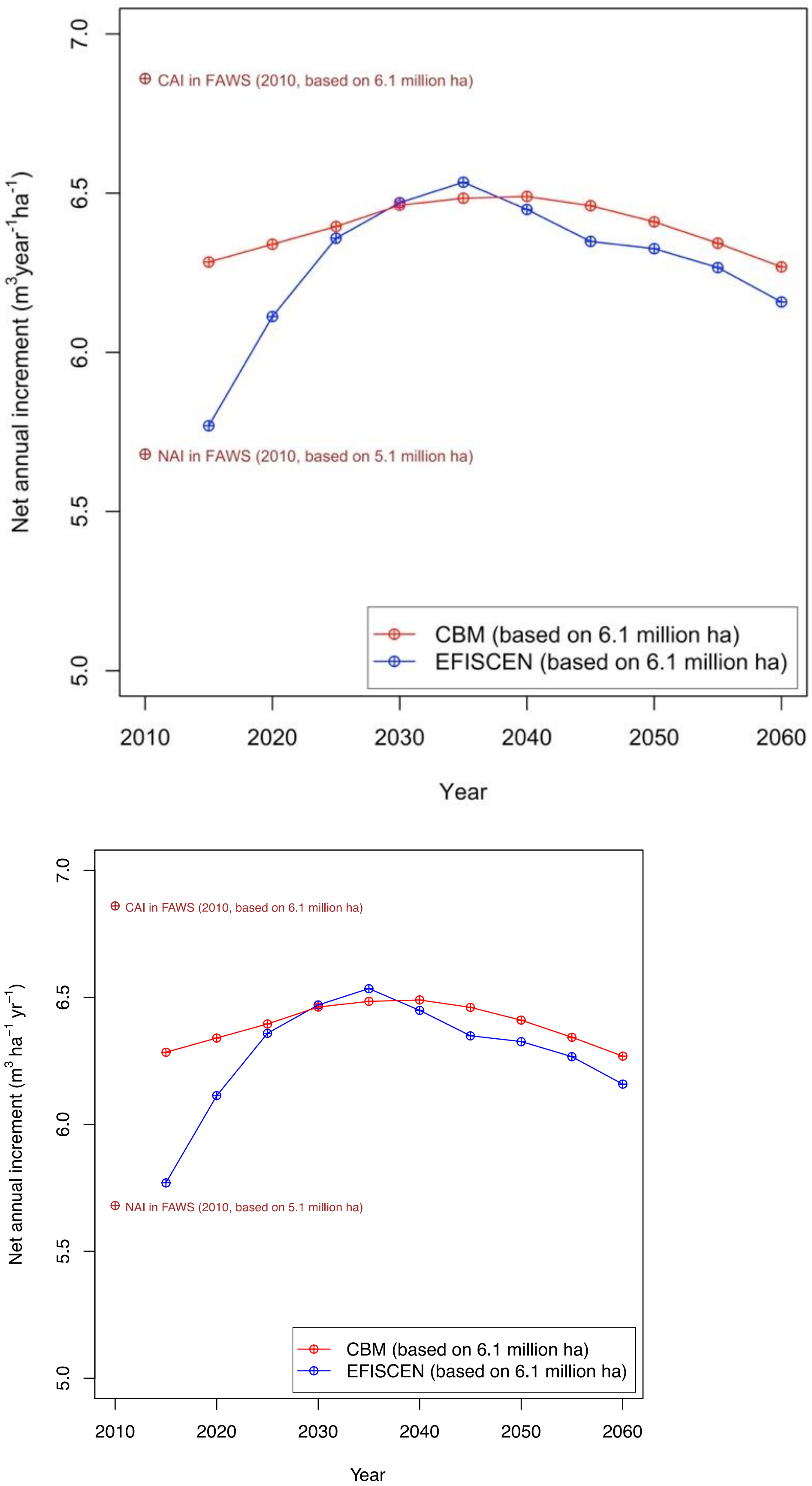

Figure 3. 5-year average NAI of growing merchantable stock in 2015-2060 (as simulated by CBM and EFISCEN).

Legend: for comparison we added the estimated CAI of merchantable aboveground volume as reported in an early stage (Forest Europe 2015) and the NAI of the standing stock from NFI-2 (2015).

One of the key driving factors for the growth and carbon dynamics in the simulations is the harvest. The CBM and EFISCEN harvest levels in Figure 4 show a constant removal of 3.8 m^3 ha^{-1} yr^{-1} (left-hand Y-axis). So, both models satisfy a demand of about 23 million m^3 (right-hand Y-axis) during the simulated period. The proportions of thinning and final felling in total wood removals remain constant, at 60% and 40%, respectively. There is one key difference in harvest application: whereas in CBM the harvest is specified per forest type, in EFISCEN, the allocation is more dynamic (see Discussion section for more details). In fact, the harvesting level is equivalent to an aboveground volume of approximately 28 million m^3 if as well as the stems, the treetops and branches are included. After felling, the treetops and branches are not recovered, but in both models remain in the forest as slash.

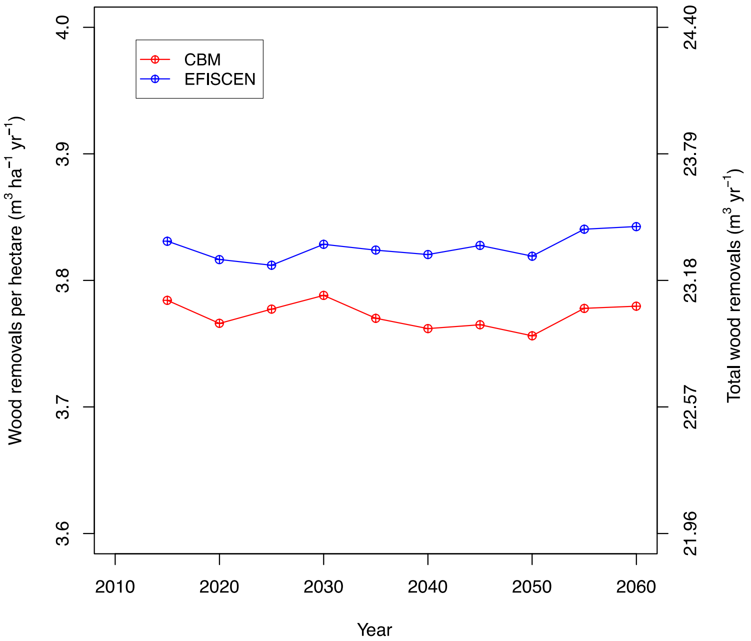

Figure 4. Dynamics of merchantable wood harvesting (overbark) in Romanian FAWS, as simulated by EFISCEN and CBM. Legend: left-hand Y-axis: removals in m^3 ha^{-1} yr^{-1} (excl. tops); right-hand Y-axis: removals million m^3 yr^{-1} (excl. tops)

To account for mortality, CBM calibrates with the available NFI figure for 2015 (0.96 m^3 ha^{-1} yr^{-1}). The resulting 0.3% annual turnover of standing merchantable wood to the pool of standing deadwood was introduced in EFISCEN as consecutive increments of 1.49% per 5-year time step (Appendix C). Next, the decay of standing deadwood was calibrated in a similar way for both models. According to NFI, on average, a Romanian standing dead tree falls over in about 11.5 years and is turned over to the forest floor pool. In both models, the decay rate was expressed as 8.8% of standing dead trees per annum. Figure 5a shows the mortality of living trees and decay of dead trees, both expressed as m^3 ha^{-1} yr^{-1}, excluding branches and roots. Because CBM started with a slightly higher initial stock (Figure 2) and ended with a larger area of older age classes in its living biomass (Figure 1), on average, the forest mortality of CBM increased more than that of EFISCEN. None of the implement mortality in forest areas subject to harvesting measures in the simulation step (thinning, final cut) and thus applied the 0.3% mortality rate to non-harvested areas only. If we had applied a negligible harvest, EFISCEN would have reached a mortality of about 1.3 m^3 ha^{-1} yr^{-1} at the end of the modelling period.

The actual standing deadwood volumes in EFISCEN and CBM in 2010 are respectively 28% and 25% less than the initial standing stock for deadwood in NFI (Figure 5b). In both models, the standing deadwood volumes decrease slightly in the first stages and after a while increase towards the end of the simulation period. This pattern arises because in the first stages the limited mortality (flux into the pool of standing deadwood) is smaller than the decay (flux out) but towards the end, the mortality starts to overtake decay.

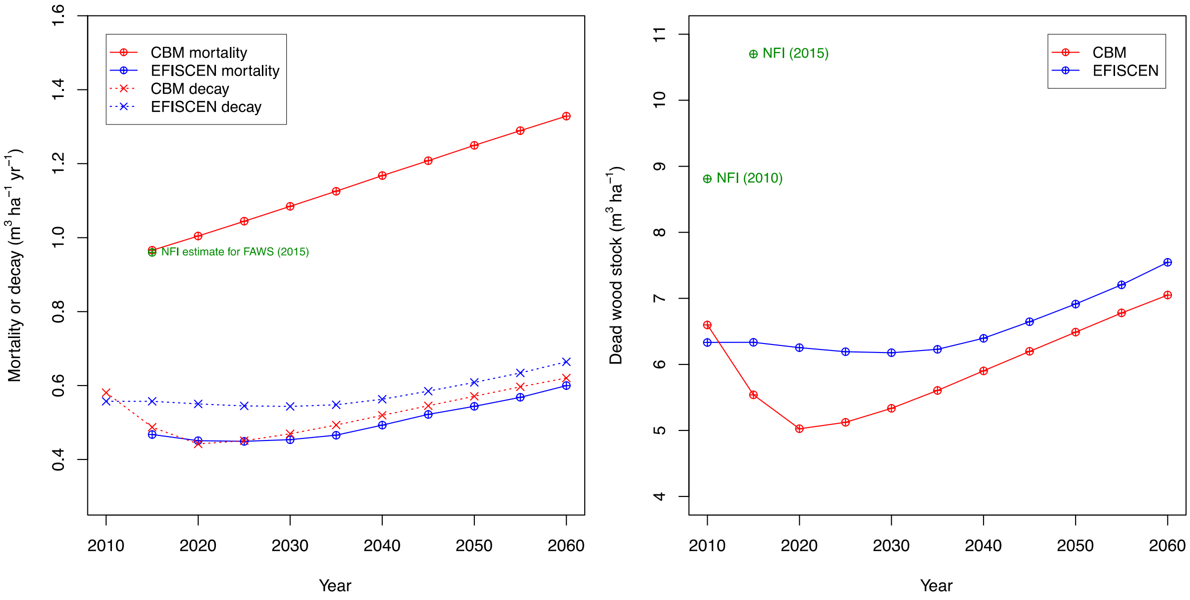

Figure 5 Dynamics of annual mortality rate, decay rate and standing deadwood stock (m^3 ha^{-1} yr^{-1}) for CBM and EFISCEN by comparison with Romanian NFI data.

(a) Legend: mortality of standing merchantable stock and the annual decay (or fall rate) of standing deadwood stock. Green triangle below of red solid line represents NFI estimate for FAWS.

(b) Legend: Standing deadwood pool in m^3 ha^{-1}, aggregated for all species at national level. In green: NFI estimates for FAWS. The pool of lying deadwood is not considered.

Carbon *stocks and fluxes*

The total carbon stock in merchantable wood differs between the models, although it steadily increases over time in both models (Figure 6a, dotted curves). In the initial year of the simulation (2010), there is already a 7% difference between the models in the C stock in merchantable wood: in EFISCEN the C stock is 0.422 billion tonnes and in CBM it is 0.452 billion tonnes. The difference in 2010 is attributable to the reconstruction from yield curves of the initial standing stocks by CBM and not using exact the same data from NFI as EFISCEN does. By 2060, the difference between the models in merchantable wood C stock has increased to 13%: 0.595 billion tonnes C in EFISCEN and 0.671 billion tonnes C in CBM, which represents an increase of +48% in CBM compared to +41% in EFISCEN, when comparing 2060 vs. 2010. There are several reasons for the larger C stock differences in 2060: a diverging NAI (on average 2% larger in CBM) and harvest (slightly lower amount and fix amounts allocation across forest types by CBM), and an increase of the standing C stock given the increasing standing stock of broadleaved forests from 2010 to 2060 by CBM (i.e. CBM simulates 22% more standing volume of broadleaved forests, i.e. with higher density, compared to EFISCEN). See the Discussion section for more details.

The C stock of total living biomass increases from 110 tonnes C ha^{-1} to 160 tonnes C ha^{-1} in CBM and from 100 tonnes C ha^{-1} to 140 tonnes C ha^{-1} in EFISCEN (derived from solid lines in Figure 6a, and divided by area). For comparison: Bouriaud et al (2019) found that aboveground biomass in Romanian beech forests increased with stand age across all management types and treatments, reaching about 150 tonnes C ha^{-1} (equivalent to 300 tonnes biomass ha^{-1}) at an age of 100 years. Their reported value is within the modelling ranges of both CBM and EFISCEN.

When we consider the actual differences for total living tree biomass, the disparity between the models is 11% in 2010 and 17% in 2060, with CBM having the higher figures, which represents an increase by +44% in CBM and by +36% in EFISCEN when comparing 2060 with the reference year 2010. This disparity might be attributable to the basic inter-model difference of 7% for merchantable wood only and to the proportion of non-merchantable biomass components in total living biomass computed by EFISCEN being 3% less than that computed by CBM. The difference in mutual C stocks grows from 13% for merchantable wood only in 2060 to 14% for total living biomass in 2060. This can be explained in the same way: at this timepoint, CBM has 1% more non-merchantable biomass in total living biomass (Table 1 shows the percentages).

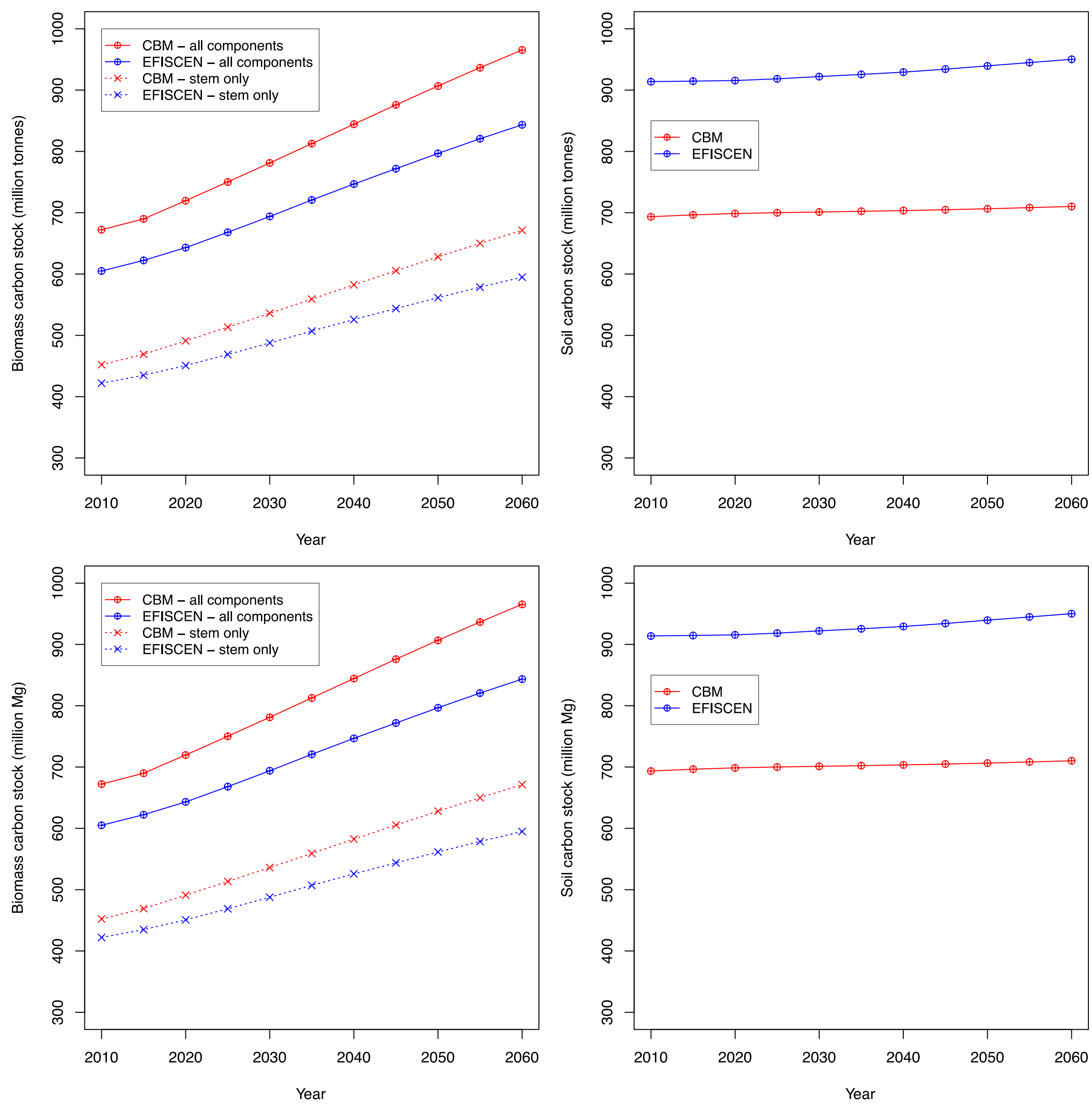

Figure 6. Trends in C stocks in Romanian forests

(a) merchantable and total living biomass (1000 tC) Legend: * stem only is merchantable timber including bark excluding foliage, branches and roots

(b) carbon stocks in forest soil estimated by CBM and EFISCEN. Note: CBM has an integrated DOM module; EFISCEN applies the Yasso submodule (Liski et al 2005).

The carbon stock in the aggregated litter and soil layers is on average 32% larger in EFISCEN than in CBM. The key factor explaining this large discrepancy is the initialization of carbon stocks in the base year 2010 (see Methods section). EFISCEN starts with just over 900 million tonnes of carbon in the Romanian forests (FAWS) through an equilibrium initialization run, whereas CBM starts with just under 700 million tonnes of carbon (Figure 6b). From 2010 to 2060, the average soil carbon stock increases from 151 tonnes C ha^{-1} to 157 tonnes C ha^{-1} in EFISCEN but from 114 tonnes C ha^{-1} to 118 tonnes C ha^{-1} in CBM. By comparison, an in-depth study (Dinca et al 2012) showed an average of 137 tonnes C ha^{-1} for the carbon stock in Romanian mineral forest soils in 2000-2006. This value is within the modelling range of both EFISCEN and CBM.

In EFISCEN, the carbon sink for merchantable timber only (defined as negative flux), starts at -9.5 million tonnes CO_2 yr^{-1} and stabilizes at around -12 million tonnes CO_2 yr^{-1}. In CBM, this flux fluctuates between -15 million tonnes CO_2 yr^{-1} and -17 million tonnes CO_2 yr^{-1} (Figure 7a). The EFISCEN's carbon sink for total living biomass starts at -12.7 million tonnes CO_2 yr^{-1}. After peaking at almost -20 million tonnes CO_2 yr^{-1}, it declines to -16.7 million tonnes CO_2 yr^{-1} in 2060. The CBM total biomass flux remains relatively stable, ranging between -20.8 and -23.2 million tonnes CO_2 yr^{-1}. At the final time step, the difference between models in the carbon sink of the total living biomass is as much as 22%. The 22% discrepancy occurs through cumulation effect of mutual differences between both models, i.e. NAI (Figure 3), proportion of non-merchantable wood components (Table 1), applied harvest level (Figure 4) and the forest types contribution to standing stock (Discussion section).

By comparison, Romanian data reported under the Climate Convention (UNFCCC 2018) are shown for 2010 and 2015 (green dots). They are in the same range as CBM. However, the reported UNFCCC data show an opposite trend to the outcomes of both models.

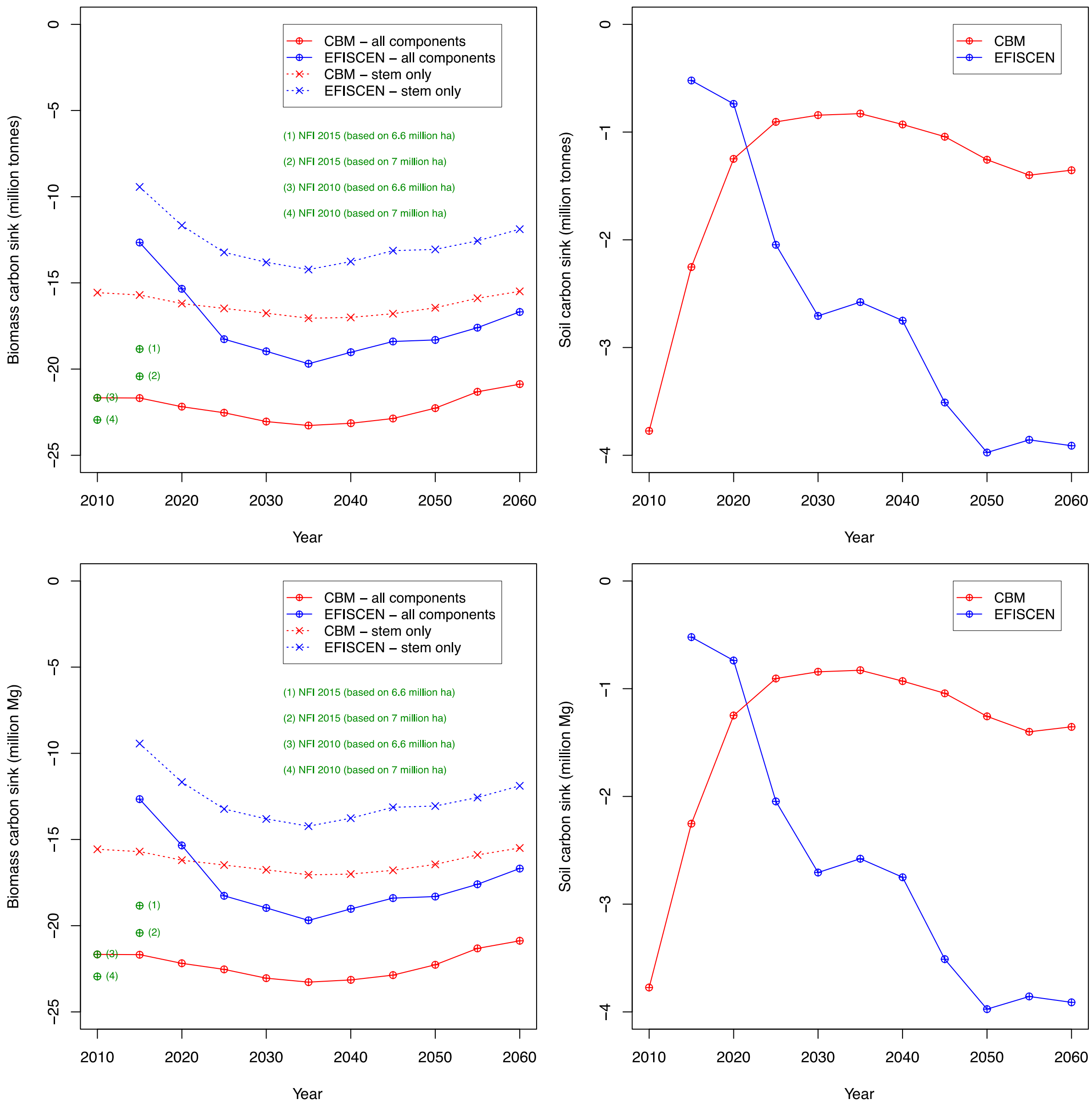

Figure 7. The carbon sinks in living biomass and soil in Romania, as modelled by EFISCEN and CBM:

(a) Annual carbon sinks for merchantable stem and total living biomass

Legend: green dots indicate the sinks for total living biomass in Forest remaining forest (6.6 million ha) and in total Romanian forest (7.0 million ha) reported to UNFCCC (2018). Negative numbers are sinks, i.e. carbon uptake by the forest biomass.

(b) Carbon sink in forest soils Legend: Negative numbers are sinks, i.e. carbon uptake by the forest soil.

The soil C sink (defined as a negative flux) starts at around -3.7 million tonnes CO_2 yr^{-1} and moves towards zero in CBM. EFISCEN's soil sink starts from zero in 2010. After the zero start, the EFISCEN sink increases, although it seems to stabilize at around -3.7 million tonnes CO_2 yr^{-1} in 2060.

There are various possible reasons for the opposing sink trends in Figure 7b. First, total living biomass stock is somewhat larger in CBM (Figure 2) and thus there is already some difference in the corresponding total turnovers of living biomass to the forest soil. Further, all slash remains in the forest and thus the decay of standing deadwood differs slightly between the models (Figure 5a). Moreover, the submodules for soil carbon have a different approach for the carbon outflow. On the one hand, EFISCEN simulates less carbon release to the atmosphere and has a clearly longer build-up of carbon in the soil due to the specific solution rates of organic carbon in the combined humus and soil layers. This difference is related to the Yasso soil submodule in which so-called AWEN values for soluble fractions in acid, water and ethanol, and non-soluble fractions are defined for small, coarse and non-woody litter (Liski et al 2005). On the other hand, apparently CBM has a relatively quick release of soil carbon to the atmosphere. As such, the CBM-specific soil carbon submodule allows for a relatively lower retention of carbon.

Discussion and conclusion

The empirical forest simulation models CBM and EFISCEN are both in use as carbon bookkeeping models for managed forests. Both models are used to obtain estimates for the reporting and accounting of forest carbon balances and can demonstrate the effects of climate change mitigation measures (e.g. Grassi et. al 2017, 2018; Nabuurs et al 2018b). We compared the forest growth and carbon dynamics by using the NFI data (2010) for Romanian FAWS; the comparison is based on simplified modelling of forest management practices.

Forest dynamics, carbon stocks and fluxes

Despite efforts to harmonize most of the input parameters, there remained six important differences in the results between the two models for forest dynamics, carbon stocks and fluxes:

(i) The initial values of merchantable standing stock volume in 2010 were 6% higher in CBM, while EFISCEN started 1.5% above the NFI reported estimate (Figure 2). The deviation of CBM from the measured standing stock in the initial year was most likely caused by the reconstruction of forest status in the initial simulation year (2010). The deviation is a cumulative effect of a) the distribution of forest types within the age classes through equal areas corresponding to a 1-year time step, and b) the user-defined volume yield curves associated with an inherent uncertainty of the fit of NFI measured data. In this case, the yield curves were derived as age-class-dependent standing stock volume per forest type and per owner type data available as averages at the region (NUTS-2) level and unfortunately not available in more detail (per NFI plot). To keep the required initialization data to a minimum, only the area and the mean growing stock volume per age class were retained in EFISCEN for the initial year of simulation. After that, the volume distribution over age classes (matrix columns) was generated by an empirically-based function (Schelhaas et al 2007). The aggregation of all individual volumes to a nationally aggregated volume may have caused the 1.5% overestimation in EFISCEN. Appendix D illustrates the detailed divergence between both models for the carbon stock (Figure D1a) and standing merchantable volume (Figure D1b) when applying a dedicated

Bland–Altman analysis. Whereas the NAI (Figure D1c) has a relatively small bias (differences close to zero on the Y-axis), over time, both the carbon and volumetric stocks show more bias, e.g. CBM simulates an annual average of 66% more biomass in these compartments than EFISCEN. Another reason for the bias effects could be the average sink approach: CBM reports annual estimates, whereas EFISCEN compiles 5-year averages for each "time step".

<u>(ii)</u> Both models show that forest ages over time. However, the age class distribution deviates during the simulation (Figure 1). By the end of simulation period, CBM has a larger area in age classes older than 140 years, whereas EFISCEN has a larger area of age classes younger than 80 years. Implicitly there is a shift of forest types' contribution to the standing volume. After 50 years of forest management, the standing stock contains relatively more broadleaved trees (higher wood density) according to CBM but relatively more coniferous (lower wood density) according to EFISCEN (Figure 8). The difference of forest type contribution in standing stock volumes is attributable to different harvest specifications at country level and the resulting harvesting volumes per forest type.

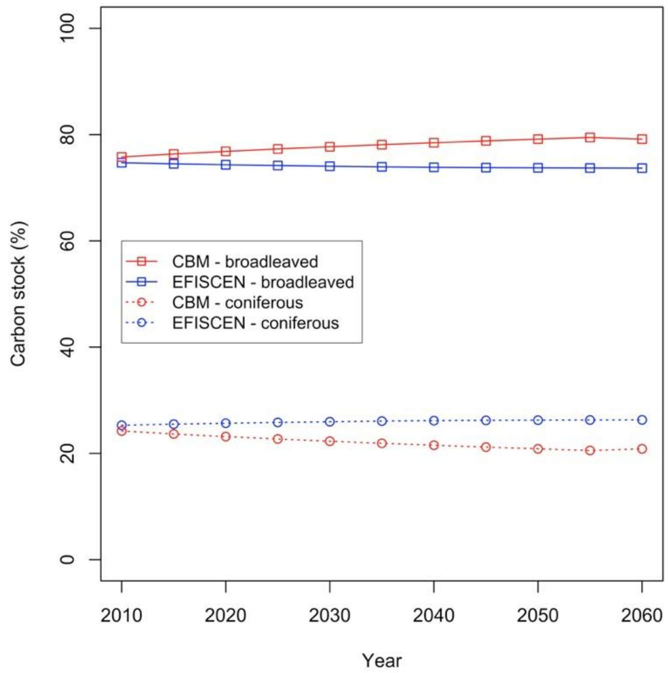

Figure 8. Carbon stocks in both models over time – divided over coniferous and broadleaved*

Legend: * the species share is expressed as % of total standing carbon stock. We roughly assumed that the mixed species are equally divided over coniferous and broadleaved species

(iii) Despite the total harvested volumes of EFISCEN and CBM differ by only about 1% in 2010-2060 (Figure 4) with a fixed ratio of 60% thinning and 40% felling throughout the modelling period. On average, around 66% of NAI is felled in EFISCEN and 64% in CBM. However, the way it was applied by each model has significant effect on simulations: EFISCEN randomly selects forest types for satisfying the total harvest volume (free allocation), whereas in CBM the thinning and final felling amounts are fixed per forest type (detailed allocation) for each year of the simulation (constant in time). This led to an unrealistic harvest of various forest types on long run, e.g. resulted in a growing contribution of broadleaved forests by CBM. From multiple choices to define harvest in CBM, harvesting applied "oldest stands felled first" on a constant amount of merchantable carbon. EFISCEN has a "time slot" (i.e. fixed lower and upper age classes) per forest type for thinning interventions, immediately followed by the minimum age class eligible for final felling. EFISCEN distributes harvest over forest types depending on the available volumes for the predetermined age classes for thinning and felling. If the thinning specifications are too tight, the required volumes will not be reached. As a result, in EFISCEN, the proportion of the harvest that is coniferous increased until 2060 and there was a corresponding decrease in the proportion of the harvest that is broadleaved.

<u>(iv)</u> Due to deviating harvest specifications, CBM simulated 59% higher contribution of broadleaved forests in the initial standing stock than the initial stock in 2010. Opposite, EFISCEN's forests have 1% more volume of coniferous trees (lower density) in their final stock than in the original stock. The overall effect is a growing standing stock carbon content in CBM (+2.5%) while in EFISCEN, the average carbon content per m^3 decreases slightly (-0.25%).

<u>(v)</u> Overall, there is an enhanced, but non-corresponding model effect on CO_2 fluxes for the forest biomass. For example, the sinks show a 22% difference in 2010-2060, i.e. -16.7 million tonnes CO_2 in EFISCEN versus -20.9 million tonnes CO_2 in CBM. Despite different but equally justifiable procedure, there is an arithmetic aggregated effect, when the small, apparently insignificant differences in NAI, harvest level achievement, harvest distribution on forest types, shares of other biomass compartments, changing the share of the forests types with different wood density in the total standing stock are all applied to relative low carbon stocks in EFISCEN versus relative high carbon stocks in CBM.

One of the most crucial elements is the estimation of non-merchantable biomass compartments (branches, foliage, roots), i.e. CBM simulates an annual average of 34% more biomass in these compartments than EFISCEN. Despite trying to harmonize the non-merchantable biocomponents as much as possible, we were left with different percentages for some of the non-merchantable biocomponents, as shown in Table 1. Whereas EFISCEN uses a straightforward approach in which a BEF specific to the forest age and type of each non-stemwood biomass compartment is applied directly to standing volume, CBM requires to be input with the relative proportions of four biomass compartments of the aboveground biomass (i.e. stemwood, bark, branches and foliage) estimated as relative to standing merchantable volume. As a result, CBM is sensitive to any underestimation of the proportion of stemwood biomass (Figure D2a) and simultaneously also to an overestimation of allocation in the other biomass compartments (Figure D2b; Figure D2c). Special attention must be paid to the stump, which is allocated to the aboveground biomass in CBM, but in EFISCEN is allocated to coarse roots. According to CBM specifications (Appendix D), about 2-3% of the aboveground biomass is represented by the stump.

<u>(vi)</u> During the simulated 50 years of forest management, the increased uptake of carbon per ha by forest soils (start and finish in Figure 7b) is only slightly larger in EFISCEN (4%) than in CBM (3%). However, both models show trend difference: the soil module of EFISCEN starts from an equilibrium at the start (after spin), and then the sink increases with time. The reverse is true for CBM: it starts from a certain sink and after 50 years that sink approaches zero. Thus, there is a large difference between the models in how they deal with carbon inflow to the soil. One way to solve the opposing trends would be to start with similarly sized forest carbon pools. For EFISCEN this means that the

initialization of soil carbon should start from actual carbon values in the soil instead of starting from a spin to the equilibrium stage (see also Methods section). As an extra feature for Europe in the near future, the soil carbon submodule of CBM could also be represented by the latest Yasso 15 model (Repo et al 2016; Järvenpää et al 2019). With regard to EFISCEN, the older Yasso 07 soil module in EFISCEN 4.2 is going to be replaced by the updated Yasso 15 version in a newly developed EFISCEN-Space model.

Simplified modelling of forest management practices

For certain ongoing forest practices, we assumed a simplified approach in both models, to facilitate comparison. Nevertheless, both models are equipped to deal with such forest practices.

(1) We did not include any natural disturbances such as windthrow, insect pests and fires, which are playing an significant role in forest dynamics in the EU. For example, the bark beetle (*Ips typographus)* is one of the most destructive forest pests, damaging spruce forest ecosystems in Europe by affecting trees that are already weakened by storms, drought or other causes (Caudullo et al 2016; Hlasny et al 2019). For that reason, separate sanitary cleaning is recommended with some sort of buffer period between thinning and felling, in order to allow the removal of standing deadwood and slash from the forest site (Bouriaud et al 2016). If needed, this can be implemented in both models.

(2) Both models applied even-aged forest management to FAWS (which accounts for about 88% of total Romanian forest), with intermediate thinning and final felling. Under current practice, about 31% of total forest area in Romania is managed by clear cut only, 41% by clear cut with two or three thinning stages, some 16% as a continuous forest cover system and the remaining 12% is not available for wood supply. Characteristics of forests operations are described according to national technical norms, i.e. average characteristics instead of large variation. The part under continuous forest cover may now result in a redistribution of harvested areas into a first age class (0-10?? years; including bare land after final felling) in EFISCEN; in practice, those partially harvested areas attain their associated slower growth rate but are not moved into the bare land category until all remaining trees are felled. CBM is in principle able to implement uneven-aged cutting, provided that input data are available for forest area in terms of age class and yield so that the growth rate of each forest type can be quantified (Pilli et al, 2013).

(3) We applied one kind of regeneration rate for all species in the models. EFISCEN applied one average young forest coefficient for regeneration: 75% of all clearcut areas have reached the first volume class after one time step, in CBM, the comparable regeneration period is two years. It is possible to further finetune the regeneration per species: for example, a 70% default for spruce (Schelhaas et al 2007). Such a 5pp lower regeneration in EFISCEN requires the corresponding CBM parameter to be changed simultaneously: i.e. prolonging CBM's regeneration time by about 1 year.

(4) We did not distinguish specific regional or local growth conditions. This omission may affect the accuracy of growth and yield projections in both models to some extent. Via an extra evaluation, we concluded that the yield curves applied in CBM correspond to a correspond to stand growth that is attributed to the 3rd or 4th site productivity class in the official Romanian forestry yield handbook (Giurgiu and Draghiciu, 2004). Both models allow for a further division into site indices.

(5) In our comparison we did not consider carbon uptake by HWP (IPCC 2014). Instead, we assumed instantaneous oxidation for the HWP at the time of harvest. Current rules for national reporting under the UNFCCC and accounting under the Kyoto Protocol allow for alternative approaches for estimation of carbon storage by wood products (*IPCC 2006, 2014*). It will be possible to insert the selected HWP method in future versions of the CBM and EFISCEN models.

(6) We applied a minimal deforestation rate of 570 ha yr^{-1} (-0.01% of FAWS) in our BAU and this element had negligible effects for the output in both models. However, if a country's deforestation rates were larger, any difference in terms of merchantable stocks and related carbon fluxes would become more visible. CBM accounts explicitly for losses in all carbon pools during deforestation at any stage, following the IPCC guidance for national GHG inventories (IPCC, 2003). This procedure is different from the EFISCEN approach, in which deforestation is assumed to take place after a final felling, when the area has already been allocated to bare land. Nevertheless, this analysis excludes C stocks lost by deforestation by both models.

Conclusions

The two modelling approaches are in essence similar but have many differences in their details. EFISCEN runs parameters with a standing volume, 5-year average net increment and area in age classes of 10-year intervals (in accordance with common forest management practices), with additional 5-year outputs for C stocks and changes. CBM runs C stocks and changes in time steps of 1 year and its output is organized in age classes of 20-year intervals. Although EFISCEN also provides 5-year output in terms of carbon stocks and fluxes, CBM is more geared towards annual reporting of carbon stocks and fluxes to the UNFCCC.

Both models reasonably match the recorded data in the Romanian NFIs in 2010. Although both perform well, their estimates differ and are also different from the aggregated estimates presented in Forest Europe (2015) and UNFCC (2018) reports. Overall, an adequate pre-processed input of yield and growth is needed to ensure unbiased initial values and synchronized forest dynamics. Despite model's ability to capture forest practices particularities we have considered simplification of available data . For long simulations, representation of harvest is crucial yielding unrealistic results (when model implements too strict rules). In the end, carbon fluxes in merchantable stock and total living biomass are critical. If these models are to be used in the global stocktake, the averages they calculate for the same data period must coincide (this also holds for the harmonized proportions for the bio-compartments). Our comparison focused on two models only, i.e. CBM and EFISCEN, as they are currently the models most used by the EU Member States for forest dynamics, carbon stocks and fluxes.

Nevertheless, as noted in the introduction, other types of forest and carbon modelling are available. For that reason, it is recommended to undertake a so-called coupled model inter-comparison project (CMIP) for national scale modelling, similar to the project IPCC carried out for an evaluation of global forest vegetation models (CMIP-5; CMIP-6).

Improvements are already in progress: the new EFISCEN-Space is eagerly anticipated and CBM continues to be refined. EFISCEN-Space will have a modelling approach running on each NFI plot, with tree densities and individual tree data such as diameter and height. These NFI plot data will allow for better representation of mixed forests, uneven-aged forest, actual forest management and site- specific growth conditions, thereby making a climate-sensitive modelling approach possible. Refining the representation of climate change impacts is the subject of ongoing research on both models: for example, the effects of temperature changes on decomposition rates and on forest growth. The most challenging need is to improve soil carbon modelling. Ultimately, the theoretical, model-specific initialization of carbon soil values should be replaced by real-time, on-the-spot measurements of the carbon content in the litter and soil layers.

Additional files A through D

Appendix A Overview of current input requirements for CBM and EFISCEN

Appendix B *Overview of parameters for forest available for wood supply (FAWS) in the initial year of simulation*

Appendix C *Harmonization of other forest status parameters used as inputs in the reference scenario*

Appendix D Bland–Altman representation for both models: the bias of key elements in greater detail

Abbreviations

BAU: business as usual (basic run scenario); C: coniferous tree species; CBM abbreviation from the CFS-CFS3: Carbon Budget Modelling of the Canadian Forest Services; DOM: dead organic matter; DW: deadwood; EFISCEN: European forest information scenario model; FAWS: forest available for wood supply; HWP: harvested wood products; IPCC: International Panel on Climate Change; LULUCF: land use, land-use change and forestry; MCPFE: Ministerial Conference on Protection of Forests in Europe; NAI: net annual increment; NC: non-coniferous species; NFI: national forest inventory (IFN in Romanian); NUTS-2: Nomenclature of territorial units of statistics (derived from French terminology); SFM: sustainable forest management.

Authors' contributions

GJN and VB initiated the design of the study on behalf of the FORCLIMIT project. VB and RS further elaborated the comparison between both models, harmonized the model parameters and analysed the data. Whereas VB and ID focused on the CBM modelling, RS was response for the EFISCEN modelling. RS completed the paper, after which GJN and VB assisted in finalizing the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Consent for publication

Not applicable

Ethics approval and consent to participate

Not applicable

Literature references

Green text = reference only included in one of the Appendices

Red text = suggestion by reviewer #1

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Anexa 5. Metodologie pentru recoltarea biomasei erbacee din pajiști.

Localizare spatială a suprafrafețelor de probă: suprafețele de probă sunt insirate pe curba de cea mai mare pantă, la distante de cativa metrii in asa fel să acopere dimensiunile pajistii.

Suprafața de probă are 0,5m x 0,25m si este definită de un cadru fix metalic cu pini de fixare in sol. Adâncimea de colectare a rădacilor este de 40 cm (tinând cont de panta terenului).

Prelevare probe teren: Recoltare iunie, august si octombrie/noimbrie (când stocul de biomasă supraterană este minim). Probele sunt codificate și transferat în laborator.

Repetiții probe: 1 singur bloc, cu 10 suprafețe de probă.

Pre-procesare: solul mineral a fost indepartat prin uscare cu jet usor de apă pana la spalare totală de sol mineral.

Determinări laborator: Biomasa a fost clasificată în 3 categorii: supraternă verde, supraterană uscată și subterană (rădacini). Materialul vegetal a fost separat biomasă supraterană și biomasă subterană. Biomasa supraterana a fost separată în biomasă vie și biomasă moartă prin taiere cu o lamă ascuțită la punctul de inserție al parții aeriene pe cea subterană. Biomasa moartă a fost identificată ca frunze uscate culese manual in laborator. Biomasa vie supraterană a fost separată in două componente prin taiere cu lama la 3 cm de partea groasă, in biomasă supraterană recoltabilă (ex. consumabilă de animale sau la coasă) și partea de bioamsă supraterană neconsumabilă.

Initial probele de biomasă au fost așezate pe tăvițe din hărtie și lăsate la uscat la termperatura camerei. Apoi au fost uscate în etuvă la 85^0 până la masă constantă, cântărite la balanța analitică cu precizie de 0,0001 g.

Anexa 6. Assessing carbon stock changes matched to land use and land-use change under climate frameworks (Draft)

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Keywords: National forest inventory, sampling design, carbon stocks, model-dependent inference, UNFCCC, LULUCF , KP

Introduction

Land is a limited resource and knowledge about land use and land-use change is important. For example, land-use change is assumed correlated with large GHG emissions (e.g. Houghton et Hackler 2001, Foley et al. 2005, Le Quéré et al. 2011).Under climate frameworks for Annex I Parties (e.g. (UNFCCC 2013; IPCC 2006), changes in carbon pools (living biomass, dead wood, litter, soil organic carbon and harvested wood products) should be matched to land use and land-use change and traced back in time. The United Nations Framework Convention on Climate Change (UNFCCC) requires such reporting for at least 36 land-use categories (IPCC 2006). The KP uses a similar approach but is an accounting model that accumulates land use categories into activities (Höhne, Niklas, et al. 2007). The EU-regulation is built on the same models [6]. For all three reporting frameworks, a land-use change matrix is required that could trace both gross and net land use changes. Specific climate policy requirements focus on data quality and “Annex I Parties shall quantitatively estimate the uncertainty of the data used” (24/CP.19).

Land cover probably correlates with land use but the land cover may change without changing the land use. On the other hand, land use may change if the predominant land use changes without major changes in land cover. A young forest may look very different from an old one, but the land use is “Forest land”. Sometimes agroforestry combines different land uses at the same time on the same land or land use may change during the year. Thus, FAO and the climate frameworks have introduced the concept of “predominant land use”. The purpose is to report land into one land use category only –without double counting or excluding land from the reporting. A land use category has a definition sometimes including a minimum area. Activities that are built on land use categories seldom have a defined minimum area.

It’s probably more challenging to estimate and delineate land use from land cover using remote sensing techniques than by direct measurements in the field (REF?). Few available parallel assessments show good agreement at aggregated national scale (REF). A spatial assessment unit is used for monitoring land use or activities and it often refers to the resolution of a remote sensing pixel or the resolution of underlying data for a map. Generally, the spatial assessment unit should be the same over the period assessed and to have a higher resolution than the minimum area for defining a land use category. It should be noted that the resolution of chosen spatial assessment unit may influence on the results. One example is when a land use category encompasses small patches of other land use categories. Then given resolution, the smaller land use category may incorrectly be included and reported under the larger land use category. If a field-sampling plot that can be delineated into more than one land use category is used for estimating land use and land-use change, then a land use conversion down to zero can be detected. And if the land use is correctly measured on the sampling plots, the estimates will be unbiased.

Figure.1 describes the concepts of land use (UNFCCC), activity (KP) and spatial assessment unit. At t1 for a periodical inventory using permanent ground sampling plots, the land use consist of Forest land (FL) and the activity Forest management (FM) is reported under the KP. The circular sample plot (here sampling unit) represents the total area (the rectangle) and in this specific case the estimated area of FL/FM is 100% and the same as the true for the total area. At t2, 64% of the total area of FL has been converted to Settlements (S) and is reported as Deforestation (D) under the KP. The remaining area is reported as FL remaining FL or FM. Observe that, using the circular sampling plot as spatial assessment unit, the estimated D is 63% and that only the emission of one harvested tree is reported under D. Delineation of land uses and the geographic positioning of trees on the plots are required to report changes in living biomass matched to land use and land-use change on delineated plots.

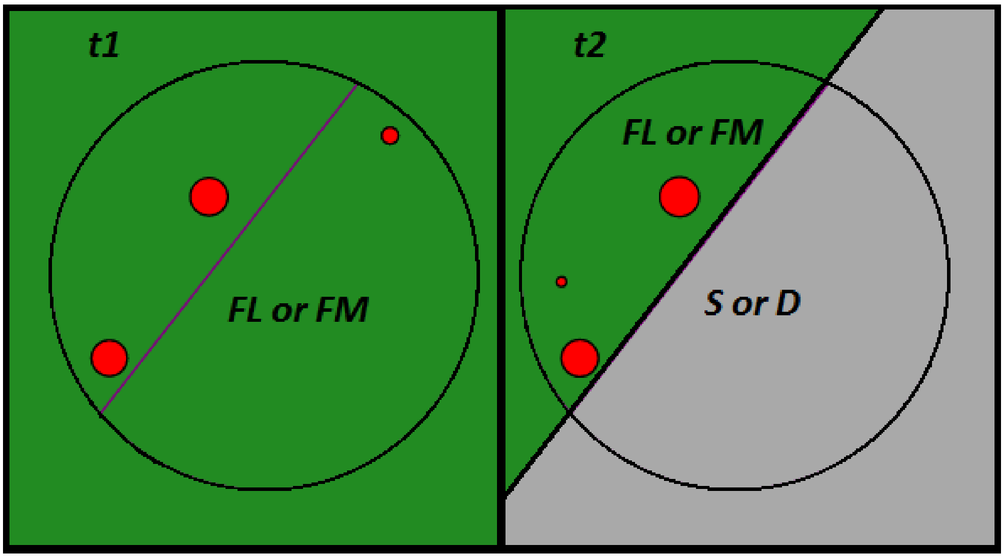

Figure 1) The true area is 100% FL/FM at t1 and a sampling unit is by using area based sampling estimating that 100% of the area is FL/FM. At t2, 64% of the area has been converted to S/D and the estimated area of S/D is 63%. The positioning of trees on delineated plots is central for matching changes in carbon pools (living biomass) to land use and land-use change. Red dots refer to living trees and the size of each dot is proposal to its size. Using the stock change method between t1 and t2, one small harvested tree is reported as an emission under S/D while a new small tree and the difference in size of two larger trees are reported as a removal under FL/FM

The occurrence/total area, size, shape of land use categories may influence on the accuracy of estimates. Most monitoring systems will estimate common land use categories more precise than uncommon. The minimum area for defining a land use category may introduce another monitoring problem. If, for example, the minimum area for defining Forest land is 0.5 ha, and an area of Forest land of exactly 0.5 ha is partly deforested or naturally downgraded by say 0.0001 ha, then the whole 0.5 ha is assumed converted to another land use category –this because the definition do not longer hold. Independently of monitoring system used, the major difficulty is to identify land use and borders between such. The general problem is to implement a continuous accurate assessment design for monitoring land-use changes (and corresponding changes in carbon pools).

The reporting under climate frameworks is annual but the data may reflect a trend. A commonly used approach is the stock change method that estimates changes in carbon pools as the difference between two consecutive measurements (another approach is to monitor flows through gains and losses). A permanent periodic design (the same sample units are revisited) is encouraged (compared with a temporary) since it improves the accuracy of estimates and it's also possible to obtain estimates of both gross and net land use conversions (required under the UNFCCC). A five-year inventory cycle is suggested but almost any cycle is accepted. A long inventory cycle may miss detecting multiple land use changes and thereby miss reporting emissions connected to the not-identified land use changes, as well as increasing uncertainty on when such conversions have occurred.

The inventory designs for reporting changes in carbon pools matched to land use may be sample based or a total inventory (or combined). The idea with using a sample based approach is to measure the variable of interest on the sample units and thereby most of the uncertainty will arise from that a sample and not the entire population was measured. A total wall-to-wall inventory does not introduce a sampling error but maybe systematic errors because it is difficult to (without bias) measure carbon stock changes on all land. In practice, it's likely that only wall-to-wall methods based on RS-data can generate unbiased estimates (REF). The RS-designs are usually combined with "ground truth" from field measurements or by models to match land use and land-use change to changes in carbon pools.

Most Annex I Parties under the UNFCCC/ KP base their monitoring of land use and land-use change on remote sensing (RS) data (as annual Landsat assessment, e.g. Australia) or on data from their national forest inventory (e.g. Finland). This is often challenging and the estimates are usually combining multiple data sources, e.g. Australia (ground truth complemented by RS-data and by, models; FullCAM;), data from national forest inventories or by other supporting material as ancillary statistics from agencies. A second general approach is to use cadastral (Czech R), vector maps (Denmark) or land cover maps for at least two occasions in time to estimate land use and land-use change (Netherlands). At least one country builds its reporting on a complete field survey (wall-to-wall;Japan) and one country builds the reporting on field sample plots only (Sweden).

"Although many authors (McRoberts 2011; Tomppo et al.2011) point it out that remote sensing alone will not be viable option, it remains to be clarified what combinations of remote sensing and field surveying are appropriate, as well what estimation techniques should be applied when combining the two sources." This far no country has introduced relatively new techniques as model-based approaches for improving their estimates of land use and land-use change. For example, a model based approach may model land use from RS-data that is calibrated by "ground truth". However, the techniques have been introduced for improving estimates of changes in e.g. living biomass.

In the present study we will estimate land use and land-use change (and for a few examples changes in carbon pools) given a field based approach and using a sampling design for a case country. We have selected Sweden as case country and the Swedish LULUCF reporting under climate frameworks are based on the Swedish National forest Inventory (NFI). We will estimate the accuracy of estimates given sampling intensity and properties of the land use categories. In addition, we will imitate an ongoing approach in Romania. The Romanian NFI combines field sampling plots with aerial photos. Finally, we will introduce a model based approach (post-stratification) to study if this approach improves the estimates /***Check New Zealand***/. From a climate reporting approach, we will discuss advantages and disadvantages using different approaches.

Material and methods

*Swedish LULUCF data

Under the climate framework, Sweden has adapted 15 national land use categories to IPCCs six broad land use categories (Forest land (FL), Cropland (CL), Grassland (GL), Settlements (S), Wetlands (W) and Other land (OL). Changes in carbon pools and areas are reported for FL, CL, GL and S that are assumed managed while only areas are reported for the unmanaged land use categories (OL and W). Details about definitions of land use categories are found in the National Inventory Report. Activities under the KP are built on these land use categories. Deforestation (D) is defined as a land use conversion from FL to another managed land use category and the areas are accumulated from 1990. Land cannot leave this activity. The activity Afforestation/Reforestation (AR) is the opposite (managed land to Forest land) and is also accumulated from 1990 and can only leave this category for D. The activity Forest management (FM) refers to FL remaining FL but also FL converted to unmanaged land and unmanaged land converted to FL are considered FM. Cropland management (CM) is an activity on CL that is not reported under D. Finally Grazingland management (GM) is an activity on GL that is not reported under D or CM (CL converted to GL stays as CM).

Changes in carbon pools are matched to land use and land-use change based on estimates from the National Forest Inventory (NFI). The NFI is quite unique in the sense that it covers all land (not only Forest land), was established before the base year (1990) and has a permanent sampling design. A permanent sampling design is required to monitor both gross and net land use transfers to produce a land use matrix.

The NFI is an annual, systematic cluster-sample inventory of Sweden. Each year roughly 870 sample clusters are inventoried. The square shaped clusters are distributed all over the country in a pattern that, due to autocorrelation, is denser in the southern part than in the northern part of the country. Each cluster, that constitutes one sampling unit, consists of four to eight sampling plots. A sampling plot has a radius of 10 m and can be delineated into more than one land use category. Each year around 6000 sample plots are inventoried and a five-year inventory cycle is used for five different cycles (established 1983, 1984, 1985, 1986 and 1987, respectively. Data for years between consecutive inventories are interpolated (REF to

NIR or figures?). The biomass is estimated for singular living trees using allometric models (Marklund, Petersson and Ståhl)

**Romanian LULUCF data

*** One land use grid cover whole country (500x500 m2) using aerial photos, land use estimates based on aerial photo interpretation and ground truth ***.

Case 1: Monitoring carbon pools changes matched to land use and land-use change using field sampling plots only

Change in living biomass (2012-2013), total biomass (2013) and area (2013) were estimated for activities under the KP. The estimator and variance estimator used are found in Appendix 1. Data from the Swedish NFI was used and the stock change method was applied (REF NIR). In total 4344 tracts (or around 30000 permanent sample plots) covering all land were used. For areas, the influence of different sample intensity (number of tracts used) on SE was assessed by assuming simple random sampling.

Case 2: Combining land use from aerial photo interpretation with ground truth

Twenty tracts were subjectively selected from permanent sample plots from the Swedish NFI. Ten of these tracts included at least one plot/plot part of AR and another ten of D. The tracts consisted of 15x8 plus 5x4 = 140 plots but one plot was removed for technical reasons. To imitate the inventory design of the Romanian NFI, each plot was matched to an aerial orthophoto at two consecutive inventories (t1 and t2). Sometimes, t1 and t2 didn't exactly correspond between the two data sets. Uncertainty in geographically matching the two data sets may also arise from the identification of plot centers using GPS. The orthophotos were viewed on a display via ArcMap. When needed, land was delineated by a line into different land use classes. Areas per plot intersection were automatically measured.

Results

Case1

Based on ground measured field plots and given design for 2013, the change in living biomass under FM in Sweden was estimated 31.5 Mton CO2/yr. The corresponding estimated accuracy of this estimate was 3.32 MtonCO2/yr. The relative error (SE/gross growth) is approximately 2% (Skogsdata 2015; Table 1). The area under FM was estimated to 27.4 Mha with an estimated SE of 0.27 Mha or an uncertainty of around 1% (Table 2). Changing from around 1000 to 30000 sampling units will probably reduce the uncertainty from around 2.0 to 0.4 %, respectively. The relative uncertainty for area is much higher for more uncommon activities –around 7% for AR, D and GM and around 3% for CM. If using 10000 sample units, the relative uncertainty for area would approximately be around 5% or lower (Table 1).

Table.1) Change in living biomass (2012-2013) and total biomass (2013) per KP-activity. Biomass refers to living trees dbh>99 mm at breast height. Minus=emission

2013		FM		D		AR		CM		GM	
		Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Diff AGB	[Mton CO2/yr]	23.8	2.50	-1.01	0.43	0.91	0.14	0.19	0.08	0.26	0.06
Diff BGB	[Mton CO2/yr]	7.68	0.82	-0.34	0.15	0.30	0.05	0.07	0.03	0.11	0.02
Diff total B	[Mton CO2/yr]	31.5	3.32	-1.35	0.58	1.21	0.18	0.25	0.11	0.37	0.08

Total AGB	[Mton CO2]	3176	19.9	2.55	0.27	11.1	0.71	5.88	0.48	13.4	0.31
Total BGB	[Mton CO2]	1065	6.70	0.91	0.10	3.74	0.24	2.13	0.18	5.36	0.31
Total B	[Mton CO2]	4241	26.7	3.46	0.37	14.8	0.95	8.02	0.66	18.8	0.61

Table.2) Areas (2013) per KP-activity. SE in italics are extrapolated assuming SRS

2013		FM		D		AR		CM		GM		
		Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	n
Area	[kha]	27382*	269	266	17.8	281	19.0	2877	93.3	462	26.0	4344
			560		*37.1*		*39.6*		*194*		*54.1*	*1000*
			396		*26.2*		*28.0*		*137*		*38.3*	*2000*
			250		*16.6*		*17.7*		*86.9*		*24.2*	*5000*
			177		*11.7*		*12.5*		*61.5*		*17.1*	*10000*
			102		*6.77*		*7.22*		*35.5*		*9.88*	*30000*

*=not corrected for FL in the mountain area

Case 2

Land use was assessed from aerial photo interpretation and matched to ground truth (measurements on NFI sample plots) and the ground truth land use was assumed to be correct (Table 3). Around 93% of FL remaining FL was correctly interpreted from aerial photo images. The incorrect assessments consisted of WL (four plots) and OL (1 plot). GL remaining GL was incorrectly assessed on one plot as CL. Part of two plots were incorrectly identified as S on CL remaining CL. Three plots/plot parts were incorrectly classified as FL or CL for S remaining S. Deforestation was incorrectly classified for 3 of the plots. For two plots the S was assumed already at t1 and only a part of the plots was actually D. For one plot a thinning was observed. The suspected reason for the observed thinning was either forestry or a land use conversion to GL (new land pastures), but the land use was not change from FL to GL (so incorrect). Few AR plots were correctly classified. One type was abandoned GL or CL that by definition are considered FL and small plants are hard to identify using an aerial photo. The second type of incorrect AR, was when plots that constituted FL and with a small proportion of S at t1, were converted to FL. Almost every plot identified as “no change” was correctly assessed while about every second in the category “change”. The latter class was quite uncommon with only minor changes in land use.

Table.3) Correspondence between aerial photo interpretation and ground truth (n=139).

Grount truth					Aerial photos
t1	t1	t2	t2	n	Correct at t1 and t2
FL	100%	FL	100%	72	93%
GL	100%	GL	100%	4	75%
CL	100%	CL	100%	15	87%
WL	100%	WL	100%	3	100%
S	100%	S	100%	10	67%

FL	100%	CL,GL,S	0-100%	9	67%
CL,GL,S	0-100%	FL	100%	12	25%
FL+CL,GL or S	No change			7	86%
FL,CL,S	Change			2	50%
WL	100%	WL	100%	3	100%
Other combination	100%	Other combination	100%	2	100%

Discussion

- Model self-regulating –the relative accuracy increases for larger areas. Problem D (that is accounted differently) that is quite uncertain and varies al lot between years (large fluxes small area)
- CM I more accurate than GM (probably reason is that GM is smaller, more spread while CM larger homogenous patches)
- General pros and cons compare to other approaches (consistency, match carbon to land, design)
- Suggest an appropriate sampling intensity –compare with Romania,+another country
- We cannot do anything about the population but probably more variation in Romania
- Sample intensity (Romania 30000 compare to 4000 is ok)
- Design (Romania has improved the accuracy by matching aerial photo to NFI plot)
- Other pools (only living biomass) and mention the estimation and monitoring of dead wood. RO NFI monitors all pools (SOM and LT were collected in 2012)

***Benefits of increasing inventory cycles and intensity advantages and disadvantages and how this can influence the accuracy of estimating changes in area and carbon stocks, later on GHG emissions associated.

***Different land uses have different carbon stocks, during changes from land use to another land use it is assumed that the carbon stocks over time will reach the average carbon of the new land use, and later on emissions and removals of CO2, can be estimated on this basis, benefits of increasing inventory cycles and intensity

*** When rare events/small areas as Deforestation or even Afforestation, age dependent/duration since conversion started allowing better assessment of CSC?

***Advantages for using NFI data offers a strong positioning being able to provide sample complete information on land use categories, but there will be a need to extend information from different sources.

***Forest definitions:

Using different data set for land use and land cover sample based with remote sensing information, may have an important influence because can causes inconsistent definitions among land use classes.

Land use and management is quite different between countries.

*** Trends during land use changes can be cyclical, meaning emission from land use can occur more regular because and they are associated with timber harvesting

** How many rare events / conversions) can occur and how can we include them in the right category if we increase by changing inventory cycle from 5 years to 10, 15,30 and if uncertainty for area will increase or decrease. Following the results mentioned above creating a tree decision can be relatively helpful. (explanations if is there any change between an inventory 5 cycle and we have a change which will last 1 or 2 year, do we consider land use change? And if the inventory cycle will increase at 10 years and we have a temporary change which can last longer then 2 year and then returns as the main category, we will not consider a change at all because of the length of the inventory. Establishing thresholds can improve decisions.

Appendix 1

Estimators and estimators of variance for case 1

We suggest a ratio estimator where A is the measured area, $\hat{A}$ is the estimated area and $\hat{Y}$ is the estimated variable of interest for a region/stratum. $\hat{A}$ And $\hat{Y}$ can be estimated separately using the Horvitz-Thompson estimator.

$$\tilde{Y} = A \cdot \frac{\hat{Y}}{\hat{A}} = A \cdot \hat{R} \qquad \text{[Formula 1]}$$

The variance and an estimator of the variance may be expressed as:

$$V(\tilde{Y}) = A^2 \cdot V(\hat{R}) = V(\hat{Y} - \hat{R} \cdot \hat{A})$$

$$\hat{V}(\tilde{Y}) = \hat{V}(\hat{Y} - \hat{R} \cdot \hat{A})$$

Alternatively:

$$\hat{V}(\tilde{Y}) = \frac{A^2}{\hat{A}^2} \cdot \hat{V}(\hat{Y} - \hat{R} \cdot \hat{A})$$

Assuming SRS, wtr:

$$\hat{V}(\tilde{Y}) = N^2 \cdot \frac{1}{n} \cdot \left(1 - \frac{n}{N}\right) \cdot s^2_{y-\hat{R}\cdot a}$$

$$\hat{V}(\tilde{Y}) = \frac{(\bar{A} \cdot N)^2}{(\bar{a}^2 \cdot n)} \cdot \left(1 - \frac{n}{N}\right) \cdot s^2_{y-\hat{R}\cdot a}$$

The estimator is quite robust when$\bar{A} = \bar{a}$, but if not:

$$\hat{V}(\tilde{Y}) = \frac{\left(\frac{A}{N} \cdot N\right)^2}{(\bar{a}^2 \cdot n)} \cdot \left(1 - \frac{n}{N}\right) \cdot s^2_{y-\hat{R}\cdot a}$$

$$\hat{V}(\tilde{Y}) = \frac{A^2}{\bar{a}^2} \cdot \frac{1}{n} \cdot \left(1 - \frac{n}{N}\right) \cdot s^2_{y-\hat{R}\cdot a}$$

$$\hat{V}(\tilde{Y}) = \frac{A^2}{(\sum a)^2} \cdot n \cdot s^2_{y-\hat{R}\cdot a} \qquad \text{[Formula 2]}$$

Explaining the last term:

$$s^2_{y-\hat{R}\cdot a} = \frac{1}{(n-1)} \cdot \sum_{i=1}^{n} (y_i - r \cdot a_i)^2$$

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Anexa 7. A comparison of weighting approaches in nonlinear allometric models and their effects on large area biomass prediction

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Abstract

To be developed.

Keywords: biomass prediction, uncertainty, error propagation, nonlinear allometric models, weighted regression

Introduction

To be developed.

An exact analogy between log-transformation and weighted nonlinear approach is not possible since the error distribution is assumed normal in nonlinear approach and lognormal in log-transformation approach. However, using as weights in nonlinear approach the squared back-transformed predicted biomass from log-transformation approach produces parameter estimates that are very similar between the two fitting approaches.

Logarithmic transformation works in a way that data is re-scaled, so that the units are stretched (on both coordinate axes) for small values of involved variables (e.g. AGB, D and H) and compressed for large ones. Therefore, the heteroscedastic relationship between response variable and the predictor(s) becomes homoscedastic while the relationship also being linearized. Although achieving homoscedasticity and linearity is not guaranteed by the log-log transformation, this is a subject of discussion which is beyond the aim of this study, therefore we will not discuss this aspect here.

2. Material and methods

2.1. Data

2.1.1. Biomass data

We used a total of eight biomass datasets in this study. The first dataset (Dataset 1, Schepaschenko et al. 2017) is a subset of Dataset 5, containing only Norway spruce trees; it was meant to be used in conjunction with the inventory dataset (section 2.1.2) to investigate the effects of different weighting approaches on biomass prediction over large areas. The characteristics of the biomass datasets are presented in Table 1. Dataset 7 resulted from the merging of Datasets 2, 4, 5 and 6.

Table 1. The characteristics of the biomass datasets.

Dataset	Region	Species	Latitude range (Deg.)	Sample size	D range (cm)	H range (m)	AGB range (kg)	References
Dataset 1	Europe	Norway spruce		517	5.0−67.6	4.0−42.8	4.9−3364.2	(Schepaschenko et al. 2017)
Dataset 2	Tropical	Multiple	−24.9, 25.0	4004	5.0−212.0	1.2−70.7	1.2−76063.5	(Chave et al. 2014)
Dataset 3	Romania	Norway spruce	45.4, 47.6	240	0.6−10.0*	0.5−5.5	0.1−15.5	(Dutcă 2018a)
Dataset 4	Global	Multiple	−51.6, 62.3	3489	5.0−139.6	1.5−46.5	0.4−16418.4	(Falster et al. 2015)
Dataset 5	Europe and Asia	Multiple	31.5, 69.9	5144	5.0−72.9	2.3−42.8	0.6−4291.3	(Schepaschenko et al. 2017)
Dataset 6	Canada	Multiple	43.9, 64.0	8659	5.0−74.3	2.5−52.2	2.2−2951.4	(Ung et al. 2017)
Dataset 7	Global	Multiple	−51.6, 64.0	21296	5.0−212.0	1.2−70.7	0.4−76063.5	Datasets 2, 4, 5 and 6

*Dataset 3 (Dutcă 2018a) uses diameter at collar height instead of diameter at breast height.

2.1.2. Inventory data

The models developed based on biomass Dataset #1 (i.e. calibration dataset) were further applied to estimate biomass in 243 sample plots of pure Norway spruce (i.e. inventory dataset). The 243 plots containing a total of 4946 trees, were selected from Romanian NFI, based on two conditions, simultaneously: (1) the plots contain only Norway spruce trees; (2) the H-D ratio of trees within plots ranges only between 0.5 and 1.7. This decision is justified by the fact that plot data should be within the same range as biomass data (with regard to H-D ratio), and by the fact that trees outside this H-D ratio range may be trees that are damaged (e.g. broken trunks) or trees with inaccurate measurements of either D or H. Because the Romanian NFI grid for mountain area (where pure Norway spruce occur) is 4 by 4 km, the 243 plots correspond to a forest area of 388.8 thousand hectares.

Height-diameter (H-D) ratio is one of the main drivers of variance in biomass allometric models (Feldpausch et al. 2010, Dutcă et al. 2018). We checked whether the distribution of H-D ratio for calibration dataset matches that of inventory dataset. Figure 1 shows a good agreement between histogram (calibration dataset) and density curve (inventory dataset). H-D ratio ranged between 0.36 and 2.56 for the calibration dataset and between 0.42 and 2.11 for the inventory dataset. The ranges of D and H were also similar to calibration dataset (Table 1), varying between 5.6 to 72.2 cm and respectively between 3.1 and 47.5 m.

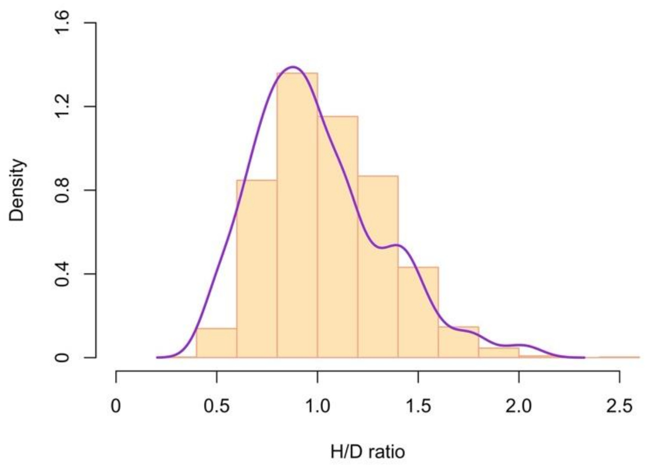

Figure 1. The distribution of H-D ratio for the calibration dataset (histogram) and the inventory dataset (violet line)

2.2. Testing of weighting approaches

2.2.1. Allometric biomass models

(a) Aboveground biomass predicted as a function of D

$$\mathrm{AGB} = \beta_{01} \cdot \mathrm{D}^{\beta_{11}} + \varepsilon_1 \qquad \text{(Equation 1)}$$

(b) Aboveground biomass predicted as a function of D and H

$$\mathrm{AGB} = \beta_{02} \cdot \mathrm{D}^{\beta_{12}} \cdot \mathrm{H}^{\beta_{22}} + \varepsilon_2 \qquad \text{(Equation 2)}$$

Where AGB is the tree aboveground biomass (in kg), D is the diameter at breast height (in cm), H is the tree height (in m), b_{01} and b_{02} are the intercepts of the log-scale linear allometric models, b_{11} and b_{12} are the parameters of D, b_{22} is the parameter of H, e_1 and e_2 are the error terms, $e_1 \sim N(0, s_1)$ and $e_2 \sim N(0, s_2)$, where the s_1 and s_2 are the residual standard errors.

2.2.2. The weights to correct heteroscedasticity

Since in their nonlinear power-law form the allometric models usually exhibit heteroscedasticity (increase of variance with the predictor or response variable), several weighting approaches were implemented:

Approach #1. The weight of ith observation (w_i) was calculated simply as the inverse of diameter (D_i) of the ith tree (Kralicek et al. 2017):

$$w_i = \frac{1}{D_i} \qquad \text{(Equation 3)}$$

Approach #2. This approach uses ${D_i}^2$ instead of D_i (Kralicek et al. 2017):

$$w_i = \frac{1}{{D_i}^2} \qquad \text{(Equation 4)}$$

Approach #3. The inverse of ${D_i}^4$ (Cunia 1964):

$$w_i = \frac{1}{{D_i}^4} \qquad \text{(Equation 5)}$$

Approach #4. The inverse of squared D^2H:

$$w_i = \frac{1}{{D_i}^4 {H_i}^2} \qquad \text{(Equation 6)}$$

Approach #5. Prediction of heteroscedastic variance as a function of D. This approach was proposed by (Harvey 1976) and used by (Balboa-Murias et al. 2006, Picard et al. 2012), and consists in: (i) fitting a nonlinear unweighted model to the data, and calculate the residuals ($\hat{e}$); (ii) fitting a linear model in log-log scale to predict the squared residuals as a function of D: $\ln\left({\hat{\varepsilon}_i}^2\right) = a + k \cdot \ln(D_i)$; (ii) using the slope of the linear model (i.e. k) to calculate the weights of i^{th} tree:

$$w_i = \frac{1}{{D_i}^k} \qquad \text{(Equation 7)}$$

Approach #6. Prediction of heteroscedastic variance as a function of D, but using a grouping method: (i) fitting an unweighted nonlinear model to data and calculate the heteroscedastic residuals ($\hat{e}_i$); (ii) sort the pairs D_i and $\hat{e}_i$ in ascending order with respect to D; (iii) group the pairs D_i and $\hat{e}_i$ in u groups of size 25; (iv) for each group, calculate the mean of D_i ($\overline{D_u}$) and the variance of $\hat{e}_i$ (${\sigma_u}^2$); (v) log-log transform the $\overline{D_u}$ and ${\sigma_u}^2$ values; (vi) predict $\overline{D_u}$ as a function of ${\sigma_u}^2$ using the following linear model: $\ln(\overline{D_u}) = a + g\ln({\sigma_u}^2) + \varepsilon$; (vii) using the slope of linear model (i.e. g) to calculate the weight of i^{th} tree:

$$w_i = \frac{1}{{D_i}^g} \qquad \text{(Equation 8)}$$

Approach #7. Prediction of heteroscedastic variance as a function of predicted AGB, similar to approach #6 (predicted AGB is used instead of D), as in (Dutcă et al. 2019):

$$w_i = \frac{1}{{\widehat{AGB}_i}^g} \qquad \text{(Equation 9)}$$

Approach #8. Mimicking logarithmic transformation: (i) fit a linear model on log-log transformed data, using similar independent variable(s) as in the nonlinear model; (ii) calculate the predicted ln(AGB) of i^{th} tree (i.e. $\ln\widehat{(AGB)}_i$); (iii) calculate the weight of i^{th} tree as:

$$w_i = \frac{1}{[\exp(\ln\widehat{(AGB)}_i)]^2} \qquad \text{(Equation 10)}$$

Including the back transformation correction factor (Baskerville 1972, Sprugel 1983) is not necessary since the correction factor is a constant and, therefore, would have a redundant effect.

Approach #9. Inverse of squared observed AGB:

$$w_i = \frac{1}{AGB_i^{\,2}} \qquad \text{(Equation 11)}$$

Approach #10. Prediction of heteroscedastic variance as a function of predicted AGB (McRoberts and Westfall 2014). The difference between this approach and approach #7 is that here the intercept of the model to predict the group variance is set to origin: (i)

2.2.3. Testing of heteroscedasticity

Breusch-Pagan test is widely used to test heteroscedasticity (i.e. homogeneity of variance) in linear models (Breusch and Pagan 1979). However, to the best of our knowledge there is no test specifically targeted to weighted nonlinear models, therefore we adapted the Breusch-Pagan test to nonlinear weighted models using the following steps:

(i) calculate the weighted residuals ($\widehat{ew}_i$), resulted from the weighted nonlinear models:

$$\widehat{ew}_i = \frac{AGB_i - \widehat{AGB}_i}{\sqrt{w_i^{-1}}} \qquad \text{(Equation 12)}$$

Where AGB_i is the observed AGB of *i*th tree; $\widehat{AGB}_i$ is the predicted AGB of *i*th tree from a weighted nonlinear model; w_i is the weight of *i*th tree, the same that was used to fit the weighted nonlinear model.

(ii) define the auxiliary linear models that predict squared weighted residuals as a function of independent variable(s):

$$\widehat{ew}_i^{\,2} = a_1 + b_1 D + \varepsilon \qquad \text{(Equation 13)}$$

$$\widehat{ew}_i^{\,2} = a_2 + b_2 D + c_2 H + \varepsilon \qquad \text{(Equation 14)}$$

(iii) retain the R^2 values of these linear models and use them further to calculate the c^2:

$$\chi^2 = df \cdot R^2 \qquad \text{(Equation 15)}$$

Where *df* is the number of degrees of freedom (*df* = 1 for Equation 13 and *df* = 2 for Equation 14).

(iv) calculate the p-value of the Chi Square statistic. The null hypothesis of homoscedasticity is rejected if $p < 0.05$.

2.3. Exploring the effects of weighting approaches on large area biomass prediction

To investigate the effects of different weighting approaches in nonlinear allometric models on large-area biomass estimates we used Dataset 1 (section 2.1.1) in conjunction with the inventory dataset described at section 2.1.2. Using a Monte Carlo error propagation approach with an integrated ‘bootstrap residuals’ procedure we aimed to predict the mean biomass and its standard error over a large forest area. Using the ‘bootstrap residuals’ instead of the more commonly used variance-covariance based error propagation is justified by fact that the expectation surface between models parameters is curved for nonlinear models (Bates and Watts 1988), whereas the variance-covariance matrix is usually based on linear approximation using Taylor series, which may be biased.

2.3.1. Adjustment of heteroscedastic residual standard error within error propagation process

Because variance is heteroscedastic in allometric models, the residual standard error in not constant across the predictor range. To propagate the error from residual variance, we sampled from a normal distribution $\mathcal{N}(0, 1)$, which was truncated to the interval [-3, 3], and then adjusted the sampled value with the predicted standard deviation ($\widehat{\sigma}_{\mathrm{i}}$), as a function of predicted biomass ($\widehat{\mathrm{AGB}}_{\mathrm{i}}$). We used a procedure in 8 steps: (i) calculate $\widehat{\mathrm{AGB}}_{\mathrm{i}}$ and residuals (ε_{i}) based on weighted nonlinear allometric model; (ii) the pairs $\widehat{\mathrm{AGB}}_{\mathrm{i}}$ and ε_{i} were ordered ascending with respect to $\widehat{\mathrm{AGB}}_{\mathrm{i}}$; (iii) the pairs $\widehat{\mathrm{AGB}}_{\mathrm{i}}$ and ε_{i} were aggregated into groups of size 25; (iv) for each group, the mean $\widehat{\mathrm{AGB}}_{\mathrm{i}}$ ($\overline{\overline{\mathrm{AGB}}}_{\mathrm{g}}$) and the standard deviation of ε_{i} (σ_{g}) were calculated; (v) the resulted values ($\overline{\overline{\mathrm{AGB}}}_{\mathrm{g}}$ and σ_{g}) were log-transformed (using natural logarithm); (vi) a linear model was fitted: $\ln(\sigma_{\mathrm{g}}) = a + b \cdot \ln\left(\overline{\overline{\mathrm{AGB}}}_{\mathrm{g}}\right) + \varepsilon$; (vii) the model was back transformed, using a correction factor; (viii) the residual standard error ($\widehat{\sigma}_{i}$) was predicted further as a function of $\widehat{\mathrm{AGB}}_{\mathrm{i}}$: $\widehat{\sigma}_{i} = \exp(a + \frac{\sigma^2}{2}) \cdot \widehat{\mathrm{AGB}}_{\mathrm{i}}^{\,b}$, where σ^2 is the residual variance of the linear model developed at step (vi).

2.3.2. Propagation of errors in AGB prediction based on Monte Carlo approach

The AGB prediction and its uncertainty over 243 plots was assessed, following a Monte Carlo simulation procedure, adapted from McRoberts et al. (2015, 2016):

1. For the k^{th} replication (K = 2000 replications), an allometric model was fitted to the resampled dataset (based bootstrap residuals) and then the estimated parameters were further used on resampled inventory dataset to calculate tree biomass.

1.1. *Resampling of homoscedastic residuals*. The homoscedastic residuals (e_i') were calculated based on heteroscedastic residuals (e_i, in Eqs. 1, 2) and on the weights (w_i calculated from section 2.3):

$$\varepsilon_{i(k)}' = \frac{\varepsilon_i}{\sqrt{w_i^{-1}}} \qquad \text{(Equation 16)}$$

The vector containing all 517 values was resampled with replacement.

1.2. *Calculation of resampled AGB*. The resampled AGB is based on predicted AGB (from weighted nonlinear model), to which the resampled heteroscedastic residuals were attached by addition:

$$AGB_{r1} = \hat{\beta}_{01} \cdot D^{\hat{\beta}_{11}} + \varepsilon_1' \cdot \sqrt{w_1^{-1}} \qquad \text{(Equation 17)}$$

$$AGB_{r2} = \hat{\beta}_{02} \cdot D^{\hat{\beta}_{12}} \cdot H^{\hat{\beta}_{22}} + \varepsilon_2' \cdot \sqrt{w_2^{-1}} \qquad \text{(Equation 18)}$$

1.3. *Fitting a nonlinear weighted model on resampled AGB data*:

$$AGB_{r1(k)} = \beta_{01(k)} \cdot D^{\beta_{11(k)}} + \varepsilon \qquad \text{(Equation 19)}$$

$$AGB_{r2(k)} = \beta_{02(k)} \cdot D^{\beta_{12(k)}} \cdot H^{\beta_{22(k)}} + \varepsilon \qquad \text{(Equation 20)}$$

1.4. *Resampling of inventory dataset*. The inventory dataset (see Section 2.1.2) was resampled with replacement.

1.5. *Tree level biomass*. In the k^{th} replication, for the i^{th} tree on the j^{th} plot in the resampled dataset (step #1.4), the AGB was calculated. The AGB was calculated using in Eq. (1) and Eq. (2), the parameters estimated at step #1.2 (Eqs. 16 and 17); to the resulted tree AGB prediction, the random residual sampled at step #1.3 was attached by addition:

$$AGB_{ij(k)} = \hat{\beta}_{02(k)} \cdot D^{\hat{\beta}_{12(k)}} + \hat{\varepsilon}_{(k)} \cdot \hat{\sigma}_{2_{ij(k)}} \qquad \text{(Equation 21)}$$

$$AGB_{ij(k)} = \hat{\beta}_{01(k)} \cdot D^{\hat{\beta}_{11(k)}} \cdot H^{\hat{\beta}_{21(k)}} + \hat{\varepsilon}_{(k)} \cdot \hat{\sigma}_{1_{ij(k)}} \qquad \text{(Equation 22)}$$

1.6. *Plot level biomass extrapolated to hectare*. To extrapolate the biomass of each plot to hectare, we used an extrapolation factor, which was differentiated by tree size. Within Romanian NFI, the trees with diameter at breast height smaller than 28.5 cm are measured within a 200 m^2 plot, whereas the trees larger than this value are measured on a 500 m^2 plot. Therefore, the total biomass of trees with D < 28.5 cm was multiplied by a factor of 20 and the total biomass of trees with D < 28.5 cm was multiplied by a factor of 50:

$$AGB_j = 50 \cdot \sum_{i=1}^{n_j} AGB_{i(D \le 28.5)} + 20 \cdot \sum_{i=1}^{n_j} AGB_{i(D > 28.5)} \qquad \text{(Equation 23)}$$

Where $AGB_{i(D \leq 28.5)}$ represents the aboveground biomass of tree *i* from plot *j*, for those trees in the plot with D smaller than 28.5 cm; $AGB_{i(D > 28.5)}$ represents the aboveground biomass of tree *i* from plot *j*, for those trees in the plot with D larger than 28.5 cm.

1.7. *Mean biomass per hectare*. The mean biomass per hectare for the kth replication ($\overline{AGB_k}$) was calculated as:

$$\overline{AGB_k} = \frac{1}{m}\sum_{j=1}^{m} AGB_j \qquad \text{(Equation 24)}$$

Where m is the total number of plots in the inventory dataset (m = 243) and AGB_j is the plot level biomass extrapolated to hectare (step #1.5).

1.8. *The between-plots variance*. The between-plots variance for the kth replication was calculated as:

$$var(\overline{AGB_k}) = \frac{1}{m(m-1)}\sum_{j=1}^{m}(AGB_j - \overline{AGB_k})^2 \qquad \text{(Equation 25)}$$

The steps #1.1 to #1.7 were replicated 2000 times. To estimate the between-simulations mean biomass and associated variance, we repeated 5000 times each loop of 2000 replications.

2. Each loop (i.e. 2000 replications of steps #1.1 to #1.7) was repeated n_{rep} = 5000 times, so that the man biomass per hectare and its standard error to stabilize. The following indicators were calculated:

2.1. *Population mean biomass per hectare* ($\hat{\mu}$), was as calculated as:

$$\hat{\mu} = \frac{1}{5000}\sum_{n_{rep}=1}^{5000}(\overline{AGB_k})_{n_{rep}} \qquad \text{(Equation 26)}$$

2.3. *The mean within-simulation variance*, was calculated as:

$$\overline{Var_{ws}} = \frac{1}{5000}\sum_{n_{rep}=1}^{5000} var(\overline{AGB_k})_{n_{rep}} \qquad \text{(Equation 27)}$$

2.2. *The between-simulation variance*, was calculated as:

$$Var_{bs} = \frac{1}{5000-1}\sum_{n_{rep}=1}^{5000}(\overline{AGB_{k(n_{rep})}} - \hat{\mu})^2 \qquad \text{(Equation 28)}$$

2.4. *The total variance of population mean biomass per hectare*, was calculated as per (Rubin 1987):

$$var(\hat{\mu}) = \overline{Var_{ws}} + \left(1 + \frac{1}{5000}\right) \cdot Var_{bs} \qquad \text{(Equation 29)}$$

2.5. *Standard error of population mean biomass per hectare*, was calculated as:

$$SE(\hat{\mu}) = \sqrt{var(\hat{\mu})} \qquad \text{(Equation 30)}$$

2.4. Data processing

Statistical analysis was performed in R (R Core Team 2017) with the Rstudio interface (RStudio Team 2016) and using the packages ‘nlme’ (Pinheiro et al. 2018), ‘MASS’ (Venables and Ripley 2002).

3. Results

3.1. Testing of weighting approaches

The results of Breusch-Pagan test for heteroscedasticity are presented in Table 2. When $p < 0.05$ the null hypothesis of homoscedasticity was rejected and the residuals were assumed heteroscedastic, whereas when $p > 0.05$ we assumed homoscedastic residuals, as the result of consideration for the alternative hypothesis. The greater number of p-values larger than 0.05 for models based on single predictor (Table 2) suggests that single predictor models are easier to correct for heteroscedasticity. For the single predictor models (Equation 2, models based on D), the only weighting approach that produced homoscedastic weighted residuals for all biomass datasets is the approach #6 (i.e. variance predicted as a function of D, based on grouping method). However, for models based on two predictors (D and H, Equation 2), the weighting approach #6 produced homoscedastic residuals only for two out of six datasets and, what is more, none of the tested approaches was able to remove heteroscedasticity for all datasets.

Table 2. The Breusch-Pagan test results (p-values of the test), by model form and weighting approach.

Model form	Weighting variable	Dataset 1 (Norway spruce)	Dataset 2 (Chave et al. 2014)	Dataset 3 (Dutcă 2018b)	Dataset 4 (Falster et al. 2015)	Dataset 5 (Schepas chenko et al. 2017)	Dataset 6 (Ung et al. 2017)
$AGB = \beta_0 \cdot D^{\beta_1} + \varepsilon$	D^{-1}	4.59e-34	5.14e-136	7.75e-17	1.59e-177	7.55e-181	0.0
	D^{-2}	1.30e-33	4.36e-172	3.62e-18	1.02e-212	1.25e-192	0.0
	D^{-4}	1.02e-06	2.49e-102	2.18e-09	6.06e-80	2.20e-58	1.78e-102
	$D^{-4}H^{-2}$	2.71e-08	6.12e-15	1.63e-06	2.81e-10	2.76e-17	2.81e-05
	D^{-k}	**0.6359**	4.87e-111	4.06e-13	4.12e-184	**0.1925**	1.95e-90
	D^{-g}	**0.7693**	**0.1511**	**0.1491**	**0.3886**	**0.6373**	**0.6025**
	$\widehat{AGB}^{-g}$	**0.4249**	**0.0727**	0.0029	**0.2007**	0.0259	3.85e-06
	$[\exp(\ln(\widehat{AGB}))]^{-}$	**0.0647**	2.63e-05	**0.7684**	4.41e-05	0.0152	0.0069
	AGB^{-2}	**0.6355**	**0.5882**	**0.8746**	**0.4127**	0.0031	1.06e-18
	D^{-1}	1.42e-25	1.44e-105	6.61e-17	1.73e-220	3.10e-154	0.0

$AGB = \beta_0 \cdot D^{\beta_1} \cdot H^{\beta_2} + \varepsilon$	D^{-2}	4.23e-24	1.12e-132	3.17e-17	2.74e-240	2.84e-157	0.0
	D^{-4}	6.35e-04	1.61e-97	1.01e-04	2.02e-79	2.28e-49	2.41e-139
	$D^{-4}H^{-2}$	8.37e-08	8.15e-18	2.72e-07	1.27e-35	3.09e-45	1.36e-46
	D^{-k}	**0.6166**	1.89e-11	6.01e-03	3.26e-11	2.75e-21	6.08e-09
	D^{-g}	**0.6475**	1.49e-11	0.0097	0.0208	**0.13122**	3.75e-09
	$\widehat{AGB}^{-g}$	0.0020	1.99e-04	0.0056	3.23e-05	1.62e-18	9.60e-43
	$[\exp(\ln(\widehat{AGB}))]^{-}$	0.0106	3.93e-05	0.0258	6.06e-08	4.81e-15	2.49e-16
	AGB^{-2}	0.0318	5.02e-05	**0.0581**	4.56e-05	3.61e-20	4.36e-52

Using D^{-2} to correct for heteroscedasticity produced lower p-values compared to D^{-1}, for four out of six datasets, which suggests that D^{-2} performed worse to correct heteroscedasticity compared to D^{-1}. For dataset 6 the p-value could not be calculated when using D^{-1} or D^{-2}. The other fixed functions D^{-4} or $D^{-4}H^{-2}$ resulted in an increase of the p-value compared to D^{-1} or D^{-2} but not sufficiently to reach the significance threshold of 0.05 for any of the datasets.

3.2. The effects of weighting approaches on large area biomass estimation

Table 3. The mean predicted biomass per hectare and its standard error by model form and weighting approach; the model parameter estimates for calibration dataset (Dataset 1).

Model form	**Weighting approach**	**Weighting variable**	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\mu}$ (Kg ha^{-1})	SE($\hat{\mu}$) (Kg ha^{-1})
$AGB = \beta_0 \cdot D^{\beta_1} + \varepsilon$	#1	D^{-1}	0.1014	2.4418	-	186139.3	9131.5
	#2	D^{-2}	0.1033	2.4368	-	185776.7	9087.5
	#3	D^{-4}	0.0872	2.4881	-	187668.4	9380.3
	#4	$D^{-4}H^{-2}$	0.0722	2.5389	-	190062.2	9909.8
	#5	D^{-k}	0.0813	2.5113	-	189722.6	9625.2
	#6	D^{-g}	0.0804	2.5151	-	190130.4	9676.1
	#7	$\widehat{AGB}^{-g}$	0.0798	2.5175	-	182886.0	9285.3
	#8	$[\exp(\ln(\widehat{AGB}))]^{-2}$	0.0787	2.5224	-	188005.0	9165.3
	#9	AGB^{-2}	0.0709	2.5290	-	177453.7	8671.6
$AGB = \beta_0 \cdot D^{\beta_1} \cdot H^{\beta_2} + \varepsilon$	#1	D^{-1}	0.0265	1.7694	1.1241	184523.2	9268.1
	#2	D^{-2}	0.0342	1.8006	1.0150	186048.4	9150.4

	#3	D^{-4}	0.0514	1.8845	0.8001	182365.9	8853.1
	#4	$D^{-4}H^{-2}$	0.0667	1.9814	0.6096	173160.7	8502.5
	#5	D^{-k}	0.0564	1.9096	0.7434	184411.2	8951.8
	#6	D^{-g}	0.0558	1.9071	0.7494	179359.4	8733.0
	#7	$\widehat{AGB}^{-g}$	0.0590	1.9341	0.7026	178515.2	8656.7
	#8	$[\exp(\ln(\widehat{AGB}))]^{-2}$	0.0615	1.9475	0.6741	177621.8	8653.4
	#9	AGB^{-2}	0.0550	1.9317	0.7101	173644.6	8478.8

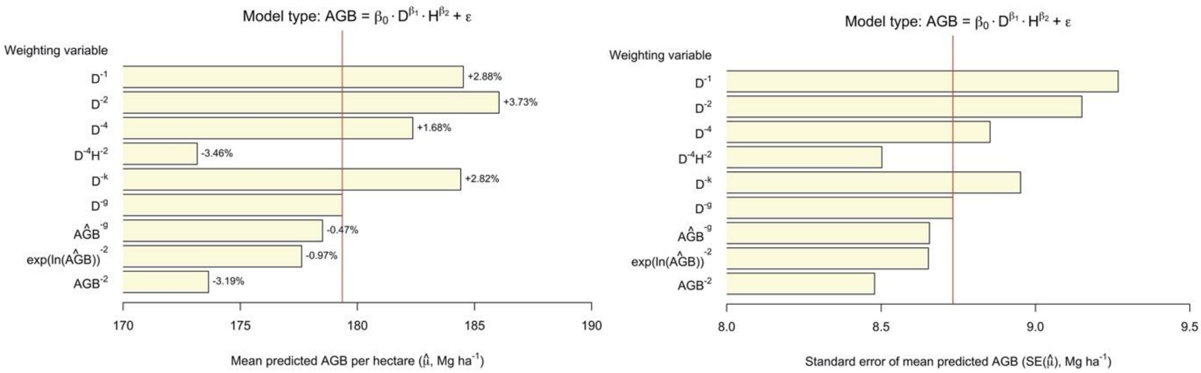

Figure 2. The mean predicted biomass and its standard error by model type and weighting variable

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Anexa 8. Sampling trees to develop allometric biomass models: How does tree selection affect model prediction accuracy and precision?

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Abstract

Developing allometric biomass models is an important process because reliability of forest biomass and carbon estimations largely depend on the accuracy and precision of such models. The effects of tree sampling on tree aboveground biomass (AGB) prediction accuracy and precision are complex and can, therefore, be difficult to quantify. In this paper we use a Monte Carlo simulation to investigate how model prediction accuracy and precision are affected by tree sampling approaches. Because diameter at breast height (D, in cm) is the most common predictor of tree AGB (in kg dry weight), we focused our analysis on the AGB-D relationship. The following sample characteristics were investigated: (i) sample size; (ii) extent of the D-range (difference between the largest and the smallest D value); (iii) position of D-range (characterized by the starting point of D-range); and (iv) the size-distribution (distribution of D) of sample trees. We found that, although the natural variability of AGB-D relationship was a key driver for both prediction accuracy and precision, the above sample characteristics were important for improving prediction accuracy. Although having a negligible effect on precision, both sample size and size-distribution of sample trees, greatly influenced prediction accuracy. We demonstrate that selecting a constant number of trees for each D class (i.e. uniform distribution of the sample trees over the D-range) generally produced models that were more accurate predictors of AGB. The extent and position of D-range, although considerably affecting the goodness of fit and the standard errors of allometric model parameters, had only a marginal effect on AGB prediction accuracy and precision. Furthermore, we showed that R^2 was a poor indicator of model prediction accuracy and precision, due to its sensitivity to changes in D-range. These findings inform certain practical recommendations we report for improving the accuracy and precision of biomass prediction.

Keywords: allometric biomass models, tree sample size, aboveground biomass, diameter at breast height, diameter distribution, sampling characteristics

Abbreviations

D	tree diameter at breast height (in cm);
AGB	aboveground biomass of a tree (in kg dry weight);

D-range an interval of simulated D observations used to develop an allometric model, and characterized by the starting and ending points of the interval;

S_3 a D-range between 0.1 and 60 cm;

S_2 a D-range between 10 and 60 cm;

S_1 a D-range between 20 and 60 cm;

I_{min} a D-range between 30 and 60 cm;

B_1 a D-range between 30 and 70 cm;

B_2 a D-range between 30 and 80 cm;

B_3 a D-range between 30 and 90 cm;

I_{max} a D-range between 0.1 and 90 cm;

RSE residual standard error;

n sample size;

β_0 the intercept of a linear allometric model in logarithmic scale;

β_1 the slope of linear allometric model in logarithmic scale;

SE(β_0) standard error of the intercept;

SE(β_1) standard error of the slope;

R^2 coefficient of determination;

P_A standard deviation of relative bias, reported as a measure of prediction accuracy;

P_P mean coefficient of variation of predicted biomass, reported as a measure of prediction precision.

1. Introduction

It is widely accepted that forests play a critical role in the fight against climate change (Grassi et al., 2017), and that the accumulation of carbon in tree biomass is regarded as an important service provided to society. However, the development of sustainable mitigation measures and programmes such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) requires that accumulation of carbon in forests is accurately and precisely estimated. Estimating carbon accumulation in forests is typically achieved using forest inventory records, to which allometric models are applied (Brown, 2002; Chave et al., 2004; Clark et al., 2001; Stephenson et al., 2014). To determine carbon sequestration forest biomass is first estimated, then, using a constant proportionality ratio, e.g. 0.47 (IPCC, 2006), the equivalent carbon content may then be calculated, which can be further converted to express CO_2. Therefore, since the ratio between biomass and carbon is a constant, the terms ‘carbon accumulation’ and ‘biomass accumulation’ have approximately the same meaning.

Producing accurate and precise predictions of biomass is challenging for several reasons. First, it needs an unbiased forest inventory design with accurate measurements of tree attributes. Second, it requires that allometric biomass models are representative for the forest inventory data to which the model is applied. Selection of the allometric model has been shown to be an important step for reducing biomass prediction uncertainty (Picard et al., 2015). Allometric biomass models are nonlinear regression models that typically use tree diameter at breast height (D, in cm) and/or tree height (H, in m) to predict tree aboveground biomass (AGB, in kg dry weight). Models are based on a sample of trees for which biomass was measured. Representativeness of the model to the forest inventory data requires that sample trees are selected from the inventoried population. Allometric biomass models were shown to be greatly influenced by site conditions (Dutcă et al., 2018a). This in turn may increase the complexity of tree sampling and reduce their transferability of the models to other sites (Dutcă, 2019).

The range of tree sizes and their distribution across the range are important prerequisites for determining sample strata. The range represents the difference between largest and the smallest value of predictor (e.g. D) for the sample trees used to build the model. The distribution of sample trees (on D-range) is often referred to as 'D class distribution' (Chave et al., 2004; Roxburgh et al., 2015) because D is usually measured in forest inventories in scales of increment categories (e.g. intervals of 2 cm). However, when developing allometric biomass models, diameter at breast height (D) is measured as accurately as possible and represented as a continuous variable.

Because allometric models are site-specific (Dutcă, 2019; Dutcă et al., 2018a), there are numerous examples of published allometric models based on trees sampled from one or few forest stands (Chojnacky et al., 2014; Jia et al., 2015; Marziliano et al., 2015; Morhart et al., 2016, 2013; Mosseler et al., 2014; Zianis et al., 2005), which therefore have limited and less than optimal D-range. Alternatively, allometric models may be deliberately developed to represent biometrics of small trees only (e.g. Pajtík et al. 2008; Dutcă et al. 2010; Blujdea et al. 2012; Ciuvat et al. 2013). Nevertheless, tree size is subject to natural limitations; maximum tree height is influenced by physiological stress and resource abundancy as well as hydraulic constraints (Koch et al., 2004). Although maximum tree height is physically limited, trees continue to accumulate biomass by increasing their diameter (Stephenson et al., 2014). Generic allometric models and biomass databases often include very large trees, for example, D of up to 212 cm (Chave et al., 2014), up to 293 cm (Jucker et al., 2017) or even as much as 648 cm (Falster et al., 2015).

The process of biomass measurement is very resource intensive. It is, therefore, important that sampling is optimized to ensure that the resulting allometric model predicts biomass as accurately and precisely as possible. In this paper, using a Monte Carlo analysis, we investigate which approaches of tree selection affect biomass prediction accuracy and precision and how these factors exert their influence. The sample characteristics that were investigated are: (i) sample size; (ii) the extent of D-range (i.e. difference between largest and the smallest sample tree); (iii) position of D-range (i.e. the starting or ending point of the range); and (iv) the distribution of sample trees (i.e. the frequency distribution of selected trees across the D-range).

To demonstrate the effects of sample characteristics on biomass prediction accuracy and precision we performed a simulation study. This involved the following steps: (1) bivariate sets of AGB-D data were simulated to capture key characteristics of the sample trees (e.g.

AGB-D variability, sample size, D-range, size-distribution of the sample trees); (2) allometric biomass models were fitted to simulated data; (3) the allometric biomass models were then applied to predict the biomass in a plot and the errors from model parameters and residual variability were propagated to determine their effects on plot AGB prediction; (4) the AGB prediction accuracy and precision (at plot level) were assessed; (5) an examination was made to identify which characteristics of the sample trees considered in the first step (i.e. AGB-D variability, sample size, D-range, size distribution of the sample trees) affected the model's prediction accuracy and precision, and to determine the nature and extent of these affects. Our study aims to inform improvements in the overall accuracy and precision of biomass prediction for forests, and to suggest measures for developing robust allometric biomass models.

2. Material and methods

2.1. Some rationale on the simulation design

Although logarithmic transformation (Huxley, 1932; Snell, 1892) is widely regarded as a standard procedure in the development of allometric biomass models, its use is the subject of some debate (Kerkhoff and Enquist, 2009; Packard, 2012; Packard and Boardman, 2008; Xiao et al., 2011). The standard assumptions of this type of transformation are: (i) heteroscedasticity, which is common in allometric models, is entirely removed by transformation; and (ii) because errors are lognormally distributed when back-transformed (original scale), they will be normally distributed in log-log scale. If these two assumptions hold true, then the back-transformed errors can be assumed to be multiplicative (Cole and Altman, 2017). In other words, the back-transformed residuals may be expressed as a ratio between observed and predicted biomass and therefore indicate the percent variation of observed biomass relative to predicted biomass. However, if the two assumptions do not hold true, then the logarithmic transformation is not recommended, as the general assumptions of a linear model (e.g. normality of residuals, homogeneity of variance) would not be met. Xiao et al. (2011) showed that although both the multiplicative and the additive error-type relationships occur in nature, multiplicative errors were much more frequent. Also, because diameter at breast height (D) is the most common predictor of individual tree aboveground biomass (AGB), we have focused our simulation on AGB-D relationship, starting with a log-log linear model:

$$\ln(\mathrm{AGB}) = \beta_0 + \beta_1 \cdot \ln(\mathrm{D}) + \varepsilon \qquad \text{(Eq. 1)}$$

Where: AGB is the aboveground biomass (in kg dry weight); D is the diameter at breast height (in cm); 'ln' is the natural logarithm; β_0 and β_1 are the model parameters in logarithmic scale; and ε is the additive error term (additive for the log-log scale), normally distributed with a mean of zero. We then defined some true parameters for a hypothetical population. Because the population is hypothetical, to make the values of parameters credible, we derived the parameters from a real biomass dataset reported by Schepaschenko et al. (2017). The true model parameters for our hypothetical population were:

$$\ln(\mathrm{AGB}) = -2.11 + 2.33 \cdot \ln(\mathrm{D}) + \varepsilon \qquad \text{(Eq. 2)}$$

Starting with these true parameters, we generated random sets of ln(AGB) – ln(D) data which were further fitted. The error term (e in Eq. 2) is normally distributed with the mean zero and standard error of residuals, RSE. The resulting model was then applied to a plot dataset to estimate the biomass. Each generated dataset had specified characteristics, such as RSE (residual standard error) of log-log model, number of observations, D-range extent, position and distribution. A Monte Carlo approach (described below) was used.

2.2. Natural variability of AGB-D relationship

Sampling design should capture the natural variability of AGB-D relationship that is intrinsic to the population. Because we assumed that heteroscedasticity is removed by logarithmic transformation and that errors are lognormally distributed in original scale, the natural (or intrinsic) variability of AGB-D relationship can be expressed as the residual standard error (RSE) of the log-log linear model (see Eq. 2). Since the residuals of a back-transformed log-log linear model show relative variation of AGB (relative to predicted AGB), the RSE can be interpreted, for original scale, as a form of coefficient of variation (Cole and Altman, 2017). We tested two values of RSE in this study, 0.2 and 0.3, which can be interpreted as 20% and 30% coefficient of variation. These two values lie within the expected range for allometric biomass models (Roxburgh et al., 2015).

2.3. Sample characteristics

2.3.1. Number of observations (sample size)

The number of sample trees necessary to develop an allometric model depends on the precision required, the level of intrinsic variability in the AGB-D relationship and other factors. Roxburgh et al. (2015) performed a simulation study to find the number of sampled trees necessary to develop allometric models. They concluded that, given the intrinsic variability of trees and the differences between distribution of tree diameters used to construct the model and the distribution of tree diameters of the inventory data, a number of anywhere between 17 to 166 trees were required to obtain prediction with a standard deviation within 5% from the mean. However, Picard et al. (2012) suggested that approximately a minimum number of 100 trees was needed to construct reliable volume models. In our simulation design we tested three values of sample size, n = 100, n = 150 and n = 1000 trees. The first two values (n = 100 and n = 150) were intended to determine the effect of a 50% increase in sample size, as to compare it to a 50% increase in RSE (from RSE = 0.2 to RSE = 0.3). The third value (n = 1000) was intended to see how increasing the sample size influences model prediction performance.

2.3.2. The extent of D-range

The range of diameter at breast height (D) used in allometric biomass models varies greatly. In a review of allometric models, Zianis et al. (2005) most models were based on a relatively narrow D-range with no consistent starting point (minimum D) for the range. For example, the largest tree of 90 cm was recorded in an allometric model for *Quercus ilex* in Italy and the minimum recorded diameter was 20 cm. Comparable maximum limits of D-range are reported in recent biomass datasets for boreal and temperate forests (Schepaschenko et al., 2017; Ung et al., 2017), and larger D-range are reported for trees sampled in tropical regions (Chave et al., 2014; Falster et al., 2015; Jucker et al., 2017). For our simulation study, we assumed a maximum D-range in allometric biomass models between 0.1 and 90 cm (after the D-range reported by Zianis et al., 2005), and divided the range into three equal diameter intervals of 30 cm. Starting from the second interval (i.e. I_{min} = [30, 60]), we gradually expanded I_{min} in two directions (i.e. towards small diameter and towards large diameters) until reaching the limits of the maximum D-range. This resulted in seven D-ranges. We examined the entire D-range (i.e. I_{max} = [0.1, 90]), thereby testing a total of eight D-ranges (as summarised in Table 1).

Table 1

D-ranges used for simulation (D is the diameter at breast height)

Code	D-range (cm)	Description
S_3	[0.1, 60]	I_{min} + 30 cm towards small diameters
S_2	[10, 60]	I_{min} + 20 cm towards small diameters
S_1	[20, 60]	I_{min} + 10 cm towards small diameters
I_{min}	[30, 60]	The minimum D-range
B_1	[30, 70]	I_{min} + 10 cm towards large diameters
B_2	[30, 80]	I_{min} + 20 cm towards large diameters
B_3	[30, 90]	I_{min} + 30 cm towards large diameters
I_{max}	[0.1, 90]	The maximum D-range

2.3.3. The position of D-range

The position of D-range is characterized by the starting point of D-range. Each member of each pair of identical D-range extent began at a different position (Table 1). For example, the ranges S_1 and B_1 have the same 40 cm range but their starting positions differ by 10 cm. This difference increases to 20 cm for S_2 vs. B_2 and to 30 cm for S_3 vs. B_3 (Table 1).

2.3.4. Distribution of sample trees

The frequency distribution required for sampling trees and for developing robust models is an important consideration because it determines the level of resources and logistics required for measuring biomass. If trees were entirely randomly sampled, the sample size-distribution would approach that of the population. However, trees are not entirely randomly sampled because the sample is first stratified for each D-class, before random sampling is conducted within D-classes (McRoberts et al., 2015). A ‘D class’ groups trees within a specified D-range. Thus, for a 2 cm D class the entire D-range is divided into intervals (classes) of 2 cm (e.g. D = 10 to 12 cm). Workers therefore are able to determine how they represent frequency distributions through their selection of the range represented and the bins for each D-class. Nevertheless, the distribution of sample trees will influence how well the model is informed across the range of D, with consequences for confidence in model prediction. In our simulation, we explored four types of distribution (Fig. 1):

(a) Uniform distribution on D-range (Fig. 1, a) of the sample frequency, where a constant number of sample trees is selected for each D class.

(b) Normal distribution on D-range of the sample frequency (Fig. 1, b), where the sample frequency reflects a normal distribution of D. In other words, the largest number of sample trees is from the middle of D-range and decreases towards the margins of the range;

(c) Uniform distribution on ln(D)-range (Fig. 1, c1), which, for the original scale is equivalent to inverse of uniform distribution (Fig. 1, c2, the result of exponentiation of observations sampled from a uniform distribution on ln(D)-range).

(d) Normal distribution on ln(D)-range (Fig. 1, d1). This is equivalent to lognormal distribution on D-range (Fig. 1, d2). For both, the uniform and normal distribution on ln(D)-range, a larger number of small trees is sampled compared to large trees (Fig. 1, c2 and d2).

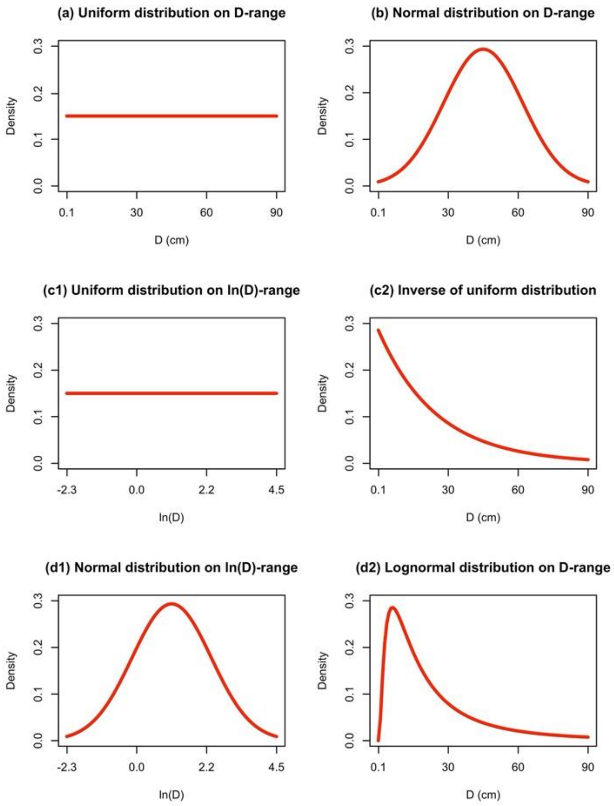

Fig. 1. Distributions of sample trees used for simulations: (a) Uniform distribution on D-range (D is the tree diameter at breast height); (b) Normal distribution on D-range; (c1) Uniform distribution on ln(D)-range, which is equivalent to the inverse of uniform distribution (c2); (d1) Normal distribution on ln(D)-range, for which, the equivalent of original scale is the lognormal distribution (d2).

It is relatively straightforward to define D-limit ranges for uniform distributions. However, the normal distribution for D theoretically extends to infinity. For our simulation we therefore sampled from a truncated normal distribution, for which the lower and upper bounds of D-range were established using the 'truncnorm' package in R (Mersmann et al., 2018). We set the D-range to correspond to $\pm$ two standard deviations, equal to an interval expected to include 95% of observations from a normal distribution. The mean of the normal distribution (μ_d) was the mean of D of the corresponding sample:

$$\mu_d = D_{min} + \frac{(D_{max} - D_{min})}{2} \qquad \text{(Eq. 3)}$$

and the standard deviation (σ_d) was calculated as:

$$\sigma_d = \frac{\mu_d - D_{min}}{2} \qquad \text{(Eq. 4)}$$

where D_{min} and D_{max} are the minimum and maximum limits of the D-range of interest (Table 1). For example, the normal distribution for I_{min} = [30, 60] cm was defined by the mean, μ_d = 45, with standard deviation, σ_d = 7.5.

2.4. Plot data

We compared the accuracy and precision of model simulations for estimating the biomass in a plot. Each allometric model developed on simulated data was applied to estimate the biomass in a 500 m^2 plot. The plot contained 21 trees for which biomass was predicted as a function of D using all simulated models. Because I_{min} = [30, 60] was the largest interval common to all the D-ranges tested, we selected a plot that contained only tree diameters that fell within this interval (Fig. 2). The purpose of this plot was therefore to provide a reference for prediction for all the simulated models in this study. In total, 0.96 million allometric models (5000 simulations × 2 RSE values × 3 sample sizes × 4 types of distribution × 8 D-ranges) were simulated. Therefore, the value of AGB predicted from this plot is that it provides a baseline for comparing AGB results predicted by other model that use different sample characteristics.

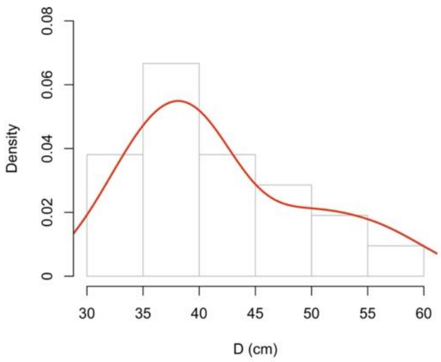

Fig. 2. The size distribution of the 21 sample trees in the plot. Note: D is the diameter at breast height; the red curve represents the kernel density; the grey bars represent the density of each D-class (width of 5 cm).

It is known that models have a poorer prediction performance at the extremes of the covariate range. For example, a biomass model developed on sample trees with a D-range of 0.1 to 90 cm would normally perform best when predicting biomass for trees at the centre of D-range (D = 45 cm) and progressively worse approaching the sample extremes of D = 0.1 cm or D = 90 cm. Therefore, one study objective was to investigate how models perform across the D-range. Consequently, another reason for working with a single plot with D-range restricted to I_{min} was to investigate the performance of models when only part of the D-range was used for prediction. A third reason for working with only one plot was to exclude other potentially confounding sources of uncertainty. In this study we aimed to describe only that uncertainty arising from model parameters and residuals, and intentionally avoided introducing potentially confounding effects of between site variations.

2.5. Monte Carlo simulation

A Monte Carlo analysis was used to assess the effects of sampling approaches on biomass prediction. We followed the next steps:

1. For the *k*th simulation (K = 5000, is the total number of simulations), an allometric model was developed and then applied to predict biomass in the plot. The allometric model was developed based on simulated ln(AGB)-ln(D) data selected from the hypothetical population:

   1.1. defined a vector representing the errors of log-log linear model. The length of this vector was equal to the sample size (i.e. three values of sample size were used in this analysis, n =100, n = 150 and n = 1000, see section 2.3.1). The elements of the vector were randomly selected from a normal distribution with the mean zero and standard deviation either 0.2 or 0.3. Later in the simulation design, the standard deviation of this distribution will become the residual standard error (RSE) of the allometric model. Two values of RSE were used, RSE = 0.2 and RSE = 0.3, see section 2.2.

   1.2. defined a vector containing sample ln(D) values, which were randomly selected from a specific distribution type (i.e. four types of distribution were used, see section 2.3.4) and a specific D-range (i.e. a total of eight ranges were used, Table 1). Because models were fitted in log-log scale for uniform and normal distributions of D-range (Fig. 1, a and b), we randomly selected the sample D values from a uniform and normal distribution on D-range and then log-transformed the sampled values (to obtain ln(D) values). For uniform and normal distributions on ln(D)-range, we sampled the ln(D) values directly in log-log scale, from a uniform and respectively normal distribution on ln(D)-range (Fig. 1, see c1 and d1). For each of the k^{th} simulation, a distinct set of ln(D) values was generated, $\ln(D)_{(k)}$.

   1.3. defined a vector (the length of the vector equals the sample size, see section 2.3.1) containing the sample ln(AGB) values. Using the $\ln(D)_{(k)}$ values (obtained at step 1.2) and the error term (obtained at step 1.1) in Eq. 2, we generated the set of ln(AGB) values, which is also distinct for each of the k^{th} simulation, $\ln(AGB)_{(k)}$.

   1.4. fitted a linear model on the bivariate set of $\ln(AGB)_{(k)}$ (obtained at step 1.3) and $\ln(D)_{(k)}$ values (obtained from step 1.2):

$$\ln(\mathrm{AGB})_{(k)} = \beta_{0(k)} + \beta_{1(k)} \cdot \ln(\mathrm{D})_{(k)} + \varepsilon_{(k)} \qquad \text{(Eq. 5)}$$

   1.5. We retained the standard errors of model parameters, $SE(\beta_{0(k)})$ and $SE(\beta_{1(k)})$, and the coefficient of determination for the k^{th} simulation ($R^2_{(k)}$):

$$R^2_{(k)} = 1 - \frac{\sum(\ln(\mathrm{AGB})_{i(k)} - \ln\widehat{(\mathrm{AGB})}_{i(k)})^2}{\sum(\ln(\mathrm{AGB})_{i(k)} - \overline{\ln(\mathrm{AGB})}_{(k)})^2} \qquad \text{(Eq. 6)}$$

Where $\ln(\mathrm{AGB})_{i(k)}$ is the *i*th observed ln(AGB) in the k^{th} simulation; $\ln\widehat{(\mathrm{AGB})}_{i(k)}$ is the *i*th predicted ln(AGB) in the k^{th} simulation and $\overline{\ln(\mathrm{AGB})}_{(k)}$ is the mean of all ln(AGB) values in the k^{th} simulation.

1.6. defined the variance-covariance matrix to account for the covariance between $\beta_{0(k)}$ and $\beta_{1(k)}$ in the following steps.

2. The allometric model developed within steps #1.1 to #1.6 (one model for each k^{th} simulation) was used to estimate the plot biomass. To propagate the uncertainty from each allometric model (i.e. from model parameters and residual variance) to the plot level estimates, a loop of J = 5000 repetitions was used, adapted from McRoberts et al. (2015, 2016). For the j^{th} repetition:

2.1. defined a vector containing two values ($\beta_{0(j)}$ and $\beta_{1(j)}$) sampled at a time from a bivariate normal distribution (based on variance-covariance matrix of the allometric model developed at step 1.6, and on model parameters, $\beta_{0(k)}$ and $\beta_{1(k)}$, from step 1.4);

2.2. defined a vector containing one error term (ε_j) sampled at a time (one for each j^{th} repetition) from a normal distribution with the standard deviation equal to the residual standard error of the k^{th} allometric model (Eq. 5).

2.3. calculate the predicted biomass for each tree ($\widehat{\mathrm{AGB}}_i$) in the plot based on the sampled parameters (from step 2.1) and error (from step 2.2):

$$\widehat{\mathrm{AGB}}_i = \exp(\beta_{0(j)} + \beta_{1(j)} \cdot D_i + \varepsilon_j) \qquad \text{(Eq. 7)}$$

2.4. calculate the predicted plot biomass ($\widehat{\mathrm{AGB}}_j$) as the sum of individual tree predictions:

$$\widehat{\mathrm{AGB}}_j = \sum_{i=1}^{m} \widehat{\mathrm{AGB}}_i \qquad \text{(Eq. 8)}$$

Where m = 21, and m is the total number of trees in the plot.

3. The mean plot biomass, standard error of the mean and the relative bias were calculated over all J repetitions:

3.1. the mean predicted plot AGB over J repetitions:

$$\overline{\widehat{\mathrm{AGB}}_k} = \frac{1}{J} \sum_{j=1}^{J} \widehat{\mathrm{AGB}}_j \qquad \text{(Eq. 9)}$$

3.2. standard error of the mean:

$$\hat{\sigma}_k = \sqrt{\frac{1}{J-1} \sum_{j=1}^{J} (\widehat{\mathrm{AGB}}_j - \overline{\widehat{\mathrm{AGB}}}_k)^2} \qquad \text{(Eq. 10)}$$

3.3. relative bias:

$$\mathrm{Bias}_k(\%) = \frac{\left(\overline{\widehat{\mathrm{AGB}}}_k - \mu\right)}{\mu} \cdot 100 \qquad \text{(Eq. 11)}$$

where μ is the plot AGB, based on true population parameters (plot true AGB) and was calculated by applying the model based on true parameters (see Eq. 2) with a correction factor (Baskerville, 1972; Goldberger, 1968). The model was applied to all m = 21 trees in the plot and then the sum of individual tree biomasses was calculated. RSE is the residual standard error and can take one of two possible values, 0.2 and 0.3 (see section 2.2):

$$\mu = \sum_{i=1}^{m}(\exp(2.11 + \frac{RSE^2}{2}) \cdot {D_i}^{2.33}) \quad \text{(Eq. 12)}$$

4. Measures of prediction accuracy and precision were calculated over all simulations (K = 5000 simulations):

   4.1. The standard deviation of relative bias, reported as a measure of prediction accuracy (P_A):

$$P_A = \sqrt{\frac{1}{K-1}\sum_{k=1}^{K}(Bias_k - \overline{Bias})^2} \quad \text{(Eq. 13)}$$

Where $\overline{Bias} = \frac{1}{K}\sum_{k=1}^{K}(Bias_k)$

   4.2. The mean coefficient of variation of predicted biomass, reported as a measure of prediction precision (P_P):

$$P_P = \frac{1}{K}\sum_{k=1}^{K}\frac{\hat{\sigma}_k}{\overline{\widehat{AGB}_k}} \cdot 100$$
(Eq. 14)

Where $\hat{\sigma}_k$ is the standard error of predicted biomass (Eq. 10); $\overline{\widehat{AGB}_k}$ is the mean predicted plot biomass (Eq. 9).

2.6. Prediction accuracy and precision

Prediction accuracy and precision are used to describe the performance of an estimator (Walther and Moore, 2005). This study adopts the definition that prediction accuracy is the difference between a predicted value and the true value (Walther and Moore, 2005). Because our simulation design calculated 5000 values (therefore 5000 ‘differences’ between predicted and true plot AGB, which are normally distributed with a mean of zero), accuracy was reported as the standard deviation for these 5000 values (Standard deviation of relative bias, P_A, Eq. 13). Furthermore, prediction precision is a measure of ‘the statistical variance of an estimation procedure’ (Walther and Moore, 2005) which is a form of uncertainty arising from random variation. In this study, the precision was reported as the mean coefficient of variation of predicted biomass at plot level (P_P) in Eq. 14.

2.7. Data processing

Simulation analyses were performed in R (R Core Team, 2017) with the RStudio interface (RStudio Team, 2016) and using the packages “MASS” (Venables and Ripley, 2002) and “rtruncnorm” (Mersmann et al., 2018).

3. Results

3.1. The effects on standard errors of model parameters and on goodness of fit

The simulation results demonstrate that with increasing D-range, the standard errors of model parameters ($SE(\beta_0)$ and $SE(\beta_1)$ in Eq. 5) decreased while the R^2 values (Eq. 6) increased (Fig. 3 and Appendix 1). Greater standard errors denote a less precise estimation of model parameters, whereas larger R^2 values indicate a better fit of the model to the data. The effects were stronger when the D-range increased towards including small trees (Fig. 3, $S_1 – S_3$) compared to large diameter trees (Fig. 3, $B_1 – B_3$). When increasing the extent of D-range, the largest reduction of $SE(\beta_0)$ and $SE(\beta_1)$ and the largest increase of R^2 occurred for normal distribution on ln(D)-range (Fig. 3, d1-d3). Although in Fig. 3 only presents results for n = 100 and RSE = 0.3, similar patterns were obtained for other values of sample size and RSE (Appendix 1).

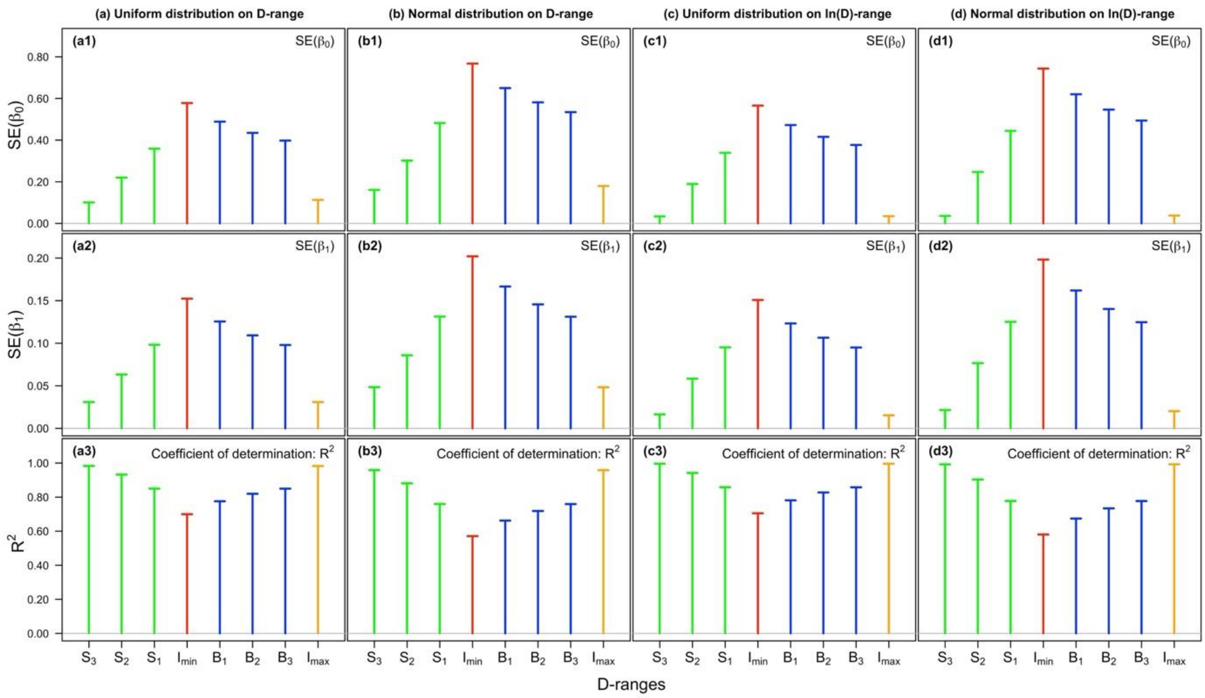

Fig. 3. The standard errors of model parameters $SE(\beta_0)$ and $SE(\beta_1)$, and the model goodness of fit (R^2) for a log-log transformed allometric biomass model (Eq. 5), different types of sample tree distribution and different D-ranges. For D-ranges S_3 to I_{max} (x-axis), see Table 1. Note: Each column of graphs, referred to as (a) to (d), represents a different type of sample tree distribution (for more information see section 2.3.4); $SE(\beta_0)$ is the standard error of the intercept in Eq. 5 and was calculated as the mean over all K=5000 simulations: $SE(\beta_0) = \frac{1}{K}\sum_{k=1}^{K}[SE(\beta_{0(k)})]$, where $SE(\beta_{0(k)})$ is from step 1.5 in section 2.5; $SE(\beta_1)$ is the standard error of the slope in Eq. 5, calculated as $SE(\beta_1) = \frac{1}{K}\sum_{k=1}^{K}[SE(\beta_{1(k)})]$, where $SE(\beta_{1(k)})$ is from step 1.5 in section 2.5; R^2 is the coefficient of determination, calculated as

$R^2 = \frac{1}{K}\sum_{k=1}^{K}(R^2{}_{(k)})$, where $R^2{}_{(k)}$ is from Eq. 6. This figure only presents data for models based on one value of sample size (*n* = 100) and one value of residual standard error (RSE = 0.3); the data for all values of sample size tested in this study (i.e. *n* = 100, *n* = 150 and *n* = 1000) and all values of RSE (i.e. RSE = 0.2 and RSE = 0.3) are presented in Appendix 1.

The standard errors of model parameters were affected by both RSE and sample size. However, the model goodness of fit (R^2) was affected mainly by the RSE with sample size only having a slight influence.

When RSE was increased by 50% (from 0.2 to 0.3) the standard errors of model parameters (intercept and slope) increased by the same 50% rate (SD = 0.31%; calculated based on values presented in Table A1, and Table A2 in Appendix1) whereas the effect on R^2 was dependent on the extent of the D-range and on the type of distribution (Fig. 3). For models based on smaller D-ranges and on trees sampled over a normal distribution (on either D or ln(D)), the effects of increasing RSE on R^2 were stronger.

When sample size was increased by 50% (from 100 to 150 trees), the standard errors of model parameters reduced, on average, by 18.7% (SD = 0.36%). When sample size was increased by 1000% (from 100 to 1000) the standard errors decreased by 68.7% (SD = 0.33%). Nevertheless, increasing the sample size by 50% (from 100 to 150) and tenfold (from 100 to 1000) led to relatively small changes in mean values for R^2 of only 0.07% and 0.18% respectively (see Appendix 1).

3.2. The effects on biomass prediction accuracy

As expected, residual standard error (RSE) was an important driver for prediction accuracy (expressed as standard deviation of relative bias, P_A, Eq. 13). A low P_A value means that the difference between predicted AGB and true AGB is small, and therefore the model is more accurate. When RSE was increased from 0.2 to 0.3 (therefore, by 50%), P_A increased by approximately the same ratio (i.e. by an average of 51.4%, SD = 2.3%; mean and SD were calculated from 96 P_A values presented in Table A4, Appendix1, using all possible permutations for 8 D-ranges, 3 values of sample size and 4 types of distribution). The effect was stronger for models based on shorter D-ranges (Fig. 4 and Table A4 in Appendix 1). Sample size was also an important factor affecting biomass prediction accuracy, although its effect was weaker when compared to that of RSE. When sample size was increased by 50% (from 100 to 150), P_A decreased by an average of 18.4% (SD = 1.2%; calculated on 96 values in Table A4). Increasing the sample size by tenfold (from 100 to 1000) resulted in an average decrease of P_A of 67% (SD = 0.8%; calculated on 96 values in Table A4). These effects were very similar to those found for standard errors of model parameters (when sample size increased by 50%, the standard errors decreased by 18.7%; when sample size increased tenfold, the standard errors decreased by 68.7%).

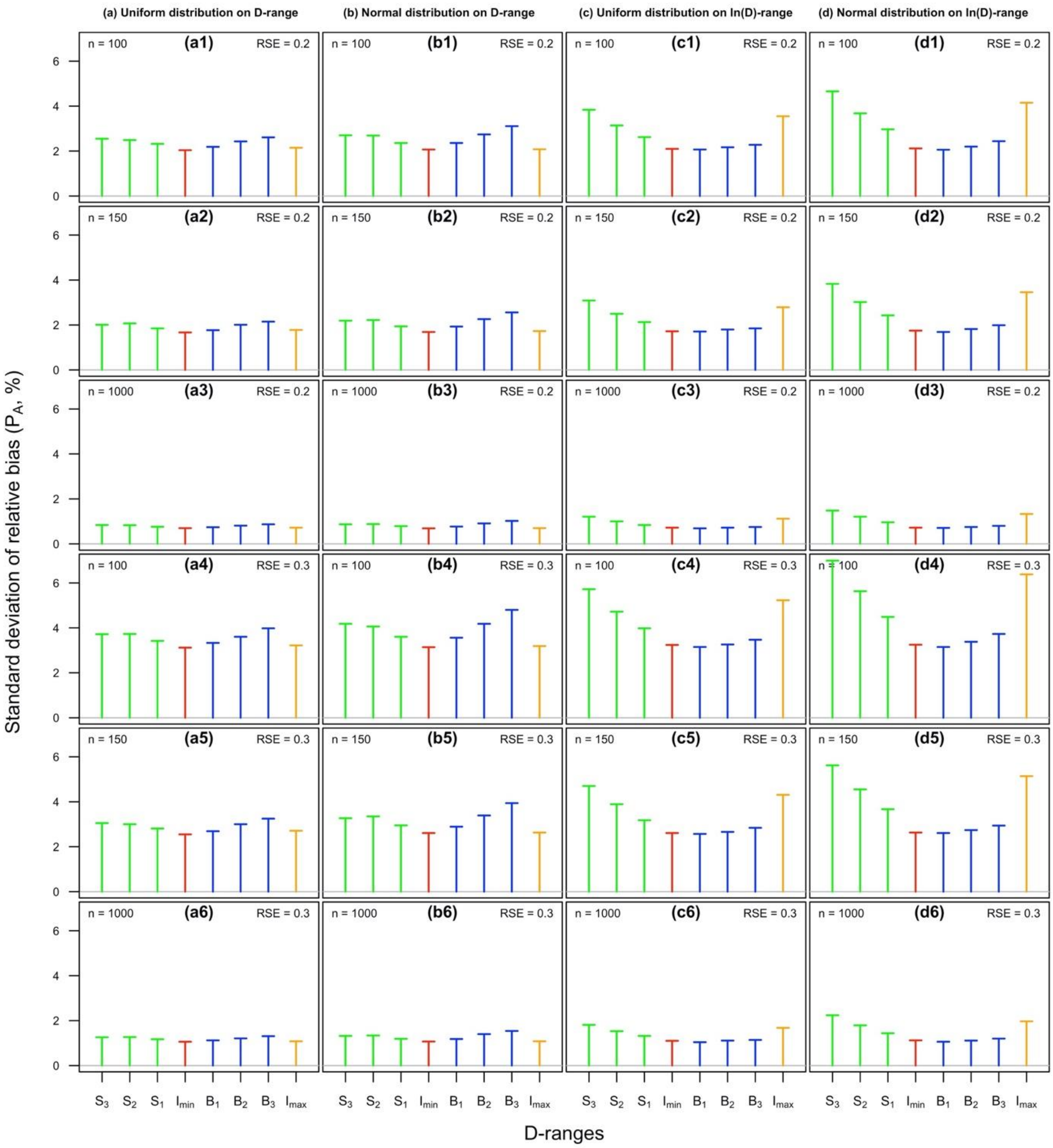

Fig. 4. The standard deviation of relative bias, describing prediction accuracy (P_A, Eq. 13, see section 2.5) for different characteristics of the sample. For D-ranges S_3 to I_{max} (x-axis), see Table 1. Note: Each column of graphs, referred to as (a) to (d), represents a different type of sample tree distribution (for more information see section 2.3.4); The rows 1-3 are for sample sizes (n) of 100, 150 and 1000 trees respectively and RSE = 0.2. Rows 4-6 repeat the same sample sizes for RSE = 0.3.

The variation in P_A values was lowest for uniform distribution on D-range (Fig. 4, a1-a6). This means that models constructed with trees selected along a uniform distribution of D-range produced more stable prediction accuracies across the D-range represented by models.

In other words, sampling a constant number of trees for each D-class mitigates losses in allometric model accuracy when only limited D-range is available for prediction.

However, models that were based on trees selected over uniform or normal distributions over transformed ln(D) range (Fig. 4, c1-c6 and d1-d6), produced larger P_A values for $S_1 – S_3$ ranges compared to $B_1 – B_3$. The cause of these differences lies in how well the model was informed over the range of D = 30 to 60 cm. We mentioned above (section 2.3.4) that the uniform or normal distribution on ln(D) range (see Fig. 1, c1, c2, d1 and d2) assume that a greater number of smaller trees are selected than larger ones. Therefore, the models based on uniform and normal distribution on ln(D)-range (Fig. 4, c1-c6 and d1-d6) are better informed towards the left (small tree) side of D-range distribution. However, the models based on $S_1 – S_3$ (in Fig. 4, c1-c6 and d1-d6) emphasise the right (larger tree) side of D-range for prediction (e.g. models based on S_3 were developed for D = 0.1 to 60 cm and were used to predict biomass of trees with D = 30 to 60 cm), which is less well informed. Therefore, the models based on $B_1 – B_3$ ranges produced more accurate predictions of AGB compared to models based on $S_1 – S_3$ ranges.

Because the models based on $S_1 – S_3$ and $B_1 – B_3$ ranges used only part of the entire available D-range for prediction (e.g. the model based on S_3 although being developed for D = 0.1 to 60 cm, was used to predict the biomass of trees with D = 30 to 60 cm), these were preferentially tuned to predict I_{min} with $S_1 – S_3$ or $B_1 – B_3$. Since prediction accuracy is poorer at the margins of D-range (for any given model) it is to be expected that P_A values increase slightly (for models based on $S_1 – S_3$ and $B_1 – B_3$ in comparison to models based on I_{min}). However, both I_{min} and I_{max} based models used the central portion of D-range for prediction and therefore these two can be compared to assess how increasing the extent of D-range affects prediction accuracy. Increasing the range from I_{min} to I_{max} did not improve the prediction accuracy and had the opposite effect. This was especially notable for distributions on ln(D)-range (Fig. 4, c1-c6 and d1-d6) for which the P_A value increased by up to 98%. For models based on uniform and normal distribution on D-range (Fig. 4, a1-a6 and b1-b6) a much smaller increase, of up to 6.6%, was observed.

We demonstrated the effects of increasing D-range from I_{min} to I_{max} when the number of observations remained constant. Therefore, although the models based on I_{max} exhibit greater R^2 and smaller standard errors for model parameters (Fig. 3), their prediction accuracy was poorer compared to models based on I_{min} (Fig. 4, see I_{min} vs. I_{max}). This suggests that the absolute number or density of observations for each part of D-range (or for each diameter class) is important. For the specific D-range of the plot data (i.e. D = 30 to 60 cm), the models based on I_{max} had a lower density of observations, compared to models based on I_{min}, since the same number of observations had to be distributed over a wider D-range (in the case of I_{max} based models). These results are important, because they demonstrate in comparison to model fitting and the standard errors of model parameters, that RSE (in log-log scale) and the absolute number of trees across the D-range are more important determinants of prediction accuracy.

3.3. The effects on biomass prediction precision

Although increasing the D-range the standard errors of model parameters decrease and the R^2 increases (Fig. 3), producing therefore improved models, this improvement was not reflected in the precision of biomass prediction (here, expressed as the mean coefficient of variation of predicted biomass, P_P, in Eq. 14). The P_P did not decrease with the increasing D-range and in some cases even increased slightly (Table 2).

Table 2

The mean coefficient of variation of predicted biomass (P_P, Eq. 14), for uniform and normal distribution on D-range and ln(D) range, for sample sizes of n = 100, n = 150 and n = 1000, for residual standard error RSE = 0.2 and RSE = 0.3 and for D-ranges S_3, S_2, S_1, I_{min}, B_1, B_2, B_3 and I_{max} (for more information on D-ranges, see Table 1).

D-range	Uniform distribution on D-range			Normal distribution on D-range			Uniform distribution on ln(D)-range			Normal distribution on ln(D)-range		
	n=100	*n*=150	*n*=1000	*n*=100	*n*=150	*n*=1000	*n*=100	*n*=150	*n*=1000	*n*=100	*n*=150	*n*=1000
RSE = 0.2												
S_3	20.32	20.29	20.22	20.35	20.30	20.22	20.53	20.41	20.23	20.78	20.54	20.26
S_2	20.31	20.24	20.21	20.32	20.32	20.20	20.44	20.33	20.22	20.54	20.38	20.22
S_1	20.30	20.26	20.20	20.30	20.30	20.22	20.39	20.29	20.20	20.44	20.34	20.22
I_{min}	20.27	20.25	20.20	20.30	20.25	20.21	20.28	20.28	20.20	20.26	20.23	20.20
B_1	20.28	20.27	20.21	20.28	20.25	20.21	20.25	20.26	20.21	20.26	20.27	20.21
B_2	20.29	20.31	20.21	20.39	20.31	20.22	20.29	20.26	20.20	20.25	20.25	20.21
B_3	20.35	20.32	20.21	20.45	20.35	20.23	20.27	20.27	20.21	20.30	20.27	20.21
I_{max}	20.28	20.25	20.21	20.31	20.27	20.21	20.49	20.36	20.20	20.64	20.49	20.25
RSE = 0.3												
S_3	30.94	30.82	30.72	31.07	30.82	30.73	31.30	31.02	30.74	31.68	31.36	30.78
S_2	30.91	30.82	30.71	30.96	30.88	30.70	31.18	30.98	30.73	31.28	31.01	30.75
S_1	30.85	30.81	30.72	30.90	30.88	30.71	30.98	30.89	30.72	31.08	30.94	30.72
I_{min}	30.80	30.78	30.71	30.81	30.78	30.69	30.85	30.80	30.71	30.89	30.83	30.70
B_1	30.86	30.75	30.70	30.90	30.85	30.70	30.89	30.81	30.72	30.85	30.80	30.68
B_2	30.95	30.83	30.69	31.04	30.83	30.73	30.94	30.77	30.69	30.93	30.83	30.70
B_3	30.93	30.88	30.72	31.09	30.98	30.73	30.92	30.81	30.70	30.96	30.88	30.72

I_{max}	30.82	30.78	30.71	30.79	30.76	30.70	31.22	30.99	30.73	31.44	31.14	30.76

From Table 2 it can be seen that P_P is highly related to residual standard error (RSE). Earlier it was mentioned (section 2.2) that RSE in log-log scale can be interpreted as a form of coefficient of variation for the original D-range scale. The slight increases in P_P values over and above base levels of 20% and 30% (for RSE values of 0.2 and 0.3 respectively) are due to uncertainty in model parameters, since P_P values contain errors propagated from both model parameters and residual variance. Therefore, RSE was the main driver of model prediction precision, with a very small proportion produced by uncertainty in model parameters (up to 5.3%). Increasing RSE by 50% (from 0.2 to 0.3) resulted in an average increase in P_P of 52.1% (SD = 0.2%; the mean and SD were calculated on the 96 P_P values presented in Table 2, for each value of RSE), regardless of sample size, D-range and distribution type. However, sample size, although greatly influencing prediction accuracy, had little effect on prediction precision. Since increasing the sample size directly affected the standard errors of model parameters (producing a decrease in standard errors) and since the propagated errors from model parameters represent only a very small proportion of P_P (up to 5.3%), it is to be expected that sample size will have little effect on prediction precision. Increasing the number of observations by 50% (from 100 to 150), had the effect of reducing P_P by 0.33% (SD = 0.29%), and increasing observations tenfold (from 100 to 1000) led to a reduction in P_P by 0.81% (SD = 0.56%). However, both these effects were found not to be significantly different from zero change (p = 0.26 and p = 0.16 respectively).

4. Discussion

4.1. Factors influencing biomass prediction accuracy and precision

The effects of tree sampling and data treatment approaches on biomass prediction accuracy and precision are subtle and can sometimes be counterintuitive. Findings here reveal certain characteristics of sampling strategies that are important for improving model prediction accuracy and precision. Of these it is the natural variability of the AGB-D relationship (expressed by RSE) that is the main driver for prediction accuracy and precision, thus an increase in RSE of 50% resulted in proportionally similar improvement in accuracy and precision. Increasing sample size was also found to be important for improving model accuracy but less so for improving precision. The finding that the effect of sample size on prediction accuracy depended on RSE and D-range, and was a function of $1/\sqrt{n}$, where n is the sample size, was consistent with results published from earlier studies (Chave et al., 2004; Picard et al., 2012).

Analyses demonstrate how a wider D-range improves model fit and the standard errors of model parameters (Fig. 3). This may also help to ensure that results from statistical tests are properly representative of allometric model performance, because the reduction of standard errors will increase the likelihood that null hypotheses (for no difference) are correctly rejected in analyses such as t- and F- tests (Dutcă et al., 2018b). However, we also showed that, although the model based on a wider D-range had a better fit, the prediction accuracy was poorer (Fig. 4, see I_{min} vs. I_{max}). This result, which may be surprising, can be explained by the frequency of the observations across the D-range. If the number of observations remain constant, increasing the D-range inevitably reduces the density of observations with negative consequences on AGB (aboveground biomass) prediction accuracy. Often, increasing the range of D is achieved by merging datasets for different D-ranges. In this event, the density of observations across the D-range is not reduced and the resulting increase of sample size increases prediction accuracy.

Furthermore, Roxburgh et al. (2015) suggested that the optimal size distribution of sample trees to develop allometric models is the one that most closely matches the distribution of trees to which the model is applied. Although our plot data appears to be lognormally distributed (Fig. 2), the greatest accuracy (lowest P_A value) was obtained for models based on a uniform distribution of D-range. This finding is in contradiction with results reported by Roxburgh et al. (2015). Because our plot D data only appeared to be lognormal, we further investigated this phenomenon by generating a new D dataset of 1000 observations lognormally distributed on I_{max} range. We investigated whether the model based on uniform distribution (developed for the same I_{max} range) produced lower P_A and P_P values (when predicting AGB of this new D dataset of 1000 observations) than the model based on lognormal distribution. The results confirmed that uniform distribution on D-range produced lower P_A and P_P values (model based on uniform distribution: P_A = 3.2% and P_P = 30.8%; model based on lognormal distribution: P_A = 6.3% and P_P = 31.4%). We repeated the comparison, for models based on uniform vs. normal distribution on D-range, when predicting AGB of 1000 trees normally distributed. Again, the model based on uniform distribution produced lower P_A and P_P values compared to model based on normally distributed sample trees (model based on uniform distribution: P_A = 3.5% and P_P =30.8%; model based on normal distribution: P_A = 3.6% and P_P = 30.9%). Therefore, our results indicate that models based on uniform distribution of the sample trees on D-range perform better (produce more accurate and precise predictions) regardless of distribution of the trees to which the model is applied.

4.2. Small trees are more informative in allometric models

We demonstrate that, for models based on similar number of observations and similar extent of D-range (and similar residual standard errors in logarithmic scale), if models include smaller diameter trees, the standard errors of model parameters were reduced and R^2 values were greater (e.g. see S_3 vs. B_3 in Fig. 3). Therefore, it is suggested that small trees are generally more informative in allometric models, compared to large trees. However, this seemingly anomalous finding can be explained by (or represents the indirect effect of) the heteroscedastic nature of the relationship between biomass and tree diameter. The variance in allometric models is not constant and increases with D (Zianis, 2008). As a result, to fit a nonlinear model the observations are usually weighted inversely to residual variance (the lower the residual variance, the larger the weight and vice-versa) (Dutcă et al., 2019). Logarithmic transformation on the other hand, performs a similar function: it re-scales data so that units are stretched for small values of variables (D and AGB) and compressed for large ones. Therefore, log-log transformation more heavily weights the influence of small trees over large ones, to ensure that residuals are comparable residuals across predictor range (i.e. homoscedasticity).

As the lowest residual variance usually occurs for the smallest D values (Zianis and Mencuccini, 2004), small trees are more heavily weighted and have a greater influence on regression models than larger trees. Therefore, small trees impart more information to models, and exert greater overall influence over the standard errors of model parameters and goodness of fit. Given the fact that small trees require less effort for biomass measurement, they are highly cost-effective to sample. Nevertheless, we have demonstrated that, although the models that included small trees produced smaller standard errors of model parameters and larger R^2 values, they did not necessarily produce more accurate or precise predictions of AGB (Fig. 4 and Table 2).

4.3. Selection criteria of allometric models

Goodness of fit (R^2 of linear model in log-log scale) is often reported with allometric biomass models, and is widely accepted as a criterion for model selection (Sanquetta et al., 2018). The assumption is that a model with the best fit will reasonably predict the biomass of other trees. Our results confirm that R^2 was not affected by sample size (Sanquetta et al., 2018). However, we showed that R^2 was a poor indicator of model prediction performance with respect to both accuracy and precision. Plotting the R^2 against P_A (Fig. 5, a) and P_P (Fig. 5, b) we observed no clear relationship between R^2 and model prediction accuracy or precision.

Although not sensitive to changes in sample size, R^2 was sensitive to variations in D-range (Fig. 3 and Appendix 1). Models yielded greater values of R^2 for the maximum extents of D-range (i.e. I_{max}, see Fig. 3) and when distribution of sampled trees was uniform on ln(D)-range (R^2 = 0.998, Fig. 3 and Table A3, Appendix 1). However, we showed that the extent of D-range did not affect prediction accuracy nor precision, and that actually the models based on trees sampled along a ln(D)-range produced poorer prediction accuracies. These findings suggest that R^2 may not be a reliable indicator of model prediction performance.

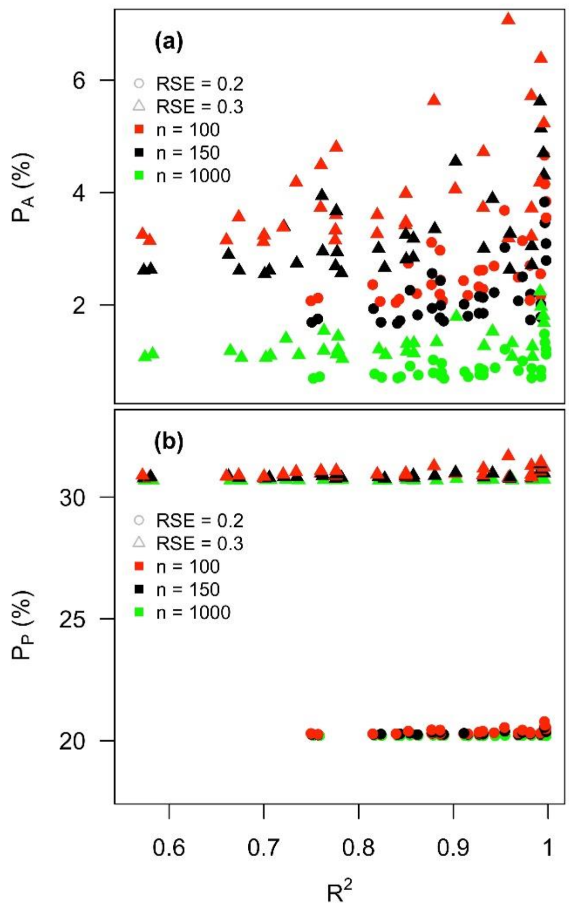

Fig. 5. The relationship between model goodness of fit (R^2, Eq. 6) and prediction accuracy (P_A, standard deviation of relative bias in %, Eq. 13) (a) and between R^2 and prediction precision (P_P, mean coefficient of variation of predicted biomass in %, Eq. 14) (b). Note: The plotted P_A values are from Table A4 (Appendix 1); the P_P values are from Table 2; the model R^2 values are from Table A3 (Appendix 1); larger P_A values show lower prediction accuracy; larger P_P values show lower prediction precision.

4.4. Limitations of the study

Our study has the following limitations. Firstly, the conclusions are only valid if the assumptions hold that heteroscedasticity is removed by logarithmic transformation and that errors are normally distributed in log-log scale. Secondly, because the study was limited to the relationship between AGB and D, the conclusions should not be extrapolated to other types of relationships. Thirdly, this study did not consider the uncertainty arising from between site variation. Fourthly and finally, we have assumed that the diameters of trees in the inventory (plot) dataset were always within the D-range used to construct the model. We did not investigate the consequences of predicting AGB of trees outside the range of diameters used to construct the models.

4.5. Recommendations

Study findings suggest that the following guidelines will be useful in the preparation of reliable allometric models:

(1) **Select a constant number of trees for each D class (use a uniform distribution of sample trees).** Results demonstrate that the models based on uniformly distributed sample trees over the D-range (D is the diameter at breast height) produced more accurate AGB predictions (AGB is the aboveground tree biomass), regardless of D-distribution of the inventory dataset. Also, variations in prediction accuracy across D-range were minimal.

(2) **Avoid using R^2 as criterion for model selection**. Findings suggest that R^2 (coefficient of determination) alone is not a strong indicator of model prediction performance.

(3) **Use strategies to avoid unnecessary large levels of RSE in allometric models**. Because RSE (Residual Standard Error of the model in log-scale) is indicative of the intrinsic AGB variability for any given D, it cannot be naturally reduced. However, because RSE was a key driver of both prediction accuracy and precision, it is recommended that strategies are adopted to help reduce unnecessary AGB variability, such as: (i) avoiding using generic allometric models, where species effect is ignored and, therefore, to use species-specific allometric models wherever possible; (ii) test and include additional predictors in the models that may explain part of the residual variance, such as tree height, crown diameter and wood density.

5. Conclusions

The key conclusions drawn from this study are as follow: (i) residual variance was the most important driver of model's prediction accuracy and precision; (ii) increasing the sample size improved prediction accuracy (although its effect was weaker than that of residual standard error), but had negligible effect on prediction precision; (iii) increasing the extent of D-range, although improving both the goodness of fit and standard errors of model parameters, did not affect prediction accuracy nor precision; (iv) the size distribution of sample trees was important for prediction accuracy; we found that uniform distribution of D-range was optimal, regardless of the distribution of the inventory dataset; (v) small trees were more informative in allometric models, due to the effects of inherently heteroscedastic variance; (vi) R^2 was not a good indicator of prediction performance of allometric models.

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Anexa 9. A template of data for PREBAS calibration and application

1 Site description data

1.1 Required variables

Table 1.1 Variables of the site summary information

Names	Unit	Description
SiteID	-	SiteID is for identifying the plot of the forest.
ClimateID	-	ClimateID is for identifying the regions. Several sites might belongs to a same ClimateID, which means that they share the same weather condition.
Latitude	degree	Latitude of the plot in decimal unit, WGS84 (World Geodetic System 1984).
Longitude	degree	Longitude of the plot in decimal unit, WGS84 (World Geodetic System 1984).
Elevation	m	The elevation of the site. This variable is optional. If possible, providing the aspect and slope of the site will also be helpful in checking data and model output.
SoilType	-	Classification based on soil textures. For instance, sand, loam, light clay, etc.
SoilDepth	mm	Thickness of soil or ecosystem rooting depth.
FieldCapacity	mm	Soil property. Field Capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased. The value range is 0 to1000.
WiltingPoint	mm	Soil property. Permanent wilting point or wilting point is defined as the minimal amount of water in the soil that the plant requires not to wilt. The value range is 0 to 1000.
SiteType	-	Classification based on site fertility. This column can be replaced by site index, site class, site form, or any other phytocentric and geocentric indicators of forest site productivity. If using site index, please indicate the reference age by changing the name of the variable. For instant, 'Hdom_100' means the dominant height at age 100.

PREBAS do not require Longitude and Latitude as inputs. However, the location information is essential in collecting useful data and information from other databases in both model calibration and application.

SoilType is used for gap-filling and validating the FieldCapacity and WiltingPoint records. FieldCapacity and WiltingPoint can be estimated based on the soil texture (SoilType).

1.2 Data format

Site description data should be provided in format of tables like csv files (comma delimited). Below an example of the site description table：

SiteID	ClimateID	Latitude	Longitude	SoilType	Soil Depth	FieldCapacity	Wilting Point	Site Type
1	1	39.33902	-9.21183	Loamy Sand	1275	0.25	0.15	2
2	1	39.33902	-9.21183	Loamy Sand	1275	0.25	0.15	2
3	1	39.33891	-9.22342	Sand Loam	1275	0.305	0.18	2
4	1	39.33891	-9.22342	Sand Loam	1275	0.305	0.18	3
5	1	39.33891	-9.22342	Sand Loam	1275	0.305	0.18	2
…	…	…	…	…	…	…	…	…
19	14	39.314407	-8.909976	Sand Loam	1275	0.305	0.18	1
20	14	39.314329	-8.92157	Sand Loam	1087.5	0.305	0.18	2

2 Weather data

2.1 Required variables

Table 2.1 Variables of the weather input for PREBAS

Names	**Unit**	**Description**
ClimateID	-	ClimateID is for identifying the regions. Several sites might belongs to a same ClimateID, which means that they share the same weather condition. (Same with Table 1.1)

Year	-	Date was separated into Year, Month, Day because the data format for different operation systems could largely differ.
Month	-	-
Day	-	-
PAR	mol PPFD m-2 d-1	Daily sum of photosynthetic photon flux density above the canopy.
TAir	°C	Daily mean air temperature
VPD	kPa	Daily mean vapour-pressure deficit
Precip	mm d-1	Daily sum of precipitation
CO2	ppm	Daily mean CO2 concentration. If this column is missing, PREBAS will use the global average daily value.

PAR (daily sums of photosynthetically active radiation) is seldom provided in global climate databases. However, it can be easily calculated from solar radiation (shortwave radiation) from established empirical relationships. The ratio of PAR to broad-band solar radiation varies from 0.4 to 0.6, and is nominally taken to be 0.44 or 0.5 when no local data for validation. Most meteorological datasets include solar radiation measurements.

2.2 Data format

Weather inputs should be provided in format of tables like csv files (comma delimited) or data.table objects in R. If many regions include long duration of the record and the combined file has millions of rows, we suggest to make each climate ID as an independent file. Then name the files in a uniform and explicit form. For instance, “ClimateID_1_1970_2005.csv” means that the climateID is 1, and observations include the years from 1970 to 2005. Below an example of the weather input table：

ClimateID	Year	Month	Day	PAR	TAir	VPD	Precip	CO2
1	1970	1	1	28.23	19.83	1.04	0	325.04
1	1970	1	2	28.77	19.41	1.12	10	325.04
1	1970	1	3	28.81	16.99	1.01	0	325.04
1	1970	1	4	16.95	17.40	0.97	0,2	325.04
...	…	…	…	…	…	…	…	…
1	2005	12	30	28.77383	19.52	1.14	0	380.9

1	2005	12	31	29.14447	21.015	1.28	0	380.9

3 Forest inventory data

3.1 Required variables

Based on the stand structure, PREBAS simulates forest dynamics at stand-level or layer-level (size-class) level. Thus, simulations of pure even-aged forest require stand average information. For the forest with mixed tree species or multiple layers, the average information for each layer or species is required.

Table 3.1 Variables of forest inventory data for PREBAS

Names	Unit	Description
SiteID	-	Identifying the plot. (Same with Table 1.1).
Year	-	The year when the forest inventory was implemented.
Rotation	-	Identifying coppice by Indicating which rotation the record belongs. 1 = first rotation, 2 = the second rotation.
Thinning	-	NoThin = No thinning was implemented this year; BeforeThin = Thinning was implemented this year and this record is the measurement before thinning; AfterThin= Thinning was implemented this year and this record is the measurement after thinning
nLayers	-	Number of layers in the plot. (Same with Table 1.1)
Layer	-	Identifying which layer this row belong. 1 = the 1st layer, 2 = the 2nd layer, etc. For even-aged pure forest, both nLayers and Layer equal 1.
Species	-	Tree species of this layer.
Age	yr	Average age of trees in this layer.
Height	m	Average height of trees in this layer.
DBH	cm	Average DBH (Diameter at Breast Height) of trees in this layer.
BasalArea	m^2 ha^{-1}	Total basal area of trees in this layer.

Density	ha^{-1}	Number of trees in this layer.
CrownBaseH	m	Average height of the crown base in this layer.
CrownWidth	m	Average crown width in this layer.
CrownLength	m	Average crown length in this layer.
Volume	m^3 ha^{-1}	Layer volume in this layer.
W_Stem	kg DM ha^{-1}	Stem biomass in this layer.
W_Foliage	kg DM ha^{-1}	Foliage biomass in this layer.
W_Branch	kg DM ha^{-1}	Branch biomass in this layer.
W_FineRoot	kg DM ha^{-1}	Fine root biomass in this layer.
W_CoarseRoot	kg DM ha^{-1}	Coarse root biomass in this layer.

Age, Height, DBH, and all the others variables concerned in the table are the average of the layer or size-class. For even-aged forests, the whole stand is referred as one layer. The variable can be estimated by choosing the medium tree of the layer, or by taking the basal-area-weighted average of all the trees in the layer. For natural uneven-aged forests with mixed species and complex structures, individual-tree level measurements are also needed.

Biomass information are only used in PREBAS calibration. After the model being calibrated, the application requires only basic inventory variables such as Height, DBH, and Density.

Forest inventory might exclude biomass investigation. Thus, destructive sample data are needed as described in section 4.1.

3.2 Data format

Forest inventory data should be provided in format of table like csv files (comma delimited). Below an example of the forest inventory table：

SiteID	Year	Rotation	Thinning	nLayers	Layer	Species	Age	Height	DBH	Basal Area	…	W neR	W_CoarseRoot
1	1970	1	NoThin	1	1	Eucalyptus globulus	4	10.4	7.8	5.174	…	776	1708
1	1971	1	NoThin	1	1	Eucalyptus globulus	5	12.5	9.4	7.457	…	1150	2532
1	1972	1	NoThin	1	1	Eucalyptus globulus	6	14.1	11.1	10.402	…	1686	3708
1	1973	1	NoThin	1	1	Eucalyptus globulus	7	15.4	13	13.987	…	2424	5332

1	1974	1	NoThin	1	1	Eucalyptus globulus	8	16.5	14	16.168	…	3120	6866
1	1975	1	NoThin	1	1	Eucalyptus globulus	9	17.1	15.2	18.968	…	4374	9622
1	1976	1	NoThin	1	1	Eucalyptus globulus	10	18.6	16	21.213	…	5890	12956
…	…	…	…	…	…	…	…	…	…	…	…	...	...
20	2002	1	NoThin	1	1	Eucalyptus globulus	35	31.6	25.4	55.016	...	38328	84322

4 Additional useful data

4.1 Destructive sample data

Destructive sample data here means individual-tree level biomass data. The information are essential for PREBAS calibration. Destructive sample data can be an independent dataset, but basic site information are still needed.

Table 4.1 Variables of destructive sample data. The default unit of the biomasses is kg dry matter (DM) per tree (kg DM).

Names	**Unit**	**Description**
D	cm	Diameter at breast height.
H	m	Tree height.
Hc	m	Height of the Crow base
Cw	m	Crown width
A_c	m^2	Cross-sectional area at crown base.
W_{Stem}	kg DM	Stem biomass
$W_{Foliage}$	kg DM	Foliage biomass
W_{Branch}	kg DM	Live branch biomass
$W_{FineRoot}$	kg DM	Fine root biomass
$W_{CoarseRoot}$	kg DM	Coarse root biomass

4.2 Classification of site fertility

The suitable method of site evaluation varies with tree species and regions. When the phytocentric and geocentric indicators of forest site productivity is missing in Table 1.1.

Please provide Age and Height information of the dominant trees for each plot. Then the site index can be calculated.

4.3 Eddy covariance data

Eddy covariance data are required for the calibration of PREBAS. Although many global eddy covariance network are providing open access data, those free datasets only cover limited tree species and regions. Thus, eddy covariance data could be considered as optional depending on the tree species and regions.

Table 4.2 Data requirement for the eddy covariance site. (Shading means same variables with previous tables)

Variable	Abbreviation	unit	time step	Data type
Soil Data				
soil depth	SoilDepth	mm	-	Site-specific
field capacity	FieldCapacity	mm	-	Site-specific
wilting point	WiltingPoint	mm	-	Site-specific
Soil water content	-	mm	Daily	Measurement
Canopy Information				
Fraction of Absorbed Photosynthetically Active Radiation	f_{APAR}	-	Daily or Yearly	light interception
Meteorological Data				
photosynthetic photon flux density	PAR	mol PPFD m^{-2} d^{-1}	Daily	weather
Air Temperature	TAir	°C	Daily	weather
Vapour pressure deficit	VPD	kPa	Daily	weather
Precipitation	Precip	mm	Daily	weather
Flux Data				
Gross primary production	GPP	g C m^{-2}	Daily	Eddy Tower

Evapotranspiration	ET	mm	Daily	Eddy Tower
Quality Flag	-	%	Daily	Eddy Tower

Extra Information could be useful, including 1) Forest inventory data of the site (remeasurements of DBH, basal area, height, etc), 2) Soil or canopy nitrogen information, e.g. C/N , 3) Shrubs and ground vegetation, e.g. LAI, chamber measurements.

f_{APAR} is either measured or calculated based on LAI (leaf area index). It changes with canopy growth or thinnings. Quality Flag is assigned to each day to indicate percentage of measured (non-gapfilled) and good quality gap-filled half-hourly data used to calculate the daily value. We prefer the nighttime partitioning method for GPP records.

4.4 Soil carbon storage

PREBAS can link the soil carbon model Yasso to simulate the dynamics of soil carbon, and also the ecosystem carbon fluxes. In this case, the information about soil carbon storage of the stand is needed. The data are optional because it’s difficult to obtain.

Anexa 10. Experiment privind descompunerea litierei

Anexa 10a. Metodologie pentru cuantificarea a ratei de descompunere a litierei si lemnului more de mici dimensiuni prin metoda "litter bag"

Definitii:

In acest experiment, "litiera" reprezintă frunze în stare naturala la sfârșitul ciclului de vegetație, "lemnul mort de mici dimensiuni" reprezintă lemn de dimensiuni inferioare celui înregistrat de Inventarul Forestier National ca lemn mort (presupunerea fiind ca acea variabila este deja înregistrată de IFN pentru tipurile de pădure în cauza). Ca urmare in acest experiment este inclus lemn sub 5.6 cm diametru.

Design experimental:

Tipuri de pădure majore
a) *gospodărită*: în molidiș, amestecuri de fag si rasinoase, si făget;
b) *virgina*: în amestecuri.
Fiecare tip major de pădure va fi reprezentat printr-o suprafață de monitorizare.
Distribuția altitudinala: trei suprafețe de monitorizare (SP) corespunzând altitudinilor la care se găsesc cele trei tipuri de pădure țintă:

- făget (cod Ffa) – 600-700m;
- amestec (AMo; ABr; AFa) – 800-1000m,
- molidiș (Mmo) – peste 1100 m.

LITIERA
Număr de probe definit în funcție de speciile prezente: 8 probe/specie * 10 momente de recoltare = 80 probe
Total probe de amplasat:
FFa = 80 probe
AFa, ABr, AMo = 80 probe Fag + 80 probe Brad + 80 probe Molid (total = 240)
MMo = 80 probe molid
VFa, Br, Mo = 80 probe Fag + 80 probe Brad + 80 probe Molid (total = 240)
TOTAL = 640 probe litieră

LEMN MORT dimensiuni mici sub 5.6 cm (diam min IFN)
Număr de probe definit funcție de speciile prezente: 3 dimensiuni lemn mort * 8 probe/specie * 2 momente de recoltare an 1 * 3 momente de recoltare an 2 * 1 momente de recoltare an 3 * 1 momente de recoltare an 4 = 56 probe
Fiecare plic (cu 3 compartimente) conține bucăți de lemn mort de cca. 15 cm lungime si 3 categorii de diametre (<2, 2-4, 4-5.6 cm)
Total probe:
FFa = 56 plicuri (fiecare cu lemn de 3 dimensiuni)
AFa, ABr, AMo = 56 plicuri Fag + 56 plicuri Brad + 56 plicuri Molid (Total = 168)

MMo = 56 plicuri molid
VFa, VBr, VMo = 56 plicuri Fag + 56 plicuri Brad + 56 plicuri Molid (Total = 168)
TOTAL = 448 plicuri cu lemn mort

Recoltare necromasă și preprocesare LITIERA: recoltare de necromasă din anul curent din locațiile stabilite. Se aduce în saci în laborator si se lasă să se usuce în aer la temperatura constanta pentru 5-7 zile. Pași:

- se pregătesc plicurile (bags);
- se cântărește plicul gol împreună cu eticheta. Denumirea probei înscrisă pe etichetă în momentul cântăririi este compusa din SP si nr. de ordine, e.g. AFa49 – proba *49* de *fag* amplasată în *amestecuri*;
- se încarcă plicul cu biomasă (cca. 15 grame la fag, 10 gr. la rășinoase) și se cântărește din nou pentru a determina biomasa;
- înregistrarea astfel (Fișierul Excel: *Litiera_forclimit_*data ultimei actualizări) (poate fi revizuit la prima recoltare de probe ML1):

Nr.	**Cod probă**	**MT0 (grame)**	**MLT0 (grame)**	**ULT**	**Data și momentul recoltării**	**MLTf (grame)**	**Tc**	**Usol**
1					e.g. 23/07/2018 (M3)			
2								

MT0 – masă plic și etichetă
MLT0 – masa plic, etichetă și litieră
ULT – Umiditate relativa proba la momentul inițial, % și STD
Data si momentul recoltării – se va indica data recoltării și momentul (unul din cele 10 momente de recoltare, ML1 pana la ML10);
MLTf – masă finală probă (masa plic, eticheta și probă)
Tc – temperatura
Usol – umiditate sol

Recoltare necromasă și preprocesare LEMN MORT:
Lemn din arbori vii pentru toate cazurile pentru a surprinde stocul de C corespunzător arborilor vii. Se usucă în laborator la temperatura constanta pentru o săptămâna. Se taie în lungime de cca. 15 cm. Se măsoară diametrul la mijloc.
Se cântăresc înainte de a fi introduse în plicuri și se înregistrează astfel (Fisierul excel: *LemnMort_forclimit_*data ultimei actualizări):

Nr.	**Cod probă**	**MT0 (grame)**	**MLT0 (grame)**	**ULT**	**Data și momentul recoltării**	**MLTf (grame)**	**Tc**	**Usol**
1					e.g. 23/07/2018 (M3)			
2								

MT0 – masă plic și etichetă
MLT0 – masa plic, etichetă și lemn mort
ULT – Umiditate relativa proba la momentul inițial, % și STD

Data si momentul recoltării – se va indica data recoltării și momentul (unul din cele 10 momente de recoltare, ML1 pana la ML10);
MLTf – masă finală probă (masa plic, eticheta și probă)
Tc – temperatura
Usol – umiditate sol

Estimarea factorului de corecție a umidității necromase la momentul inițial. După uscare în aer in laborator se colectează o probă omogenizată (din mai multe locuri) pe specie și se determină umiditatea relativă. Se usucă până la masă constantă în etuvă, la 80°C, se înregistrează masa înainte si după uscare, si se calculează valoarea medie a umidității biomasei.

Probele colectate în diverse momente de recoltare ulterioare se usucă individual în etuvă, deci nu necesita factor de corecție pentru umiditate.

Colectarea datelor de umiditatea a solului în momentul recoltării se măsoară gravimetric astfel: se colectează proba de sol de la 0-10 și 10-20 cm adâncime, se pune într-o pungă închisă ermetic. In laborator se cântărește masa totala proaspăta, se usucă la 105°C pana la masă constantă, se cântărește masa pungii. Umiditatea se calculează în procente (%).

Colectarea datelor de temperatura la nivelul litierei si la 2 m in aer – vor fi prelevate cu senzori cu înregistrare automata.

Construcția plicurilor. "Bag" este un plic: a) cu dimensiuni 20*30 cm pentru fag din plasa de țânțari cu dimensiunea ochiului de 1 mm si b) cu dimensiuni 10*10 cm pentru rășinoase din plasa de perdea fina. Plicul rezultă din plasa pliată și lipit la cald pe două margini, latura nelipita va fi capsata cu un număr egal de capse pentru plicurile de fag, sau lipita la cald la rășinoase.

Codificare. Fiecare plic/bag are un cod inscripționat cu marker permanent pe eticheta care va fi introdusa in plic.

Amplasarea probelor în suprafața de proba. Plicurile vor fi așezate în buzunarul creat prin plierea plasei cu muchia în aval, care sa limiteze/împiedice aderarea necromasei de plicuri. Buzunarul va fi fixat pe sol cu țăruși. Buzunarele vor fi întinse pe sol în șiruri, într-un dispozitiv care sa permită găsirea lor ulterioara la momentele de recoltare. Plicurile se așază în buzunar. Dispozitivul fotografiat. Arborii de lângă locul amplasării si cel care marchează accesul de la drumul rutier însemnați cu vopsea.

Probele trebuie așezate înainte de căderea majorității frunzelor astfel încât să fie acoperite natural, ori frunze proaspete vor fi împrăștiate peste plicuri.

Cordonatele geografice ale amplasamentelor Litiera&Lemn Mort

Data amplasarii plicurilor	Locatia (OS, alte repere geografice)	Coord. geografice	Comentarii
			EX. LT+LM, LT

Termene de recoltare/prelevare probe. Amplasare probe in luna octombrie-noiembrie 2017. In anul 2018 se vor efectua 7 recoltări in lunile M4 (aprilie), M5, M6, M7, M8, M9, M10. In anul 2019 se vor efectua 3 recoltări în M5 (Mai), M7 si M9. In total 10 recoltări.

Recoltare la termenele stabilite: La termenul stabilit de prelevare, se identifica locația, plicurile vor fi acoperite de frunze si posibil nevizibile. Se culeg cele 8 plicuri, i.e. primul + al 9-lea + al 17-lea +....., în așa fel să nu se piardă nimic prin ochiuri. Este foarte importanta separarea impurităților externe: cu o pensula sau lama fina se îndepărtează toata masa atașata de plic pe ambele părți, se pune apoi într-o punga. Pungile se aduc în laborator, se lasă deschisa sa se usuce în aer, apoi se usucă in etuva la 80°C (80C este compatibil cu factorul de corecție al umidității). Se cântărește conținutul total al plicului se înregistrează în tabelul de mai sus.

Alte analize necesare/posibile:
1. Gradul de descompunere poate fi descris și vizual (fotografiat) pentru fiecare moment, ca o completare de informație la partea cântărită.
2. Concentrația de minerale și azot la fiecare moment (C/N).
Parametrii obținuți privind descompunere ne sunt utili la modelul Yasso.

3. ***Fracțiunile Yasso pentru probe inițiale*** (pregatite pentru posibila prelucrare in laborator de catre partenerul Finnish Meteorological Institute, FMI (P5))

Anexa 10b. Decomposition of needle/leaf and small wood litter from European beech, Norway spruce and Silver fir: influence of mixture, climate (temperature x altitude) and forest management

1.Introduction

Litter decomposition is a fundamental process of forest ecosystems for the carbon and nutrients cycles (dead organic matter is transfered from the above-ground part of trees to the forest floor, where under the action of microorganisms and soil fauna is decomposed gradually depending on climate factors (temperature, precipitation) (Gholz et al. 2000), substrate availability/soil properties (Vesterdal 1999) and litter quality (Cornwell et al. 2008). In a meta-analysis, grouping data for 818 species from 66 decomposition experiments on six continents, Cornwell et al. (2008) found that plant functional traits as litter quality is more important than climate factors affecting litter decomposition rate (the species driven differences control predominantly the litter decomposition rate worldwidely).

2.Material and methods

Site

The study site is located in Transilvanian side of Southern Carpathians (Fagaras Mountains), Padurile Sincii forest district.

The study was carried out on European beech (Fagus sylvatica) leaves, and Norway spruce (Picea abies) and Silver fir (Abies alba) needle litter, but also on small wood litter of all three species. In October 2017, fresh fallen brown leaves were collected beneath several randomly distributed trees, while the needles were collected from branches cut from several trees selected at random. In November 2017, small wood pieces were collected from branches cut from trees recently harvested during the thinning interventions. Both litter types (leaves/needles and small wood) were stored 2 weeks in laboratory at air temperature. The litterbags were made of ??nets (20 x 30 cm; 1 mm mesh size? for beech and 10 x 10 cm; ..mm mesh size for needles) and filled with 10-20 g leaves and 5-15 g needles, respectively and labelled properly. In 6th of November 2017, on each of the four study sites 80 litterbags per species (8 replicates of 10 samplings campaigns over three years) were placed on the soil. Subsequent samples were taken according to a preplanned schedule (every month starting with 24th of April till 24 October). We dried a first set of bags at 80 C for five days and weighed and calculated for each species an average correction factor as ratio between oven dry mass and air-dry mass. We applied this correction factor to all litterbags in order to obtain the initial oven-dry mass of each leaf amount of every litterbag (we multiplied air-dry mass of all leaf bags for humidity by the average correction factor).

Data analysis

The relationship of the mass loss of leaves and needles and decomposition time is often modelled by a negative exponential decay model:

$M_t=M_0 \times \exp(-k \times t)$,

where:
-Mt is the mass at time t,
-M0 is the initial mass (mass at time 0),
-t is time in months
-k is the exponential decay coefficient or decomposition rate.
In our case, we used mass remaining as % from initial mass account (consequently, M0 = 100).

3.Results

3.1. Leaf/needle litter decomposition

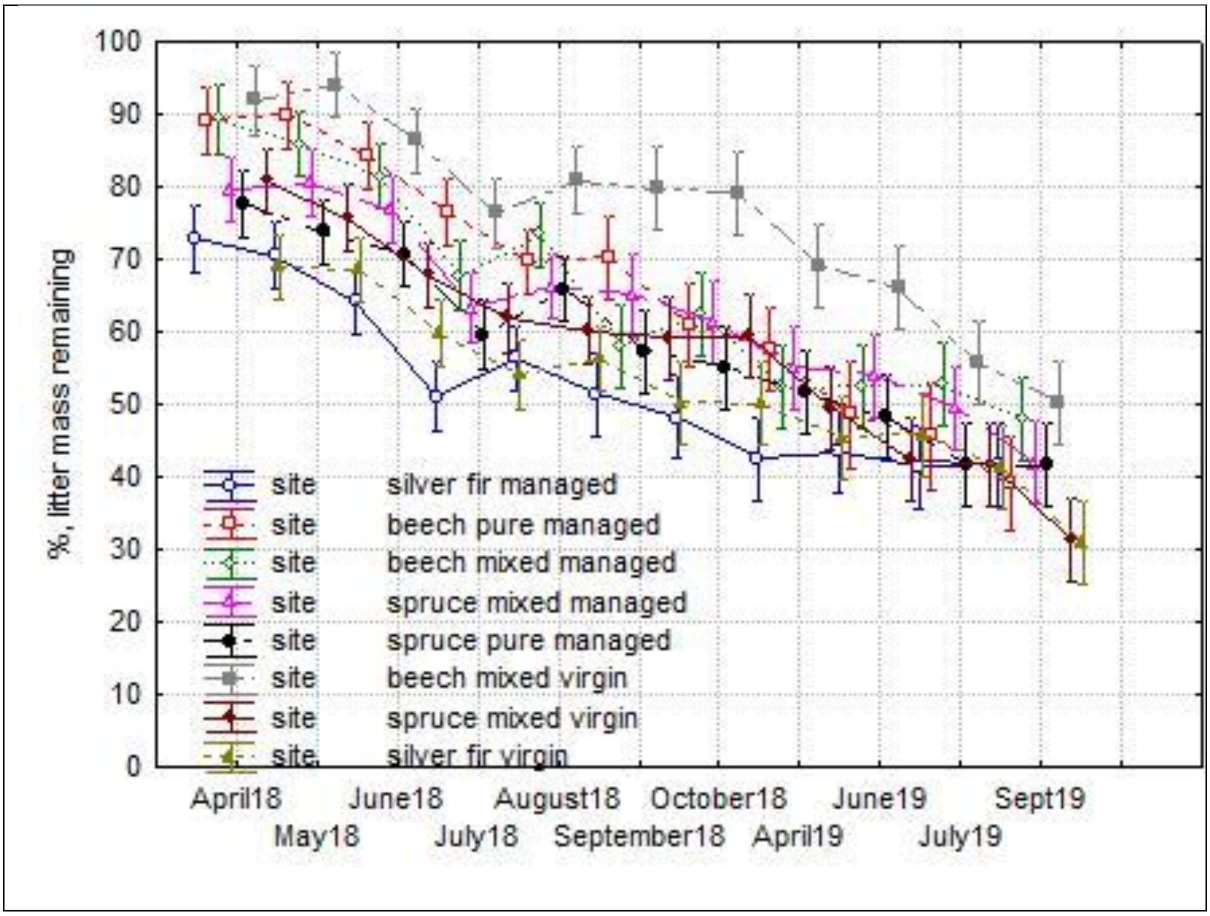
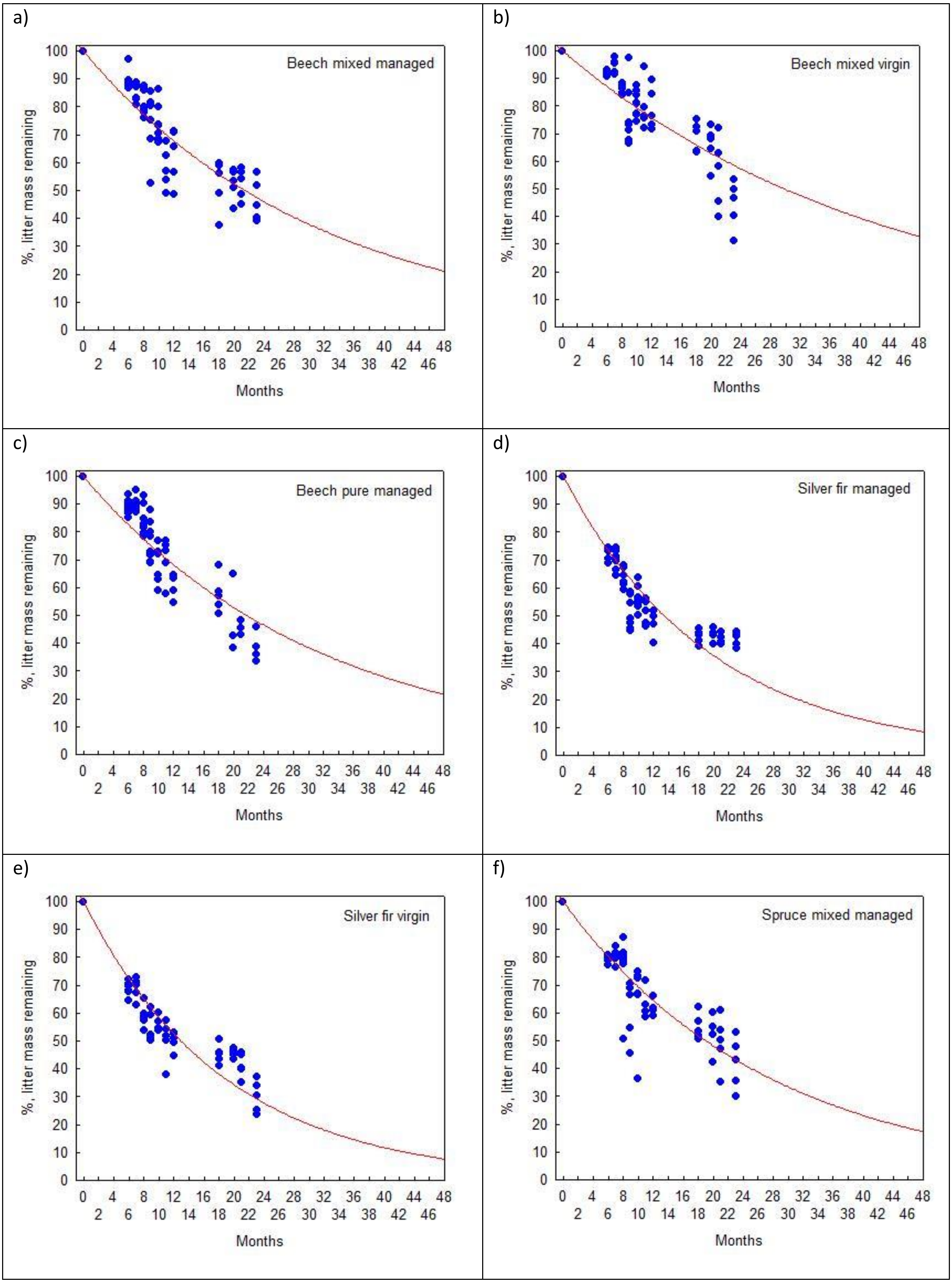


Fig.1. Leaf/needle mass remaining (as % from initial amount) for all investigated variants after each bags collection.

During the first year of experiment the mass loss


a)
Beech mixed managed
%, litter mass remaining
Months
b)
Beech mixed virgin
%, litter mass remaining
Months
c)
Beech pure managed
%, litter mass remaining
Months
d)
Silver fir managed
%, litter mass remaining
Months
e)
Silver fir virgin
%, litter mass remaining
Months
f)
Spruce mixed managed
%, litter mass remaining
Months

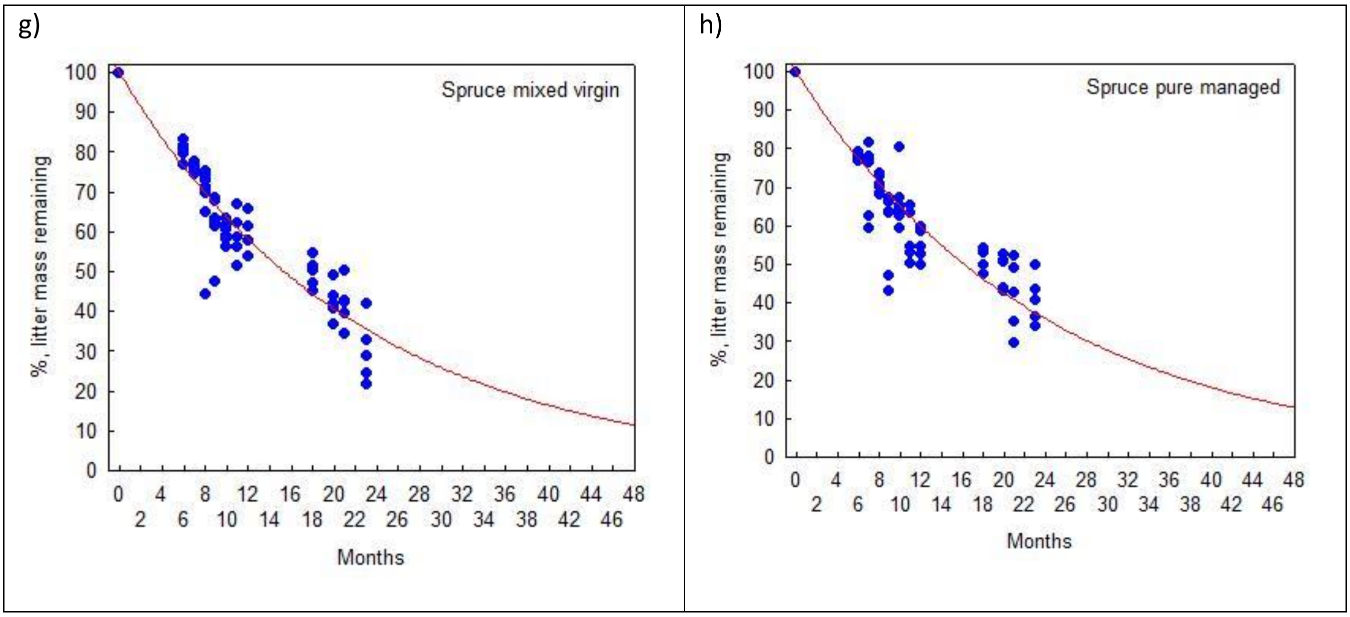
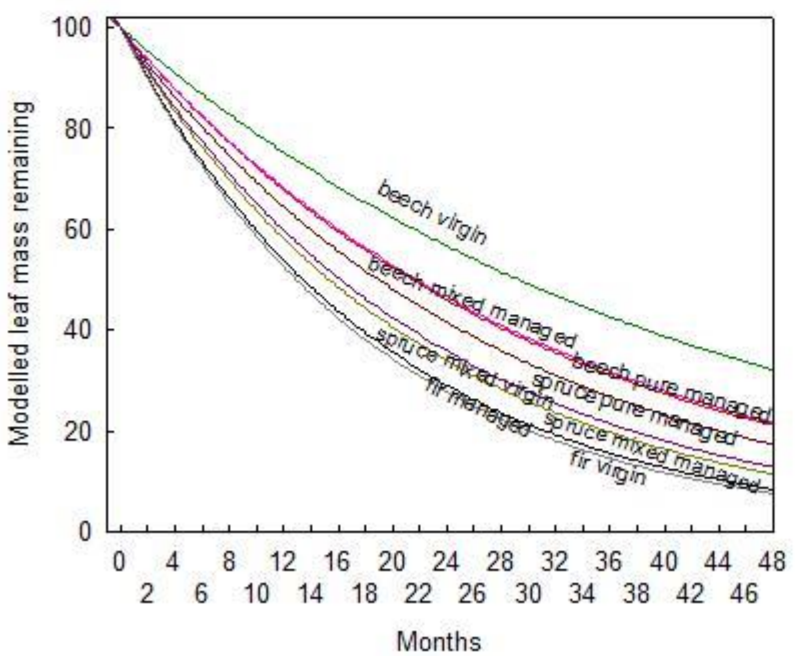


Fig.2. Litter mass remaining (as % from initial amount) modelled as a function of decomposition time (months) (y=100 x exp(-k x)) for each studied variant (a-beech mixed managed, b-beech mixed virgin, c-silver fir mixed managed, d-silver fir mixed virgin, e-spruce mixed managed, f-spruce mixed virgin, g-beech pure managed, h-spruce pure managed).

Table 1. Regression analysis (%mass remaining=100 x exp(-k x time)).

	K	p_k	R^2
Beech mixed managed	0,0324	0,000	0,74
Beech mixed virgin	0,0237	0,000	0,68
Silver fir mixed managed	0,0516	0,000	0,71
Silver fir mixed virgin	0,0535	0,000	0,72
Norway spruce mixed managed	0,0366	0,000	0,67
Norway spruce mixed virgin	0,0459	0,000	0,85
Norway spruce pure managed	0,0428	0,000	0,74



Beech pure managed	0,0237	0,000	0,77	

3.2. Small wood litter decomposition

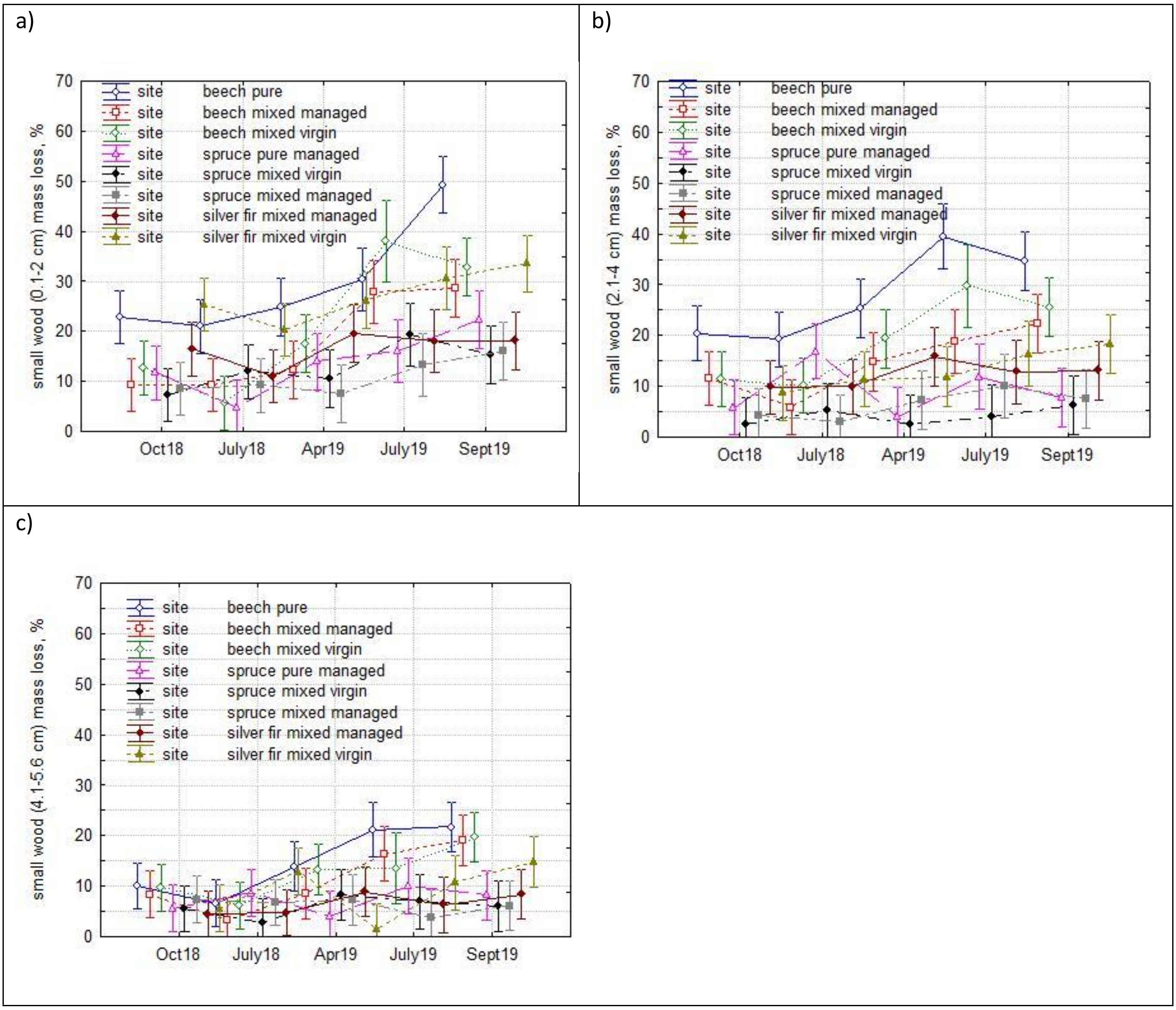


Fig.3. Small wood litter mass loss (as % from initial amount) for all forest/species variants (a) wood with d=0.1-2 cm, b) d=2.1-4.0 cm, c) d=4.1-5.6 cm

3.3. Species-specific preliminary AWEN values (intially time)

3.3.1. AWEN values for small wood

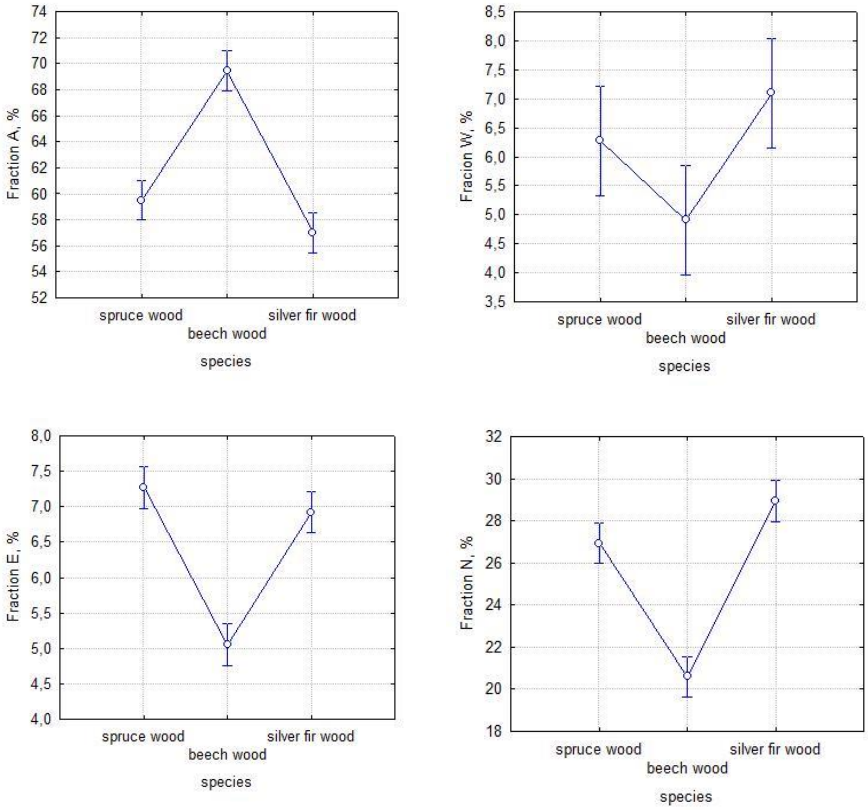
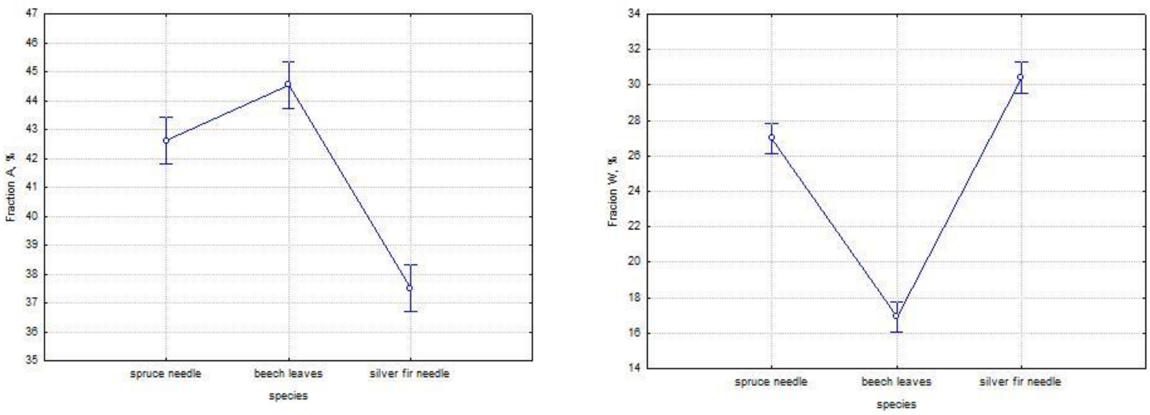


Fig. 4. Species specific variation of AWEN values of small wood.

3.3.2. AWEN values for leaves/needles



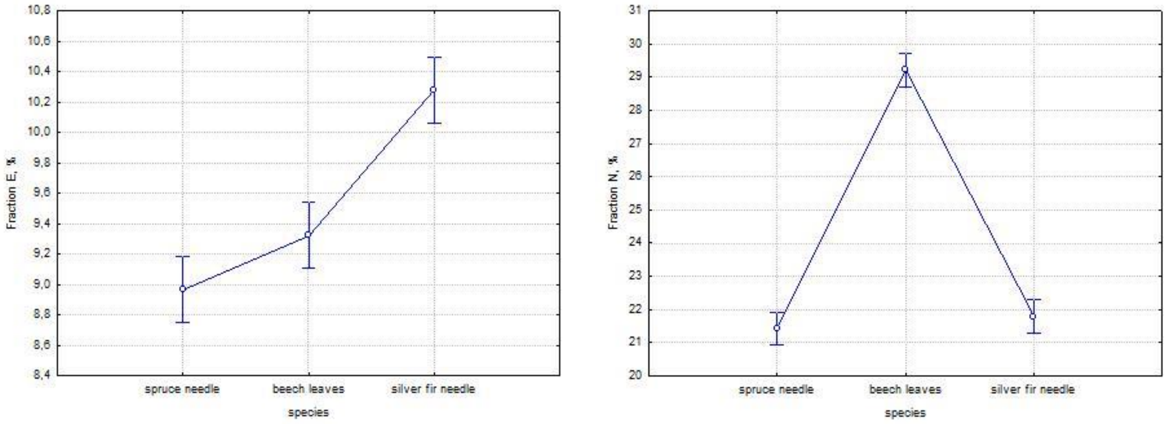
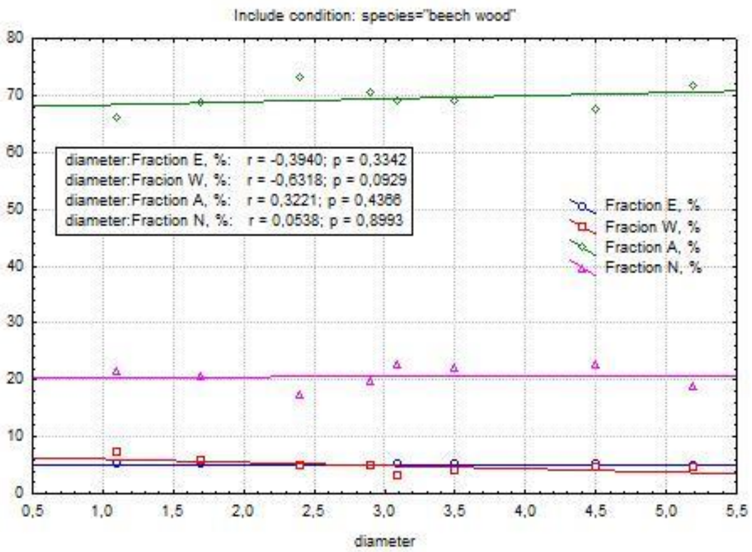
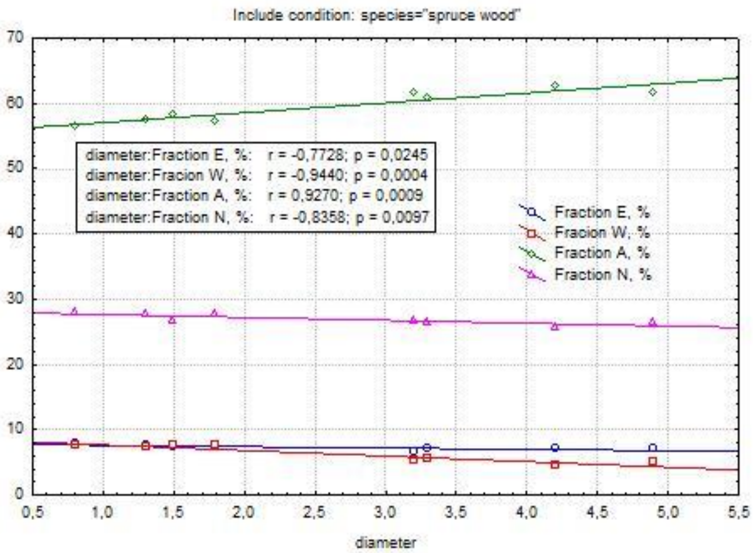


Fig. 5. Species specific variation of AWEN values of leaves/needles





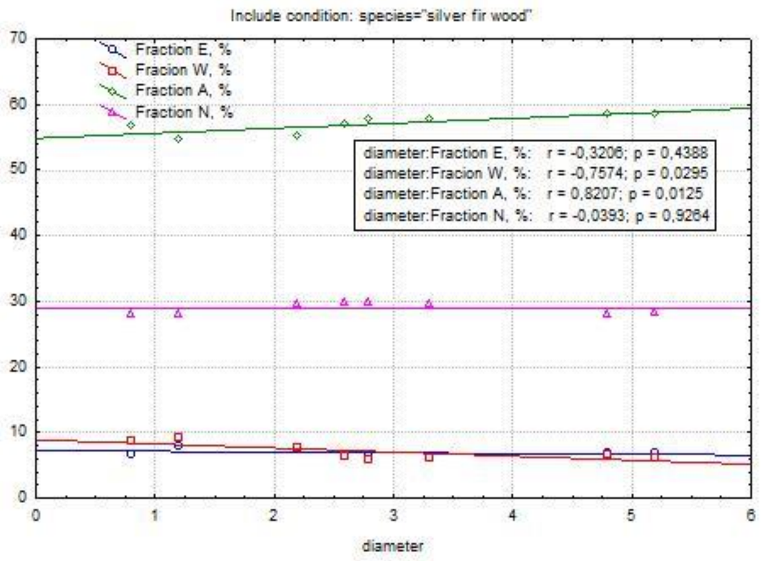


Fig. 6. Relations between AWEN values of small wood and diameter

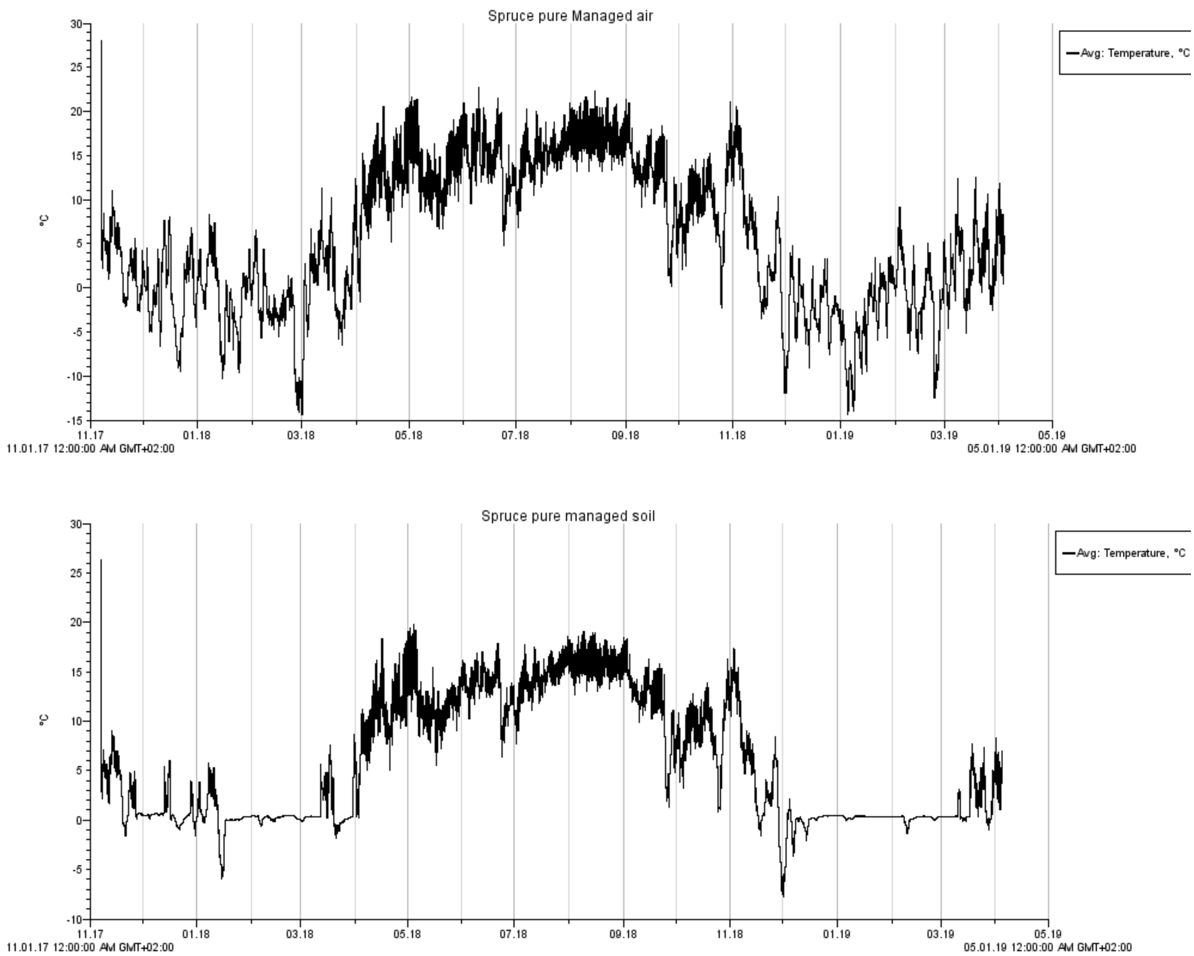


Fig. 7. Variation of air and soil temperature in sampled sites.

Discussion..... References .....