**Supplementary material** - Closing an open balance: the impact of increased tree harvest on forest carbon

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# Criteria-based exclusion of the CBI values

Criteria-based cut-off rules applied to exclude certain scenario pairs were the following:

1. harvest rate between scenarios compared less than 5% from the highest harvest level;
2. explicit difference in fertilization rate and/or tree species composition between scenarios compared;
3. explicit difference in consideration of climate change effects between scenarios compared;
4. explicit difference in forest area considered between scenarios compared.

At least one of the cut-off rules 1-4 held true for altogether 79 CBI values out of 231 CBI values (Table S1). Of these, for 24 CBI values only cut-off rule 1 held true, for 44 one of the cut-off rules 2-4 held true, and for 11 both cut-off rule 1 and at least one of cut-off rules 2-4 held true. Applying cut-off rule 1 increased the average CBI values for all the studied time horizons and reduced the standard deviation, especially in mid-term (Table S2). Applying one of the cut-off rules 2-4 increased the average CBI values for the short-term, did not influence it in the mid-term, and decreased it in the long-term. Also, the standard deviation was reduced but relatively slightly in the mid-term.

In the data obtained only from scenario pairs that did not pass the criteria, the average CBI values were noticeably lower in short- and mid-term, while considerably higher in the long-term (Table S3) compared to the values obtained when cut-off rules were applied (Table S2). The standard deviation over all time horizons was seven times higher for CBI values from scenario pairs where any of the cut-off rules 1-4 held true compared to the values after the cut-off, and on average highest in scenario pairs where harvest difference was lower than five percent.

***Table S1.*** *Number of CBI values calculated from the studies with all data and criteria-based cut-off from the selected 45 studies, for short- (1-30a), mid- (31-70a) and long-term (71-100a) time horizons. Blue: all values included, Red: values excluded based on the cut-off rules 1-4 (see above), Green: values after exclusion.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Data** | **Time horizon** | **Short** | **Mid** | **Long** | **Total** |
| All data | **CBI values** | **82** | **86** | **65** | **233** |
| CBI values removed by exclusion criteria | 1) Only harvest difference between scenarios  < 5 % (cut-off rule 1 held true) | 6 | 12 | 6 | 24 |
| 2) Only compensating factors (any of the cut-off rules 2-4 held true) | 19 | 15 | 10 | 44 |
| 3) Only both (cut off rule 1 and any of the cut-off rules 2-4 held true) | 4 | 5 | 2 | 11 |
| **4) Total (at least one of any of the cut-off rules 1-4 held true)** | **29** | **32** | **18** | **79** |
| CBI values after removal | **CBI values after exclusion** | **53** | **54** | **47** | **154** |

***Table S2.*** *The effect of criteria-based cut-off rules on the average value, standard deviation, minimum and maximum values of the CBIs in short-, mid- and long-term, as well as over all time horizons (All).* *Values are shown for all data, for data excluding CBIs that have less than 5% harvest differences between scenarios (cut-off rule 1 held true), for data excluding CBIs including any kind of growth compensation (at least one of the cut-off rules 2-4 held true), and lastly for data excluding CBIs with small harvest differences between scenario pairs and/or any kind of compensation (any of the cut-off rules 1-4 held true).*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Average CBI value*** | *All data* | *1.02* | *1.13* | *1.54* | *1.21* |
| *Scenario pairs with harvest difference <5% removed* | *1.20* | *1.53* | *1.56* | *1.42* |
| *Scenario pairs with compensating factors removed* | *1.33* | *1.13* | *1.41* | *1.28* |
| ***Scenario pairs with either harvest rate <5 % and/or any compensating factors removed*** | ***1.43*** | ***1.95*** | ***1.41*** | ***1.60*** |
| ***CBI standard deviation*** | *All data* | *1.92* | *5.51* | *2.68* | *3.80* |
| *Scenario pairs with harvest difference <5% removed* | *1.68* | *2.01* | *2.31* | *1.99* |
| *Scenario pairs with compensating factors removed* | *0.78* | *5.40* | *1.86* | *3.44* |
| ***Scenario pairs with either harvest rate <5 % and/or any compensating factors removed*** | ***0.61*** | ***1.21*** | ***0.80*** | ***0.94*** |
| ***Minimum CBI value*** | *All data* | *-7.85* | *-40.00* | *-5.04* | *-40.00* |
| *Scenario pairs with harvest difference <5% removed* | *-7.23* | *-7.38* | *-0.78* | *-7.38* |
| *Scenario pairs with compensating factors removed* | *-0.83* | *-40.00* | *-5.04* | *-40.00* |
| ***Scenario pairs with either harvest rate <5 % and/or any compensating factors removed*** | ***0.24*** | ***0.21*** | ***0.17*** | ***0.17*** |
| ***Maximum CBI value*** | *All data* | *4.30* | *23.38* | *17.70* | *23.38* |
| *Scenario pairs with harvest difference <5% removed* | *4.30* | *5.70* | *17.70* | *17.70* |
| *Scenario pairs with compensating factors removed* | *3.52* | *6.50* | *11.55* | *11.55* |
| ***Scenario pairs with either harvest rate <5 % and/or any compensating factors removed*** | ***2.80*** | ***5.70*** | ***3.34*** | ***5.70*** |

***Table S3.*** *Average value, standard deviation, minimum and maximum values for CBIs calculated only from scenario pairs that did not pass the cut-off criteria, in short-, mid- and long-term, as well as over all time horizons.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Time horizon** | | **Short** | **Mid** | **Long** | **All** |
| **Average CBI value** | Scenario pairs with <5% harvest difference | -0.29 | -0.45 | 3.37 | 0.47 |
| Scenario pairs with compensating factors | 0.30 | 1.16 | 2.13 | 1.01 |
| **Scenario pairs with either harvest rate <5 % and/or any compensating factors** | 0.12 | 0.42 | 2.63 | 0.80 |
| **CBI standard deviation** | Scenario pairs with <5% harvest difference | 2.93 | 11.87 | 7.43 | 9.09 |
| Scenario pairs with compensating factors | 3.38 | 6.02 | 5.00 | 4.79 |
| **Scenario pairs with either harvest rate <5 % and/or any compensating factors** | 3.21 | 9.08 | 5.93 | 6.75 |
| **Minimum CBI value** | Scenario pairs with <5% harvest difference | -7.85 | -40.00 | -5.04 | -40.00 |
| Scenario pairs with compensating factors | -7.85 | -7.38 | -0.78 | -7.85 |
| **Scenario pairs with either harvest rate <5 % and/or any compensating factors** | -7.85 | -40.00 | -5.04 | -40.00 |
| **Maximum CBI value** | Scenario pairs with <5% harvest difference | 3.52 | 23.38 | 17.70 | 23.38 |
| Scenario pairs with compensating factors | 4.30 | 23.38 | 17.70 | 23.38 |
| **Scenario pairs with either harvest rate <5 % and/or any compensating factors** | 4.30 | 23.38 | 17.70 | 23.38 |

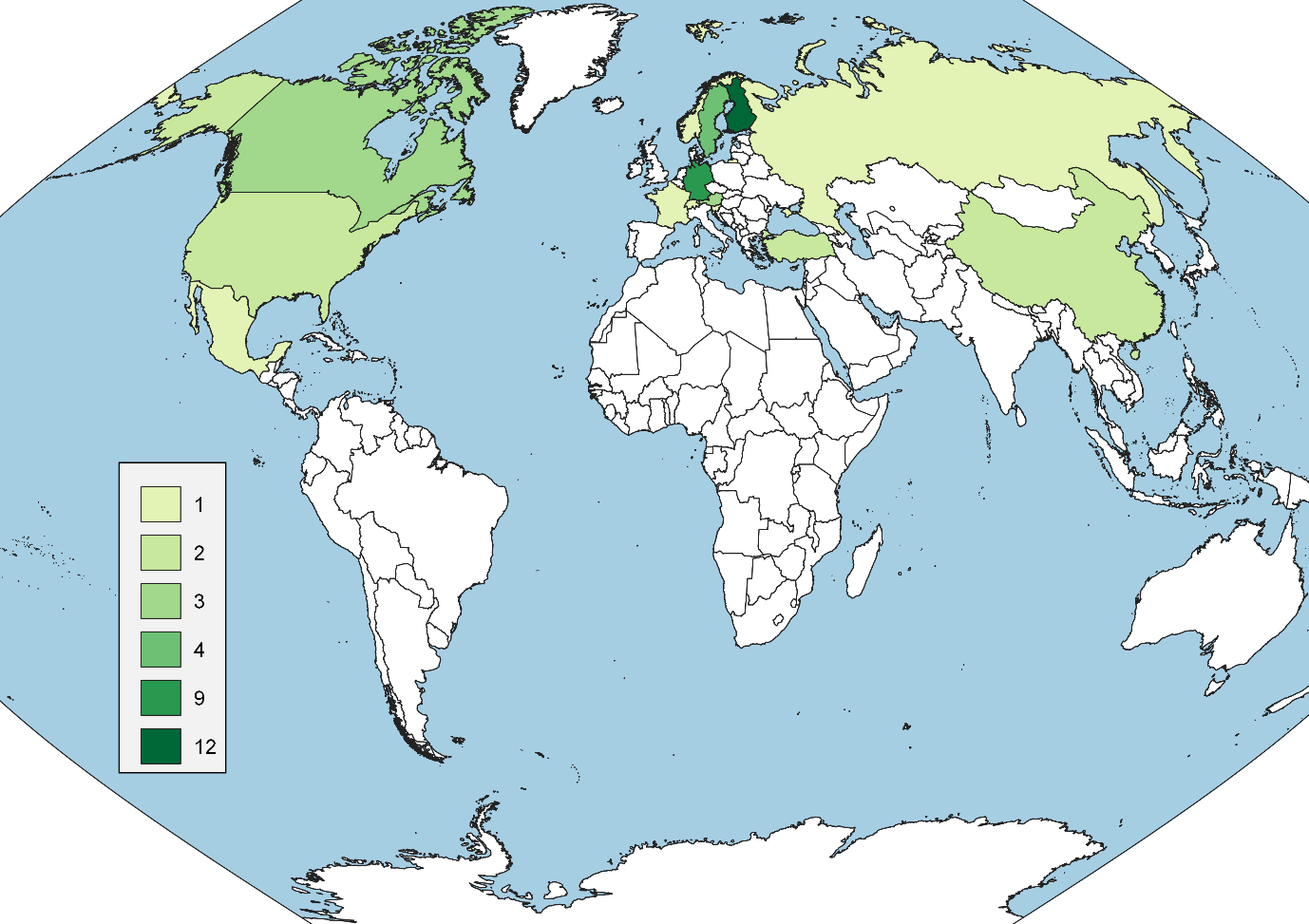
***Table S4.*** *Differences in CBI value characteristics between values calculated from the papers added in step 1 and step 3, after criteria-based cut-off. \*) 2 papers (Soimakallio et al. 2016, and Pingoud et al. 2016) which were originally added in the step 1 are considered here under SLR, since they came up also in the systematic literature review (SLR).*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Data source** | **Indicator** | **Short** | **Mid** | **Long** | **All** |
| Papers added outside SLR\* | Number of CBI values | 42 | 33 | 31 | 106 |
| CBI average value | 1.39 | 1.79 | 1.35 | 1.50 |
| CBI median value | 1.39 | 1.57 | 1.25 | 1.36 |
| CBI standard deviation | 0.66 | 1.17 | 0.75 | 0.88 |
| Minimum CBI value | 0.24 | 0.21 | 0.17 | 0.17 |
| Maximum CBI value | 2.80 | 5.04 | 2.92 | 5.04 |
| Papers added in SLR | Number of CBI values | 11 | 21 | 16 | 48 |
| CBI average value | 1.56 | 2.19 | 1.53 | 1.82 |
| CBI median value | 1.65 | 1.90 | 1.41 | 1.56 |
| CBI standard deviation | 0.39 | 1.27 | 0.91 | 1.04 |
| Minimum CBI value | 0.66 | 0.83 | 0.40 | 0.40 |
| Maximum CBI value | 2.04 | 5.70 | 3.34 | 5.70 |

The average and median CBI value was slightly higher in the studies selected in the step 3 across all time-horizons, compared to studies added in the step 1, after the criteria-based cut-off (Table S4). Standard deviation of CBI was slightly higher in the papers added in the step 3.

# Geographical distribution of the CBI values

All of the studies reviewed from which CBI values could be calculated were from the Northern Hemisphere, with an emphasis on Northern- and Central Europe (Fig. S1).



***Figure S1.*** *The map shows the number of country-specific studies (n=42), from which CBI values were calculated. There were 12 studies from Finland, 9 from Germany, 4 from Sweden, 3 from Austria and Canada, 2 each from USA, China and Turkey, and one each from France, Mexico, Norway, Russia, Switzerland and Slovenia. In addition, there were two regional studies: one for EU28 and one for EU26 countries (total n=44).*

In Table S5, the studies were roughly divided into four categories based on the biome used in the simulation: boreal forest, temperate forest, a mix of boreal and temperate forest and tropical forest. The categories were divided further into sub-categories of continental, national and landscape level studies based on the geographical scope in the simulation. CBI mean values are shown inside each sub-category using both statistical removal of outliers and criteria-based exclusion of CBI values.

***Table S5.*** *CBI values categorized by forest biome and the geographical scope of a study.*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ***Data*** | ***Geographical scope and forest biome*** | | ***Boreal*** | ***Temperate*** | ***Mixed*** | ***Tropical*** | ***All*** |
| ***All data*** | *Number of studies* | | *17* | *23* | *4* | *1* | *45* |
| *No. of short-term CBI values 1)* | | *33 / 32 / 28* | *40 / 38 / 23* | *8 / 4 / 2* | *1 / 1 / 0* | *82 / 75 / 53* |
| *No. of mid-term CBI values 1)* | | *34 / 31 / 26* | *44 / 38 / 28* | *8 / 5 / 2* | *0* | *86 / 74 / 54* |
| *No. of long-term CBI values 1)* | | *32 / 31 / 25* | *33 / 31 / 22* | *0* | *0* | *65 / 62 / 47* |
| *CBI average values* | *Short-term* | *1.42* | *0.89* | *-0.11* | *1.65* | *1.02* |
| *Mid-term* | *1.60* | *0.61* | *2.05* | *n/a* | *1.13* |
| *Long-term* | *1.55* | *1.54* | *n/a* | *n/a* | *1.54* |
| ***Statistical cut-off 2)*** | *CBI average values* | *Short-term* | *1.53* | *1.17* | *1.39* | *1.65* | *1.34* |
| *Mid-term* | *1.95* | *1.69* | *1.46* | *n/a* | *1.78* |
| *Long-term* | *1.29* | *1.23* | *n/a* | *n/a* | *1.23* |
| *Continental* | *Short-term* | *n/a* | *n/a* | *1.39* | *n/a* | *1.39* |
| *Mid-term* | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* |
| *Long-term* | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* |
| *National* | *Short-term* | *1.64* | *0.98* | *n/a* | *1.65* | *1.26* |
| *Mid-term* | *1.74* | *1.15* | *0.60* | *n/a* | *1.22* |
| *Long-term* | *1.21* | *0.84* | *n/a* | *n/a* | *1.04* |
| *Landscape* | *Short-term* | *1.43* | *1.41* | *n/a* | *n/a* | *1.43* |
| *Mid-term* | *2.00* | *2.24* | *2.75* | *n/a* | *2.14* |
| *Long-term* | *1.23* | *1.36* | *n/a* | *n/a* | *1.30* |
| ***Criteria cut-off 3)*** | *CBI average values* | *Short-term* | *1.56* | *1.26* | *1.50* | *n/a* | *1.43* |
| *Mid-term* | *1.98* | *1.92* | *n/a* | *n/a* | *1.95* |
| *Long-term* | *1.51* | *1.29* | *n/a* | *n/a* | *1.41* |
| *Continental* | *Short-term* | *n/a* | *n/a* | *1.50* | *n/a* | *1.50* |
| *Mid-term* | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* |
| *Long-term* | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* |
| *National* | *Short-term* | *1.65* | *1.30* | *n/a* | *n/a* | *1.47* |
| *Mid-term* | *1.74* | *1.39* | *n/a* | *n/a* | *1.50* |
| *Long-term* | *1.46* | *1.00* | *n/a* | *n/a* | *1.44* |
| *Landscape* | *Short-term* | *1.47* | *1.20* | *n/a* | *n/a* | *1.36* |
| *Mid-term* | *2.05* | *2.31* | *n/a* | *n/a* | *2.17* |
| *Long-term* | *1.54* | *1.40* | *n/a* | *n/a* | *1.47* |

1) Number of CBI values in short-, mid-, and long-term perspectives in the four forest biome categories when all values are included / statistical outliers are removed / values based on exclusion criteria are removed.

2) Values removed based on the statistical cut-off (Methods).

3) Values removed based on the criteria-based cut off (Supplementary Table S1)

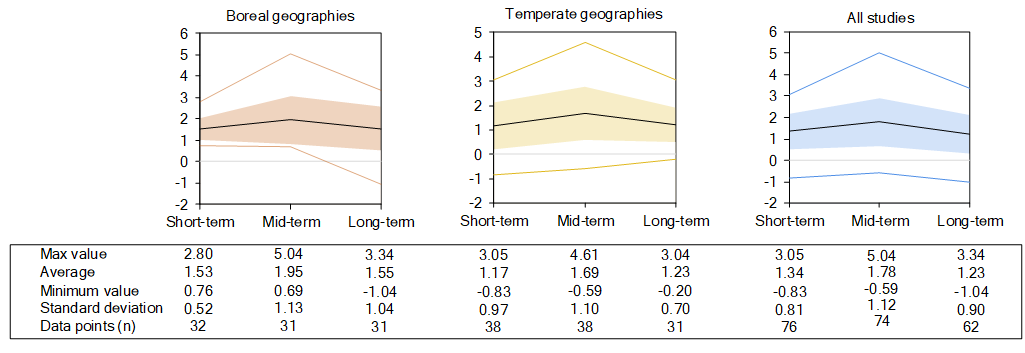
***Table S6.*** *Differences in CBI value characteristics between differing forest carbon pools accounted for in the studies after criteria-based cut-off.*

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Forest carbon pools included in the study** | | | | | | | | | | | |
|  | Biomass and soil | | | | Biomass | | | | Living biomass | | | |
| Time-horizon | Short | Mid | Long | All | Short | Mid | Long | All | Short | Mid | Long | All |
| Number of CBI values | 31 | 29 | 21 | 81 | 17 | 18 | 15 | 50 | 5 | 6 | 5 | 16 |
| CBI average value | 1.54 | 1.71 | 1.72 | 1.65 | 1.31 | 2.06 | 1.20 | 1.55 | 1.14 | 2.84 | 1.17 | 1.79 |
| CBI median value | 1.56 | 1.52 | 1.54 | 1.54 | 1.28 | 1.54 | 1.10 | 1.34 | 0.86 | 2.62 | 1.11 | 1.61 |
| CBI standard deviation | 0.61 | 1.06 | 0.84 | 0.85 | 0.54 | 1.37 | 0.81 | 1.05 | 0.73 | 1.23 | 0.40 | 1.18 |
| Minimum CBI value | 0.40 | 0.41 | 0.45 | 0.40 | 0.24 | 0.21 | 0.17 | 0.17 | 0.33 | 1.66 | 0.57 | 0.33 |
| Maximum CBI value | 2.80 | 5.70 | 3.34 | 5.70 | 2.10 | 5.04 | 2.43 | 5.04 | 2.02 | 4.61 | 1.55 | 4.61 |

***Table S7.*** *Statistical significance of the differences in CBI values between study groupings after criteria-based cut-off. P-value is given between studies grouped by method of data selection, geographical location of the study (BOR = boreal, TEMP = temperate), and by forest carbon pools included in the study (BM = biomass, BMS = biomass and soil, LBM = living biomass). Significance threshold is set to .05. \*) 2 papers (Soimakallio et al. 2016, and Pingoud et al. 2016) which were originally added in step 1 are considered here under step 3, since they came up also in the systematic literature review (SLR).*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | ***P*-value between groups** | | | | |
|  | Data selection | Geographies | Forest carbon pools | | |
| time-horizon | Step 1 / Step 3 \* | BOR / TEMP | BM / BMS | BM / LBM | BMS / LBM |
| short | .30 | .06 | .20 | .64 | .30 |
| mid | .26 | .86 | .36 | .23 | .08 |
| long | .51 | .33 | .07 | .93 | .052 |
| all | .07 | .29 | .57 | .48 | .66 |

No significant differences between CBI values were detected in any of the pairs of groups compared with a significance threshold of .05 (Table S7). However, if the significance threshold had been set to .10, there would have been significant difference between data selection groups considering all values, but not within single time-horizons. In addition, the differences in short-term values between boreal and temperate geographies, in long-term values between biomass and biomass + soil, and in mid-term values between biomass + soil and living biomass would have been significant with 10% threshold



***Figure S2:*** *Average, standard deviation (orange, yellow and blue zones) and min-max values for aggregated carbon balance indicator (CBI) values in terms of tC/tC from studies covering boreal geographies (left), temperate geographies (middle) and all studies (right). Only showing datapoints remaining when applying statistical cut-off.*

In Fig. S2, the average, standard deviation, minimum and maximum values are shown for studies remaining after applying statistical cut-off criteria.

# Temporal trends of the CBI values derived from single studies

The temporal behaviour of CBI indicators derived from single studies as opposed to aggregated average values, is shown in Fig. S3 and S4. There is a large variation in CBI values between the studies, and no clear trend for the temporal behaviour of the CBI value (Figure S3). However, for a slight majority of the studies the CBI value seems to increase in the short- to mid-term comparison and decrease from mid- to long-term; a similar trend found in the CBI average values with statistical and criteria-based cut-offs.

***Figure S3:*** *CBI absolute values and their development for scenario pairs selected by applying statistical cut-off (left) and exclusion criteria (right).*

n=38; 22 negative

n=44; 30 negative

n=42; 20 negative

c)

b)

a)

n=27; 12 negative

n=32; 22 negative

n=31; 11 negative

f)

e)

d)

***Figure S4:*** *Percentage change in CBI scenario pairs over time. In the top row (a, b, c), we compare the development of scenario pairs selected by applying statistical cut-off rule only. In the bottom row (d, e, f), we compare the development of scenario pairs selected by applying criteria-based cut-off rules only. Figures show comparisons between mid-term to short-term (a, d), long-term to mid-term (b, e) and short-term to long-term (c-f) indicator values.*

In Fig. S4, the percentual change in CBI for scenario pairs over short-term to mid-term, mid-term to long-term and short-term to long-term periods are illustrated by drawing trajectories. One line corresponds to the per cent change in CBI between the mentioned time-classes for one scenario pair. When the statistical cut-off rule was applied, the following data was obtained: (a) the short-mid yielded 42 trajectories, out of which 20 were decreased; (b) mid-long yielded 44 trajectories, out of which 30 decreased; (c) short-long yielded 38 trajectories, out of which 22 decreased. Applying criteria-based cut-off rules: (d) the short-mid comparison yielded 31 trajectories, out of which 11 decreased; (e) mid-long yielded 32 trajectories, out of which 22 decreased; (f) short-long comparison yielded 27 trajectories, out of which 12 decreased.