Supplementary materials for: A spatially explicit decision support system for assessment of tree stump harvest using biodiversity and economic criteria

S1. Expert evaluation of biodiversity criteria during stump harvest

S1.1. Background

To investigate and estimate potential impacts of stump harvest on the viability of deadwood affiliate biodiversity we conducted semi-structured, face-to-face interviews with nine species experts (including co-author Jörgen Sjögren). With the exception of one species expert, all experts were actively researching the significance of stump harvest for the diversity and viability of their expertise organism group (i.e., bryophytes, fungi, insects/beetles, and lichens). All experts were affiliated with the Swedish University of Agricultural Sciences. A minimum of two experts were interviewed per organism group. Interviews and related discussions lasted between 45-60 minutes.

The background and aim of the project was explained in writing beforehand via e-mail and at the start of the interviews. The objective of these semi-structured interviews was two-fold: (i) to identify main problems related to stump harvest for a majority of deadwood affiliate biodiversity (open-ended qualitative questions), and (ii) to assign biodiversity scores for stumps (short answer or rating-scale responses). After having interviewed half of the experts (one per organism group), their answers were used, together with findings in the relevant literature, to update and re-formulate the final interview questions used for the whole expert group. Hence, the final interview questions (S1.2) were formulated to evaluate stump values (characteristics and location) in relation to four “species profiles” identified as important: (k1) sun-exposed deadwood obligate species, (k2) sun-exposed deadwood facultative species, (k3) sun-exposed deadwood dependent species of conservation concern and red-listed species, and (k4) species dependent on shaded stumps.

Evaluation of stumps for common species that are (k1) obligate (strictly) or (k2) facultative (partly) dependent on sun-exposed deadwood has also been identified as important based on scientific literature, particularly with stumps forming a major component of the extant resource for these species (e.g., [1-4]) and current government recommendations by the Swedish Forest Agency [5]. Third, the importance of stumps for (k3) wood-dependent species (foremost beetles/diptera; [6-11] but also few fungi [6]) of conservation concern and red-listed species has also support in the scientific literature. Lastly, the proximity of shaded stumps located on the northern side of high conservation value forests (e.g., possible positive edge effects, or spillover effects, of forest-interior cryptogams in matrix habitats bordering high conservation value forests such as nature reserves) also have some scientific support [12]. The protections of critical habitat by having restricted stump harvest in buffer zones around streams, wet areas, tree retention, created high stumps etc. was lifted as an import precautionary principle by experts and included in the recommendations by the Swedish Forest Agency [5].
S1.2. Final interview questions (translated from the original Swedish format)

When the respondent did not know the answer this was always notified for all questions. Scores assigned were later transformed to range between 0 and 1. Some parts were not included in the final biodiversity criteria selection for the DSS, when judged not to be relevant or data deficient.

Part 1
Background

Name:
Expertise organism group:
If applicable, provide two example of species occurring on cut stumps:
(1) Common sun-exposed deadwood obligate species:
(2) Common sun-exposed deadwood facultative species:
(3) Species of conservation concern and red-listed sun-exposed deadwood dependent:
(4) Shaded deadwood dependent species:
Are there other important ‘groupings/profiles’ of species within the organism group?
Which are the most common/prevaling dispersal mechanisms of species in the group?
How far can the species within the group disperse (interspecific variation)?

Part 2
Relative importance of cut stumps as deadwood habitat

How many species (number, proportion) in the organism group are deadwood dependent?
How many of these utilize stumps?
(1) Common sun-exposed deadwood obligate species:
(2) Common sun-exposed deadwood facultative species:
(3) Species of conservation concern and red-listed sun-exposed deadwood dependent:
(4) Shaded deadwood dependent species:
If knowledge is lacking, estimate proportion of species utilizing stumps:

If knowledge is lacking, estimate proportion of species utilizing stumps:
How many species utilize stumps in total?
(Profile 1): 0-10% 11-25% 25-50% 51-75% 76-100%
(Profile 2): 0-10% 11-25% 25-50% 51-75% 76-100%
(Profile 3): 0-10% 11-25% 25-50% 51-75% 76-100%
(Profile 4): 0-10% 11-25% 25-50% 51-75% 76-100%

Part 3
The importance of stump characteristics

Score the importance of tree species, where 1 = very low value/can be harvested and 10 = very high value/should not be harvested (e.g., “NoGo”)

| Very low value | Medium value | Very high value |
|----------------|--------------|----------------|
| 1 2 3 4 5 6 7 | 8 9 10       |

Species profile 1:
Spruce 1 2 3 4 5 6 7 8 9 10
Pine 1 2 3 4 5 6 7 8 9 10
Deciduous 1 2 3 4 5 6 7 8 9 10

Species profile 2:
Score the importance of **stump diameter** (i.e., size), where 1 = very low value/can be harvested and 10 = very high value/should not be harvested (e.g., “NoGo”)

| Species profile 1:       | Very low value | Medium value | Very high value |
|--------------------------|----------------|--------------|-----------------|
| < 20 cm                  | 1 2 3 4 5 6 7 8 9 10 |
| 20-50 cm 1              | 1 2 3 4 5 6 7 8 9 10 |
| > 50 cm                  | 1 2 3 4 5 6 7 8 9 10 |

| Species profile 2:       | Very low value | Medium value | Very high value |
|--------------------------|----------------|--------------|-----------------|
| < 20 cm                  | 1 2 3 4 5 6 7 8 9 10 |
| 20-50 cm 1              | 1 2 3 4 5 6 7 8 9 10 |
| > 50 cm                  | 1 2 3 4 5 6 7 8 9 10 |

| Species profile 3:       | Very low value | Medium value | Very high value |
|--------------------------|----------------|--------------|-----------------|
| < 20 cm                  | 1 2 3 4 5 6 7 8 9 10 |
| 20-50 cm 1              | 1 2 3 4 5 6 7 8 9 10 |
| > 50 cm                  | 1 2 3 4 5 6 7 8 9 10 |

| Species profile 4:       | Very low value | Medium value | Very high value |
|--------------------------|----------------|--------------|-----------------|
| < 20 cm                  | 1 2 3 4 5 6 7 8 9 10 |
| 20-50 cm 1              | 1 2 3 4 5 6 7 8 9 10 |
| > 50 cm                  | 1 2 3 4 5 6 7 8 9 10 |

**Extra question if difficult to answer:**
What diameter size characterize a small, medium and large cut stump?
How would you score the three size classes (e.g., differences in assigned score values between classes)?

**Part 4**

**Importance of the location of the cut stump**

Score the importance of **stumps located at different distances to a potential dispersal source**, where 1 = very low value/can be harvested and 10 = very high value/should not be harvested (e.g., “NoGo”)

| Very low value | Medium value | Very high value |
|----------------|--------------|-----------------|
| 1 2 3 4 5 6 7 8 9 10 |
Species profile 1:
- 0-15 m: 1 2 3 4 5 6 7 8 9 10
- 16-50 m: 1 2 3 4 5 6 7 8 9 10
- > 50 m: 1 2 3 4 5 6 7 8 9 10

Species profile 2:
- 0-15 m: 1 2 3 4 5 6 7 8 9 10
- 16-50 m: 1 2 3 4 5 6 7 8 9 10
- > 50 m: 1 2 3 4 5 6 7 8 9 10

Species profile 3:
- 0-15 m: 1 2 3 4 5 6 7 8 9 10
- 16-50 m: 1 2 3 4 5 6 7 8 9 10
- > 50 m: 1 2 3 4 5 6 7 8 9 10

Species profile 4:
- 0-15 m: 1 2 3 4 5 6 7 8 9 10
- 16-50 m: 1 2 3 4 5 6 7 8 9 10
- > 50 m: 1 2 3 4 5 6 7 8 9 10

Are these distances relevant for species in the organism group? If not, which distances are relevant?

Score the importance of stumps located on different ground moisture, where 1 = very low value/can be harvested and 10 = very high value/should not be harvested (e.g., "NoGo")

|            | Very low value | Medium value | Very high value |
|------------|----------------|--------------|-----------------|
| Species profile 1: | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 |
| Dry        | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 |
| Moist/wet  | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 |

Species profile 2:
- Dry: 1 2 3 4 5 6 7 8 9 10
- Moist/wet: 1 2 3 4 5 6 7 8 9 10

Species profile 3:
- Dry: 1 2 3 4 5 6 7 8 9 10
- Moist/wet: 1 2 3 4 5 6 7 8 9 10

Species profile 4:
- Dry: 1 2 3 4 5 6 7 8 9 10
- Moist/wet: 1 2 3 4 5 6 7 8 9 10

Part 5
Other factors/variables to consider
Are there other factors to consider when evaluating the importance of individual or populations of stumps for species in the organism group?
(1) Common sun-exposed deadwood obligate species:
(2) Common sun-exposed deadwood facultative species:
(3) Species of conservation concern and red-listed sun-exposed deadwood dependent:
(4) Shaded deadwood dependent species:
Part 6
Knowledge gaps
Which knowledge gaps are central to consider when evaluation the importance of individual or populations of stumps for species in the organism group?
(1) Common sun-exposed deadwood obligate species:
(2) Common sun-exposed deadwood facultative species:
(3) Species of conservation concern and red-listed sun-exposed deadwood dependent:
(4) Shaded deadwood dependent species:

Part 7
The importance of the surrounding landscape (within the stand and the surrounding landscape)
For a Norway spruce dominated forest (in three different geographical regions) score the conservation value of stumps positioned:
1. close to the northern side of a high conservation value forest
2. close to the southern side of a high conservation value forest
3. in the middle of a clear-cut
4. close to a grouped tree retention patch
5. close to one or several deadwood high stumps
6. close to a swampy or wet forest retention patch

| Very low value | Medium value | Very high value |
|---------------|--------------|-----------------|
| 1             | 2            | 3               | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Organism group:
Northern Swe: 1 2 3 4 5 6 7 8 9 10
Central Swe: 1 2 3 4 5 6 7 8 9 10
Southern Swe: 1 2 3 4 5 6 7 8 9 10

If no difference between geographical regions can be distinguished, can you provide a score for Sweden as a whole?
Do values depend on the different species profile groups?

Map used for discussing the different cases of surrounding factors in relation to stump values.
51.3 Additional details concerning interview results

Interviews confirmed that dependency on sun-exposed deadwood was important to fungi, insects and lichens. The vulnerability of species of conservation concern and red-listed species was largely an issue for insects. Shaded stumps located on the northern side of high conservation value forests were foremost important to bryophytes (see Table 1 in main manuscript).

Stump characteristics such as tree species and size were pointed out as substrate variables known to be important to all organism groups. However, the values assigned to different tree species varied slightly with dependency on sun-exposure (facultative vs. obligate species) and vulnerability (i.e., species of conservation concern and red-listed species) (Table 1 in main manuscript).

Experts agreed that it was too difficult to assign very detailed scores for stumps of different size classes, but that small stumps should on average have 0.1 lower conservation score compared to medium-sized stumps, and 0.1 higher value for large-sized stumps compared to medium-sized stumps. Experts generally agreed that stumps with diameters below 20 cm could be considered small and stumps with diameters larger than 50 cm could be considered large, with the rest as intermediate medium-sized stumps. Reasons for ‘scoring up’ larger stumps was that substrate heterogeneity, microclimatic stability and buffering effect, life span, and quantity of available resources increase with size (e.g., [13]).
S2. Maps of harvested stump density and hauling time (colours) at Abrahamsdammen study forest, and resulting spatial distribution of unharvested stumps (dots).
Figure S2. The result from the DSS over Abrahamsdammen study forest with dots representing unharvested individual stumps with biodiversity scores $P_B > 0.5$ and economy scores $P_E < 0.5$ at medium (a and b) and high (b and d) biodiversity conservation scenarios, both under the medium bioenergy price scenario. The color of the dots in a and b represent the density of harvested stumps ($m^3$/ha) in the specific harvester location. The color of the dots in c and d represent the hauling time (min/MWh) of harvested stumps in the specific harvester location. The continuous high cost areas where stumps are left unharvested were often the result of the hauling time dependency on the spatial density of harvested stumps.

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