Supplementary file

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Quantifying and resolving conservation conflicts in forest landscapes via multiobjective optimization

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1 Scheme summarizing the two-steps procedure to handle conservation conflicts.

Procedure to handle conservation conflicts

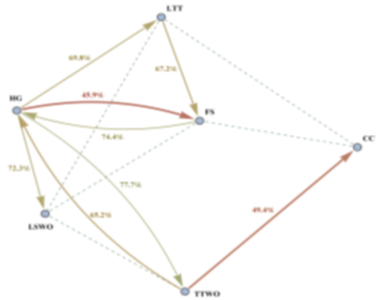
1) Evaluate the intensity of the conflicts between two biodiversity objectives (*f1* and *f2*) in the landscape...

... via a **compatibility index**:

$$R_1(2) = \frac{f_2(x^{1:2})}{MLC_2} \times 100\%$$

Pareto optimal solution with the highest possible value of f_1 and the smallest value of f_2

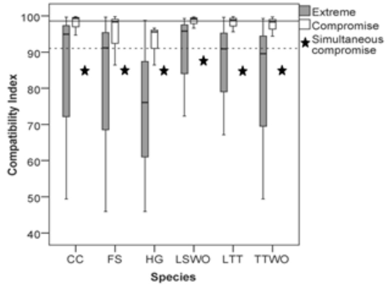
maximum landscape capacity for f_2



2) Find **compromise solutions** to resolve the conflict between biodiversity objectives ...

... via a management plan minimizing the maximum relative deterioration among objectives with respect to their MLC:

$$\text{minimize} \max\left(\frac{MLC_1 - f_1(x)}{MLC_1}, \frac{MLC_2 - f_2(x)}{MLC_2}\right)$$



2 Compatibility indices and proportions of management options.

Table S2 Values of compatibility indices between pairs of species based on their maximum habitat availability, and compromise solutions. For each pair of species designated as *1* vs. *2*, the first two columns contain compatibility indices $R_1(2)$ and $R_2(1)$, respectively. The column Compromise contains the minimum relative level of HA (as percentage of their MLC), which is achieved for both species simultaneously by a forest management plan obtained by solving problem **6.** with $k = 2$. Species abbreviations: CC = capercaillie, FS = flying squirrel, HG = hazel grouse, LTT = long-tailed tit, LSWO = lesser-spotted woodpecker, TTWO = three-toed woodpecker.

1 vs. *2*	$R_1(2)$	$R_2(1)$	Compromise
CC vs. FS	99.67%	97.20%	99.83%
CC vs. HG	98.74%	90.16%	99.31%
CC vs. LTT	99.60%	92.71%	99.82%
CC vs. LSWO	97.62%	88.11%	99.10%
CC vs. TTWO	90.69%	49.39%	94.73%
FS vs. HG	74.45%	45.93%	86.43%
FS vs. LTT	86.15%	67.16%	98.27%
FS vs. LSWO	93.83%	96.87%	99.17%
FS vs. TTWO	94.23%	88.46%	98.35%
HG vs. LTT	69.80%	90.97%	95.60%
HG vs. LSWO	72.29%	89.71%	96.62%
HG vs. TTWO	77.74%	65.20%	94.38%
LTT vs. LSWO	94.71%	98.73%	99.38%
LTT vs. TTWO	90.80%	88.33%	98.85%
LSWO vs. TTWO	99.30%	97.72%	99.72%

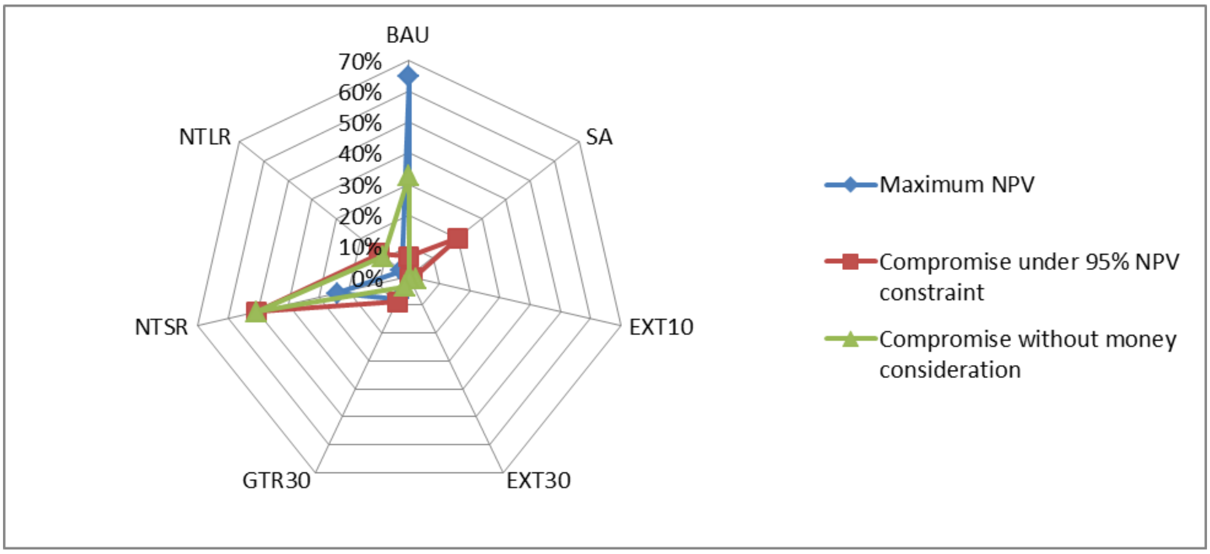


Fig. S2 Percent values of the proportions of management options applied for obtaining the maximum Net Present Value from timber extraction, the simultaneous compromise solutions for all the six species with and without money constraints.

3 Species and their habitat availability

Capercaillie (*Tetrao uralensis*) is a game bird with high social and economic value. It also has conservation value being listed as near threatened in the latest national red-list of Finland (Rassi et al. 2010). Further, capercaillie is an umbrella species: Pakkala et al. (2003) showed that the overall species richness of breeding forest birds was higher in the vicinity of capercaillie leks, and on a larger scale the density of capercaillie closely coincides with the overall game animal richness index describing the total abundance of 15 other forest dwelling mammal and bird species with diverse ecology and habitat requirements. Capercaillie was formerly considered associated with old or mature forests but lately shown to inhabit rather young forests as well (Miettinen, 2009). Lekking sites are characterized by spruce (*Picea abies*) understorey under pine (*Pinus sylvestris*) canopy.

Based on personal communication with experts (P. Helle and P. Valkeajärvi) we formulated three sub-utility functions to describe the suitability of a stand as capercaillie lekking site:

1. pine volume (m3/ha)

$$w_{pine} = \begin{cases} 0, & if\ v_{pine} \leq 60 \\ 0.05 * v_{pine} - 3, & if\ 60 \leq v_{pine} \leq 80 \\ 1, & if\ v_{pine} > 80, \end{cases}$$

2. spruce volume (m3/ha)

$$w_{spruce} = \begin{cases} 0, & if\ v_{spruce} \leq 5 \\ 0.2 * v_{spruce} - 1, & if\ 5 < v_{spruce} \leq 10 \\ 1, & if\ 10 < v_{spruce} \leq 20 \\ -0.1 * v_{spruce} + 3, & if\ 20 < v_{spruce} \leq 30 \\ 0, & if\ v_{spruce} > 30, \end{cases}$$

3. density of trees (#stems/ha)

$$w_{density} = \begin{cases} 0, & if\ stems/ha \leq 500 \\ 0.01 * stems/ha - 5, & if\ 500 < stems/ha \leq 600 \\ 1, & if\ 600 < stems/ha \leq 800 \\ -0.005 * stems/ha + 5, & if\ 800 < stems/ha \leq 1000 \\ 0, & if\ stems/ha > 1000. \end{cases}$$

Habitat suitability for the capercaillie is a product of these three functions

$HSI_{capercaillie} = w_{pine} * w_{spruce} * w_{density}$,

and varies between 0 (not suitable) to 1 (high quality). It equals to one when pine volume is high (>80m3/ha), spruce volume is at an intermediate level (10-20 m3/ha), and stem density is intermediate (600-800 stems/ha).

The Hazel grouse (*Bonasa bonasia*) is a game bird, and suggested to be an indicator of adequate levels of deciduous trees at boreal forest landscapes (Angelstam 1992). It is a resident bird whose occurrence is mainly influenced by the within-stand structure of forests. It inhabits mixed forests and favors dense coniferous (particularly Norway spruce) or deciduous cover below the canopy (Angelstam et al. 2004). Following Angelstam et al. (2004) and Öhman et al. (2011) we formulated the following sub-utility functions to describe habitat suitability of a stand for the Hazel grouse.

1. forest age

where *age* is the age of the dominating trees,

$$w_{age} = \begin{cases} 0, & if\ age < 20 \\ 0.1 * age - 2, & if\ 20 < age \leq 30 \\ 1, & if\ 30 < age \leq 60 \\ -0.012 * age + 1.72, & if\ age > 60 \end{cases}$$

2. proportion of deciduous trees (%) of the total tree volume

$$w_{dec} = \begin{cases} 0, & if\ p_{dec} \leq 5 \\ 0.066 * p_{dec} - 0.33, & if\ 5 < p_{dec} \leq 20 \\ 1, & if\ 20 < p_{dec} \leq 0.4 \\ -0.05 * p_{dec} + 3, & if\ 40 < p_{dec} \leq 60 \\ 0, & if\ p_{dec} > 60 \end{cases}$$

3. proportion of spruce (%) of the total tree volume

$$w_{spruce} = \begin{cases} 0, & if\ p_{spruce} \leq 20 \\ 0.2 * p_{decspruce} - 4, & if\ 20 < p_{spruce} \leq 25 \\ 1, & if\ p_{spruce} > 25 \end{cases}$$

Habitat suitability for the hazel grouse is a product of these three functions

$HSI_{hazel\ grouse} = w_{age} * w_{dec} * w_{spruce}$,

and equals to one when the age of forest is between 20 and 60 years, proportion of deciduous trees of the total tree volume is intermediate (20-40 %) and the proportion of spruce is high (>25%).

Three-toed woodpecker (*Picoides tridactylus*) is a widespread bird species that prefers mature, often conifer-dominated forests with dead or dying treesfor feeding and breeding. The species is predominantly a hole-nester, relatively resident and specialized to use bark beetles and other insects found in dead and decaying trees (Pakkala et al. 2002). It is suggested an indicator species for overall species richness of forest birds (Pakkala 2012).

According to Roberge et al. (2008), the probability of presence of the three-toed woodpecker on a site (in central Sweden) is a function of the total basal area (BA; m^2/ha) of fresh dead-wood (recently died trees), and can be reliably predicted by a logistic equation

$$w_{dw} = 1/(1 + e^{-(3.55BA-4.46)}).$$

According to Pakkala et al. (2002), when the total timber volume of living trees is below 60 m^3/ha, a stand is non-habitat for three-toed woodpecker. Following this we define

$$w_{vol} = \begin{cases} 0, & if\ v_{total} < 60 \\ v_{total}/200\,, & if\ 60 \leq v_{total} \leq 200 \\ 1, & if\ v_{total} > 200 \end{cases}$$

The habitat suitability index for the three-toed woodpecker is a product of these two functions

$HSI_{ttwo} = w_{dw} * w_{vol}$.

and is related to the probability of presence. The value is close to one when the total volume living trees is > 200 m3/ha and basal area (BA; m2/ha) of fresh dead-wood is > 2.5m2/ha. The latter threshold level translates into about 20m3/ha of dead-wood in a mature stand (*vtotal*> 200).

Lesser-spotted woodpecker (*Dendrocopos minor*) is a resident bird species that prefers woodlands with old deciduous trees and a high amount of deciduous snags. Deciduous trees dominate both as a foraging and nesting substrate, and nesting holes are excavated in rotten dead wood (Angelstam et al. 2004).

According to Roberge et al (2008), the probability of presence of the lesser-spotted woodpecker on a site is a function of the basal area (BA; m^2/ha) of fresh deciduous dead-wood (recently died trees) and can reliably be predicted by a logistic equation

$$w_{dw} = 1/(1 + e^{-(6.32BA-2.96)}).$$

According to Angelstam et al. (2004), the lesser-spotted woodpecker is associated with deciduous forests older than 60 yrs. Following this we define

$$w_{vol} = \begin{cases} 0, \ if\ age < 60 \\ age/200\ ,\ if\ 60 \leq age \leq 200 \\ 1, \ if\ age > 200. \end{cases}$$

The habitat suitability index for the lesser-spotted woodpecker is a product of these two functions

$HSI_{lswo} = w_{dw} * w_{vol}$.

and is related to the probability of presence. The value is close to one when basal area (BA; m2/ha) of fresh deciduous dead-wood is >1.5m2/ha and the age of the stand is > 200 years.

Long-tailed tit (*Aegithalos caudatus*) is a resident bird species feeding on small invertebrates. Suitable habitat is dominated by middle-aged to old deciduous stands composed of alder (*Alnus spp.*) and birch (*Betula spp.*, Jansson and Angelstam 1999). Jansson and Angelstam (1999) found that occupied forests had a minimum basal area of all living trees 11 m2/ha (mean 18 m2/ha) and 21 % deciduous trees (mean 66%). Based on this information we formulated the following three sub-utility functions:

1. forest age

$$w_{age} = \begin{cases} 0, & if\ age < 30 \\ 0.033 * age - 1, & if\ \ 30 \le age < 60 \\ 1, & if\ age \ge 60 \end{cases}$$

2. total basal area

$$w_{ba} = \begin{cases} 0, & if\ BA \le 10 \\ 0.2 * BA - 2, & if\ \ 10 < BA \le 15 \\ 1, & if\ BA > 15 \end{cases}$$

3. proportion deciduous tree of total timber volume

$$w_{dec} = \begin{cases} 0, & if\ p_{dec} \le 20 \\ 0.025 * p_{dec} - 0.5\,, & if\ 20 < p_{dec} \le 60 \\ 1, & if\ p_{dec} > 60 \end{cases}$$

The habitat suitability for the long-tailed tit is a product of these three functions

$HSI_{ltt} = w_{age} * w_{dec} * w_{ba}$,

and equals to one when the age of forest is > 60 years, proportion of deciduous trees of the total tree volume is > 60%, and total basal area of trees is >15 m2/ha. Basal area of 15 m2/ha translates into total volumes well above 100 m3/ha in forests that are older than 60 years.

The Siberian flying squirrel (*Pteromys volans*) is defined as vulnerable in Finland by IUCN (The International Union for Conservation of Nature) classification (Rassi et al. 2010). The species is included in Habitats Directive Annex IV of European Union (92/43/EEC) and is, therefore, declared to be in need of strict protection. The species has declined since the mid-20th century (Hokkanen et al. 1982). It has suffered from intensive forestry that has resulted in the reduction of its habitat, i.e. spruce-dominated old forests mixed with deciduous and cavity trees (Hokkanen et al. 1982; Hanski et al. 2000).

We used our own experience on flying squirrel habitat requirements (Reunanen et al. 2002, 2004; Hurme et al. 2007) to formulate sub-utility functions for the flying squirrel:

1. spruce vol m^3/ha

$$w_{sprucevol} = \begin{cases} 0, & if\ v_{spruce} \leq 140 \\ 0.028 * v_{spruce} - 4, & if\ 140 < v_{spruce} \leq 175 \\ 1, & if\ v_{spruce} > 175 \end{cases}$$

2. proportion of spruce of total timber volume (%)

$$w_{sprucep} = \begin{cases} 0, & if\ p_{spruce} \leq 50 \\ 0.1 * p_{spruce} - 5, & if\ 50 < p_{spruce} \leq 60 \\ 1, & if\ p_{spruce} > 60 \end{cases}$$

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3. volume of deciduous trees m^3/ha

$$w_{dec} = \begin{cases} 0, & if\ v_{dec} \leq 12 \\ 0.333 * v_{dec} - 4, & if\ 12 < v_{dec} \leq 15 \\ 1, & if\ v_{dec} > 15 \end{cases}$$

The habitat suitability for the flying squirrel is a product of these three functions

$HSI_{fs} = w_{sprucevol} * w_{sprucep} * w_{dec}$,

and equals to one when the volume of spruce is > 175 m3/ha, the proportion of spruce of the total timber volume is >60%, and the volume of deciduous trees is > 15 m3/ha.

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