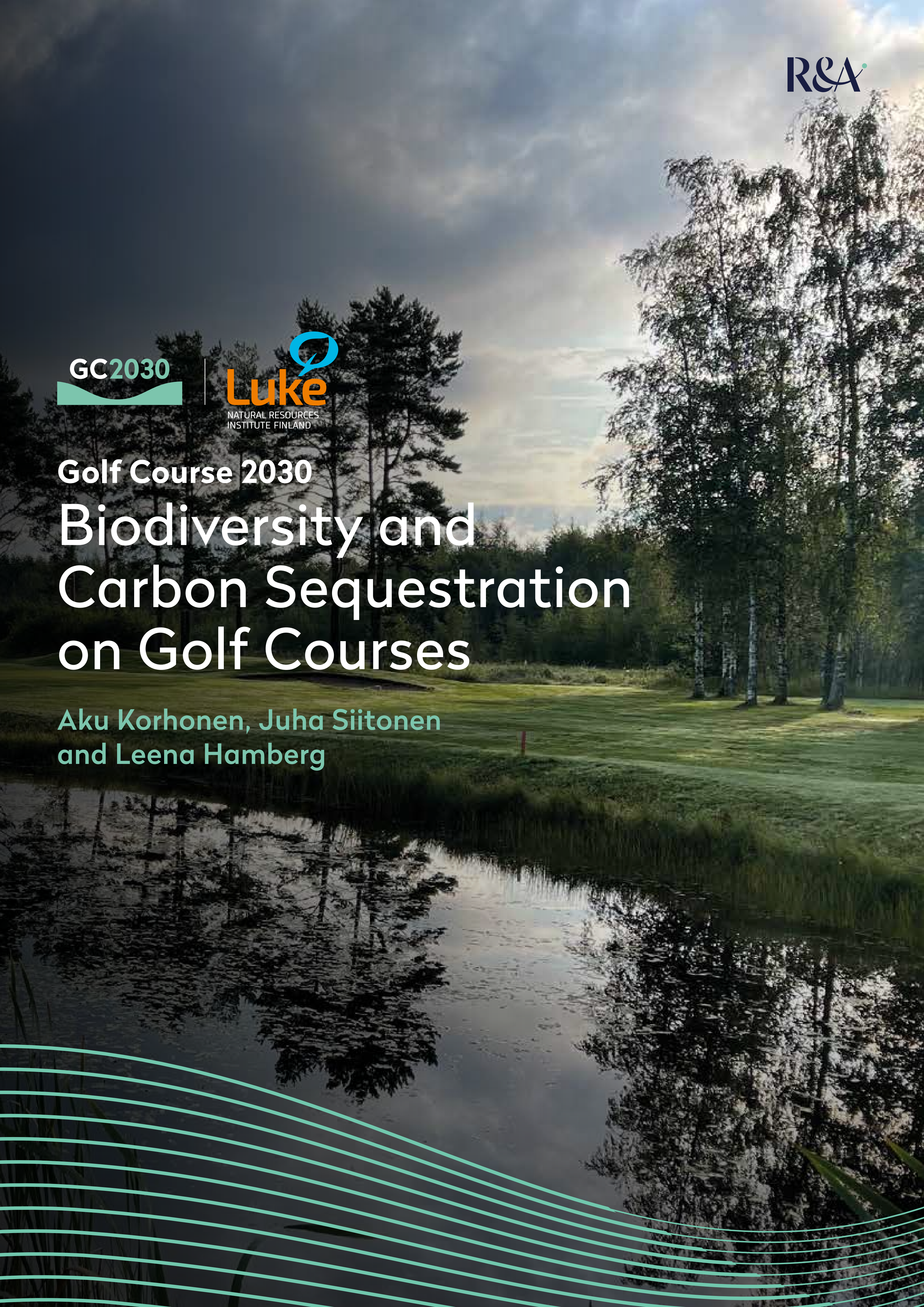

Golf Course 2030

Biodiversity and Carbon Sequestration on Golf Courses

Aku Korhonen, Juha Siitonen and Leena Hamberg

Contents.

Although golf courses are intensively managed by humans, they contain various natural environments, ranging from managed open turfgrass areas to more natural, shaded forests and aquatic habitats. Different habitat types often occur in close proximity on golf courses, creating transitional zones or ecotones that can provide habitats for species requiring such diverse environments.

This literature review concentrates on the potential of golf courses to maintain and promote biodiversity, which encompasses a variety of natural habitat types and species diversity. Additionally, possibilities to address climate change and carbon sequestration on golf courses are briefly explored. Separate sections provide guidance to golf courses for enhancing biodiversity and adopting climate-friendly course management practices.

Key words: biodiversity, nature conservation-oriented management, habitat types, climate change.

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Golf courses and their habitats.

In Finland, there are over 200 golf courses with a total area of nearly 12,000 hectares (Table 1). Golf courses are established for playing golf, but they also include various built and natural environments. Typical features of golf courses include well-maintained lawns, fairways, and greens for playing, but between fairways or on their outskirts, there may also be various less-maintained green areas such as roughs, water areas, single trees or groups of trees, and forests.

Table 1. **Distribution of Finnish golf course areas based on different habitat types (Finnish Golf Union 2023).**

Habitat type	Area (ha)	Area (%)
Lawns	5,848	50
• Greens	153	1
• Teeing grounds	149	1
• Foregreen	153	1
• Fairways	2,913	25
• Maintained roughs	1,460	13
• Ranges	1,020	9
Water hazards	149	1
Bunkers	32	<0.5
Paths and roads on golf courses	44	<0.5
Other areas (incl. forests and wooded areas)	5,717	49
Total	11,790	100

In Finland, many golf courses include water hazards, wetlands, or forests, and many of them have been established at least partially on former farmland (Table 2). Golf courses are typically open, mosaic-like areas, where maintained and less maintained areas with low or tall vegetation, as well as other habitats, vary. Different habitat types occur in close proximity on golf courses, creating transition zones or ecotones that can provide habitats for species requiring such environments.

Table2. **Occurrence of different habitat types on Finnish golf courses (Finnish Golf Union 2023).**

Habitat type	Occurrence on Finnish golf courses (%)
Flowing water (incl. ditches)	49
Lake (golf course on a lakeside)	20
Water hazards, wetland	71
Sea (golf course extends to seashore)	8
Forests and woodlands	84
Individual old park trees	8
Previous agricultural land (at least partly established on agricultural land)	75

Significant habitats on golf courses and their species communities.

The diversity of birds and insects, such as butterflies, beetles, and bees, depends on the diversity of vegetation present on a golf course.

Figure 1. Golf courses typically include a variety of natural habitats.

Biodiversity refers to the variability among habitats, communities, and species (Korhonen et al. 2022). The goal of maintaining biodiversity is not to maximize the number of species but to preserve various habitats, including those with low species richness, and the characteristic species associated with each habitat. Biodiversity also encompasses the preservation of genetic diversity among individuals of the same species.

Golf courses consist of various natural habitats, often characterised by diverse soil types, the presence of small bodies of water, woodlands, bunkers, and varying heights of vegetation, ranging from well-maintained greens and fairways to less-maintained roughs and meadows (Saarikivi et al. 2010).

The variety of habitats found on a golf course significantly impacts its biodiversity. Especially, vegetation creates habitats for other species. Many species depend on the diversity of trees, shrubs, and understory vegetation, making vegetation crucial for the composition and diversity of the animal population (McKinney 2002, Colding and Folke 2009). For example, the diversity of birds and insects, such as butterflies, beetles, and bees, depends on the diversity of vegetation present on a golf course.

The presence of natural habitats increases the diversity of plant and animal species on golf courses, including the number of rare species (Nooten et al. 2018). Areas with original vegetation that have been preserved between and along the edges of playing areas typically host more diverse and species rich communities than the well-maintained playing areas. This is because the structure of vegetation in these areas is more diverse than in the areas used for playing. Therefore, it is important to conserve original meadows and woodlands, or even expand them whenever possible. The larger the original habitats are, the more diverse are the species communities that can be preserved. Golf courses also contain unique vegetation types and habitat combinations, which can host specific species communities (Hui et al. 2017b).

When golf courses are established in forests or areas with a natural or semi-natural landscape, their ecological value often decreases (Colding and Folke 2009). In such cases, there may no longer be suitable habitats for species adapted to the stable conditions found in the interior of the forest, and there is a risk of destroying habitats for rare and endangered species. On the other hand, if a golf course is located in an urbanised area or is established on conventional agricultural land, it is expected to increase local biodiversity.

Golf courses can play a role in the conservation of species, especially in urban areas, their surroundings, and in areas of intensive agriculture (Colding and Folke 2009, Saarikivi et al. 2010). For example, an English study found that bird, carabid (ground beetle), and bumblebee diversity on golf courses was more diverse and abundant than in nearby farmland (Tanner and Gange 2005).

Paying attention to ecological values in golf course design and habitat management can, over time, enhance biodiversity even in broader areas (Tanner and Gange 2005, Colding and Folke 2009). Therefore, golf courses should be integrated into the planning of larger green space networks to better ensure the preservation of various species' habitats in the future (Nooten et al. 2018).

Many golf courses have characteristics that are important for biodiversity, providing habitats for endangered and regionally rare plant and animal species (Colding and Folke 2009). For example, they can serve as breeding grounds for amphibians and nesting environments for birds.

How to increase the biodiversity of golf courses

- **Preserve or create natural vegetation areas:** Leave parts of the golf course natural or plant areas with indigenous vegetation, such as forests, trees, meadows, and aquatic plants. This allows for the presence of a wide variety of species on golf course.
- **Favour areas including trees:** Trees are especially important in maintaining biodiversity. They provide habitats, shelter, and food for many species.
- **Support meadows and other natural open areas.**
- **Reduce highly maintained lawn areas.**
- **Create nesting sites for pollinators:** Both decaying wood and sandy areas provide nesting sites.
- **Raise awareness:** Educate golf course staff and players about the importance of biodiversity and how they can contribute.

The most intensive maintenance is applied to greens, followed by teeing grounds, fairways, and the surrounding roughs.

Fairways and roughs

Golf courses are typically either 9-hole or 18-hole layouts. Golf is played on the turf areas of golf courses, which consist of various intensively managed areas. The most intensive maintenance is applied to greens, followed by teeing grounds, fairways, and the surrounding roughs (Allan-Perkins et al. 2019). Greens are maintained with very short grass, and they are often watered and fertilised regularly. Sand is also applied to the grass on greens to improve aeration and water permeability. Pesticides may be used on greens for pest control.

Fairways receive less intensive maintenance. The grass on fairways is allowed to grow taller than on greens, but they are still subject to watering, fertilisation, and pesticide use. Roughs receive the least amount of maintenance. Vegetation in the roughs is allowed to grow taller than on fairways, and the use of fertilisers and pesticides is minimal.

In an American study, it was found that there was no difference in the abundance and species richness of soil bacteria among the differently intensively managed turf areas on golf courses, including greens, fairways, and roughs (Allan-Perkins et al. 2019). However, the intensity of maintenance did impact the soil fungal community, with the poorest fungal diversity being found on heavily maintained greens, while the richest fungal diversity was observed in the roughs. Fairways also had a higher fungal diversity compared to greens. These differences were attributed to the intensity of pesticide use. Similarly, in an English study, it was observed that the most intensively managed turf areas, namely greens and teeing grounds, had significantly smaller microbial communities compared to less intensively managed fairways and roughs (Bartlett et al. 2008).

Figure 2. Outside the fairways, there is space for flowering plant species that enhance the biodiversity of the golf course by providing habitats and food for animals. Meadows and fields are crucial for pollinating insects, so it is essential to ensure the presence of flowering plants from spring to autumn.

Intensive lawn mowing has been observed to reduce plant and invertebrate biodiversity while benefiting pest insects and weeds (Watson et al. 2020).

In a study conducted in Finland, pitfall traps were set up on golf course fairways, their edges, roughs, woodlands, and bunkers, in vegetation typical of golf courses (Saarikivi et al. 2010). The traps captured a variety of carabids (ground beetle) species, but they were primarily common species found in open areas or generalist species capable of efficiently spreading and living in various habitats. Despite the presence of open habitats, such as bunkers and pond edges, on golf courses, specialised species adapted to open habitats were not found. Golf courses also did not provide suitable habitats for forest species, as they were only observed at the edges of woodlands and in woodlands adjacent to the golf course. It is interesting to note that in the study, an endangered ground beetle species, *Chlaenius nigricornis*, was found at the edge of a pond on Hiekkaharju golf course. High carabid species richness was attributed to the high habitat diversity on golf courses. The highest species richness and biodiversity were discovered at Tali golf course, which is an older course with less modified vegetation but more diverse environments than the other studied courses. Tali golf course features old trees and a dense canopy cover in a unique urban park setting.

Diversifying vegetation also increases the abundance and biodiversity of animal species, such as arthropods (insects) (Pornaro et al. 2018). Diversifying turf vegetation, for example, with clover, can benefit bee populations (Rasmont et al. 2005). An Italian golf course was studied to explore methods for diversifying the vegetation containing grasses, such as couch grass *(Elytrigia repens)* and red fescue *(Festuca rubra)*, in the roughs (Pornaro et al. 2018).

The most effective way to diversify the vegetation was by cutting the grass, removing the clippings, aerating the soil, and sowing new plants from seeds bird vetch *(Vicia cracca)*, red clover *(Trifolium pratense)*, and meadow sage *(Salvia pratensis)*. Only cutting, removing clippings, and aerating, or leaving the grass uncut, yielded poorer results. However, a single cutting session was insufficient to maintain the sown plant species. Multiple cutting sessions are required to prevent the originally present grasses from outcompeting the newly planted flowering plants.

How to increase the biodiversity of turf areas on golf courses

- **Reduce intensive mowing:** Where possible, decrease the intensity of mowing in turf areas. Even a small reduction in mowing intensity can benefit biodiversity.
- **Increase rough areas:** Expanding the rough areas on the golf course can be beneficial. Tall, flowering vegetation in roughs provides habitats for invertebrates and serves as a food source for pollinators. You can introduce diversity by varying the height and plant species in the roughs. Maintaining diverse, flowering roughs may require occasional mowing to prevent dominant grasses from taking over.
- **Create habitat for native species:** Consider creating habitat for native species that have become rare due to changes in land use, such as maiden pink *(Dianthus deltoides)* or other native wildflowers. Establishing dry meadows is most successful in nutrient-poor and sandy soils. Regular maintenance, such as mowing, can help maintain these habitats.

Water hazards can host a variety of species, including amphibians, dragonflies, water bugs, and diving beetles, and they can support diverse aquatic vegetation.

Water hazards and other small water bodies on golf courses

Golf course water hazards are often artificial, as is their immediate vicinity, which is heavily modified by human activity. Nevertheless, many species of aquatic environments can utilise golf course ponds as habitats or breeding grounds. These water hazards can host a variety of species, including amphibians, dragonflies, water bugs, and diving beetles, and they can support diverse aquatic vegetation. Ponds and wetlands in golf courses also function as valuable breeding sites for local nesting waterfowl and as stopover points for migratory birds (Puustinen et al. 2001, Sammalkorpi et al. 2005), especially in areas where natural wetlands are scarce. At night, these water bodies can attract foraging bats (Parker et al. 2019). Golf courses with small, fishless water bodies can be significant habitats for species that favour such environments. For example, in Sweden, a quarter of all ponds in the Stockholm region are found on golf courses (Colding et al. 2009).

In a study conducted in the Greater Helsinki area of Finland, it was observed that golf course ponds hosted frog populations of similar size to those in natural ponds (Saarikivi et al. 2013). Similarly, in a study in the Stockholm region of Sweden, no significant differences in amphibian or aquatic invertebrate biodiversity were found between golf course ponds and similar natural ponds, despite the assumption that golf course ponds might be subject to higher chemical pollution (Colding et al. 2009).

Figure 3. At Hirsala Golf Course, a water hazard connects to a transitional area featuring natural marsh vegetation on one side. This extensive water hazard includes a variety of open water areas, submerged and floating aquatic plants, as well as shoreline vegetation with emergent plants.

These findings suggest that golf courses, within the constraints of the local landscape, can indeed support various forms of aquatic biodiversity. In addition to permanent open water hazards, biodiversity can be enhanced by the presence of more vegetated and seasonally wet pools, as well as small flowing streams.

Water hazards and ponds

Permanent water hazards and other ponds that remain filled with water throughout the year can be considered habitats similar to natural ponds, providing environment for aquatic organisms that require open water. In ponds, water quality, vegetation, and other biota interact in various ways. High nutrient levels in water can promote the growth of aquatic vegetation, which, in turn, absorbs nutrients. On the other hand, rapid proliferation of nutrient-loving algae can lead to water turbidity, which impairs the habitat for submerged aquatic plants (Scheffer et al. 1993). Massive algal blooms can be unsightly and may cause unpleasant odours when they decompose. Cyanobacterial blooms can also be toxic to aquatic organisms or animals seeking food or water in the affected water.

A study on the biodiversity of constructed water bodies in Netherlands found that the diversity of aquatic invertebrates and the number of endangered species were highest in nutrient-poor waters (Vermonden et al. 2009). Similarly, nutrient-rich but clear-water pools with abundant submerged vegetation were also diverse in terms of species, especially featuring a high number of aquatic snails. In contrast, the diversity of aquatic invertebrates was lowest in the most nutrient-rich and turbid waters, where submerged vegetation was absent.

Natural structural features enhance the biodiversity value of ponds. These features can include gently sloping shorelines with natural vegetation. The zone of emergent vegetation extending from the water's edge into shallow water is crucial for many aquatic invertebrates that seek food among the plants and find protection from predators in these areas (Oertli and Parris 2019). Emergent plants include tall grasses and herbs like reeds, rushes, cattail, iris, and some sedges. Within these plant communities, a variety of other lower wetland plant species can typically be found.

In ponds with steep edges, the zone of emergent vegetation formed by tall grasses can become narrow. This can increase the risk that water recedes from the emergent zone entirely during the summer, leaving some aquatic organisms without the necessary protection (Liao 2022). Therefore, it is advisable to maintain a sufficiently high water level, especially during the summer, in at least some of the golf course water hazards to prevent the complete withdrawal of water from the emergent zone.

Natural structural features enhance the biodiversity value of ponds.

In addition to emergent plants, the presence of submerged and floating-leaved vegetation in deeper water has also been found to have a positive relationship with aquatic invertebrate biodiversity (Vermonden et al. 2009). Some species also require open water habitats to thrive (Liao et al. 2023).

Small natural ponds and constructed water features that are not connected to larger water bodies are typically fishless unless fish have been intentionally introduced. Fish are efficient predators of small aquatic invertebrates and compete for food resources with waterfowl, among other species. For instance, the critically endangered horned grebe *(Podiceps auritus)* prefers fishless waters, and this species has been observed breeding in ponds on golf courses in Finland. Keeping ponds fishless can enhance their value as habitats for aquatic invertebrates like diving beetles (Liao et al., 2020) and as environments for birds (Haas et al. 2007). Even in fish-inhabited ponds, it is possible to create refuge areas for small vertebrates by increasing emergent vegetation (Liao et al. 2023).

Many species that utilise ponds spend part of their life in terrestrial habitats. For example, amphibians and many insects are aquatic only during their larval stages and return to water mainly for breeding or overwintering as adults. Facilitating the movement of animals between water and terrestrial habitats can be achieved by preserving natural vegetation around ponds as corridors or patchy stepping stones leading to more extensive natural areas. Most species can likely traverse even open grassy areas, but taller vegetation provides better protection for small animals from predators.

Seasonal wetlands

In addition to permanently open water bodies, seasonally drying ponds also play a significant role for species dependent on water. Temporary ponds often have lower species richness in aquatic communities compared to permanent ones, but they harbour specialised species that may not thrive in permanent ponds (Hassall et al. 2011, Oertli and Parris 2019). Seasonally drying ponds can promote the abundance of insect species, for example, those that are vulnerable to predation by fish and large aquatic invertebrates in permanent water bodies (Zedler 2003). The increased insect abundance benefits other animals that prey on them. Especially in the spring, seasonal ponds have been observed to attract more birds and other wildlife than permanently open water bodies (Dixneuf et al. 2021). On golf courses, these seasonal wetlands or depressions can occur naturally, or their formation can be encouraged by directing and collecting meltwater and runoff.

Figure 4. By arranging stones along the streambed and its edges, conditions for trout spawning are created, and the stream's flow and meandering are shaped to enhance biodiversity.

Streams and rivulets

Streams and flowing water channels, such as brooks, are common landscape features on golf courses. The characteristics and species found in flowing waters depend heavily on the environment and conditions in the headwaters of the watercourse (Jonsson et al. 2017). Additionally, a golf course can impact a stream beyond the portion that runs through it. Therefore, planning for the management of watercourses should ideally be done at the scale of the entire watershed, crossing property boundaries.

Flowing waters create various microhabitats due to the small-scale variations in the channel's shape and structure. In streams, it is beneficial to promote variations in channel width and depth, meandering, and different types of substrate and roughness on the bottom. Especially on former agricultural or forestry lands, watercourses are often heavily modified by human activities, sometimes straightened into ditches. In such cases, creating structural variability might require restoration efforts, such as reshaping the channel through excavation or adding rocks, gravel, or coarse woody debris to the channel (Ahola and Havumäki 2008).

In small streams, the species communities are closely linked to the riparian zone – the area surrounding the stream channel. The riparian vegetation along the channel binds the soil on the streambanks, preventing its erosion and reducing the transport of sediments and chemical pollutants into the water from the surroundings. Leaf litter produced by vegetation, particularly deciduous trees in the riparian zone, serves as an important food source for the benthic organisms in the streams. Trees and branches that have fallen into the stream are particularly effective in trapping debris carried by water, making them valuable structures for the stream's ecosystem (Koljonen et al., 2012). Wood in the water also serves as a significant food source and substrate for aquatic microbes (Brüchner-Hüttemann et al. 2019) and the aquatic invertebrates that depend on them (Hax and Golladay 1993).

Riparian zones with trees not only contribute leaf litter but also provide shade, creating contrasts in vegetation relative to the open areas of the stream channel. This shading limits the growth of large, fast-growing aquatic and shoreline plants, which in turn frees up more space for aquatic mosses that thrive in flowing waters (Turunen et al. 2019).

How to enhance biodiversity in water hazards and other small water bodies on golf courses

- **Create variation between water hazards:** Adjust shade from trees, the structure of shorelines, the ratio of vegetation cover and open water, and seasonal water level to create diversity among different water hazards. Water hazards can also vary by size.
- **Reduce fertiliser and pesticide use:** Avoid the use of these chemicals near water bodies and on slopes where surface runoff flows directly into water bodies.
- **Control excessive nutrient loading:** Leave a natural buffer zone of vegetation around the shoreline where no fertilisers are applied. Allow space for vegetation that can absorb excess nutrients and remove excessive plant material when necessary. If vegetation will be cleared, it is best to do so in the autumn. Use a pump to keep water oxygen-rich deep in the water.
- **Border water hazards with less managed areas:** Surround water hazards at least from one side with less intensively managed vegetation, such as roughs or woodlands. Utilise shoreline bushes of ditches or streams associated with water hazards as ecological corridors.
- **Favour gentle shorelines:** Loosely sloping shoreline areas make it easier for wildlife to move between land and water and provide space for shoreline vegetation.
- **Introduce natural organic matter:** Increase the amount of leaf litter, branches, and logs in the water to provide habitat and food sources for aquatic organisms.
- **Avoid, monitor, and manage invasive species:** Be vigilant about invasive species and take action to prevent their spread into water hazards and other water bodies.
- **Study the local biodiversity:** Investigate the biodiversity of nearby small water bodies and explore opportunities to create additional habitats for species that require specific conditions.

The transition zones between wooded areas and open spaces are often rich in biodiversity, as they provide habitat for species from both open environments and forests.

Transition zones between open fields and forest edges

Some species also appear to prefer these transitional zones. Hungarian studies have found specific arthropod species that favour transition zones between deciduous forests and grasslands (Magura et al. 2001, Horváth et al. 2002, Magura 2002, 2017). However, in Nordic studies on ground beetles (carabid beetles) conducted in managed forest environments, a similar preference for forest and open area transition zones has not been observed (e.g., Heliölä et al. 2001, Niemelä et al. 2007). On the other hand, in Finnish research conducted on golf courses, it was observed that great tits *(Parus major)*, blue tits *(Cyanistes caeruleus)*, and pied flycatchers *(Ficedula hypoleuca)* preferred and produced more offspring in nest boxes placed near the edge of open areas compared to similar nest boxes located 50 meters inside the forest (Saarikivi and Herczeg 2014).

The benefits of these transitional zones are largely related to plant diversity and variation. Such diversity is typically abundant in broad natural transition zones (Magura et al. 2017). Therefore, it is advantageous to leave a buffer zone between forest edge trees and open grassy areas, allowing shrubs to develop and permitting grassy vegetation to grow at least partially without intensive maintenance. A dense shrub layer at the forest edge can enhance bird biodiversity (Melin et al. 2018).

Forest edges between wooded areas and open spaces provide favourable habitats for many deciduous trees and shrubs. The increased light at forest edges enhances the flowering and fruiting of species like rowan *(Sorbus aucuparia)* and bird cherry *(Prunus padus)*, which, in turn, benefits pollinators and fruit-eating animals. The sun-exposed forest edge is also a suitable environment for many insects and fungi that inhabit dead or dying wood, particularly on broadleaved trees such as aspen *(Populus tremula)* but also on other deciduous tree species (Kaila et al. 1997, Martikainen 2001, Sverdrup-Thygeson and Ims 2002, Lindhe and Lindelöw 2004, Lindhe et al. 2005, Junninen et al. 2007, Ranius et al. 2011, Koch Widerberg et al. 2012, Lariviere et al. 2023).

The edge effect observed in forest understory vegetation (Hamberg et al. 2009) and ground beetle species (Noreika and Kotze 2012) – which refers to the change in species composition when transitioning from the sunny and warm forest edge to the shaded and cooler forest interior – can extend several tens of meters from the forest edge into its interior. If closed forest communities are present within the golf course area and there is a desire to preserve them, their living conditions can be safeguarded by mitigating the edge effects. This involves reducing the penetration of solar radiation, wind, and airborne particles from the forest edge into the forest interior. This can be achieved by avoiding unnecessary clearing of trees and undergrowth (Koivula et al. 2019) and allowing the edge of the wooded area to grow as dense as possible. The most effective barrier effect at the edge can be achieved with evergreen conifers, such as spruce (Hamberg et al. 2009). Additionally, at the outermost forest edge, in front of conifers, flowering trees and shrubs can be favoured.

Forest edges between wooded areas and open spaces provide favourable habitats for many deciduous trees and shrubs.

How to enhance biodiversity in the transition zone between open fields and forests

- **Favour natural vegetation at edges:** Allow shrubs and herbaceous vegetation to develop in the transition zone between the forest and open area.
- **Promote native tree and shrub species along the edges of wooded areas.**
- **Favour dead wood:** Preserve dead and dying trees in the edge forests, especially large deciduous trees, as they are valuable for heat-loving saproxylic (wood-dependent) insects.
- **Let the forest edge grow dense:** If you wish to protect the characteristic species of closed forests, let the forest edges grow dense.
- **Add bird nest boxes:** Consider placing bird nest boxes, especially for tits, in the trees along the forest edge.

Forests naturally host a variety of species that may not be found in other habitat types on golf courses.

Wooded areas and intermediary zones including trees

In Finland, approximately half of the total area of golf courses consists of various maintained grassy areas, with the other half comprising water hazards, bunkers, and other landscaped areas outside the actual playing fields (Table 1). Additionally, a significant portion of this landscaped area may be wooded. While the primary purpose of golf courses is to facilitate the game of golf, wooded and forested areas alongside fairways are often kept open to make it easier to find golf balls that have strayed from the fairways and into the trees. However, these wooded areas and forest patches on golf courses can provide habitat for wildlife species dependent on forest environments.

Because wooded areas on golf courses are not part of the playing area itself, they are well-suited for supporting biodiversity. Forests naturally host a variety of species that may not be found in other habitat types on golf courses.

Wooded areas attract species that use trees for food, habitat, or breeding sites, as well as their predators and other associates. These species may include mammals, birds, arthropods, and various small invertebrates, as well as bryophytes, lichens, fungi, and diverse microbial communities. Additionally, many species that are not directly dependent on trees still prefer forest environments.

The tree canopy, including the upper parts of trees and their crowns, represents only one part of a forest. The understory vegetation beneath the canopy and the forest floor, shaped by tree roots and litter, also contribute unique characteristics and host distinct species. Since the essential features of forest ecosystems are largely created by trees collectively, individual trees or small groups of trees growing between fairways cannot provide the similar biodiversity benefits. However, trees growing in open areas also have their own unique ecological value (see section on Old Park Trees – page 31).

The composition of species in wooded areas depends on the quality of the forest. Site-specific factors such as climate, soil composition, nutrient levels, and moisture determine the types of forest ecosystems that can develop in a given location. For example, fertile clay soils can support the development of deciduous forests, while nutrient-poor sandy soils might give rise to pine heathlands, each with its own distinct species composition.

The size and shape of wooded areas also influence the quality of forest habitats. The narrower the wooded area, the larger the proportion of transitional zone, where the influence of adjacent open areas can be strong. In narrow wooded strips, specialised forest species have fewer opportunities compared to larger, continuous forested areas, even if the tree cover is similar. On the other hand, narrow tree strips may provide suitable habitats for sun-loving species that do not thrive in the shaded conditions of dense forests.

Many biodiversity-enhancing structures develop naturally in forests, but their development is often a process that spans at least decades. Therefore, in forest environments, biodiversity is best conserved by preserving pre-existing crucial structural elements. However, the quality of forest habitats and their ability to sustain biodiversity can also be actively enhanced within the constraints set by site conditions.

Figure 5. Vegetation typical of harsh growing conditions in forests can thrive on open intermediary areas of golf courses if the soil conditions are suitable and trampling is not too intense.

Biodiversity is also increased by having trees of different ages, sizes, and conditions in different canopy layers in wooded areas.

Forest structure

In wooded areas, the diversity of tree species and variation in the age structure of trees enhance small-scale biodiversity in the environment, i.e., the number of different microhabitats. Each tree species has specialised associated species, and their presence depends on the occurrence of the right host tree species (Keto-Tokoi and Siitonen 2021). Therefore, increasing the diversity of tree species generally expands the opportunities for diversifying the species composition. Biodiversity is also increased by having trees of different ages, sizes, and conditions in different canopy layers in wooded areas.

Variation created by different tree species, developmental stages, and stem densities influences the understory vegetation (Uotila and Kouki 2005, Ampoorter et al. 2014, Tonteri et al. 2016). Mixed-species forests and forests with varying tree structures can host a diverse range of plant species from deciduous and coniferous forests, as well as semi-open and closed forests. A similar small-scale variation is also an important factor explaining the biodiversity of forest floor invertebrates (Niemelä et al. 1996). Further variation is introduced by coarser-scale variations in the forest structure, where certain areas within a forest may be more conifer-dominated while others are more deciduous-dominated (Huuskonen et al. 2021).

Tree plantations and forest stands that have previously been managed as commercial forests are often structurally uniform and lack tree species diversity. To enhance diversity in such areas, one can accelerate the diversification of the tree structure by creating gaps within the even-aged stands, allowing for natural regeneration of deciduous trees and shrubs (Maher-Hasselquist et al. 2021, Saukkonen and Valkonen 2022). New tree species can also be introduced by planting them in these gaps.

On golf courses, it is advisable not to limit to just the most common main tree species but to also favour native broadleaved trees, such as birches, rowans, bird cherries, and willows. The wooded areas bordering open grassy areas often have abundant edge habitats that are suitable for many light-demanding deciduous tree species. For biodiversity, it is essential to maintain undisturbed thickets in wooded areas as they are favoured environments for many forest birds (Klein et al. 2020).

Old and large trees are valuable structural features for biodiversity. As trees age and grow, their structure becomes more diverse, and various microhabitats accumulate within the tree (Kõrkjas et al. 2021b). Because trees have a long lifespan, and their biodiversity values develop slowly, it is essential to preserve the oldest and largest trees in the forest stand for as long as possible.

How to increase forest biodiversity

- **Favour diverse forest structure:** In uniform stand structures, variation can be created by making gaps where new tree species can be introduced through planting or natural regeneration.
- **Preserve undisturbed thickets in some places.**
- **Retain the oldest trees.**
- **Favour native infrequent species:** In forest stand management, prioritize the preservation of native tree species that are otherwise scarce in the surrounding landscape.

Figure 6.
Active management for biodiversity can be considered when a forest site includes only one tree species and when all trees are even-aged.

Tree microhabitats

Structural features associated with individual trees can themselves serve as biodiversity-enhancing microhabitats. These structures typically develop as a result of aging and damage to trees and may include, for example, cavities excavated by woodpeckers, rot holes, pockets under loose bark, bare barkless wood surfaces, fire scars, resin flows, branch fractures and dead branches, witches broom, surface vegetation on trees, perennial fungal fruiting bodies, and animal nesting structures (Kraus et al. 2016, Kõrkjas et al. 2021a).

The greater quantity and diversity of tree microhabitats have been suggested as one reason for the higher biodiversity of certain groups of organisms in unmanaged and managed forests (Paillet et al. 2010, 2018). In Central European studies, the diversity of living tree microhabitats (Paillet et al. 2018) and the abundance of specific microhabitat types (Basile et al. 2020) have been found to be related to the diversity or abundance of some taxonomic groups, although not all target groups have shown such connections. To date, there have been no published studies on the effects of tree microhabitats on species diversity in boreal forests.

While there is still limited evidence regarding the quantitative effects of tree microhabitats on biodiversity, numerous examples exist of the connections between specific microhabitat types and species or groups of species (Hämäläinen et al. 2023, Table 3). Based on this, tree individuals with a variety of microhabitats can be considered potentially valuable for biodiversity. However, in conventional forest management, favouring the healthiest tree individuals often leads to the felling of such valuable or potentially valuable trees for deadwood or complete removal. In such cases, microhabitats in living trees are destroyed or their developmental trajectories are prematurely disrupted. Therefore, it is advisable to thoroughly discuss the goals of forest management with foresters when planning forest work.

Various microhabitats naturally form over time in living trees, but their development is often associated with unpredictable natural phenomena, such as damage caused by animals, pathogens, or weather events. Certain tree species, like aspen and oak, have higher prevalence and more diverse microhabitats than others (Kõrkjas et al. 2021a). Individuals of these tree species often survive for a long time even when damaged, which means that the microhabitats formed on them also persist for an extended period. In Finnish conditions, goat willow *(Salix caprea)* is a noteworthy, fairly early declining but resilient tree species, with ample opportunities for the development of various microhabitats (Siitonen and Hamberg 2012).

Table 3. **Tree microhabitats and their significance for species (see Figure 8).**

Microhabitat	Formation	Significance for species
Cavities and rot holes	Hollows and cavities form in tree trunks as a result of heartwood decay and excavation by woodpeckers. Woodpeckers often prefer trees with wood that has already been softened by decay, but at least the black woodpecker can excavate its cavity in a hard trunk.	Hollows and cavities serve as natural nesting and hiding places for hole-nesting birds and some mammals, such as flying squirrels and bats.
Dead branches and canopies in living trees	Individual branches or canopy limbs on trees may die and remain attached to the tree.	Dead branches provide a different microhabitat for species dependent on dead and decaying wood, especially when compared to similar deadwood on the ground.
Pockets under loose bark	In patches where the living bark tissue had died, outer bark can partially detach from the trunk. A gap forms between the bark and the wood.	In bark pockets, various invertebrate animals inhabit. Larger bark pockets serve as nesting sites for birds like the Eurasian treecreeper and hiding spots for bats.
Exposed wood surfaces	Exposed wood is revealed when branches tear or break, as well as in areas where the cambium layer has died and the bark has fallen off.	Exposed wood surfaces attract fungi and insects that feed on wood, as well as lichens that grow on wood surfaces.
Cracks on trunks	Cracks extending into the trunk can form due to freezing, twisting, or decay.	Cracks provide hiding places for various invertebrates.
Polypores and other fruiting bodies	Fungi living in the trunks produce fruiting bodies on the surface of the trunk, which can be annual or perennial.	Many insects use the fruiting bodies of fungi or their spores as their food source. Fruiting bodies also host parasitic microfungi and microbes.
Epiphytic bryophytes and lichens	Bryophyte and lichen covered patches on tree branches and trunks provide shelter and habitats for small organisms.	Epiphytic bryophyte and lichen vegetation hosts invertebrate communities, that provide food for birds. Some forest birds store their winter food among bryophytes and lichens.

How to preserve tree microhabitats

- **Do not remove damaged or structurally unusual trees** unless they pose an obvious danger or other significant harm.
- **Remember to discuss biodiversity-related management goals and constrains** clearly with contractors or workers before conducting any forest management activities in wooded areas.
- **Communicate with the golf course's user community** about the valuable structural features of the trees and their significance for wildlife. Highlight charismatic species on the course and the tree structures that are important to these species, such as 1) the musk beetle *(Aromia moschata)* and old goat willows, 2) the Siberian flying squirrel and its nest holes in aspen trees, and 3) the velvet-top fungus *(Phaeolus schweinitzii)* and old coniferous trees.

Dead wood

In Finland, there are approximately 4,000 to 5,000 species that depend on dead and decaying wood (Siitonen 2001). Among these species, hole-nesting birds and wood-rotting fungi with large perennial fruiting-bodies are perhaps the most noticeable and well-known examples. However, the majority of species that rely on deadwood as their habitat are less conspicuous invertebrates, fungi, and microorganisms.

Preserving biodiversity dependent on deadwood starts with having a diverse living tree population from which deadwood forms when trees or their parts die. Which species can be found living on a piece of deadwood is determined by several different factors such as tree species, mode of tree death, ground contact, size, decay stage, and surrounding environmental conditions (Stokland et al. 2012).

The biodiversity of species living in deadwood increases with the amount of deadwood, as deadwood dependent species are usually strongly resource-limited. At the stand level, for example, the richness of beetle species living in deadwood has been observed to increase significantly with deadwood volume, at least up to 20 m^3/ha of volume (Siitonen et al. 2001).

The size of deadwood also affects species richness. Larger deadwood hosts more wood-decaying fungi species than smaller-diameter deadwood, but smaller-diameter dead-wood, such as branches, may contain species not necessarily found on larger-diameter deadwood (Juutilainen et al. 2011).

Figure 7. A standing dead pine tree at the boundary between the green and the bog is a scenic element as well as a source of food and habitat for other species. During the game, there may be an opportunity to observe woodpeckers.

Deadwood forms naturally in forest areas as trees weaken and die. However, if a forest is logged and the wood is removed or if weakened and dead trees are cleared away, deadwood does not accumulate unless specific measures are taken to preserve it. In young forests, it may take decades until large, coarse woody debris develops. In built environments, deadwood can be introduced more quickly by bringing it in from outside. Large, slowly decomposing deadwood can serve as landscape elements in park-like settings (Nieminen 2020).

In forestry practices, such as thinning or individual tree removal, the accumulation of deadwood can be promoted by leaving felled trees in place. Trees that are to be removed can be cut high up, leaving behind a tall stump or a standing snag several meters high. In managed forests, artificial snags have been found to serve as habitats for some endangered beetle species (Jonsell et al. 2004, Lindhe and Lindelöw 2004). Standing, decaying trees, especially deciduous trees, are essential nesting sites for cavity-nesting birds (Vatka et al. 2014, Andersson et al. 2018), so it is advisable to save them whenever possible.

During tree felling, the woody debris can be placed in the terrain in a way that minimizes disruption to the golf course's use, and they can be moved if necessary. The placement of deadwood pieces can also increase the variety of deadwood habitats. Deadwood exposed to abundant sunlight may host different species communities than deadwood in shaded conditions (Vogel et al. 2020).

Standing, decaying trees, especially deciduous trees, are essential nesting sites for cavity-nesting birds.

How to increase the amount of deadwood

- **Avoid unnecessary removal of dead trees.**
- **Do not remove standing dead trees** if they do not pose a specific hazard.
- **Collect dead branches that have fallen** on lawns and other well-kept areas and move them to wooded areas where they can blend into the high vegetation.
- **Save removed trees as tall stumps and logs whenever possible.** The cut part can be moved elsewhere if needed, such as deeper into the forest where it is less obtrusive.
- **Maintain different deadwood habitats by preserving:**
  - deadwood from different tree species
  - both standing and downed deadwood
  - trees of different sizes, including larger ones
- **Place deadwood in areas with different light and moisture conditions** across the landscape, including in water bodies.
  - For example, aspen supports several rare and endangered species that thrive in sunny conditions.

Species communities on forest soils

Litter produced by trees is an important factor influencing the local biodiversity and abundance of soil-dwelling invertebrates (such as nematodes, earthworms, springtails, mites) in forest ecosystems. Deciduous trees, which produce easily decomposable leaf litter, tend to support a richer community of soil organisms compared to conifers, which produce acidic and slowly decomposing litter. Therefore, deciduous trees often enrich the soil fauna in conifer-dominated forests (Koivula et al. 1999, Korboulewsky et al. 2016). On the other hand, the slowly decomposing litter layers formed by conifer needles can themselves serve as important habitats for certain species.

Tree root associated fungi play an essential role in the microbial communities of forest soils. Fungi associated with tree roots, especially ectomycorrhizal fungi, are different species than those associated with herbaceous plants growing in open areas. Even if the trees are planted, typical forest-associated soil microbiota develops naturally over time. In a study conducted in Finland, it was observed that ectomycorrhizal fungal communities associated with trees growing in constructed park areas were almost as diverse as those in natural forests (Hui et al. 2017a). The presence of trees and the choice of tree species are the most significant factors influencing mycorrhizal fungal communities.

How to increase soil biodiversity

- **Diversify the selection of tree species** and leave tree litter (such as leaves and needles) on the ground to decompose.
- **Leaf litter from deciduous trees can improve conditions for many forest floor and soil microorganisms,** especially in areas dominated by conifers. Broadleaved trees and aspen produce particularly high-quality leaf litter.
- **Leave fallen leaves on turf areas** after chipping or move them to nearby forest areas.

Old trees include many microhabitats that are absent from young, vigorously growing trees.

Old park trees

Old, broadleaved trees are essential habitats for two highly diverse groups of organisms: species that inhabit living trees in hollows and other dead parts of trees, and lichen species that grow on tree trunks.

Old trees include many microhabitats that are absent from young, vigorously growing trees (Figure 8). These microhabitats include hollows in the trunk, dying and dead branches, large branches, bark injuries and scars, woodpecker holes, sap leaks, and fungal fruiting bodies (Siitonen 2012, Larrieu et al. 2018). Each of these microhabitats hosts species that are specially adapted to that particular microhabitat. The number of these microhabitats, or microhabitat richness, increases as trees age (Siitonen 2012, Keto-Tokoi and Siitonen 2021).

Research specifically on the saproxylic species, which live on damaged or decaying wood in old broadleaved trees, has not been conducted extensively on golf courses in any of the Nordic countries. However, findings from studies conducted in city parks and estate parks can be applied to golf courses where such tree species are present. There are 17 golf courses known to have old park trees, which accounts for 8% of the golf courses (Table 2). It is likely that park trees have been planted on other golf courses as well. However, since most golf courses were established after the early 1990s, the planted trees are still young and have not had enough time to develop microhabitats. The most valuable old trees for biodiversity are found on golf courses that include old estate parks, tree alleys, or similar cultural environments. Old park trees may also occur as individual trees or groups of trees in the forests of golf courses.

For saproxylic species, a particularly important microhabitat is hollow trees and the decomposing wood dust and litter that accumulates at the bottom of these hollows, forming "mulm". In a Swedish study, less than 1% of oak trees that were at most a hundred years old had hollows, half of the oak trees aged between 200 and 300 years were hollow, and all oak trees over 400 years old were hollow (Ranius et al. 2009). In the case of maples and common limes *(Tilia × vulgaris)*, hollows can develop in trees less than 100 years old. In a study of park trees in Helsinki, it was found that approximately 6% of the measured broadleaved trees with a minimum diameter at breast height of 30 centimetres had hollow trunks, and additionally, about 9% of the trees had smaller hollows in their trunks (Peuhu and Siitonen 2011). The likelihood of a tree becoming hollow was influenced by the tree species, tree diameter, and the openness of the environment. Hollows were more common in maples and lindens than in oaks, elms, and ashes, and in larger trees compared to thinner ones (Kymäläinen 2011). They were also more common in trees growing in open areas than in those growing in shade.

Hollows in deciduous trees and the decay within the tree trunks are caused by heartwood-decaying fungi. The heartwood in the tree trunk is composed of dead cells, which heart-wood-decaying fungi typically colonize through branch tears or other trunk injuries. Most broadleaved trees share a similar fungal community responsible for decay, but oak, in particular, have their own set of fungi (Niemelä et al. 2012, Niemelä 2016). For oaks, sulfur polypore *(Laetiporus sulphureus)* is typically responsible for heartwood decay. In elms and ashes, a common species is dryad's saddle *(Polyporus squamosus)*, which can also grow on linden and maple. Hollow common lindens are primarily decayed by artist's bracket fungus *(Ganoderma lipsiense)*, which can occur on many other deciduous tree species as well. On maple trees, mossy maple polypore *(Oxyporus populinus)* and northern tooth fungus *(Climacodon septentrionalis)* are common decaying fungi, with their spores typically entering the wood through branch crack on the trunk. In parks with broadleaved trees, there are also rare and endangered decaying fungi, such as the threatened geasy bracket *(Auranti-porus fissilis)*, primarily found on elms, and the threatened *Spongipellis spumeus*, which grows on maples, elms, and ashes. Exclusive to old oaks are the threatened *Phellinus robustus* and the dark red, tongue-like, and slimy beefsteak fungus *(Fistulina hepatica)*.

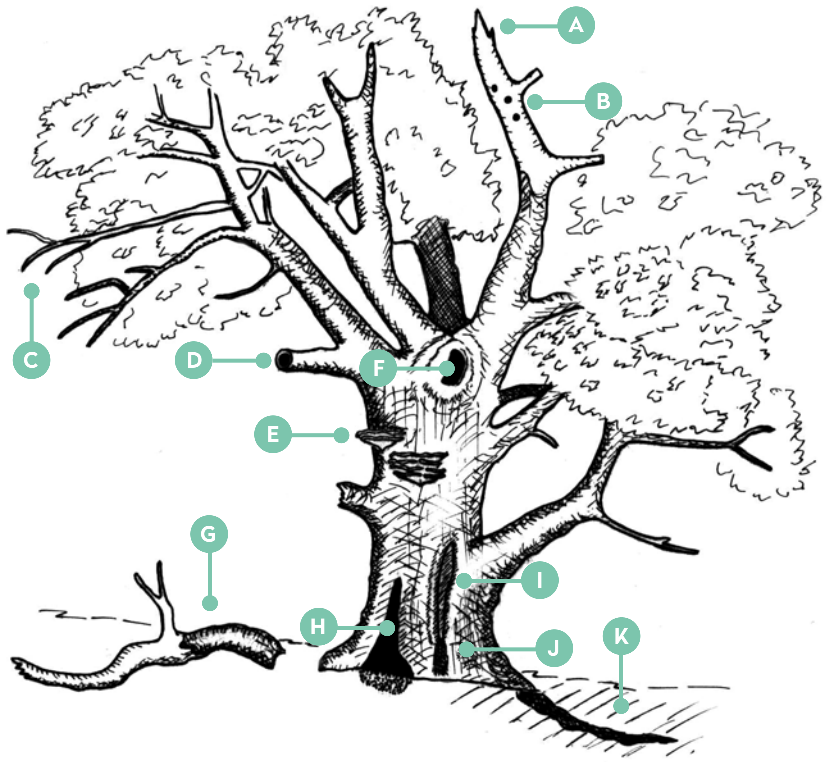

Figure 8.
Microhabitats in an old oak tree (Siitonen 2012). Various microhabitats host specialised saproxylic species.

A = Dead limb
B = Woodpecker hole
C = Dead branches
D = Branch cavity
E = Sulphur polypore fruiting bodies
F = Trunk cavity
G = Large fallen branch
H = Base cavity,
I = Barkless knob,
J = Resin flow
K = Dead roots underground

Within these cavities created by decay fungi and other heartwood-decaying organisms, a diverse community of invertebrate species thrives (Siitonen 2012). Some of the most abundant groups of species within these cavities include beetles, dipterans (flies), and hymenopterans (wasps and ants). In a study focused on beetles living in hollow trees in Helsinki and Vantaa's mansion parks, a total of 131 beetle species associated with decaying wood were found in three parks and fifteen trees (Peuhu et al. 2019). This included several rare species, such as the beetle species previously classified as near-threatened *Eucnemis zaitzevi*, *Quedius microps*, and *Cryptophagus fuscicornis*, as well as the near-threatened *Eledona agricola*. All the species found in Helsinki's mansion parks are likely to occur in the hollow trees of golf courses as well.

In Finland, the most diverse community of species within hollow trees, including many endangered species, is found in Turku's Ruissalo (Karhu et al. 1995). Among the endangered invertebrates associated with hollow oaks, you can find the vulnerable hermit beetle *(Osmoderma barnabita)*, strictly protected under the EU Habitats Directive, which is only found in Ruissalo and the surrounding oak forests (Landvik et al. 2016). There are also near-threatened species like *Mycetochara humeralis* and *Pentaphyllus testaceus*. The hermit beetle has also been found in the trees on the Aura Golf course (Landvik 2000, Laji.fi 2023), where, in principle, all other endangered species found in Ruissalo could also occur.

Hollow trees are often more suitable for saproxylic beetle species in open environments compared to closed forests (Ranius and Jansson 2000, Koch Widenberg et al. 2012), likely because the temperature inside the tree cavities is higher in open environments, allowing for faster larval development.

Several cavity-nesting birds and various bat species use the hollows in old trees for nesting and roosting. Among cavity-nesting birds, species like the common starling, stock dove, tawny owl, and the near threatened Eurasian wryneck have regularly nested on Helsinki Tali golf course (Talin luontoikkuna 2023). The common starling also occurs in the nesting bird species of the Master Golf course in Bodom Lake, Espoo (Kiema 2022). All of these cavity-nesting species prefer open, sparsely wooded deciduous forests with open areas, making golf courses and their surrounding environments suitable habitats for them.

In Finland, there are 13 species of bats (Laji.fi 2023), and in Ruissalo, nine of these species have been observed (Ruissaloinfo 2023). Most bat species in Finland also prefer habitats like old deciduous forests with open areas or those adjacent to water bodies. Bats have been surveyed on golf courses in Hirsala, where the Daubenton's bat and northern bat were observed (Kylliäinen 2019). It can be assumed that golf courses and their surroundings are potentially suitable habitats for most of our bat species.

Old park trees support a diverse and unique lichen community on their trunks. This community includes many species that are rare and more typical of southern distribution areas (Vitikainen 2009, Stenroos et al. 2011).

How to enhance biodiversity associated with old park trees

- **Plant park trees in the golf course.**
- **Allow old park trees to continue growing even with decay or fungi.** However, regularly inspect these trees and take necessary safety measures to ensure the safety of golf course users.
- **Create open areas around trees:** Diversity of beetles associated to old park trees increases when there are open areas around them.

Carbon sequestration.

Golf courses should aim to maintain a carbon balance, where the amount of carbon sequestered or stored on the course equals or exceeds the amount released into the atmosphere.

On golf courses, carbon is sequestered through the process of photosynthesis by vegetation, but it is also released into the atmosphere during maintenance activities, which involve the use of various equipment and chemicals, such as fertilisers (Bartlett and James 2011).

Areas subject to intensive maintenance practices release more carbon into the atmosphere than they can sequester (Bartlett and James 2011, Figure 9). According to an English study, the largest carbon emissions result from mowing grass areas, the use of nitrogen fertilisers, and irrigation (Mark et al. 2011).

The most significant emissions come from intensely managed teeing grounds and greens, whereas fairways and roughs contribute less. A significant portion of a golf course's carbon emissions comes from the use of nitrogen fertilisers. Therefore, special attention should be paid to the maintenance of grass areas (Petrosillo et al. 2019).

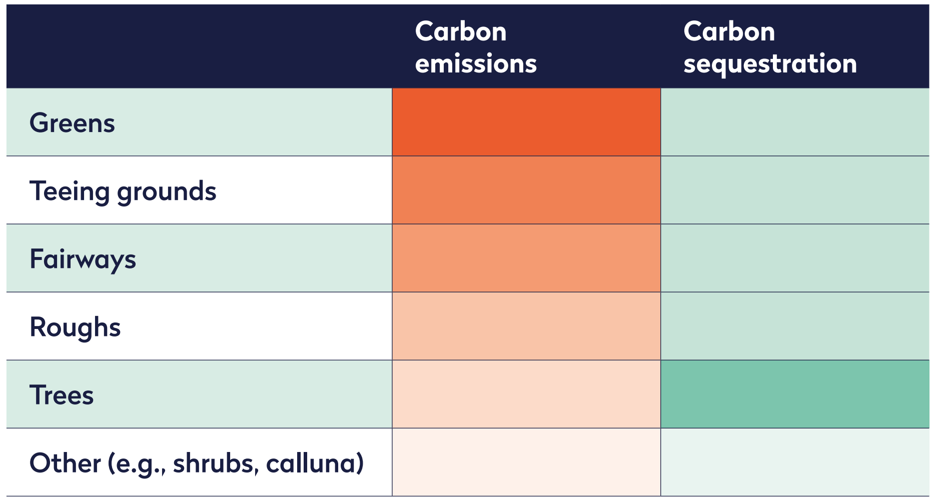

Figure 9. Maintained turf areas on golf courses release more carbon into the atmosphere than less maintained forests and shrublands (darker orange colour indicates higher emissions). In addition to natural soil respiration, carbon dioxide emissions result from turf fertilisation, irrigation, mowing, aeration, and pesticide use. Forests sequester more carbon than well-maintained turf (darker green colour indicates better carbon sequestration). The image is based on data from the publication by Mark et al. (2011).

According to a study conducted in England, the most intensively maintained areas of golf courses have reduced soil-bound carbon (Bartlett et al. 2008). This reduction is likely due to the lower abundance and diversity of soil fungi in the most intensively maintained areas of golf courses (Allan-Perkins et al. 2019). The amount of carbon sequestered by microbes was twice as high on fairways and roughs compared to teeing grounds and greens (Bartlett et al. 2008). Significantly more microbially-bound carbon was found at a depth of 0-75 mm in the soil compared to deeper layers. This soil layer contains abundantly roots and accumulates cut grass clippings, which provide a food source for microbes. Consequently, microbial populations are higher in this layer, which in turn supports other organisms. According to a study conducted in urban woodlands in Finland, the diversity of soil bacterial species increased with an increase in soil carbon content (Hui et al. 2017b).

Trees sequester significantly more carbon than maintained turf areas and release less carbon into the atmosphere (Bartlett and James 2011). The amount of wooded area on a golf course plays a crucial role in determining the overall carbon emissions of the golf course (Mark et al. 2011). The more trees a golf course has, the smaller its overall carbon emissions tend to be.

Factors such as the size, shape, and vegetation structure of the golf course (including the proportion of trees and less maintained areas compared to greens and teeing grounds) significantly influence whether more carbon is sequestered on the golf course than is released into the atmosphere (Bartlett and James 2011).

How to increase carbon sequestration on a golf course

- **Reduce maintenance of turf areas where possible.**
- **Decrease the use of fertilisers**, especially nitrogen-based fertilisers, which can be a significant source of carbon emissions.
- **Leave grass clippings on the ground.**
- **Promote the growth of trees** and allow forests to flourish.
- **Plant more trees.**
- **Increase the area of non-turf areas.** These areas have the potential to enhance carbon sequestration.

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