Golf Landscapes: Biodiversity and multifunctionality of golf landscapes

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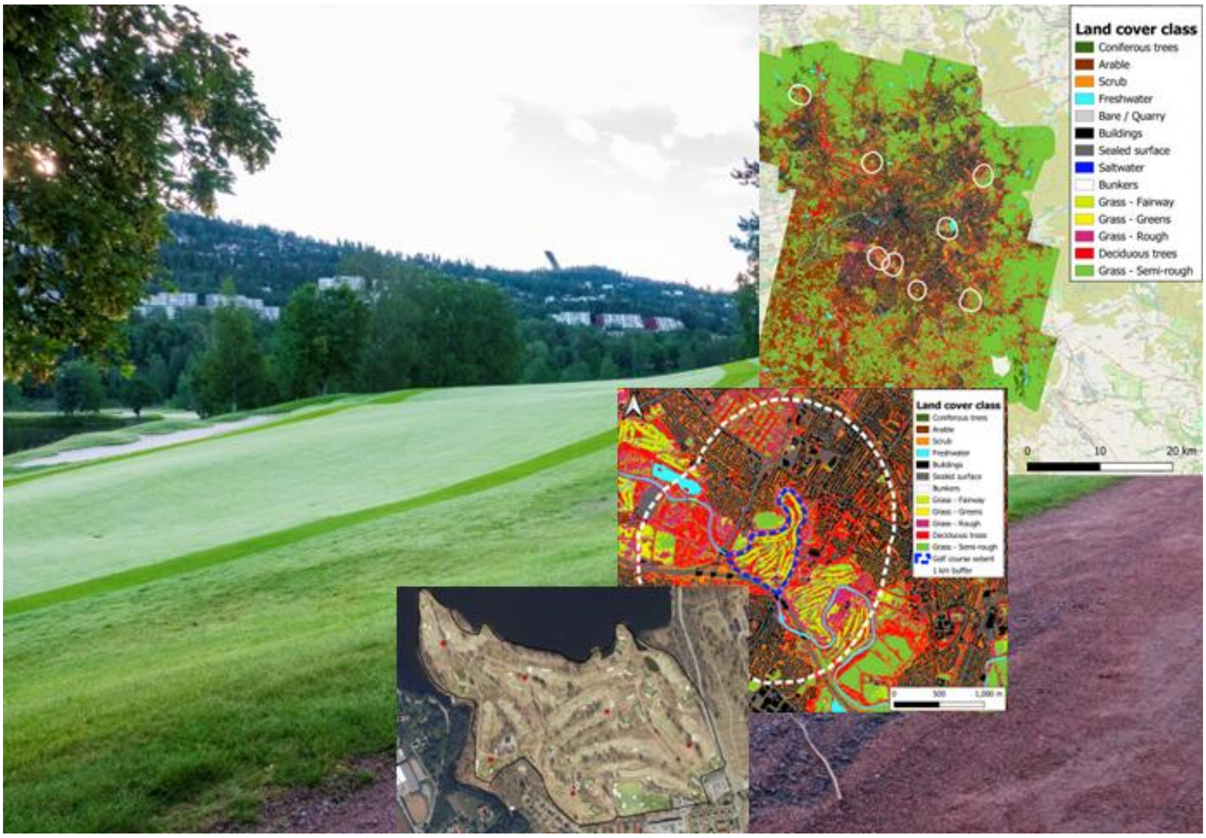


1 CONCLUSIONS ON BENEFITS AND ADVICE FOR THE GOLF AND TURFGRASS SECTOR

We documented that the regional context is important when it comes to how golf course design and management can be adjusted to the landscape. This means that there are some general recommendations that can be followed, but the key message is to include methods to analyse characteristics of the local landscapes and to adjust the design accordingly.

Our approach can be refined to methods that consultancies can include in their solutions for design and redesign of golf courses, including the use of satellite data and habitat indicators to describe landscape composition. Such implementation would improve biodiversity support on individual courses and strengthen the impact of on-course measures to provide habitats and resources for different organisms. Our results also support the importance of initiatives to include and maintain diverse habitats on golf courses.

2 INTRODUCTION

Golf courses provide numerous benefits and services to local communities (Colding & Folke 2009). There is also accumulating evidence for their positive effects on biodiversity providing several habitats and ecosystem functions (Nooten et al. 2018). However, the importance of golf courses for biodiversity will depend on how organisms move and use resources over their lifetime, interact with other species, and contribute to a self-sustaining nature. These processes are best understood in a wider landscape, notably how actions taken to support biodiversity on the golf course contribute resources and opportunities for the organisms also in the surroundings, and correspondingly how the same actions can benefit from processes and qualities in the surrounding landscape. The link between biodiversity and multifunctionality of golf courses is strong, so facilitating biodiversity also has a potential to improve other functions and services provided by the golf course, including not at least the golfing experience. Improving golf course contributions to biodiversity and functions in a wider landscape and in a conservation perspective, may also strengthen support for golf courses in society.

Modern urban and peri-urban landscapes show a high degree of spatial fragmentation causing increased edge effects and reduced areas of natural core habitats. Here the restoration of habitats as well as of structural and functional connectivity is central to maintain ecological integrity. Most golf course have been established in simplified or degraded landscapes resulting from intensified agriculture and forestry. Here golf courses contribute to biodiversity and ecological functions as corridors for dispersal and reproduction habitats like ponds for amphibians and insects, soil and dead wood for insects, trees and shrubs as nesting places for birds. In addition, specific resources can be included in golf course design such as wildflowers in roughs, shrubs and trees along edges that are providing pollen and nectar resources for pollinating insects, host plants for herbivorous insects etc. To include such solutions in the design and management of a course is feasible, and there are many good examples of how to do it (ref to sterf handbook). However, how to design and manage solutions that also contribute to biodiversity and multifunctionality in the landscape is more challenging. The impact will depend on the land use and composition of the surroundings determining the types of biotopes and species found there.

While there have been numerous studies on the effects of landscape structure on biodiversity and ecological functions (for a review, see Walz 2011), few of these have considered the effects of golf course. There has also been a general failure to transfer the existing scientific knowledge in landscape ecology to society in ways that could contribute to golf course design and management (Nassauer & Opdam 2008). A review by Petrosillo et al. (2019) called for more studies on the effects of golf course on ecological functioning, considering both landscape composition and spatial configuration. There is a need for more detailed knowledge of the landscape-ecological processes in golf course, the response of certain ecological functions to modified golf course design, and how golf course landscapes can be arranged to promote biodiversity and ecological functions. Simple methods are needed to optimise the contribution of golf course to ecological functions and landscape ecological characteristics, and to make these methods accessible to golf course managers.

The Golf Landscapes project aimed to understand how characteristics of the surrounding landscape and the course itself impact the observed biodiversity on courses. Further, the potential to identify approaches to assess and document existing qualities and biodiversity potential and to prioritise approaches to develop the golf course potential will be explored. Specific questions we addressed were; are there characteristics of the surrounding landscape that affects the biodiversity support of golf courses?; how unique are the habitat contributions of golf courses compared to the surrounding landscape?; how is species richness related to habitat richness and other course landscape metrics?; what are the relationships between course size and the richness of species and habitats?; and are there general patterns across regions.

3 WORKSHOP – LANDSCAPE INTEGRATION IN GOLF COURSE DESIGN AND MANAGEMENT

With the intention to increase relevance and precision of project output we ran a workshop with golf course designers to gain a better understanding of how landscape perspectives are addressed in golf course planning, (re)design and management including motivations, limitations, and bottlenecks.

Participants: Achim Reinmuth (SRG), Caspar Grauballe (ByCaspar), Rowan Rumball (Former-STRI), Edwin Roald (Eureka Golf), Maria Strandberg (STERF), Johannes Kollmann (TUM), Miriam Wiesmeier (TUM), Tommy Lennartsson (SLU), Christopher Marston (UKCEH), Carl Frisk (NIBIO), and Hans Martin Hanslin (NIBIO)

Motivation for biodiversity actions: The consensus from the participants was that the key motivation for biodiversity actions on golf courses was external communication with respect to permits, policy and legislation rather than a genuine interest of the golf course management and the investors. Thus, a core element of improved biodiversity is image building, This said, there are many involved individuals, such as managers, landscape architects and green keepers with a genuine interest to promote biodiversity friendly approaches in the golf industry.

Obstacles and bottlenecks: The participants identified three main obstacles to further biodiversity improvements: lack of long-term commitment, lack of interest and knowledge from the players and redesigns lacking in scale and scope. While there are many short-term projects attempting to create biodiversity friendly solutions, most fail to enact long-term change and benefits. The gradual replacement of motivation, management, policies, players and personnel further contributes to the lack of continuation, leading to the loss of the fragile red thread. The lack of interest and knowledge from players is another major issue, as there is little organic grassroot support to encourage positive change, as such positive change is not necessarily maintained due to lack of positive response and feedback from players. Lastly, redesigns are primarily small-scale element-specific and concern golf-features and playability rather than biodiversity, as redesigns are mostly monetarily encouraged to enhance playability and player experience, with large scale redesigns being rare. Another comment reflected the complicated issue of combing near-natural landscapes of high biodiversity with the formalized rules and highly managed systems of the golf sport.

Status of the landscape perspective: The landscape perspective is being considered in the golf industry, but primarily from the lens of the players' experience. The play needs to be special and emotionally enticing, as such the beauty of the background is mostly considered to blend surrounding areas and enhance the playability of the course and the incorporation of golf features. In some cases, special features might be incorporated into the landscapes to enhance the heterogeneity of the landscape or specific habitats, such as specific types of heathlands, or certain tree species for specific insect interactions. Furthermore, golf courses in heavily urbanised areas likely play a significant role in the local landscape quality, due to lack of other large continuous green features. This is not, however, an intentional choice or action by golf managers or courses.

Approaches for an integration of biodiversity support in golf course design and management: Two main aspects of future improvement of biodiversity support were discussed, i.e. knowledge exchange and long-term standards from regional municipalities. The first point was that knowledge exchange is required at multiple levels, primarily facilitated towards players. Understanding of both general biodiversity benefits and individual species knowledge is likely to encourage genuine interest and engagement in holding golf course management accountable for improving biodiversity conditions of their courses. Emphasis would be on training players as biodiversity ambassadors. A fine line is likely present here, as players are on courses to play, not to be force-fed what can be perceived as biodiversity and policy propaganda. However, knowledge dissemination is also required to inform investors and landscape architects and managers. The message should be that integrated biodiversity strategies are needed for the sport and courses to remain relevant, as positive changes in biodiversity are likely to remain societally relevant. The second point was that regional municipalities, the landlords of all golf course inferred land, should enact, enforce and guide long-term biodiversity policies for these areas. This would force golf course managers to develop long-term biodiversity plans and strategies and be held accountable on improving conditions on their courses. Another positive point was emphasized, that upcoming younger landscape architectures have a general better understanding of the importance of biodiversity support and how to address sustainability, leading to the suggestion of a gradual improvement with replacement of staff and management over time. A general increase in understanding of the landscape-biodiversity connection is required to facilitate a more holistic approach to responsibly manage and improve the resources golf managers, courses and organizations possess.

4 APPROACH

Our approach was to conduct fieldwork to obtain species occurrence data of birds and vegetation and relate these to qualities of the golf courses themselves and their surrounding landscape based on landscape metrics describing the spatial patterns of the distribution of different land cover types. To get a good coverage of course designs and landscape contexts eight courses were selected in each of the regions of Copenhagen, Manchester, Munich, Stockholm and Oslo (Table 1) based on size and landscape compositions and invitations. The national golf unions contributed to find suitable courses. Courses were mainly 18 holes, with some 9- and 27-hole courses. Courses were also selected in Copenhagen where we also conducted land cover mapping. Due to uncertainty about species data quality, however, these were excluded from further analyses. Species richness is a simplified indicator of biodiversity but given the constraints in this project that was the approach available. The use of two species groups compensates for some of this simplification.

Table 1. Overview of regions and golf courses included in the study

Copenhagen	Manchester	Munich	Oslo	Stockholm
Albertslund	Cheadle	Aschheim	Ballerud	Arlandastad
Dragør	Denton	Dachau	Bogstad	Bromma
Furesø	Dunscar	Eichenried	Grønmo	Kyssinge
Hjortespring	Hazel Grove	Feldafing	Groruddalen	Österåkers
Køge	Northenden	Olching	Hauger	Sigtuna
Marbæk	Oldham	Strasslach	Krokhol	Söderby
Værebro	Sale	Thalkirchen	Lommedalen	Vassunda
Værløse	Whitefield	Wörthsee	Oppegård	Viksjö

4.1 GIS work

Habitat classification

Habitat types and their patterns across golf courses and surrounding areas were mapped using multi-source high-resolution satellite data available cost-free via the Copernicus programme combined with LiDAR-derived canopy height model, and field survey datasets. Satellite remote sensing is a powerful tool that is well established for habitat mapping, providing a comprehensive and efficient way to assess and monitor ecosystems across large geographic areas. This technology involves the use of Earth-observation satellites equipped with multispectral sensors that capture spectral information across different parts of the electromagnetic spectrum, enabling characterisation of different habitat types and features across the study areas. Here, 2m spatial resolution satellite imagery capable of identifying features as small as individual trees and bushes was used to map habitat distributions at high levels of detail using a random forest classifier in the cloud computing platform Google Earth Engine. Habitat classifications were checked against classifications based on landscape pictures from all positions of bird observations.

Landscape analysis

The habitat maps were used to quantify landscape composition and configuration for the areas of the golf course extent and a 1km buffer surrounding the golf course extent (excluding the golf course), using the Fragstats software package. This estimated multiple landscape metrics including patch size profiles, patch richness, edge density, diversity and evenness indices, with analysis focusing on the Simpson's diversity index and the modified Simpson's evenness index metrics as these are less sensitive to data outliers. Additionally, data on proportion coverage of different land cover types were estimated for each course and associated 1km buffer. This was done by aggregating two forested classes (deciduous and coniferous), two water classes (fresh and salt), five open classes (fairway, green, rough, semi-rough and arable), two urbanisation classes (buildings and sealed surfaces) and two other classes (bunkers and bare). The land cover proportions of the golf course and associated 1km buffer were analysed using Jaccards beta diversity, to identify the degree of overlap in land cover composition between the course and surrounding 1km buffer, and whether the golf course exhibits different land cover compositions from what is typically found in the surrounding 1km buffers. As the proportions of land use types are dependent (sum to 100%), we attempted to simplify the land use categories for use in the statistical analyses by k-means clustering with the aim of creating categories without single observations. The clustering was done per region, to allow for regional variation in typical distributions of land cover types (e.g., on average Oslo is more forested while Manchester is more urban). This resulted in two categories for the courses (more open and more forested) and two categories for the buffer (more and less urbanised). We also used the same method to cluster the size of the golf course – resulting in two categories (smaller and larger courses). Averaged land use data of these clusters are shown in Figure 5.

Due to the imbalance in cluster combinations in buffer and course composition across regions (Table 2), we could not fully exploit the power of the study design beyond the general results. Hence, new clustering approaches as described above were used.

Table 2. Summary of the different combinations of courses allocated to each golf course cluster (Open+ or Forest+) and buffer cluster (Urbanised- or Urbanised+).

	Copenhagen		Manchester		Munich		Oslo		Stockholm	
	U+	U-	U+	U-	U+	U-	U+	U-	U+	U-
Open+	1	4	0	2	2	5	2	4	2	3
Forest+	2	1	5	1	1	0	2	0	1	2

4.2 Drone work to evaluate habitat classifications

Whereas satellite Earth Observation data was used to perform the land cover mapping across all golf courses due to its broad-scale and consistent monitoring capabilities, drone-based data collection also has value in characterising land cover and habitats on golf courses at higher cm-level resolutions. This has advantages in terms of higher levels of spatial detail that can be observed in drone data, greater flexibility in when drone surveys are conducted, and reduced issues of cloud cover as drone fly under cloud whereas optical satellite imagery will be obscured by cloud cover. Disadvantages of drone surveys include the requirement for specialist operators for safety, being unable to operate drones in poor weather conditions, legal and practical restrictions on flying in some areas, and much smaller areas that can be surveyed in comparison to satellite imagery. These limitations meant that for this project satellite data was better suited for the broad-scale land cover analysis, however drone surveys were also conducted at Dunscar Golf Club in the Manchester study area as a case study for comparison. This involved drone survey flights collecting LiDAR with simultaneous aerial photography, and also multispectral optical imagery. This drone imagery served as a source of validation data for the satellite-based land cover classifications alongside the field data collection and also serves as a demonstrator for how very high-resolution drone data can serve as a permanent record and benchmark of golf course state and condition against which modification of golf course design or management practice can be compared.

4.3 Vegetation surveys

Vascular plant species richness was assessed by surveying all golf course by standardized transect walks (Tobisch et al. 2023a). To account for differences in golf course total area we used a value of 2.5 min/ha. Survey area was the entire golf course, while surroundings were not considered. Further the transect walks were area-representative as we partitioning the survey time by land cover class to obtain information on floral diversity for each individual type. The land cover classifications were calculated beforehand based on satellite images and the transects predefined (Table 2). A cut off value of 3% for land use types with low proportions was applied. Waterbodies and sealed surfaces/buildings were not surveyed, since they are not expected to add to (aboveground) plant biodiversity in a relevant way. Ornamental plantings were disregarded as well. Fieldwork methods were calibrated during a join inventory of a few selected courses in Munich early May 2024where all field personnel participated.

4.4 Breeding bird surveys

Breeding bird surveys were conducted in the period from early May to mid-June, between 04:00 and 09:00 by skilled ornithologists following a common protocol. A set of recording positions were predefined per course, and each position was surveyed for exactly five minutes. This should provide data comparable across courses and data that also is comparable to other national bird surveys. For each position, the number of pairs of each species that are seen or heard was recorded. A pair is, for example, a male heard or seen, a single female observed, a pair observed, a brood observed, or a nest of the year. The observations were divided into two categories: 1. within or outside a circle with a 50 m radius from the registration position. Field work was not carried out on days with heavy precipitation or strong wind.

4.5 Species analyses

Species richness was summed from species occurrences. Plant and bird species richness were processed and analysed in the same way. Raw species richness measurements were unsuitable for direct analysis due to the time-dependency from the area-specific observation method, as larger golf courses would by default have higher species numbers. Therefore, species density was calculated by dividing richness with golf course area. To identify how species density varies depending on land cover clusters and land cover diversity two linear mixed models (LMER) were created, one for each organism group. The models contained four predictor variables: the golf course clusters (more open and more forested), buffer clusters (more and less urbanised) and golf course and buffer SImpsons Diversity Index (SIDI). Region (n=4) and the size clusters (Smaller and Larger golf courses) were used as random variables, as these are likely to influence the species density. ANOVA and Tukey post-hoc test were used to quantify the cluster differences. Species richness and species density were modelled in simple linear regressions to identify the relationship to golf course size and the golf course size clusters, and how these might vary depending on region. Species richness and density were further modelled with the beta diversity between the golf course and the buffer, to identify if a more diverse difference between the two would impact species metrics on the course. Finally, species density was modelled with golf course patch richness density in the same LMER setup as mentioned above, to identify if courses with higher density of unique patches resulted in higher species diversity, generalized again over region and size clusters.

The additional data on bird abundance allowed for a combined analysis of occurrence and abundance. From these data rarefaction curves were created, which can show if the entire species pool is likely to have been sampled or not, and if some golf courses or regions are likely to be richer than others based on a fixed sample size. The species occurrence data was also used to quantify the number of red-listed and non-native species for both the organism groups on each golf course. Country-specific red-lists and non-native lists were collected from the respective governmental organisation and interest groups. For Sweden and Norway, the non-native species lists are further subdivided in categories (similar to the red-list) based on negative ecological effects and invasion potential, ranging from no known risk (NK) to severe impact (SE).

5 RESULTS AND DISCUSSION

5.1 Landscape metrics

The size of each unit of a given habitat type but also their shape and distances between units of the same habitat type are important for how many species they can support. In these analyses we call these units patches. The transition zones (edges) between habitat types are also known to very be important for biodiversity. There were some differences among regions, but differences between courses and the surrounding buffer were consistent across regions. Some metrics were however heavily affected by a few courses with deviating patterns. Overall, there were small differences in mean patch size and edge density between courses and buffers, but a considerably higher variation in patch size and a slightly higher patch richness density (more habitat types per area) in the buffer. We also found a slightly higher distance to the nearest neighbouring patch of the same habitat type in buffer. Edge density did not differ much between course and buffer, with a few exceptions. Simpson's diversity index was also similar across buffers and courses, except for two low scoring courses in Oslo and Stockholm with the buffer scoring higher in most cases (Figure 1). For both the courses and buffers there was an even distribution of area among patch types (Simpson's Evenness Index around 0.8), so the landscape composition was comparable.

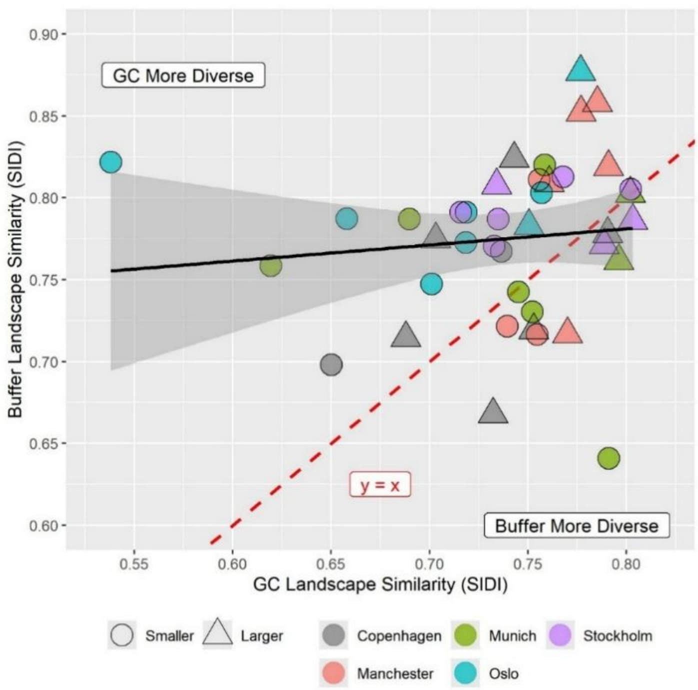


Figure 1. Simpson's patch diversity index plotted for golf courses vs. their buffers. The stippled red line shows the 1:1 relationship.

5.2 The importance of golf course area and patches

In field surveys like this, responses scale with area, as more species are observed the larger area that is surveyed. These increases are caused by the generally observed species-area relationship where the number of species increases with the total area of a habitat but also by an increasing habitat richness on larger courses (Figure 2). To correct for this area effect, we used density estimates as responses in our analyses. Even the smallest golf courses (0.1 km^2) are expected to contain diverse species communities, containing on average 50 plant species and 23 bird species. As courses get larger this substantially elevates the species communities, with an increase of 0.5 km^2 increases the average richness to 134 plant species and 38 bird species, increases of 170% and 64% respectively. As courses get even bigger the species diversity further increases, albeit by not as much. Patch density had a significant positive relationship with plant and bird species density, with higher density of unique patches on the golf course allowed for higher species density (**Figure 3**). This effect was generalized for all four regions and two size classes. The Simpson diversity index (SIDI) showed a less clear but similar pattern where the more diverse golf course landscapes had a higher species density (**Figure 3**). SIDI is a more complex estimate of diversity where more weight is given to the common patch types, while patch richness just counts the unique patch types independent of their sizes and occurrences.

5.3 Habitat classifications

We observed some general differences in habitat composition on course between regions (Figure 4). There was a higher proportion of rough and semi-rough in Oslo and Stockholm (55-60%) than Manchester and Munich (around 40%). The sum of fairways and greens was around 30%, except in Stockholm where it was only 19%. There were also considerably more

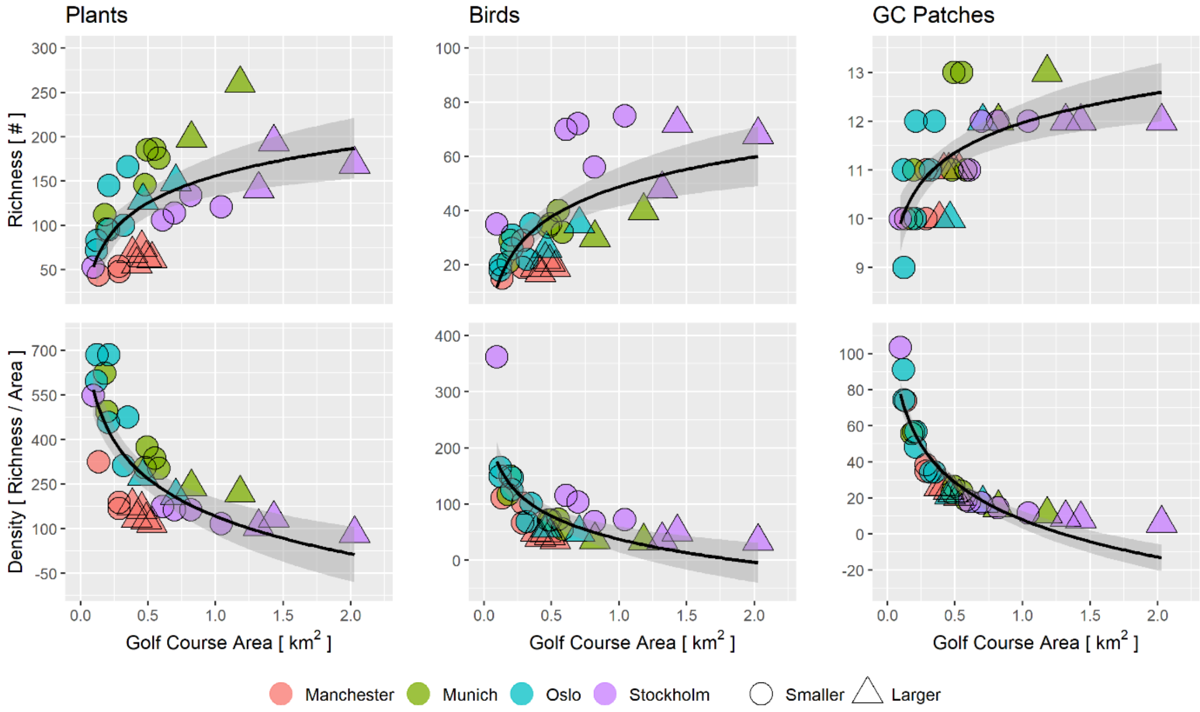
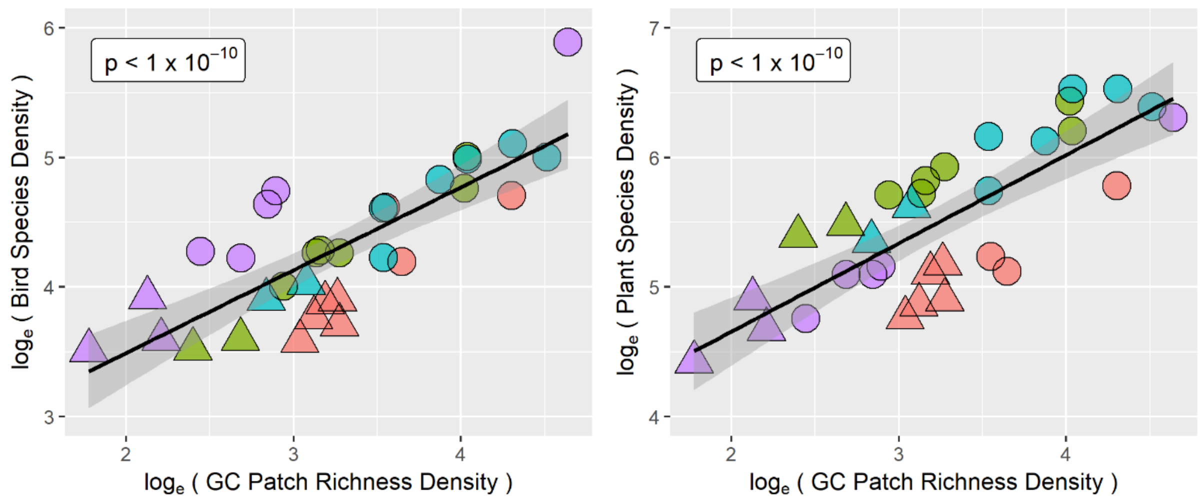


Figure 2. The relationships between golf course size and the richness and richness density of plant and bird species and habitat patches.



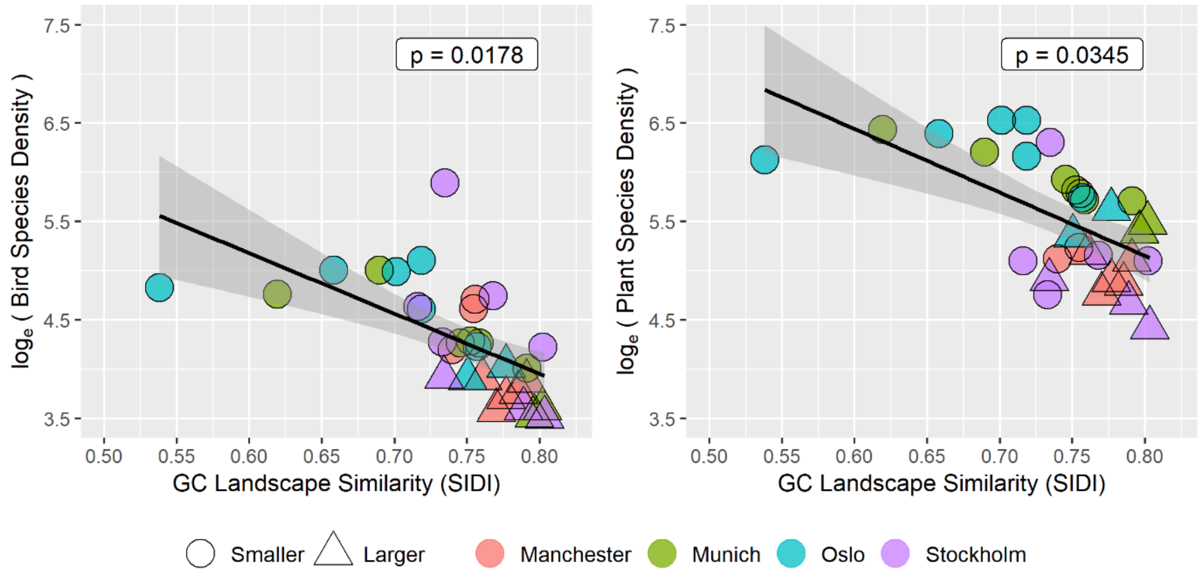
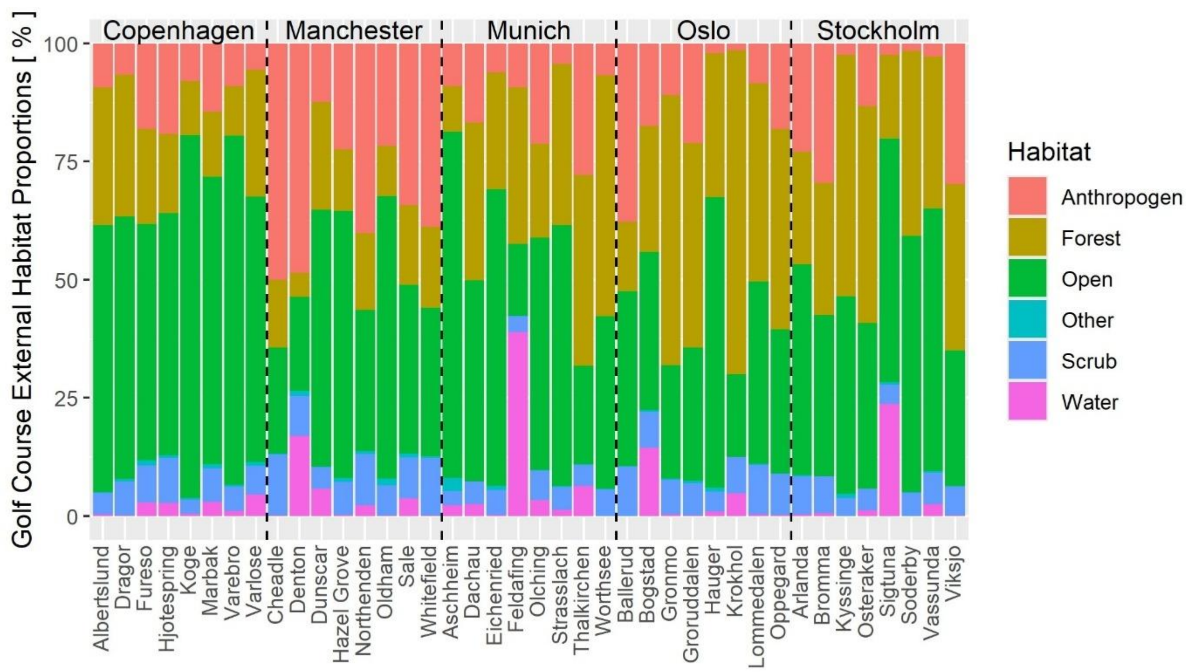


Figure 3. The relationships between bird and plant species richness density and golf course habitat patch richness density (above) and golf course landscape dissimilarity (below) across regions and course sizes. For SIDI, lower numbers indicate a more diverse landscape.

deciduous trees on courses in Munich and Manchester (20-25%) than in Oslo (7%) and Stockholm (9%). Stockholm had on average also around 5 % coniferous trees. There were a few courses standing out such as Thalkirchen in Munich with 55%, Hazel grove in Manchester with 30%, and Kyssinge in Sweden with 26% tree cover. To get a dataset suitable for analysis, these habitat types were grouped and courses clustered on these new habitat and land-use groups.



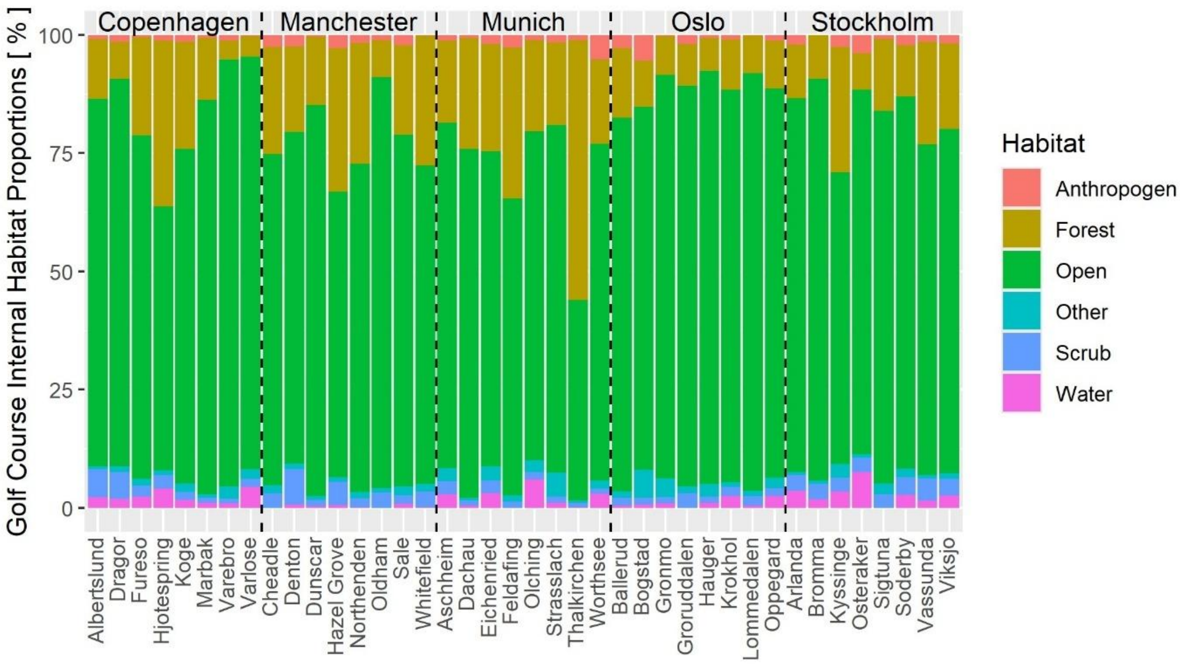


Figure 4. Proportions (%) of the different habitats and land uses classified for the courses (internal) and surrounding landscapes (external buffers) of each region.

Clustering of land cover classes resulted in two types of golf courses – one more open and one more forested and two types of buffers – one more and one less urbanised (Figure 5). In general, there were larger differences between the buffer clusters than between the golf course clusters, likely due to golf courses are more restrictive in land cover proportions due to the playable area and landscape elements, while the buffer depends on natural landscape variation. The Jaccard beta diversity revealed that golf courses contribute unique elements to the surrounding landscape, being on average 33% different in land cover distributions, ranging from 19 to 57% different. However, we did not see any clear relationship between beta diversity of the land cover difference and species metrics on the golf courses. Regional differences in both the golf course and buffer clusters were apparent. About 60% of courses were more open and 40% more forested, while the split in the buffer between more and less urbanised were more similar (almost 50/50 split). In Munich most golf courses were more open, Oslo courses were more similar while clear differences between Stockholm and Manchester courses could be observed – some more open and some more forested. For the buffer a large difference was visible (8% vs 28% urbanised cover), with the Manchester buffers being on average more urbanised than in the other regions.

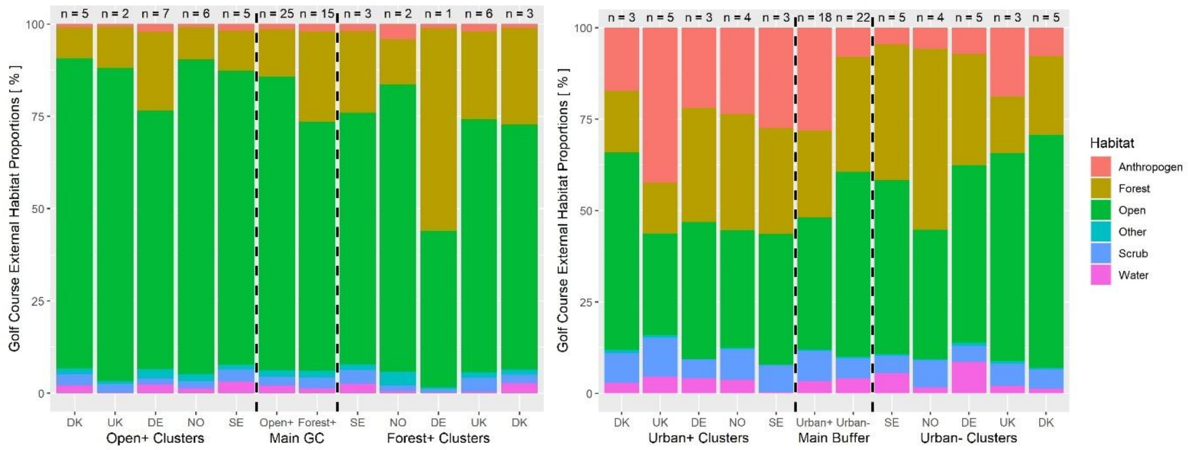


Figure 5. Clusters of golf course (left) and buffer (right) landscape types based on the proportions of the six major habitat types identified. The two central bars per figure shows the average per cluster.

5.4 Vegetation surveys

Summary vegetation data

The golf courses were able to support a wide range of plant species, with large regional differences. Manchester averaged 59 species (ranging from 44 to 75), Munich 170 (96 to 260), Oslo 117 (83 to 166) and Stockholm 129 (53 to 194). These patterns are partially dependent on the golf course areas, as such species density (species richness per km^2) proves as a more reliable indicator for species diversity. Manchester averaged density of 175 (ranging from 129 to 324), Munich 362 (220 to 623), Oslo 462 (211 to 685) and Stockholm 186 (135 to 548) per km^2. Differences between the regions and golf courses are likely partially dependent on the fact that a standard species pool can be expected on a small course, that slowly and gradually increase as golf courses become bigger and add more habitat space and landscape elements suitable for additional species. Habitat richness however, levelled off at intermediate course sizes (Figure 2), meaning that the extra size of the largest courses primarily added more of the same habitats.

The number of red-listed and non-native species varied greatly depending on the region, with red-listed being on average fewer than non-native species. Nine, seven and ten nationally red-listed species were found in Munich, Oslo and Stockholm respectively, with none in Manchester. For non-natives it was different, with 12, 64, 34 and 5 nationally non-native species in Manchester, Munich, Oslo and Stockholm respectively split over all golf courses on each region. A proportion of the red-listed species were trees, remaining species was a combination of species from dry meadows, forest-edges and wetlands. Hence, the conservation support for these species must be tailored to local conditions.

Across courses, areas with deciduous trees and the rough had the most plant species. Semi-rough also had some contribution to the species pool, while scrub areas also contributed in Manchester. As not all golf course habitats were present on all courses or in all regions, we investigated the overlap in species composition between habitats for the rough-semi rough, fairway-semi rough and deciduous forest-semi rough combinations. The number of shared species between habitats was lower than expected and varied between courses and regions. Estimated numbers for an average golf course are shown in Figure 6. A higher number of shared species in rough and semi rough was found in Munich and Stockholm with more additional species in the rough areas in Oslo and Manchester. Fairways had marginal contributions to the species pool, but Manchester had both a higher share of species with the semi rough and more new species in the fairway than in the other regions. Habitats with deciduous trees also contributed considerably to the species pool. The contribution of additional species was high in the deciduous forest areas in Manchester, Munich and Oslo, and in Munich there was also a high number of shared species with the semi rough.

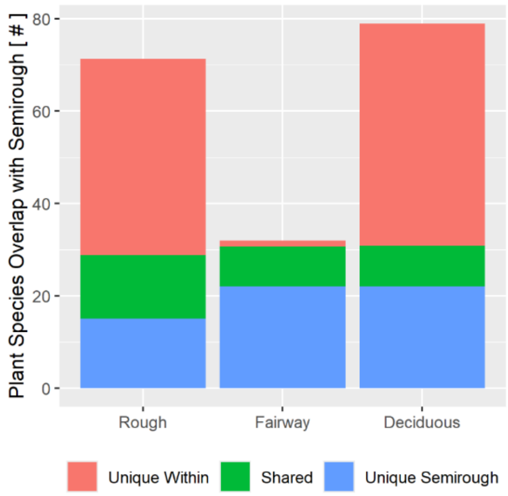


Figure 6. Patterns of shared and unique species occurrences between different habitat combinations. Numbers are averaged across golf course.

The linear mixed-modelling analysis revealed golf courses within the more urbanised buffer cluster had significantly higher diversity of plant species compared to the less urbanised cluster (Figure 7), although with a large variation between courses. This difference was not explained by the slightly higher occurrence of non-natives species in these landscapes alone. Landscape diversity (SIDI) on the golf course were significantly connected to species diversity, with more diverse golf landscapes having higher plant diversity. There was no significant difference between the golf course clusters of more open or more forested land cover, although the more open cluster had higher species diversity than the more forested cluster. There also was no significant effect of landscape diversity in the buffer. Due to including region and golf course size clusters (Smaller and Larger) in the models these results can be generalized for all regions and both small and large golf courses.

The occurrence of natural habitats on golf courses is important for many organisms (e.g. Nooten et al 2009). Our study did not distinguish between original and constructed habitats, but it was likely a combination also within course. Extensively managed systems such as woodland and rough and semi-rough areas hosted a majority of the plant species and even when constructed, may approach a natural-like structure and composition over time.

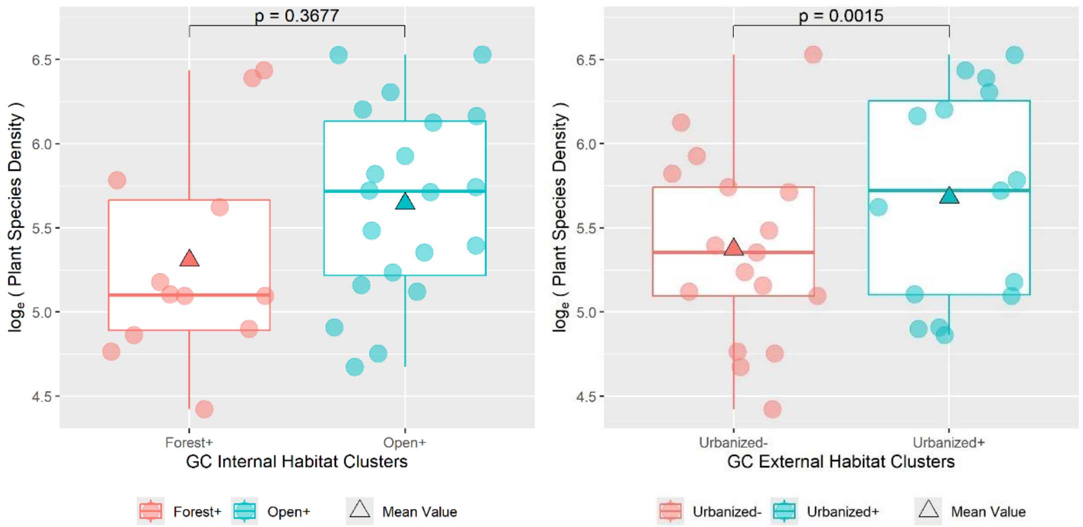


Figure 7. Observed plant species richness on golf courses in the more open and more forested golf course types and with the more urbanised or less urbanised buffers.

5.5 Breeding bird surveys

Summary bird data

A total of 132 bird species showing breeding related behaviour were observed with a total of 116 in Stockholm, 66 in Munich, 56 in Oslo and 42 in Manchester. Only 16 of the species were not found in Stockholm and 12 of these were only found in Munich (Table 2). 28 species (21%) were found in all four regions, while 59 were only found in one region. Rarefaction curves showed that the sampling intensity was sufficient to get reasonable estimates of the number of bird species in Manchester, Oslo and Munich, while more sampling likely would have added a few species to the list in Stockholm.

Table 2. Matrix of overlap in bird species occurrence between regions.

	Stockholm	Munich	Oslo	Manchester
Stockholm	116	53	54	40
Munich	53	66	41	33
Oslo	54	41	56	30
Manchester	40	33	30	42

The species pool included a diverse set of species, but key characteristics of the species were correlated across regions. For habitat preferences, about half of the species pool were forest and woodland species, and between 10 and 15% each for wetland species (including riverine and marine), species of more open areas (grasslands + shrublands) and species associated with urbanised systems. The pool of wetland species was the most variable across regions ranging from 23% in Stockholm to 10% in Manchester. Despite the high proportion of species associated with forest habitats, almost 70 % of the species pool prefer open or semi-open habitats.

Omnivorous species and species feeding on invertebrates accounted for 30-40 % of the pool each, but there are also aquatic predators, granivores, aquatic and terrestrial herbivores, and a few vertivores (owls, falcons and buzzards). A higher proportion of migratory birds (around 45%) and accordingly a lower proportion of sedentary species (35%) were found in Oslo and Stockholm, while the proportion of partially migratory species was similar across regions (around 20%). Migrating species accounted for 24 and 39% of the species pool in Manchester and Munich respectively.

Some threatened bird species (EN, VU and CR red-list categories) were observed with 9 in Stockholm, 6 in Oslo and Manchester and 3 in Munich, but also 1-4 non-natives species were observed per region. Threatened species included mainly a few passerines and wetland birds (waders, ducks, gulls and terns) but also swallows and swifts. As the red-list status differs between countries, there was not much overlap. 19 of the observed species were threatened in at least one of the regions. *Chloris chloris* and *Sturnus vulgaris* were the two species with most overlap, occurring and threatened in three of the four regions while 16 of the species were only threatened in one region. 6 of the threatened species per region only occurred on one golf course, while 8 occurred on five or more courses. Distribution of threatened species was uneven among regions, especially the Swedish courses had a high number of threatened species per course (up to 7), while courses in the other regions had lower numbers (from 0 to 5).

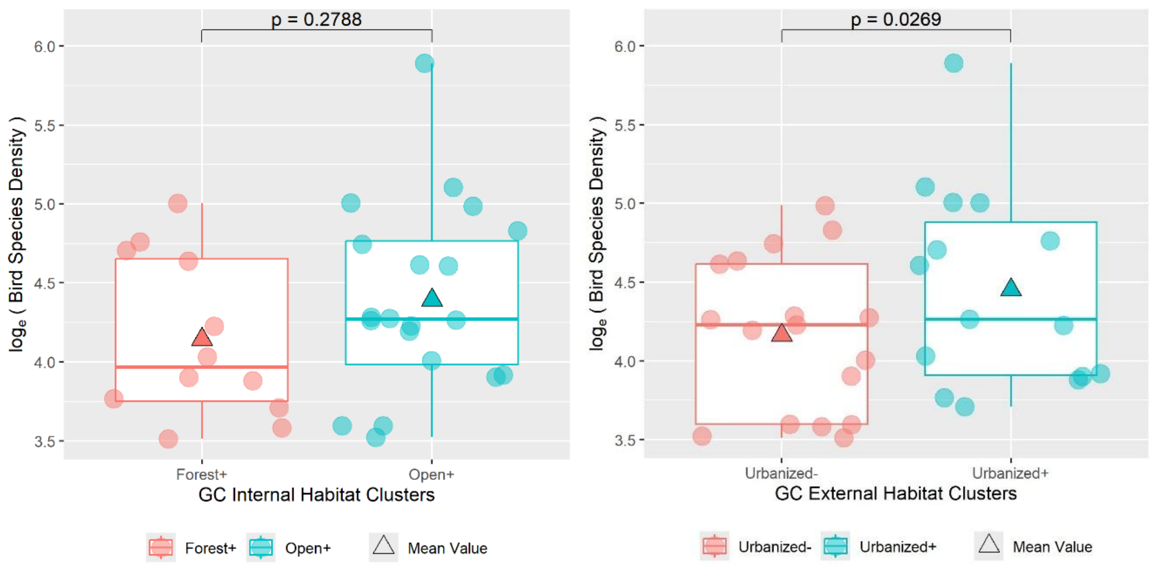


Figure 8. Observed bird species richness on golf courses in the more open and more forested golf course types and with the more urbanised or less urbanised buffers.

The linear mixed-modelling analysis revealed golf courses within the more urbanised buffer cluster had significantly higher diversity of bird species compared to the less urbanised cluster (Figure 8), although also here with a large variation between courses. Landscape diversity (SIDI) on the golf course were significantly connected to species diversity, with more diverse golf landscapes having higher bird diversity. There was no significant difference between the golf course clusters of more open or more forested land cover, although the more open cluster had higher species diversity than the more forested cluster. There also was no significant effect of landscape diversity in the buffer. Due to including region and golf course size clusters (Smaller and Larger) in the models these results can be generalized for all regions and both small and large golf courses.

Plant species richness can potentially be used as a proxy for bird species richness both directly as available resources, but also through the relationship between plants species richness and habitat diversity. Hence a positive relationship is expected. In our analyses we found positive relationships for all regions (Figure 9). Regions followed the same trends, but the Stockholm region had a much higher number of birds species per plant species.

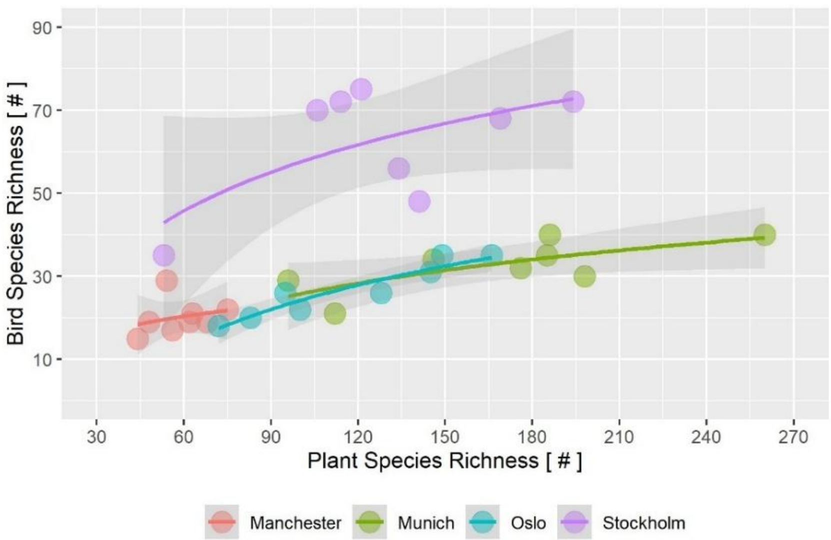


Figure 9. The relationship between observed species richness of birds and plants across the golf courses.

Overall, our study documented the occurrence of a good number of breeding bird species per course, higher than what is usually found in intensive agricultural areas and typical urban parks and green areas. This has also been found in other studies (Ormiston and Cristol 2025). Region and the habitat composition of the course had a strong impact on these numbers also determining the occurrence of species in addition to the common generalists. The surrounding landscape had less effect, although such characteristics has been found to be important in other studies (Porter et al 2005). However, more urbanised landscapes supported a higher bird richness on the courses, confirming that moderately urbanised landscapes may provide more resources than more intensive agricultural or forested landscapes. Further, the golf landscape has a filtering effect where species of open to semi-open habitats are favoured, thus may function as replacement habitats of species from other semi-natural or open system that are lost in the landscape (PanEuropean Common Bird Monitoring Scheme 2025). The importance of water for bird occurrence on courses is well documented in many studies but was not analysed in detail in our study. Species composition however indicated that wetland birds was a highly variable component of the species pool across courses. We do not have information on the breeding success of the species observed, as an indication of the habitat quality. That is an important challenge for further studies and data is lacking worldwide (Cristol and Rodewald 2005, Ormiston and Cristol 2025).

6 CONCLUSIONS

- Species richness of birds and vegetation on golf courses is determined by a combination of landscape characteristics and course configuration as also found earlier (e.g. Hodgkison et al 2007), although the landscape contributions are complex and probably more relevant for birds and other mobile organisms.
- Golf courses provide unique landscape elements that are not found in the surrounding landscape – on average 33%. Such contributions to beta diversity as unique contributions in the landscape have strong effects on the species pool.
- A higher richness of birds and plants are found on courses in urbanised landscapes, and this is not related to a higher occurrence of non-natives species there.
- Habitat richness on the course is associated with a higher species richness of both birds and vegetation, while habitat richness in the surrounding buffer was of less importance.
- Areas with rough and deciduous forests and woodlands are important habitat types for plant and bird species richness, although all major habitat types (except the greens) contribute opportunities for additional species. Deciduous trees contribute more species than coniferous trees, but the coniferous systems have some unique contributions.
- Although larger golf course will host the most species rich communities, even small golf courses can host rich species communities. Larger courses need a stronger focus on increasing habitat diversity to realise their potential for biodiversity support.
- Our approach with species richness of two well studied organism groups points to important relationships with the landscape composition, but a more thorough investigation of other organism groups is recommended to get good data on the potential of golf courses to support biodiversity.

7 RECOMMENDATIONS FOR DESIGN AND MANAGEMENT

- The landscape configuration is not critical for the performance of golf courses as habitats for plants and birds. As higher species richness was found on courses in an urbanised grid, more attention could be paid to improving habitat diversity and quality on courses in other landscapes such as those dominated by forestry and agriculture.
- To establish and maintain habitat richness on the course is important independent of the landscape setting. Increasing the number of unique habitats on the golf course will increase species density, both for plants and birds, but this approach should be based on the occurrence of relevant habitats in the surrounding landscape – both the current composition and the historical landscape. To keep patches of original habitats in design and redesign is important for continuity. It is easier to keep than to reconstruct or restore biodiversity.

- Estimates of habitat richness and SIDI are good candidate indicators for assessment and monitoring of potential biodiversity support. The use of drone data with multispectral camera can be used to refine the partitioning of habitat types. Accordingly, the extent of rough+semi rough and deciduous woodland and forest can be used more directly as indicators of habitats supporting biodiversity. As we used broad categories for the habitat classifications, this can be refined for local conditions to give a better management tool.
- The principle of golf course contributions to landscape beta diversity can guide the restoration or rehabilitation of local habitat types that have become rare or has been lost in the surrounding landscape. This depends on a habitat mapping of the landscape and a feasibility evaluation.
- Given the importance of rough and semi-rough areas for the species pool, it is important to keep and maintain these habitats, even when technological developments such as robot cutters make management easier.

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