Biodiversity of aquatic invertebrates in urban ponds: effects of land use

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ABSTRACT

Urban ponds have the potential to hold large abundance and diversity of aquatic invertebrates, which could maintain an overall high biodiversity in the urban landscape. Little is known about how aquatic systems, such as ponds, are affected by the fast rate of urbanisation caused by an increasing human population together with the expansion of cities. The aim of this study was to investigate how landscape variables affect the abundance of six invertebrate groups. Thirty ponds in Stockholm, Sweden, were studied by sampling aquatic invertebrates of the taxonomic groups: Bivalvia, Gastropoda, Odonata, Trichoptera, Coleoptera and Hemiptera. The percentage of open land, developed land, forest and other water bodies around the ponds were investigated to examine possible correlations with invertebrate abundances. In addition, the relationship between the ponds distance to the city centre and invertebrate abundances were examined. The results indicate that the surrounding landscape has an important effect on the abundance of aquatic invertebrates living in the urban ponds. Odonata abundances showed increasing abundances with percentage of forest cover and decreasing abundances with more developed land. Bivalvia and Trichoptera abundances together with Odonata were found positively correlated with distance to the city centre. No significant results were found for Coleoptera, Hemiptera and Gastropoda. Since the taxonomic groups were affected differently by the landscape variables in the urban area, further investigation on how landscape variables affect the diversity of aquatic invertebrates are needed. Such knowledge would contribute to understand how the landscape variables should be optimised to maintain a high biodiversity in urban ponds.

1.0 INTRODUCTION

1.1 Urbanisation and biodiversity

Today we face an increasing human population density together with expanding cities resulting in a fast rate of urbanisation. Urbanisation, the increase in size and population density of cities, have shown to have a large negative impact on biodiversity (McDonald et al. 2008, McKinney 2008, Concepción et al. 2015), and this effect is increasing due to human population growth and migration (McGranahan and Satterthwaite 2003, McDonald et al. 2008). For example, urbanisations impact has been shown to affect species assemblages, with specialists replaced by generalist species leading to a decreased biodiversity, but urbanisation also affects meta-communities’ dynamics and interactions (Concepción et al. 2015). Interestingly, some taxonomic groups seem to be less affected by urbanisation while other taxa are neutral or may even have a higher biodiversity in urban compared to rural areas (Jones & Leather 2012). Urbanisation has also been shown to increase biodiversity through the effect of increasing habitat diversity (Breuste et al. 2008). Because impacts vary, there is a growing need to further investigate and understand the consequences of both current and future urbanisation on biodiversity in urban areas.

A conservation strategy that can be used to help maintain biodiversity in urban areas is to integrate urban residents with nature so that they are a part of nature rather than separated from it (Puppim de Oliveira et al. 2011). One way of implementing this practise is by applying green areas to cities which help maintain the overall biodiversity (Breuste et al. 2008, Forman 2008).
Green areas are for example parks and gardens but also roundabouts and roadside verges. These green areas can be seen as islands in an urban landscape (Faeth & Kane 1978) and can therefore be viewed upon with the island biogeography theory (MacArthur & Wilson 1967). The theory describes how proximity to other islands and the mainland together with size of the island affects the species richness capacity. The migration rate is affected by the island’s connectivity and the extinction rate is correlated with its size. Larger islands are more likely to hold different and larger habitats which will increase the species richness. Islands close to mainland will have a larger migration rate than islands with lower connectivity. Green areas in the urban landscape can be seen as an urban archipelago. Small and isolated green areas might have lower migration rates and higher extinction rates than larger and more connected green areas, leading to lower species richness.

The positive effect of green areas on biodiversity is large, but these areas also contribute to the wellbeing of residents (Breuste et al. 2008). With increasing urban areas, green areas will become more important in the future as wildlife habitats, primarily for movement corridors and refugia, but also as genetic reservoirs for conservation work (Zapparoli 1997).

The majority of studies that have investigated the effects caused by urbanisation on biodiversity have been on terrestrial habitats (Faeth & Kane 1978, Miyashita et al. 1998, Saarinen et al. 2005, McKinney 2008, Jones & Leather 2012, McDonnell & Hahs 2013, Prescott & Eason 2018). Little is known, however, about the aquatic habitats in urban environments, which thus are in need of more research. One such aquatic environment is urban ponds, where the habitat may potentially be affected by many different environmental factors such as: habitat fragmentation, increased temperature, water pollution, species introduction, water runoff, and the percentage of impervious land (Heino et al. 2017, Prescott & Eason 2018). Some studies have shown that urban ponds also have a great value when it comes to maintaining biodiversity in urban areas (Goertzen & Suhling 2013).

Interestingly, several studies have found that urban ponds may have similar invertebrate biodiversity as in rural ponds (Le Viol et al. 2009, Goertzen & Suhling 2014, Hassall & Anderson 2015, Hill et al. 2017, Prescott & Eason 2018). This might be explained by the “intermediate disturbance hypothesis” (Connell 1978), where intermediate disturbance disrupts the succession of the ecosystem and maintain a high equilibrium of biodiversity, restraining the dominant species and allowing less competitive species to coexist. Intermediate disturbance of ponds would hypothetically be found in low and moderate urbanised areas like suburbs, and thus be associated with the distance to the city centre.

Thus, one other factor that could affect biodiversity in city ponds is distance to the urban centre. This urban-rural gradient can be used to estimate changes in diversity when investigating effects of urbanisation (McDonnell & Pickett 1990, Forman 2008). Studies on diversity of terrestrial invertebrates along the urban-rural gradient have found different results, ranging from: negative effect, no change, and even some with positive correlations (Jones & Leather 2012, McDonnell & Hahs 2013). It would therefore be of interest to further investigate how the variable distance to city centre affects invertebrates in urban ponds.

Land use around green areas have been shown to affect colonisation and food resources for terrestrial invertebrate communities and isolation of green spaces also play an important role.
in determining invertebrate richness and abundances (Blair & Launer 1997, Miyashita et al. 1998). Similarly, the proportions of arable land and industry surrounding ponds together with the number of buildings have previously been linked to biodiversity and beta diversity of aquatic insects (Blicharska et al. 2017, Heino et al. 2017).

Studies made on urban ponds in Sweden are few (Blicharska et al. 2016, Blicharska et al. 2017, Heino et al. 2017, Johansson et al. 2019), and they all focus on biodiversity of species communities and beta-diversity rather than individual taxon and their general trends when it comes to abundance of individuals. Hence, more studies are needed. The aim of this study was therefore to investigate how the landscape variables forest, open land, developed land and other water bodies coverage around the ponds together with distance to the city centre affects biodiversity in thirty ponds in the city of Stockholm, Sweden.

Knowledge on species richness in urban ponds and how different taxon are affected by environmental factors is of large importance and could provide justification for creation of new ponds and preventing destruction of existing ones. Information on which factors relate to high richness and biodiversity of invertebrates could maximise the selection of green and wet areas for establishing new urban ponds, together with improving the management of these areas. With the continuous expansion of urban areas, knowledge of how to maintain and even increase the biodiversity of cities is of great concern.

1.2 Why study invertebrates?

An excellent group of bio-indicators that may allow us to understand how some of the variables in urban environments affect biodiversity are invertebrates (Jones & Leather 2012). Invertebrates are a diverse group that gives a good indication of the general biodiversity in an area. They are also easy to sample, present in many trophic levels, have short generation times which makes them respond fast to anthropogenic changes in soil and vegetation, and important in cycling of organic matter, nutrients, pollution and soil aeration (McIntyre 2000, McIntyre et al. 2001).

This study focused on four orders: aquatic beetles (Coleopterans), dragonflies (Odonatans), aquatic true bugs (Hemipterans), caddisflies (Trichopterans) and two classes: freshwater snails (Gastropods) and mussels (Bivalves). These invertebrates represent different functional groups with regard to trophic level, dispersal etc, and may therefore represent an overall biodiversity for the city ponds. The number of individuals per taxon is analysed against the different landscape variables to find possible trends. More specific, the following question will be answered: what is the correlation between abundance of invertebrate taxa and the landscape variables?

I predict that the abundance of aquatic invertebrates per taxon will increase with distance to the urban centre, following the urban-rural gradient seen in previous studies (Blair & Launer 1997, Concepción et al. 2015). I also predict that the number of aquatic invertebrates will be negatively affected by higher coverage of developed land (Goertzen & Suhling 2013, Concepción et al. 2015, Blicharska et al. 2017, Heino et al. 2017). Vegetation plays an important role for shelter and foraging for the order Odonata (Buchwald 1992) and it is therefore likely that forest coverage will be positively associated with this specific order, but also in regards for the other taxa.
2.0 MATERIALS & METHODS

2.1 Study area
The study covers thirty randomly selected urban ponds located in the central area of Stockholm, the capital city of Sweden (Figure 1). The metropolitan area of Stockholm is approximately 6500 km² and had an estimated population of 2,352,549 inhabitants in the end of March, 2019 (SCB 2019). The ponds in this study are distributed throughout the city in a total of nine municipalities (Stockholm, Nacka, Tyresö, Haninge, Huddinge, Järfälla, Sollentuna, Täby, and Danderyd) and should therefore represent the whole city.

The ponds were selected based on the definition by Biggs et al. (2005), with a slight modification. Natural or artificially made water bodies were included. The area of the ponds selected ranged between two square meters and two hectares, and only ponds that held water for at least four months a year were included. Man-made ponds with concrete walls and bottoms were excluded. The ponds were found by gathered verbal information from municipalities’ officials and scanning of maps.

Figure 1. Map over the central area of Stockholm. White dots are the chosen ponds and the yellow star marks the city centre. Terrängkartan™ vector map from Swedish mapping, cadastral and land registration authority (Lantmäteriet) editing done by using the software Qgis 3.8 (QGIS Development Team 2019).
2.2 Invertebrate sampling

The sampling strategy was derived from the guidelines by the Swedish Environmental Protection Agency (2006) and modified somewhat. In short, six sweep net samples were taken from each pond by using a bottom scoop net with a diameter of 20 cm and a mesh size of 1.5 mm. In order to cover all types of microhabitats along the shoreline, the six samples were allotted around the pond with regard to microhabitat of the shore substrate and vegetation. Each sweep net sample was taken by stroking the net in opposite directions six times in a one meter reach at a depth of two to three dm. Living invertebrates from six taxa (two classes: Bivalvia and Gastropoda; and four orders: Odonata, Trichoptera, Coleoptera, and Hemiptera) were collected, sorted, and preserved in 70% ethanol in the field. The number of aquatic invertebrates in each sorted sample was counted to measure their abundance for each urban pond. Samples with low abundances of aquatic invertebrates were counted in field while larger samples were counted in the lab. The sampling of ponds was conducted in May and June of 2019.

2.3 Landscape variables

From a map, the percentage of the following landscape variables was estimated in a circle with a diameter of 500 meter around each pond: developed land, forest, open land, other water bodies around the pond, and the distance to the city centre (measured in meter).

The area of the pond was excluded in the percentage of other water bodies. The highest amount of forest, open land and developed land cover around a pond was 89 percent, 76 percent and 71 percent respectively. The landscape variables were estimated from a vector terrain map (Terrängkartan™ vector map) from Swedish mapping, cadastral and land registration authority (Lantmäteriet) using the software Qgis 3.8 (QGIS Development Team 2019).

2.4 Statistical analysis

The data was first analysed with a canonical correspondence analysis (CCA) to visualise the response of individuals per taxon against landscape variables. CCA is a multivariate constrained ordination technique, which extracts important gradients of explanatory variables among different combinations in a dataset to visualise the data. The CCA ordination was made with 999 permutations and the significant prediction threshold was set to p-value < 0.05. Linear regressions were thereafter performed by using the ‘lm’ function in order to test for a relationship between some of the landscape variables (predictors) and number of individuals per taxa (response variable). The regressions performed were based on visualised interpretations of the results obtained in the CCA ordination plot. All analyses were performed in R-studio (R-studio Team 2016) using the ‘vegan’ (Oksanen et al. 2019) and ‘ggplot2’ (Wickham et al. 2019) packages. The mean number of individuals found in each pond (calculated from the six samples) for each taxon was used as replicate.
3.0 RESULTS

3.1 Canonical Correspondence Analysis

The canonical correspondence analysis (CCA) visualises associations with an ordination between the landscape variables (distance to city centre, forest, open land, and developed land) and the number of individuals within the specific taxon (Bivalvia, Gastropoda, Trichoptera, Odonata, Hemiptera, and Coleoptera). The landscape variables accounted for 36.07 percent of the variation for the invertebrate abundances among the ponds, and the first two axes of the ordination explained 29.55 percent (CCA1) and 5.01 percent (CCA2) of the variation respectively. However, significance was only found for the first CCA axis, CCA1: \( p\)-value = 0.037.

From the CCA ordination plot (Figure 2) it can be seen that the taxa Bivalvia, Trichoptera, and Odonata seem to be positively associated with the variables: distance to city centre, and percentage of forest cover around the ponds. This suggests that higher percentage of forest results with an increase in abundance for these taxa. The distance to the city centre seems to also affect these taxonomic groups, by showing lower abundances of individuals closer to the city centre. The taxonomic group Gastropoda show an increase in abundance with higher percentage of developed land around the ponds. Finally, the CCA ordination suggests that Hemiptera and Coleoptera show increased abundance with larger percentage of open land cover around ponds.

![CCA ordination plot with taxonomic groups (shown in red) and fitted landscape vectors (shown in blue). Abbreviations in the figure: F = Forest, DL = Developed land, OL = Open land, and DCD = Distance to city centre. Arrows indicate direction of gradients and the amount of variation in the landscape vector. Eigenvalues for constrained axes: CCA1 = 0.29547 and CCA2 = 0.05014.](image)
The landscape variable for percentage of other water bodies within the specific range had no significant effect on invertebrate abundance and was therefore deleted from the final CCA ordination plot. Furthermore, no significance was found when this landscape variable was tested against the different taxonomic groups with linear regression.

### 3.2 Linear regressions

Table 1 show the results from the individual linear regressions that were selected and analysed based on the trends visualised in the CCA ordination plot (figure 2).

<table>
<thead>
<tr>
<th>Predictor (landscape variable)</th>
<th>Response variable (Taxon)</th>
<th>p - value (* = significant)</th>
<th>r² - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>Trichoptera</td>
<td>0.181</td>
<td>0.0631</td>
</tr>
<tr>
<td>Forest</td>
<td>Odonata</td>
<td>0.0184*</td>
<td>0.183</td>
</tr>
<tr>
<td>Forest</td>
<td>Bivalvia</td>
<td>0.0742</td>
<td>0.109</td>
</tr>
<tr>
<td>Distance to city centre</td>
<td>Trichoptera</td>
<td>0.0164*</td>
<td>0.189</td>
</tr>
<tr>
<td>Distance to city centre</td>
<td>Odonata</td>
<td>0.0432*</td>
<td>0.138</td>
</tr>
<tr>
<td>Distance to city centre</td>
<td>Bivalvia</td>
<td>0.0353*</td>
<td>0.149</td>
</tr>
<tr>
<td>Open land</td>
<td>Coleoptera</td>
<td>0.107</td>
<td>0.0903</td>
</tr>
<tr>
<td>Open land</td>
<td>Hemiptera</td>
<td>0.406</td>
<td>0.025</td>
</tr>
<tr>
<td>Developed land</td>
<td>Gastropoda</td>
<td>0.348</td>
<td>0.0315</td>
</tr>
<tr>
<td>Developed land</td>
<td>Odonata</td>
<td>0.0306*</td>
<td>0.156</td>
</tr>
</tbody>
</table>

The linear regressions supported some of the interpretations from the CCA ordination (Figure 2), and the taxonomic groups Bivalvia, Odonata, and Trichoptera showed a significant effect with distance to the city centre (Table 1). These three taxonomic groups show similar trend lines in their regression plots where they all increase in abundance when the ponds are located further away from the urban centre (Figure 3).

Apart from the variable distance to the city centre, abundances of Odonata also showed a significant positive effect for forest cover and a significant negative effect for developed land cover (Figure 4, Table 1).

No significant trends were found for any of the taxonomic groups against the landscape variable percentage of open land cover. The possible trends seen in the CCA ordination plot (Figure 2)
for Trichoptera and Bivalvia against percentage of forest around the ponds were also not found significant in the linear regressions (Table 1).

The CCA ordination also suggested that Gastropoda should be positively related to the percentage of developed land, and that Hemiptera and Coleoptera should be positively related to the percentage of open land coverage around the ponds. However, these linear regressions show non-significant results for these associations (Table 1).

Even though some results were significant, the coefficient of determination ($r^2$) values maintained moderately low. This suggests that the observed outcome of the response variable (abundance for the specific taxa) is not explained only by these predictors (landscape variables). The highest $r^2$-value was reached for Trichoptera against distance to the city centre and implied that the distance to the urban centre can explain the abundance of Trichoptera by 18.9 percent (Table 1).
4.0 DISCUSSION
This study focused on the relationship between landscape variables and the abundance of taxa, instead of analysing diversity and community compositions which has been done in many other studies. By investigating how landscape variables affects the abundance of invertebrates it might be possible to manage specific taxonomic groups that are in demand of conservation with more precise conservation biology methods. This could help specific taxa in need of conservation which could further strengthen the whole community. The results indicate that the abundance for some of the taxa analysed show significant trends in being affected by the different landscape variables investigated. However, there were also trends visualised in the CCA ordination plot (Figure 2) that gave no significance when analysed with linear regression (Table 1).

4.1 Predictors for aquatic invertebrate abundance
Interestingly, the abundance of invertebrates per taxon increased for some of the landscape variables. Abundances of the taxonomic groups Trichoptera, Bivalvia and Odonata showed positive correlations with distance to the city centre, i.e. their abundances were higher further away from the city centre. These aquatic invertebrate groups seem to be most affected by the landscape variables investigated while no significant correlations were found for Coleopterans, Hemipterans and Gastropods, even though some trends were found in the CCA ordination plot. In addition, significant effects were found for the abundance of Odonata for both percentage of developed land together with percentage of forest around the ponds.

4.2 Forest and open land cover
Percentage of forest around the ponds showed possible trends with some of the taxonomic groups. The degree of forest coverage seems to affect the abundance of Trichoptera and Odonata, but also for the Bivalvia, according to the results seen in the CCA ordination plot. However, only Odonata showed a significant relationship with forest cover when analysed with linear regression.

These results are according to the prediction made in the hypothesis, i.e. forest coverage seems to play an important role by providing suitable vegetation. When forest is reduced or taken away important vegetation that provides shelter and foraging zones will decrease. Vegetation is important for Odonata biodiversity (Buchwald 1992), and this has also been shown by Johansson et al. (2019) who found that where emergent vegetation at the ponds of a certain height was associated with Odonata diversity. Thus, my result gives further support for the importance of vegetation around the ponds for Odonata diversity.

Forest cover also affected Trichoptera and Bivalvia abundances. The reason for why Trichoptera might be affected might be the same as previously described for Odonata. However, I have no good explanation for why Bivalvia was positively affected by forest cover. Open areas have previously been found to affect diving beetles and therefore implying that differences in the environment by coverage of forest and open land will harbour different beetle assemblages (Heino et al. 2019), but I did not find any effect on Coleoptera abundances with regard to the landscape variables analysed in this study.
4.3 Distance to the city centre and developed land cover

The variable percentage of developed land cover can be intuitively connected to distance to the city centre since the amount of developed land would increase closer to the urban centre. This can also be seen in the result of this study, since Odonata abundance was significantly correlated with the distance to the city centre as well with developed land coverage. The hypothesis for the variable distance to the city centre was that the abundances of aquatic invertebrates per taxon would increase with the distance, which has been found in previous studies investigating the urban-rural gradient (Blair & Launer 1997, Concepción et al. 2015). I found support for this hypothesis when analysing the data with the CCA ordination plot, since the abundances of Trichoptera, Bivalvia and Odonata was found to increase with the distance to the urban centre.

Ponds further away from urban centres might have higher connectivity to other ponds. This is because there might be a decrease of isolating developed land and an increase of forest and open land coverage which might have more water. The pond’s level of isolation can be viewed upon with the island biogeography theory (MacArthur & Wilson 1967). The level of connectivity influences the extinction rate together with the migration rate which could lead to an overall higher biodiversity in ponds within a low coverage of urban area. Ponds located in areas with larger cover of developed land, where buildings and streets might isolate the pond, could affect the species composition and also the abundance. This could be why a negative association was found for Trichoptera, Bivalvia and Odonata against the variable distance to the city centre.

Apart from being positively affected by percentage of forest cover, Odonata also showed a negative correlation with percentage of developed land coverage around the ponds. This result is according to the hypothesis, stating that the abundance of aquatic invertebrates will be negatively affected by lower coverage of forest and closer distance to the urban centre together with higher coverage of developed land around the ponds. Previous studies investigating how developed land affects invertebrate biodiversity have also found negative correlations with higher level of developed land (Pond 2012, Goertzen & Suhling 2013, Concepción et al. 2015, Blicharska et al. 2017, Gillis et al. 2017, Heino et al. 2017), but see (Le Viol et al. 2009, Johansson et al. 2019) for a different pattern. More specific, Odonata communities have been found to be negatively affected by number of buildings and residents living around the ponds (Blicharska et al. 2017), and species richness and ecological uniqueness (measured as local contribution to the beta-diversity) for Odonata have been found to be negatively associated with proportion of area with buildings and arable lands, respectively (Heino et al. 2017). Furthermore, lower levels of freshwater mussels’ abundances have been seen in rivers downstream of urban areas (Gillis et al. 2017), and Trichopterans have previously been linked to amount of residential and mining land use (Pond 2012). Thus, the amount of developed land seems to have a strong negative impact on biodiversity in urban areas.

However, it is important to note that there have been divergent results with regard to how developed land affects biodiversity in aquatic systems in urban areas. For example, Johansson et al. (2019) study on Odonata communities’ where beta diversity was investigated, did surprisingly not find Odonata communities to be associated with amount of developed land. But, this could be a result of studying stormwater ponds with too low amount of developed land around them that are needed to affect the Odonata community. Their study had a maximum of 45 percent developed land coverage which is different from my study where the maximum was 71 percent. Furthermore, Le Viol et al. (2009) also found a significant effect for Odonata together with Coleoptera and Heteroptera in family richness for developed land when they
compared highway ponds with surrounding ponds. However, Le Viol et al. (2009) did find significant results for Gastropods and developed land in the highway ponds, where these communities where higher compared to natural non-highway ponds. In the CCA ordination plot a possible trend suggests the same results as in Le Viol et al.’s study (2009) for the abundance of Gastropods and developed land, since Gastropoda are increasing with more developed land coverage. However, this trend gave no significant result with the linear regression. Hence, more work is needed on this group and its abundance relationship with developed land.

Habitat heterogeneity around ponds has been shown to affect species richness for invertebrates (Goertzen & Suhling 2013). Heterogeneity in the landscape increases the availability of different substrates and habitats, potentially resulting in larger number of species with different niches. Heterogeneity, as a result of disturbance in the succession of the habitat could be associated with the “intermediate disturbance hypothesis” (Connell 1978). This sort of intermediate disturbances might be found in suburbs where gardening and medium level of developed land are present. However, if the amount of disturbance increases, biodiversity is expected to decrease. This has previously been seen in urban centres where extensive disturbances, due to high level of developed land decreases the biodiversity of many invertebrates and only benefit mainly common and regionally widespread species (McKinney 2008, Goertzen & Suhling 2013). When it comes to abundances, higher amounts of invertebrates might be found in more favourable environments rather than environments with harsher living conditions. However, studies with variation in disturbance in urban areas are needed to explore this further, before a good understanding is reached on how the absolute amount of disturbance affect invertebrate communities.

4.4 Other contributing factors to the abundance of aquatic invertebrates

Even though landscape in the proximity around the ponds seemed to affect the abundance of individuals for some of the taxonomic groups in my study, the results still have a moderately low explanatory level according to the linear regressions r-squared values. This result suggests that there is an intertwined web of variables affecting these taxonomic groups, where for example the land cover around the ponds only explain some amount of the total variables affecting the abundance of these aquatic invertebrates together with the distance to the city centre. Other variables that have been found to affect these taxonomic groups are the depth and size of the pond, vegetation in the pond together with algae cover, precipitation, pH, temperature, and nutrient levels (Goertzen and Suhling, 2013, Heino et al. 2017, Hill et al., 2017, Henio et al. 2019, Johansson et al. 2019). Also, expanding the study period over multiple years is of importance to exclude possible fluctuation in abundancies over time due to differences between years. With this in mind, further studies on urban ponds are needed to fully understand how these environmental variables influence the abundance, community structures and biodiversity of aquatic invertebrates.
5.0 ACKNOWLEDGEMENTS

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6.0 REFERENCES


