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An Ecosystem Services approach: how does rainfall variation influence habitat provision in ponds?

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ABSTRACT

Sustainable Urban Drainage Systems (SUDS) are soft engineering solutions for urban pollution, flood risk management with the intention to mimic natural systems while maintaining hydraulic features (such as flow control). Their design is based on the SUDS triangle which incorporates water quality, water quantity, and amenity and biodiversity components. Until recently, the main focus was on diffuse pollution and how SUDS offered a unique, and feasible, solution from urban and peri-urban water courses. However, with the looming threat of climate change, the research goal has widened to include the influence of flooding and how these solutions exist to minimise the associated impacts from localised floods. In terms of amenity, and biodiversity, little research has been completed to quantify the wider benefits with respect to three main pillars of sustainability: economic, social and environmental factors. Ecosystem Services refer to the end user benefits which may be derived from the natural environment. Few studies to date assess the links between Ecosystem Services and SUDS- although conceptual studies (Jose et al., 2015; Scholz et al., 2013; Lundy and Wade, 2011) exist, none have assigned a monetary value to these services.

It is therefore the intention of this paper to make the connection between aquatic habitats (ponds) and suggest feasible methods to quantify the wider Ecosystem benefits and services. Habitat provision is of strong importance for environmental benefits. It is therefore the focus of this paper to make the connection between aquatic habitats (ponds) and the amenity and biodiversity functions offered. This will be achieved by investigating whether there is a statistically significant association between two variables (pond area, total rainfall) and ASPT (average score per taxon).

1. INTRODUCTION

Ponds refer to the features on the landscape which have been naturally formed due to glaciation or existing hollows in forest environments (Pond Action, 1998). With the number of ponds rapidly decreasing, more effort and care has been taken to establish new ponds within the urban and rural settings of the UK. The initiative refers to changes in urban planning- where size of development and pollution risk is taken into account; as well as the relative risk of flooding (SPP7; Scottish Government, 2014).

1.1 SUDS

Sustainable urban drainage systems (SUDS) build on existing drainage systems and their design incorporates flood risk management, water quality, and amenity and biodiversity. Their systems mimic natural systems and reduce pressure on drainage by providing attenuation (swales and wetlands) and retention systems (ponds). The latter is the focus of the research- which assesses the

importance of ponds in urban settings; as well as the intrinsic appeal.

1.2 Multiple benefits & ES

Ecosystem Services refers to the wider benefits derived from the natural environment (Costanza et al., 1997), and to date there are multiple interpretations on Ecosystem Service frameworks. Dailly et al., (1997) discusses the importance of environmental benefits in relation to society, and the drive to restore the systems with changes in environmental management is fundamental to this balance. Costanza *et al.*, (1997) focuses on the importance of environment at a global scale and the question whether nature should have a price. These papers were central to the development of Ecosystem Services theory (MA, 2005), but it was not until recently that the focus was on applying these policies at a national scale (NEA, 2011).

Ponds have multiple benefits, and these incorporate the three pillars of sustainability: social, economic and environmental ideals. Previous

studies look at the importance of ponds in the urban landscape (Hassall, 2014); as well as the links with amenity (Bastien *et al.*, 2012), but very few have assessed the benefits in an ecosystem services context (Scholz and Uzomah, 2013; Jose *et al.*, 2015). None have quantified the benefits relating to habitat provision, although Briers (2014) undertook a field investigation in the East of Scotland in relation to SUDS ponds.

1.3 Habitat provision (supporting ES)

The focus of the paper is: how does rainfall variation influence habitat provision in ponds? Coupled with this is one of the hypotheses for habitat provision which suggests: periods of high rainfall will reduce the number of pollution sensitive organisms in each pond. This may be tested with respect to the pond area to see whether pond size influences the water quality of the pond. Biggs *et al.*, (2005) discussed the importance of preserving ponds; as the presence of wildfowl (ducks, swans, moorhens etc) or pollution results in degradation. This is partially in relation to ponds having a smaller volume than rivers (Biggs *et al.*, 2005). However, in the case of the smallest, and perhaps isolated, ponds- the water quality is protected due to the size of catchment, so it is less likely to become degraded due to pollution (Biggs *et al.*, 2005). So the underlying question is: how does rainfall variation affect the pond ecosystem and how can these differences be accounted for?

In the context of this paper, ponds with a natural origin, and man-made, will be compared with SUDS ponds (engineered after 1994).

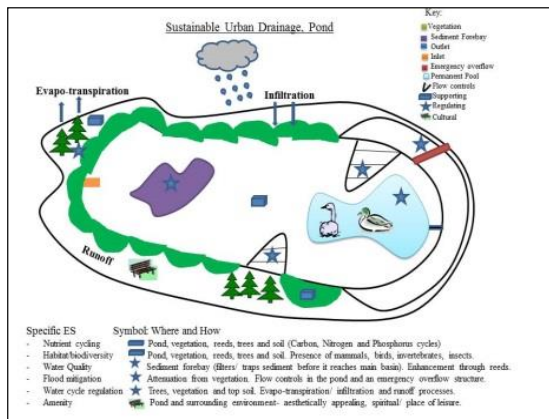


Figure 1. Ecosystem Services of ponds (SUDS as illustration, Jarvie *et al.*, 2015)

2. FIELD SITES AND METHODS

This section will outline the main study sites and the respective methods.

2.1 Field sites

For the purpose of this paper, six field sites in Edinburgh were visited at monthly intervals to assess suitability for habitat with respect to ponds with a natural origin, manmade, and SUDS (Figure 2). Natural origin implies that once the pond was natural, and has been modified by humans. Man-

made refers to a pond which was built for a purpose- for example; Inverleith pond was designed as a boating pond in the 19th Century, and was not intended to host wildlife. SUDS ponds refer to those established after 1994 and with specific engineering functions for stormwater management, and diffuse pollution, as well as the amenity and biodiversity they provide.

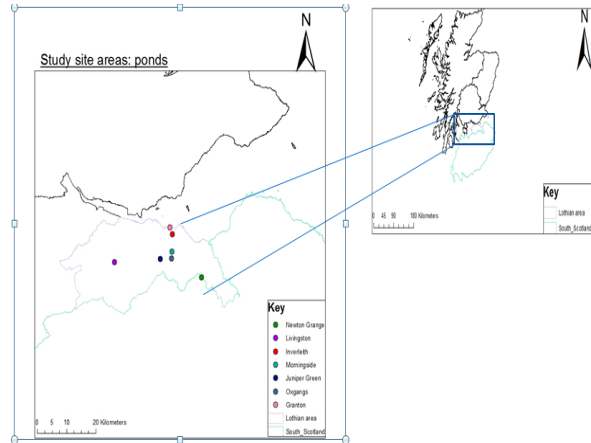


Figure 2. Map showing each study-site

2.2. Methods

The methods outlined are in accordance with the British Standards for still water; as well as the recommended guidance from NPS (Pond Action, 1998). Further details, including the framework for the methods, are documented in Jarvie *et al.*, (2015).

2.2.1 Sweep sampling

The standard approach was BS EN 10870:2012 and this refers to sweep sampling methods and other freshwater methods for still water. The method was as follows:

- Check that the net was free from debris or sediment
- Substrate was gently agitated for one minute
- The net was swept through the surface of the water column to capture surface dwellers, and this process lasts three minutes, and benthic invertebrates.
- The net was removed and emptied into a white tray.
- Invertebrate samples are stored in a bottle and preserved with alcohol.

2.2.2 Analysis of macro-invertebrates

Macro-invertebrate samples were analysed in the laboratory using a compound microscope, provided by the School of Life Sciences. Initially, samples are sieved and flushed to remove excess sediment or debris- as smaller invertebrates may be hiding. The next step was to place the macro-invertebrates in their family groups in the white tray. Counting was repeated to make the results

reliable, and if possible this was verified by an independent witness. Macro-invertebrates were placed under the microscope and identified to family level with the assistance of keys (Croft, 1986).

Out with the laboratory, data were computed using NPS BMWP (Biological Monitoring Working Party) Scores for ponds. Spreadsheets were created in Microsoft Excel and then the ASPT was calculated by dividing the BMWP score by the number of families present. ASPT is a proxy indicator for water quality and thus habitat provision.

2.2.3 Mapping vegetation and monitoring abundance

Figure 5 summarised the approach taken to record vegetation in still water environments in relation to the standard method BS EN 15460:2007. The steps are summarised below:

- Vegetation was recorded along transects
- Vegetation was categorised as: floating, submerged, and emergent
- Field results were compared with DAFOR (BS EN 15460-2007)
- Further analysis was carried out using Shannon-Index for biodiversity

2.2.4 Secondary data and analysis

Rainfall data were provided by the Met Office data service; as well as additional data on the Royal Botanic Gardens, Edinburgh, server. For the purpose of this paper, six ponds in Edinburgh were compared with six months of rainfall data to see whether patterns existed with respect to changes in ASPT. Pond area is tested in relation to the water quality proxy ASPT, because previous studies suggested that smaller ponds (areas) will be protected from degradation due to the catchment size (Biggs *et al.*, 2005). This may not be as applicable to SUDS ponds, for example, (Briers, 2014) which degrade over short timescales.

Furthermore, pond area was calculated using Edina-Digimap measurement tools and validated with field measurements collected in summer 2015.

Data were processed using tools within Microsoft EXCEL and SPSS. Preliminary tests, using Shapiro-Wilk, confirmed that the data followed a normal distribution of values ($p > 0.05$). Tests were performed to see whether there were relationships between rainfall and ASPT, and ASPT and pond area using Pearson's Product Moment.

3. RESULTS

Results will be presented for six ponds in Edinburgh (Figure 3, 4) with respect to the influence of rainfall data on the provision of habitat at the inlet and outlet of each pond. Pond area and

habitat provision- floating vegetation, and wildfowl (ducks, swans, moorhens, and coots) will also be considered.

3.1 ASPT

ASPT refers to the average score per taxon which as aforementioned is the BMWP score divided by the number of families in a given sample.

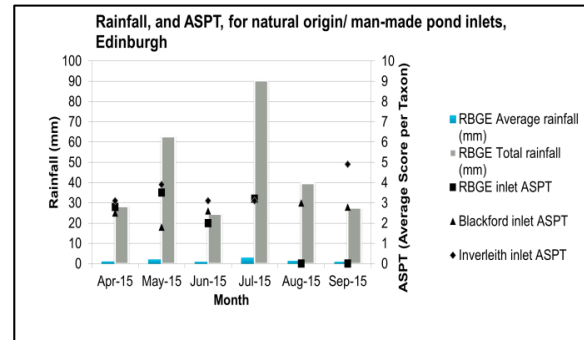


Figure 3. Comparing average monthly, and total, rainfall with ASPT for natural origin pond inlets, Edinburgh

Figure 3 reveals that September has the highest observed ASPT for the inlet during the start of the autumn season (September) which corresponds with the second lowest total rainfall with less than 30mm. 5 is fair in terms of habitat provision. In July, each pond has the same ASPT of 3.2 which is poor in terms of habitat provision for summer season. The lowest observed ASPT is 0 in August and September for the Royal Botanic Gardens- due to temporary draining.

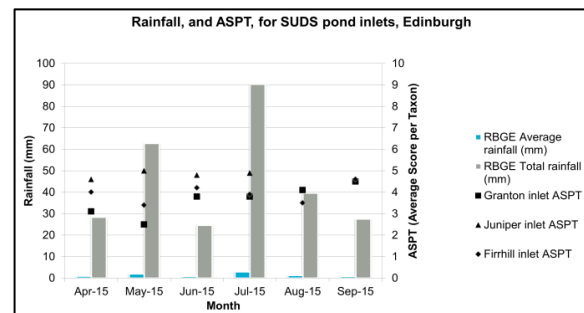


Figure 4. Comparing average monthly, and total, rainfall data with ASPT for SUDS pond inlets, Edinburgh

Juniper Green has the highest observed ASPT in May with 5 which corresponds with the second highest total rainfall (Figure 4). Juniper Green has a constant supply of water available from the grey water and rainfall harvested from the roof- which feeds into the inlet of the pond. This may explain why the ASPT is higher than other ponds at their inlets.

Granton pond has the highest ASPT in September where the second lowest rainfall is observed. Within the area sampled, there is a spawning ground for fish nearby- however the invertebrates

found tolerate pollution: such as lesser water boatman (corixidae), water hog-louse (assellidae) and non-biting midges (chironomidae). The midge population is fed on by invertebrates and Stickleback within the pond (Candolin *et al.*, 2015).

Equally, damselfly (Zygoptera) larvae are discovered near the inlet of Firrhill pond in September- where there are an abundance of small fish present (minnows). However, there were none present in previous months- which may suggest that during wetter months (July), the invertebrates seek refuge in the benthic sediment of the pond (Vadher, 2014). Furthermore, Juniper Green and Firrhill have floating vegetation present (pond weed, frog-bit and water lilies) which may factor into the differences observed through field studies.

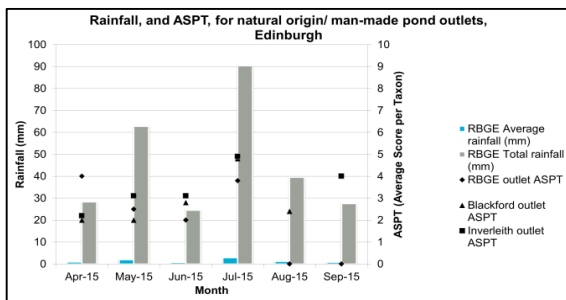


Figure 5. Comparing average monthly, and total, rainfall with ASPT for natural origin pond outlets, Edinburgh

Figure 5 highlights that outlet ASPT is highest for Inverleith in July (5) and this is fair in terms of water quality. The outlet ASPT is higher than the observed inlet, and for the case of July greater than 20 caddisflies (Trichoptera) are discovered in the field sample. Caddisflies are sensitive to organic pollution and score highly in terms of BMWP (see Jarvie *et al.*, 2015), so their presence suggests that the pond conditions are favourable for habitat. Caddisflies adapt to their surroundings, and in the case of Inverleith the substrate is wood and plant material casing. Trichoptera are important for ecosystem health as they filter organic debris and materials in the water (Wiggins, 1998; Johansen, 2015)

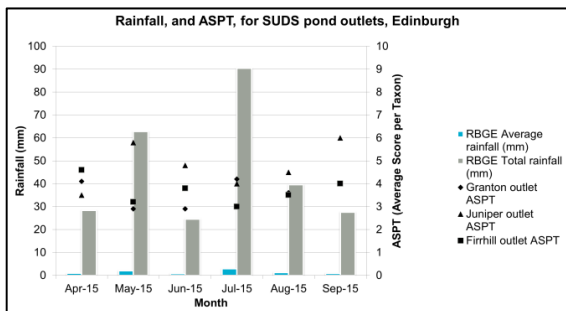


Figure 6. Comparing average monthly, and total, rainfall data with ASPT for SUDS pond outlets, Edinburgh

Juniper Green has the highest ASPT for the SUDS ponds with a range of 2 (4 to 6). In September, with lower rainfall, the ASPT is 6.

Pollution sensitive organisms are found in two of the three SUDS ponds- with a variety of families (shrimp, caseless caddis, and damselfly larvae) found at Juniper Green pond. Granton has no sensitive organisms, to date, in the main pond- although earlier studies indicate that shrimp exist in the wetland (Jarvie *et al.*, 2015). Furthermore, presence of shrimp at Firrhill outlet suggests that there is some improvement in habitat throughout the pond.

3.2 Pond area and habitat provision.

Ponds with larger pond areas do not have floating vegetation present (as indicated from previous mapping). Floating vegetation such as water lilies and frog-bit are fundamental to habitat provision in ponds (Pond Action, 1998; Grutters *et al.*, 2015), and it is interesting to note that this is absent from ponds with the larger surface area. Inverleith pond has the largest pond area with a wetland pond. The main “boating” pond has no vegetation cover present- but hosts over 200 birds: ducks, swans, moorhens, and kittiwakes. ASPT (figure 4 and 6) is better in ponds with limited or no wild-fowl present: Firrhill and Juniper Green, respectively.

Table 1. Pond area, vegetation and wildfowl.

Pond name	Pond area (m ²)	Floating vegetation (present)	Wild fowl
RBGE	1956	outlet	yes
Inverleith	9371	none	yes
Blackford	7803	none	yes
Firrhill	1688	outlet	limited
Granton	3137	none	yes
Juniper Green	192	Middle and outlet	no

3.4 Statistical Analysis

The analysis methods were chosen to investigate whether there were relationships between the water quality proxy, ASPT, and pond area; as well as any statistical difference between ASPT and rainfall data. The reason for this is to determine whether there is a clear statistical difference between stormwater retention (SUDS) ponds and pond with natural origins, and their associated habitats at the inlet and outlet. Pearson’s Product Moment was chosen as the data conformed to the normal distribution of values.

Results of the statistical tests using Pearson's Product Moment will be displayed. One objective is to see whether a relationship exists between rainfall data from the Royal Botanic Garden weather station and habitat provision using the water quality proxy ASPT. The associated hypotheses are:

H₁: There is an association between total rainfall (RBGE) and observed ASPT

H₀: There is not an association between total rainfall (RBGE) and observed ASPT

An additional objective is to see whether pond area influences habitat provision at the inlet and outlet- as characterised by ASPT. The hypotheses are:

H₁: There is an association between pond area and observed ASPT

H₀: There is no association between pond area and observed ASPT

3.4.1 Pearson's Product Moment

A moderate correlation exists between rainfall data and observed ASPT (0.557) for the inlet of Juniper Green with poorer correlations for Inverleith (0.491) and Firrhill (0.139). Weak negative correlations exist for RBGE (-2.35) and Blackford (-2.64); suggesting that there is a weak association between rainfall and observed ASPT at the pond inlet. None of the pond inlets have significant results observed; thus, the working hypothesis is rejected and the null hypothesis (there is not an association between rainfall and observed ASPT) is accepted.

Pearson's Product results indicate that a strong association exists between ASPT and pond area for RBGE (.856) and Blackford (.797) inlet for spring and summer seasons. The correlation is not significant at the 0.05 benchmark. However, a strong negative association exists between pond area and ASPT for Juniper Green (-.895) which is significant (.016). While, the larger ponds have a strong positive association, and no significance, the smallest pond has a strong negative association suggesting there is little or no association between the observed inlet ASPT and pond area.

Some association exists between the pond area and observed ASPT at the inlet of each pond. Larger ponds have strong positive correlations with the exception of Inverleith with a strong negative correlation. However, only one of six ponds had a significant result; therefore the null hypothesis is accepted for five ponds, there is no association between pond area and observed ASPT at the inlet.

A moderate-strong positive correlation exists between rainfall data and observed ASPT (0.655) for the outlet of RBGE. Weaker correlations exist for Juniper Green (.488), Firrhill (.469) and Blackford (.178). Granton has a strong negative correlation (-.815) suggesting there is no association between rainfall and observed ASPT at the outlet.

Weaker correlations exist between pond area and outlet ASPT. Juniper Green has a strong negative correlation (-.884) which is significant (.020) suggesting there is a very weak association between pond area and ASPT for the outlet. Overall, there is no association between pond area and observed ASPT.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Habitat provision has some association with rainfall availability. Ponds with natural origins have better habitat provision in terms of presence of wild fowl and fish- which adds to local biodiversity. Juniper Green pond has consistently good ASPT at its inlet- which may be due to the absence of wildfowl, or the delivery of nutrients through the system by rainfall. ASPT is a useful proxy for water quality and to indicate whether a pond provides suitable habitat for macro-invertebrates, birds and fish. The latter is of key importance for demonstrating water quality- as fish cannot survive in oxygen deficient or impacted water.

Pearson's Product results indicate that there is not an association, of statistical significance, between total rainfall and observed ASPT; and, similarly for pond area and observed ASPT. However, there is some association between the pond area and ASPT at each pond inlet.

4.2 Recommendations

- Comparison of seasons when 1 year of continuous data is available- from spring 2015- spring 2016.
- Further investigation is needed with respect to the interaction of chemical parameters for habitat provision (DO, EC, pH, and Water temperature); as well as the influence of turbidity. This will be completed after spring 2016.
- Future studies may incorporate less urban areas- as all of the Edinburgh ponds are in urban settings.

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