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Amphibians in a blue-green infrastructure stream on the NMBU campus

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Acknowledgements

This thesis marks the completion of my master's degree in Ecology at the Norwegian University of Life Sciences (NMBU). I have had the privilege of conducting my fieldwork at Norway's most beautiful campus and I'm happy to have spent so much time in and around its ponds.

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And lastly, to my siblings: I hereby rescind my previous statement regarding who's the smartest and hope that will alleviate some of the (justified) teasing I have endured since 2019.

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Abstract

Amphibians are the most threatened vertebrate group globally, facing high rates of decline and extinction, with habitat loss and degradation being the largest threat. Infrastructure development and urbanisation is a large driver of this decline, destroying both terrestrial and aquatic habitats and changing catchment hydrology. Blue-Green Infrastructures (BGIs) reintroduce natural elements into urban environments and are increasingly used to mitigate these impacts. BGIs create habitats for a range of organism groups and might provide an opportunity to create habitat for species of conservation concern. The aim of my thesis was to investigate if blue-green infrastructures can support amphibian populations.

To this end, I studied the amphibians in a "blue-green stream" that was recently constructed on the campus of the Norwegian University of Life Sciences in Ås, Norway. Observational and trapping methods were used to identify resident amphibian species. Additionally, artificial macrophytes were constructed to test their suitability for oviposition by the smooth newt (Lissotriton vulgaris). Furthermore, water temperature was measured, and the crustacean community was sampled and analyzed to identify potential constraints on amphibian presence.

The common toad (*Bufo bufo*), common frog (*Rana temporaria*), and smooth newt were found to be reproducing in the stream system. No newt eggs were found on the artificial macrophytes, however larvae were found in one of the ponds. The resident species are generalists and none of the three red-listed species were found. Fish presence, water temperature and food availability might be limiting occurrence in some parts of the stream. The red listed species moor frog (*Rana arvalis*), great crested newt (*Triturus cristatus*), was absent and their occurrence might be limited by a lack of source population, suitable terrestrial habitat, migration barriers, and unsuitable stream design. However, the moor frog and great crested newt have been found in more urban settings elsewhere and therefore should be able to colonise blue-green infrastructures, provided they are suitably designed. The Norwegian population of the red listed pool frog (*Pelophylax lessonae*) is small (<50 individuals) and only present in a few ponds in close proximity in Agder county (approximately 180 km southwest of Ås). The species is therefore not relevant to this study.

Sammendrag

Amfibier er den mest truede vertebratgruppen globalt, med alarmerende tilbakegang og høye utryddelsesrater. Den største trusselen er habitattap og ødeleggelser. Urbanisering og utviklingen av infrastruktur er en stor driver av tilbakegangen, og forårsaker ødeleggelser av terrestrisk- og akvatiskhabitat, samt endringer i nedbørfeltets hydrologi. Blå-grønn infrastruktur (BGI) reintroduserer naturlige elementer til urbane miljøer, og blir stadig mer vanlig for å forebygge og motvirke de negative effektene av urbanisering. BGI skaper habitat for en rekke organismegrupper, og kan kanskje gi mulighet til å skape habitater som kan bidra til bevaring av utsatte arter. Målet med denne oppgaven var å undersøke om blå-grønn infrastruktur kan støtte amfibiepopulasjoner.

For å oppnå dette målet studerte jeg amfibiene i en nylig konstruert «blågrønn bekk» på Norges miljø- og biovitenskapelige universitets campus i Ås, Norge. Observasjons- og fangstmetoder ble benyttet for å identifisere amfibiene som var til stede i bekkesystemet. I tillegg ble det konstruert kunstige makrofytter for å teste om disse kunne benyttes av småsalamanderen (*Lissotriton vulgaris*) til egglegging. Det ble også tatt målinger av vanntemperatur, samt tatt og analysert prøver av krepsdyrsamfunnet for å identifisere mulige begrensinger i amfibieforekomst.

Studien fant at nordpadde (*Bufo bufo*), buttsnutefrosk (*Rana temporaria*) og småsalamander reproduserte i bekkesystemet. Ingen egg av småsalamander ble funnet på de kunstige makrofyttene, men småsalamander larver ble funnet i den ene dammen. Artene funnet i bekken er generalister, og ingen rødlistede av de tre rødlistede artene ble funnet. Fisk, vanntemperatur og mattilgang kan være begrensende for forekomst i deler av bekken. De rødlistede artene spissnutefrosk (*Rana arvalis*) og storsalamander (*Triturus cristatus*) var fraværende, noe som kan skyldes en mangel på en passende «Source»-populasjon, passende terrestrisk habitat, migrasjonsbarrierer og begrensinger i bekkedesign. Spissnutefrosken og storsalamanderen har derimot tidligere blitt funnet i urbane settinger andre steder, og bør derfor kunne kolonisere blågrønne bekker, gitt et passende design. Den norske populasjonen av den siste rødlistede arten, damfrosk (*Pelophylax lessonae*), er svært liten (<50 individer) og finnes kun i 3 til 4 nærliggende tjern i Agder fylke (ca. 180 km sørvest for Ås). Arten er derfor ikke relevant for denne studien.

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1. Introduction

Amphibians are the most threatened vertebrate group globally (Luedtke et al., 2023). 41% of the amphibian species assessed by the International Union for Conservation of Nature (IUCN) are threatened with extinction and, as per 2022, 37 species are confirmed extinct (IUCN, 2023; Re:wild et al., 2023). However, due to strict requirements for declaring a species extinct there could be as many as 222 extinctions, as 185 species with no known surviving populations are listed as possibly extinct in addition to the 37 confirmed extinctions (Re:wild et al., 2023). These alarming trends of amphibian extinctions and declines provide evidence that we are likely witnessing an ongoing sixth mass extinction, with amphibian extinction rates estimated to be 200 times higher than background rates (McCallum, 2007; Wake & Vredenburg, 2008).

The reasons behind, and the drivers of, the amphibian decline are complex and there are multiple factors at play. Current threats driving amphibian declines are, among others, habitat loss or degradation, climate change, disease, invasive species and over-exploitation (Re:wild et al., 2023). These threats drive amphibian declines, but their relative importance varies between species, populations, and regions (Grant et al., 2020; Re:wild et al., 2023). However, the top threat is the loss and degradation of habitat which is currently impacting 93% of threatened species (Luedtke et al., 2023; Re:wild et al., 2023).

Amphibians can be more sensitive to habitat changes than other vertebrate species. Amphibian species with complex life cycles, such as the Norwegian amphibians, need both aquatic and terrestrial habitats that can provide resources for breeding and non-breeding activities, e.g. dispersal, overwintering sites, and shelter (Dolmen, 2008; Semb-Johansson et al., 1992; Wells, 2007). It is this dependency on multiple habitats that make them particularly vulnerable. The loss or degradation of, or isolation from, one habitat will make the species vulnerable even if the other habitats remain in good condition (Wells, 2007). The driver of habitat loss and degradation is human population growth and expansion. This is reflected when categorising the types of loss and destruction, with top threats being; agriculture, timber and plant harvesting, and infrastructure development (Re:wild et al., 2023).

Infrastructure development and urbanisation is a threat to 47% of threatened amphibians (Re:wild et al., 2023). Urbanisation results in destruction, disruption, and degradation of both terrestrial and aquatic habitat. Between 1990 and 2015 built-up area expanded with 243,000 km^2 and urban area has been projected to increase with roughly 40-67% until 2050 relative to

2013 (Denis, 2020; Li et al., 2019). Urbanisation also changes the hydrology of an area through instalments of impervious surfaces and the culverting and burial of streams (Paul & Meyer, 2001; Whitford et al., 2001). Culverting is the redirection of a stream through a closed and impermeable man-made channel, which is often buried to gain land in an urbanising area (Broadhead et al., 2013; Elmore & Kaushal, 2008). Smaller streams may just be filled in and paved over (Paul & Meyer, 2001). Stream burial and impermeable surfaces reduce the area's ability for storage, infiltration, and evapotranspiration of received water, leading to increased surface runoff which bring an increased likelihood of flooding, as well as increased levels of nutrient load, metals and other contaminants in the remaining waterbodies (Paul & Meyer, 2001; Whitford et al., 2001). There is also the additional challenge of climate change likely leading to more frequent and high-intensity rain events in temperate regions (Madsen et al., 2014; Tabari, 2020), worsening the effects of a changed hydrological regime. As climate adaption and to mitigate the negative effects of urbanisation on hydrology, many cities are starting to open previously buried streams, so called de-culverting or daylighting, and implementing blue-green infrastructures (Bergen Kommune, 2019; Debele et al., 2023; Siehr et al., 2022; Tromsø Kommune, 2020).

Blue-green infrastructures (BGI) are planned and interconnected structures of natural and semi natural vegetated (green) and aquatic (blue) areas that utilise natural processes as a nature-based solution to restore the hydrological functioning and manage stormwater in an urban landscape (Brears, 2018; Donati et al., 2022). As opposed to traditional or “grey” stormwater management, which utilise structures such as pipes and culverts (Alves et al., 2019). In addition to stormwater management, BGI can also provide several additional benefits, or so-called co-benefits, by understanding and making use of the relationships between vegetation and the hydrological cycle (Brears, 2018). These co-benefits can be economic, social and environmental (Wild et al., 2011). For example, de-culverting and restoring a stream to receive and manage more stormwater will also provide aquatic habitat, opportunities for children’s play and education, enhance visual attraction and the spaces identity, while reducing damages from potential floods (Wild et al., 2011). BGI bring nature into urban areas, which creates opportunities for biodiversity, by re-establishing habitats and increasing habitat connectivity (Nguyen et al., 2021). This might provide an opportunity to facilitate habitat for species of conservation concern, like amphibians.

BGIs may be able to provide an opportunity for habitats that could support local amphibian populations. Many studies highlight the importance of adjacent aquatic and terrestrial habitat for amphibians. The habitats size and quality, as well as proximity to other suitable habitats, and the connectivity between them, all affect dispersal ability, and the abundance and richness of amphibians in an urban pond (Knutson et al., 1999; Parris, 2006; Rubbo & Kiesecker, 2005; Sauer et al., 2022). Sauer et al. (2022) observed that amphibians seem to readily colonise urban and suburban ponds, while Holtmann et al. (2017), Knozowski et al. (2022), and Oertli and Parris (2019), all mention that urban waterbodies and wetlands show a promising future in amphibian conservation with the right management. This seems to indicate that BGIs can provide habitat for amphibians. However, BGIs also present with trade-offs (Demuzere et al., 2014; Prudencio & Null, 2018), and research is needed to look at whether a blue-green stream's functionality clashes with amphibian life history requirements.

Habitat destruction, degradation and loss is also the largest threat to Norwegian amphibians (Dervo et al., 2016b; Dervo et al., 2021e), and three out of the six amphibian species, that are registered as naturally occurring and reproducing in Norway, are listed on the Norwegian Red List of Threatened Species. The Pool frog (*Pelophylax lessonae*) is listed as Critically Endangered (CR), and the moor frog (*Rana arvalis*) is listed as vulnerable (VU) (Dervo et al., 2021c). The crested newt (*Triturus cristatus*) is currently listed as near threatened (NT), but the current decline is substantial enough that the species is on the verge of being evaluated as vulnerable (Dervo et al., 2021d; Dervo et al., 2021e). It is also worth noting that although the Smooth newt (*Lissotriton vulgaris*) is evaluated as Least Concern (LC), populations are declining and should be monitored closely (Dervo et al., 2021b). With increasing interest in blue-green infrastructure and de-culverting as a measure for stormwater management in Norway (Magnussen et al., 2017; Sandin et al., 2022), is it possible that these new patches of nature can support amphibian populations?

In this thesis, I take a closer look at the amphibians and their environment in a constructed and de-culverted stream on the Norwegian University of Life Sciences (NMBU) campus in Ås, Akershus, Norway. The thesis aims at answering the following questions:

- Are amphibians present in the stream system?
- If amphibians are present, which species, where, and how many?
- Can artificial macrophytes be used for newt oviposition?
- Can food availability be a limiting factor for newt occurrence in the stream?
- Is water temperature related to amphibian occurrence in the campus stream?

2. Method

2.1 Norwegian amphibians: Species description

The Norwegian amphibians, smooth newt (*Lissotriton vulgaris*), crested newt (*Triturus cristatus*), common frog (*Rana temporaria*), moor frog (*Rana arvalis*), northern pool frog (*Pelophylax lessonae*), and the common toad (*Bufo bufo*), all need both aquatic and terrestrial habitats (Dolmen, 2008; Semb-Johansson et al., 1992). In spring come out of hibernation and migrate to their breeding pond (Semb-Johansson & Frislid, 1981; Semb-Johansson et al., 1992). After reproducing, most of the Norwegian amphibians leave the breeding pond and migrate to terrestrial habitats where they stay until autumn with varying degrees of moisture and pond dependency (Dolmen, 2008; Semb-Johansson et al., 1992). In the autumn they all seek out frost-free habitats and hibernate through the winter (Dervo et al., 2018; Dolmen, 2008).

Newts

There are many similarities between the two Norwegian newts. Both species start their migration to the breeding pond in late April or early May and spend a couple of weeks morphing to an aquatic suit (Dervo et al., 2016a; Semb-Johansson & Frislid, 1981). The Norwegian newts start breeding in May to June when the water reaches around 10 degrees Celsius (ºC), and oviposition will start immediately after breeding (Dolmen, 2008; Malmgren, 2007; Semb-Johansson et al., 1992). The eggs are laid one by one on the leaves of aquatic vegetation, the leaf is then carefully folded around the egg for protection (Semb-Johansson et al., 1992). The eggs will hatch after 2-3 weeks depending on the water temperature (Semb-Johansson et al., 1992). After oviposition the adults will generally leave the pond, however this is dependent on food availability, and they may stay in the pond until the end of July (Dervo, 2024; Malmgren, 2007). It is more common for the crested newt to remain in the pond for a longer period as it is more water-dependent (Semb-Johansson et al., 1992). The larvae of both species eat crustaceans and incorporate small macroinvertebrates as they mature (Bell, 1975; Griffiths, 1986; Griffiths & Mylotte, 1987; Semb-Johansson et al., 1992). The larvae of the smooth newt undergo metamorphosis and emerge from the pond in July to September depending on temperature, while the crested newt larvae take somewhat longer to develop and emerge from August until October (Dolmen, 2008). The juveniles will stay on land until they reach sexual maturity (Semb-Johansson et al., 1992).

Anurans

There are three frog species confirmed to be reproducing in Norway; the common frog, the moor frog, and the northern pool frog. The northern pool frog is extremely rare in Norway, the only known occurrences in Norway is a small population (<50 individuals) in 3 to 4 ponds close in proximity in Agder County, approximately 180 km southwest of Ås and the study stream (Dervo et al., 2021a; Dolmen, 2008). The species is therefore not relevant for the current study.

The common frog reproduces from April to June and needs little warmth to start laying eggs (Dolmen, 2008; Semb-Johansson et al., 1992). The common frog can start egg-laying at a water temperature as low as 1ºC, leading to multiple cases of eggs laid in ponds with a partial ice cover (Dolmen, 2008; Semb-Johansson et al., 1992). The eggs are laid in clusters in shallow areas along the pond edge and will typically rise and float on the water surface (Dolmen, 2008; Semb-Johansson & Frislid, 1981). The eggs take around one week to hatch depending on temperature (Semb-Johansson & Frislid, 1981). The main diet of the larvae is algae, and they undergo metamorphosis between July and October, depending on the temperature of the season and when the larvae hatched (Dolmen, 2008; Semb-Johansson et al., 1992).

The moor frog reproduces in April to May, generally a week later than the common frog (Dolmen, 2008; Semb-Johansson et al., 1992). The eggs are normally laid in deeper water, and the eggs typically remain on the pond floor (Dolmen, 2008). As the eggs are laid in deeper water, the water temperatures are lower and hatching takes longer than for the common frog (Semb-Johansson et al., 1992). The larvae eat mainly algae and undergo metamorphosis in the middle of July (Dolmen, 2008; Semb-Johansson et al., 1992).

The last anuran confirmed to be breeding in Norway is the common toad. The common toad migrates to their breeding pond in April or early May and reproduces for a short period in May to June before they quickly reemerge on land and migrate to their summer habitat (Dolmen, 2008; Semb-Johansson et al., 1992). The toad waits for the water temperature to reach about 8 ºC to start laying eggs (Semb-Johansson & Frislid, 1981). The eggs are laid in long strings or strands with many eggs and are often coiled around and suspended between the aquatic vegetation (Dolmen, 2008). The eggs hatch after around 10 days, depending on temperature, and the larvae eat by scraping off algae and other small organisms that are attached to aquatic leaves (Dolmen, 2008; Semb-Johansson & Frislid, 1981). The larvae undergo metamorphosis in July to August (Dolmen, 2008). Both the adults and the larvae of the common toad are poisonous, which makes them less susceptible to predation and results in toads being more common in fish-rich ponds and lakes (Ahlén et al., 1995; Elmberg, 2023). The toad is generally less dependent on water and moisture than the frogs (Dolmen, 2008; Semb-Johansson et al., 1992).

2.2 Study area

The study stream, known as "Campusbekken" or the Campus Stream, is located on the campus of the Norwegian University of Life Sciences (later referred to as NMBU) in Ås municipality, in Akershus county, Norway.

The stream starts in the larger pond Andedammen, and runs via "Niagara", through a series of smaller ponds to the larger pond Lille Årungen. From there the stream runs along the south side of the Norwegian Veterinary Institute onto the NMBU frisbee golf course and through a constructed wetland, with two ponds, and out into Vollebekken, which outlets in Lake Årungen. At various points along the stream, pipes feed rainwater from the surrounding buildings into the stream (Fredriksen, 2023). On the frisbee golf course, there is a third pond, which drains into the Campus Stream. The pond is dubbed the Turbid Pond for this thesis and

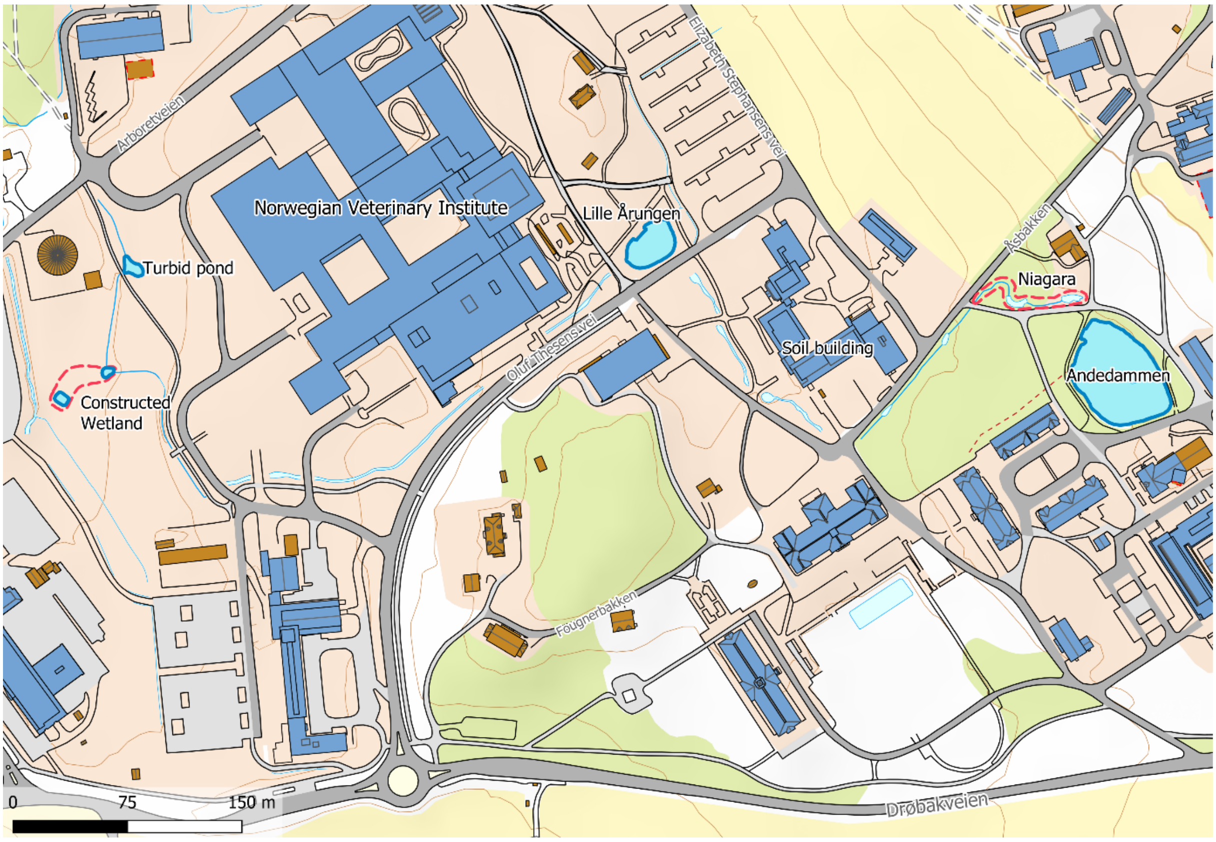

Figure 1: Map showing the stream and the surrounding area. The stream runs from Andedammen to the constructed wetland where it outlets into Vollebekken. Background map owned by Kartverket, retrieved via GeoNorge.no. Map created by Haraldstad, I., 2024.

originates from the drainage of rainwater from the Veterinary Institute building. For a visual of the area, see Figure 1.

The entire stream is man-made, though it has been constructed in increments. The age of Andedammen is unknown, all that is known is the pond was there when the university was founded in 1859 (Norsk Landskapsarkitekters Forening, s.a.-b). The first part of the stream garden named Niagara was made in the 1940s and extended in 2018 (Norsk Landskapsarkitekters Forening, s.a.-a). When the veterinary institute moved to Ås in 2020, the last stretch (from the soil building down to Vollebekken) and its ponds; Lille Årungen, Turbid Pond and the Constructed Wetland, was de-culverted. These ponds were therefore only 3 years old during the fieldwork period.

The stream was constructed as stormwater management on the NMBU campus and is designed to handle high run-off volumes and floods from high precipitation and snowmelt. The water flow is generally low and in periods with low precipitation stretches are left dry with water only remaining in the stream's ponds. In dry periods, many of the smaller ponds also dry out.

2.2.1 Pond selection and description

When identifying amphibian species in the stream, six ponds were focused on. The six ponds are referred to as Andedammen (short: A), upper Niagara (N), Lille Årungen (LÅ), the Turbid Pond (T), the Upper Wetland Pond (W1), and the Lower Wetland Pond (W2). The last two were named for their upstream and downstream location in the constructed wetland. The wetland is considered one system. These six ponds appear to be permanent which is a baseline requirement for Norwegian amphibian breeding. However, as Upper Niagara and the Turbid Pond are quite shallow, around 0.5 m and 0.3 m deep respectively, it is not unlikely that the ponds may dry out in particularly warm years.

Andedammen is the first pond and the start of the stream system. The pond is approximately 2850 m^2 and 2-3 m deep. It is fed by groundwater and rainwater from the surrounding building. Aquatic edge vegetation is concentrated along the western edge of the pond, while lily-pads are present in the entire pond. The western side of the pond also has more terrestrial vegetation, with taller trees and bushes providing significant shade along this edge. The aquatic vegetation provides potential amphibians with hiding opportunities from terrestrial predators. The pond is stocked with one species of fish, crucian carp (*Carassius carassius*).

The first pond in the stream garden Lille Niagara has a low water level and could potentially dry out in warm years. The pond is approximately 45 m^2 and around 30 cm deep. There is low vegetation along the edges and a patch of aquatic vegetation in the middle of the pond. The pond is not stocked with fish, but some small strays may wash down from Andedammen during heavy rain.

Lille Årungen is approximately 450 m^2 and around 2 meters deep. It has vegetation along all edges of the pond. The pond is not stocked with fish. Lille Årungen had a large algal bloom in late spring/early summer, a lot of which was concentrated along the pond's edges, giving shade, and hiding opportunities for potential amphibians. The outlet area of the pond has been colonised by taller emergent macrophytes which shade the immediate area.

The Turbid Pond is named after its high turbidity. It is approximately 50 m^2 and around 0.5 m deep. There are short emergent aquatic grasses along the pond's edges. The high turbidity gives low visibility and therefore good cover for potential amphibians. There is no taller vegetation around the pond and no opportunity for shade beyond the turbid water. The pond is not stocked with fish.

The constructed wetland contains two ponds. The Upper Wetland Pond is around 20 m^2 and 1 m deep. The pond is surrounded by tall emergent macrophytes, as well as some growing throughout the pond. It is not stocked with fish. The Lower Wetland Pond has emerging vegetation on three of four sides, with many taller grasses. The surface of the pond has a high cover of duckweed (*Lamna sp.*). The pond is approximately 55 m^2 and 1 m deep and does not have any fish.

2.2.2 Stream maintenance

There has been maintenance and upkeep of the stream during the fieldwork period. The Park Department also makes sure drains remain open to aid in draining water and reducing floods.

In Andedammen the waterlilies are cut every year to expose more of the water surface. This was done on the 11th of July 2023 and it took two days to cut the lilies and remove the debris. Cutting is done by boat and clean-up by people in waders, resulting in two days of disturbance in most of the pond.

The newer stretches of the stream, running from the soil building and onward, are weeded for unwanted plants, such as aggressive and invasive grasses, but are otherwise left alone to allow natural colonisation of plants. The stream garden, Niagara, has more rigorous maintenance as it is part of the historical park area on campus. This entails more intensive work such as weeding, cutting, and pruning.

The spring and early summer of 2023 was especially hot and dry leading to low water levels in the stream's ponds. During such especially dry periods, water is pumped from the local lake Årungen to Andedammen. In 2023, this was done in the last week of June to mediate the low water levels.

2.3 Data collection

All fieldwork and data collection were done during the spring, summer, and autumn of 2023. An overview of all sampling events, and where they took place, can be found in Table 1 and a map of all the sampling events can be found in Figure 2. At the start of the fieldwork, data collection was limited to the stretch of stream between Andedammen and Lille Årungen. This means that there were only temperature stations and artificial macrophytes in Andedammen and Lille Årungen, and that anurans were not looked for in the ponds downstream from Lille Årungen before the study area was expanded in late-May.

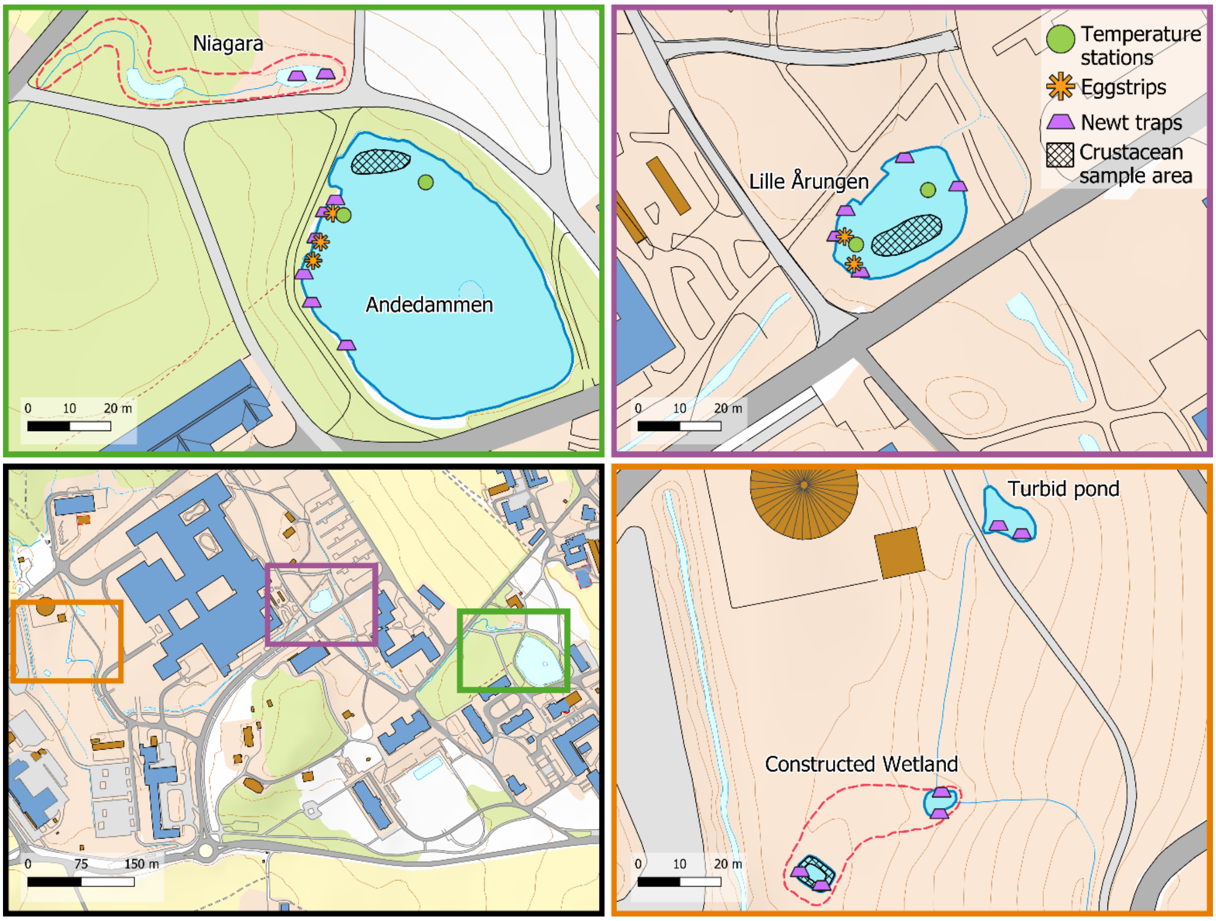

Figure 2: Map showing placement and area of all sampling events in the study area. Background map owned by Kartverket, retrieved via GeoNorge.no. Map created by Haraldstad, I., 2024.

Table 1: An overview of all sampling events in the different ponds of the campus stream.

Pond	Temperature	Crustacean net sweep	Egg strips	Funnel traps	Larvae dipnet
Andedammen	x	x	x	x	x
Upper Niagara				x	x
Lille Årungen	x	x	x	x	x
Turbid Pond				x	x
Upper Wetland Pond				x	
Lower Wetland Pond		x		x	x

2.3.1 Temperature measurements

Temperature was measured in the two largest ponds, Andedammen and Lille Årungen, to see if differences occurred between the ponds that could explain amphibian occurrence, and to get an impression of when the different species would start their breeding activities. In each pond, two temperature stations were placed.

The temperature stations were constructed by attatching a piece of wood as a flotation device at one end of a rope with an anchor at the other. About 30 cm down from the flotation device, two temperature loggers were placed along with a small weight to keep the loggers at 30cm below the surface when the water level changed. 30 cm was chosen as it is a middle-deep where we see the most newt activity (Dervo & van der Kooij, 2020), it also shows temperature relevant for the moor frog. The HOBO MX2201 Pendant Water Temperature Data Logger was used. These loggers have an accuracy of ± 0.5ºC (Onset, s.a.). They were set to log once an hour on the full hour mark (12:00, 13:00, and so on), as the temperature in a pond is mostly stable and generally does not have sudden fluctuations.

In Andedammen stations T1 and T2 were placed (Figure 3). T1 was located on the northeastern side of the pond in a shallow and sunnier area with little aquatic vegetation. T2 was located on the western side which is shaded by tall terrestrial vegetation and lily-pads.

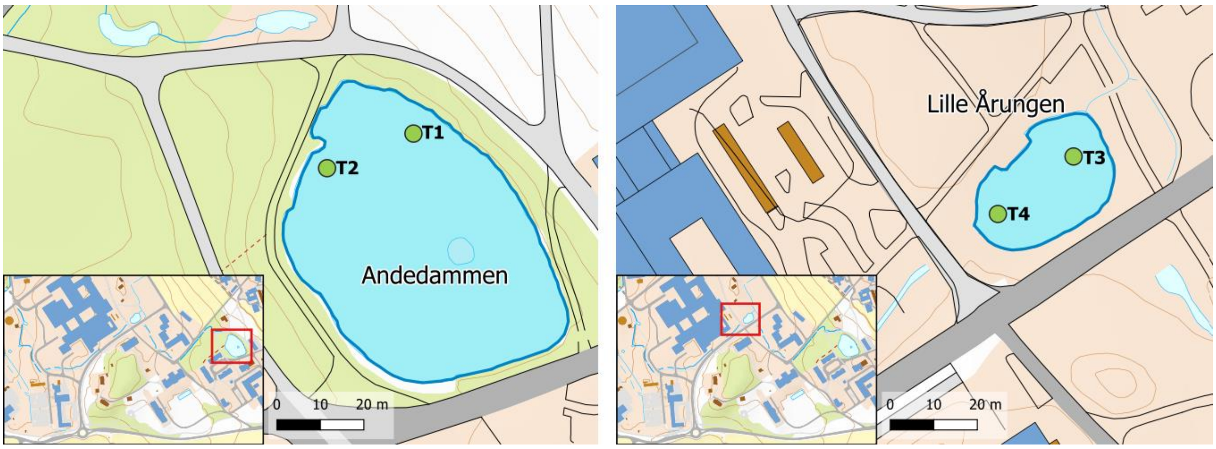

Figure 3: Map showing placement of the temperature stations, T1-T4, in Andedammen and Lille Årungen. Background map owned by Kartverket, retrieved via GeoNorge.no. Map created by Haraldstad, I., 2024.

In Lille Årungen the stations T3 and T4 were placed (Figure 3). T3 was placed south of the inlet, in a sunny area with short riparian vegetation. T4 was placed close to the tall emergent aquatic vegetation by the outlet. The loggers were placed at these sites to get a general impression of how the temperature differs between sunny and shaded areas and the inlet and outlet area, for a more diverse picture of the pond's temperature. The loggers were placed between 12:30-13:00 on the 21st of April and started logging at 12:00 the same day. This was done to check that the loggers were active before being placed as the Bluetooth range is severely affected by being submerged in water.

A short while after the loggers were placed, the wood became waterlogged and empty plastic half-litre bottles were attached as an emergency solution and later replaced with buoys. After the extreme weather event that happened in early August, the temperature loggers in Lille Årungen moved and had to be repositioned to their original spot. Maintenance on the stations was done just past the full hour (after 12:00, 13:00, etc.) to have as little effect as possible on the logged temperature.

2.3.2 Crustacean community survey

Crustacean sampling: Net sweep

To investigate food availability for newts, net sweeps were done in three ponds, Andedammen, Lille Årungen and Lower Wetland Pond. The net sweeps were standardised to two minutes in each pond, to be able to compare the samples between ponds. The sweeps were also done in the same general area within the ponds between months to ensure consistency between samples.

The net had a mesh size of 45µ, which allowed no crustacean to pass through. To procure the samples, the sides of the net were sprayed with water to ensure all the material inside was transferred to the container at the bottom of the net. Then, the container was unscrewed, and a funnel was used to transfer the contents into glass vials by spraying water through the mesh bottom of the container. A few drops of a lugol's iodine solution were added to the samples to preserve the samples and stain the organisms for easier identification. The samples were placed in an refrigerator from the sampling date until they were examined on the 15th and 17th of November. During this period, it was necessary to open a couple of the vials and add a few extra drops of the lugol's solution.

Three sweeps were done in each pond. The first net sweep happened over two days, the 8th and 9th of June, the reason being a sweep in the Upper Wetland Pond before realising that waders were needed for sweeps in Andedammen and Lille Årungen due to vegetation and algae growth. For the other sweeps, July 13th and August 31st, waders were used to ensure consistency for all samples. For a map of the approximate area where the sweeps were done see Figure 2.

Crustacean analysis

To attain an impression of the relative crustacean species abundance, a subsample was counted using a stereo microscope. The subsample was prepared by diluting the original sample with water and extracting 10 mL portions for counting crustaceans. Dilution with water served two purposes: to reduce the intensity of the colour of the Lugol solution and to prevent overwhelming crustacean densities. This ensured more accurate counting. The 10 mL portions were transferred to an acrylic board with four shallow wells, making the crustaceans easily visible and easier to count. A minimum of 200 individuals was counted in each subsample to ensure statistical reliability when calculating an estimate of the total number of crustaceans for the whole sample.

The volume of the subsample was used to determine the scaling factor necessary for estimating the total crustacean count in the original sample. This was achieved by calculating the ratio of the total volume of the diluted sample to the volume of the subsample. Multiplying the crustacean count obtained from the subsample by this ratio provided an estimate of the total number of crustaceans in the entire original sample.

For each subsample, species were identified, and their relative abundance was determined in a three-tiered system, three (3) for dominant species (>10%), two (2) for common species (1-10%) and one (1) for rare species (<1%). Not all crustaceans could be identified on a species level. However, all these crustaceans were identified as either order *Calanoida* or family *Cyclopidae*.

The average size of the crustacean species was estimated to look at the relationship between size and dominance level between the ponds. The size was estimated by taking the species maximum and minimum for each sex and calculating the average. As size was estimated on a species level, the unidentified *Calanoida sp.* and *Cyclopidae sp.* did not have an applicable value.

2.3.3 Artificial macrophytes (Egg strips)

Artificial macrophytes were constructed to test if oviposition on artificial vegetation could be facilitated for the smooth newt and be used as an egg surveying method for the species. The artificial macrophytes were constructed with 12 egg strips attached to the end of a stick. The egg strips were 5 mm wide and 30-40 cm long strips of plastic cut from a plastic grocery store bag (Figure 4). The stick was then placed in the pond so that the base of the strips on the stick was positioned around 10 cm under the water's surface with the ends of the plastic floating up to and on the water's surface (figure 5). Five artificial macrophytes were made. Three were placed in Andedammen in the vegetation along the shaded side, and the other two were placed in Lille Årungen in and around the vegetation (Figure 2). Signs were made to inform passersby that the plastic was placed in the pond with the intention of newt oviposition.

The artificial macrophytes were placed on the 9th of May and checked once a week with the intention of counting the number of eggs if present. These checks lasted until removal on the 31st of May. At that time, it was considered unlikely that they would be utilised for newt oviposition if they had not already been so.

Figure 4: Artificial macrophyte before placement. Photo: Haraldstad, I., 2023

Figure 5: The artificial macrophyte placed in the vegetation and algal growth in Lille Årungen. Photo: Haraldstad, I., 2023

2.3.4 Identifying anurans in the stream system

Observations of adults and egg clutches/strings were done to survey what anurans were present in the stream system. This was done by walking around Andedammen and Lille Årungen and along the stream ca. twice a week from April 21st to May 31st. Observations were logged with the date of observation, species, and life stage of observation. Observations during other fieldwork were also logged.

2.3.5 Identifying newts in the stream system

To confirm the presence of newts in the stream system both funnel traps and a dipnet were used. Funnel traps, to catch grown individuals, were set up in Andedammen, the first pond in Niagara, Lille Årungen, the Turbid Pond, and in the Upper and Lower Wetland Ponds, during the last days of May and in early June (Table 2). A plastic bottle was placed inside the trap to ensure that the top of the trap was above water level, ensuring that air was available for trapped individuals. Explanatory signs were placed at the pond edge asking passersby not to disturb the traps. The number of traps placed was dependent on the size of the pond. 7 traps were placed in Andedammen, 5 in Lille Årungen and 2 in each of the smaller ponds. Figure 2 shows the placement.

Table 2: An overview of trap placement and retrieval in the six ponds, and the number of traps placed in them.

Date of placement	Date of retrieval	Pond	Number of traps
28.05.2023	29.05.2023	Andedammen	7
29.05.2023	30.05.2023	Lille Årungen	5
29.05.2023	30.05.2023	Upper Niagara	2
31.06.2023	01.06.2023	Lower Wetland Pond	2
31.06.2023	01.06.2023	Turbid Pond	2
07.06.2023	08.06.2023	Upper Frisbee Pond	2

A net sweep with a dip net was done to survey newt larvae. This was done by rapidly moving the net back and forward a couple of times along the riparian vegetation, and then emptying the contents in a white basin with water. The net had a mesh size of 250µ. In each pond, a maximum of 12 net sweeps were done, stopping at the discovery of newt larvae to not cause further disturbance or stress. The sweeps were done at the same sites as the traps, except for the Upper Wetland Pond which, as a part of the wetland, was considered to be the same system as the Lower Wetland Pond. The net sweeps were done on August 30th between 15:00 and 16:30.

2.4 Data processing and visualisation

All maps were created using QGIS 3.28 Firenze. A WMS-service, owned by Kartverket retrieved via GeoNorge.no, was used for the background map. The data layers were manually created in QGIS. The pond polygons were traced from the background map provided by Kartverket. Polygons were made using 'Add Polygon', and additional details were refined using the 'Add Ring' feature. The point layers were created using 'Add Point', and the line layer was created using 'Add Line'.

Data was processed and visualised in Rstudio 2023.12.1 with R statistical language (R Core Team, 2022). R packages used in data processing and manipulation was ‘dplyr’(Wickham et al., 2023a), ‘tidyr’(Wickham et al., 2023b), and ‘lubridate’(Grolemud & Wickham, 2011). Data visualisation was done with the R packages ‘ggplot2’(Wickham, 2016), and ‘gridExtra’(Auguie, 2017).

2.4.1 Temperature data

For the temperature data, a mean was estimated between the two loggers on each temperature station, creating only one datapoint per hour for each temperature station. The data were also modified to only include complete days, i.e. 24 data points per date per temperature station. This also ensured that data from the date of placement and extraction were removed. A daily mean calculated for the ponds Andedammen and Lille Årungen to get an impression of the general temperature trends. This was done by first calculating the mean for each temperature station, then finding the mean between the two stations in each pond.

Outliers were calculated to see if any unexpected temperatures occurred in relation to the maintenance done on the temperature stations. This was done in Rstudio with the ‘boxplot.stats’-function which is a part of base R. On two temperature stations, outliers were observed. However they were not removed as, even though they were outliers for that month, they were not outliers with respect to the entire season and they did not occur in connection with temperature station maintenance.

2.4.2 Crustacean data

A nonmetric multidimensional scaling (NMDS) analysis was run on the crustacean data to look at similarities in the community composition between the ponds. The analysis was run on the species numerical dominance grading in the different ponds and months. Species that were not present in a pond were given a value of zero; 0 – absent. The analysis was run in Rstudio using the R package ‘vegan’ and the function ‘metaMDS’ (Oksanen et al., 2022). A Bray-Curtis similarity metric was used.

3. Results

3.1 Water temperature

The temperature loggers were placed in Andedammen and Lille Årungen on April 21st, 2023, and temperature measurements began at 00:00 on April 22nd. The first three days the temperature was around 11 ºC before it dropped to approximately 8 ºC in Andedammen and 5 ºC in Lille Årungen due to a weather change (Figure 6). The highest temperatures were recorded during mid and late June in Andedammen and mid and late July in Lille Årungen, each at a depth of 30 cm (Table 3).

Table 3: Maximum and minimum water temperature recorded at the four temperature stations. T1 and T2 were located in Andedammen in an open sunny area and a more shaded area, respectively. T3 and T4 in Lille Årungen, by the inlet and outlet of the pond. All loggers were placed at a water depth of 30cm.

Temperature station	Max. temperature	Min. temperature
T1	22.3 ºC June 17th at 22:00	3.6 ºC October 30th at 06:00
T2	23.1 ºC June 28th at 20:00	3.4 ºC November 2nd at 23:00
T3	23.2 ºC July 21st at 16:00	3.6 ºC October 22nd at 05:00
T4	23.4 ºC July 16th at 15:00	3.4 ºC October 22nd at 05:00

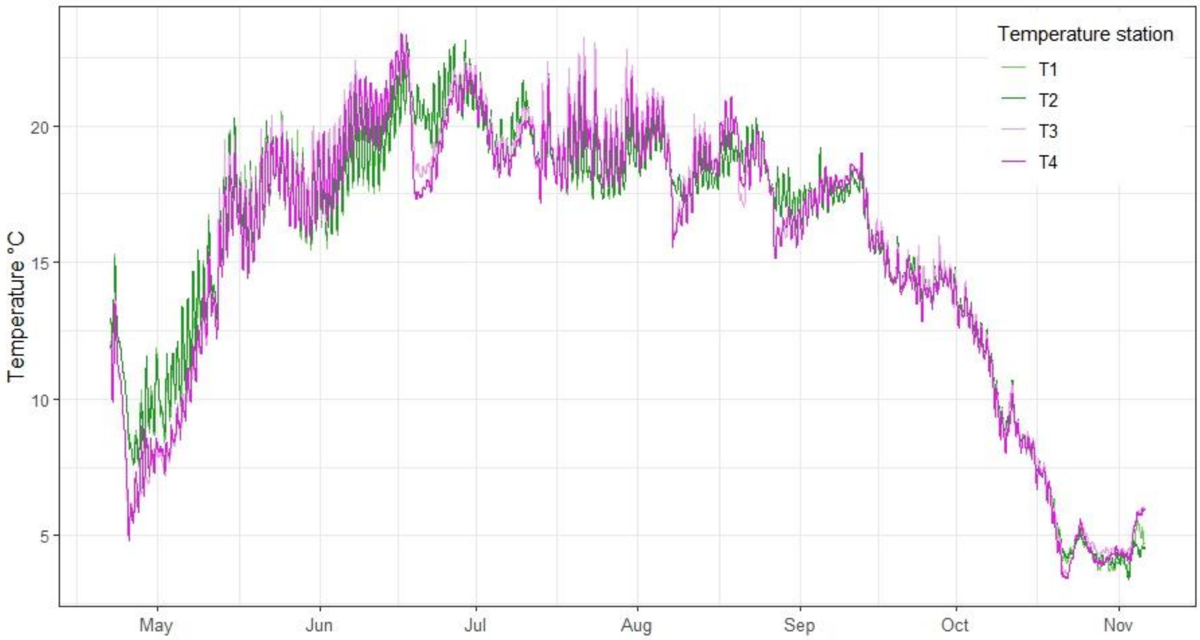

Figure 6: Water temperature at four stations from 22.04.23 to 05.11.23. T1 and T2 were located in Andedammen in an open sunny area and a more shaded area, respectively. T3 and T4 in Lille Årungen, by the inlet and outlet of the pond. All loggers were placed in a water depth of 30cm.

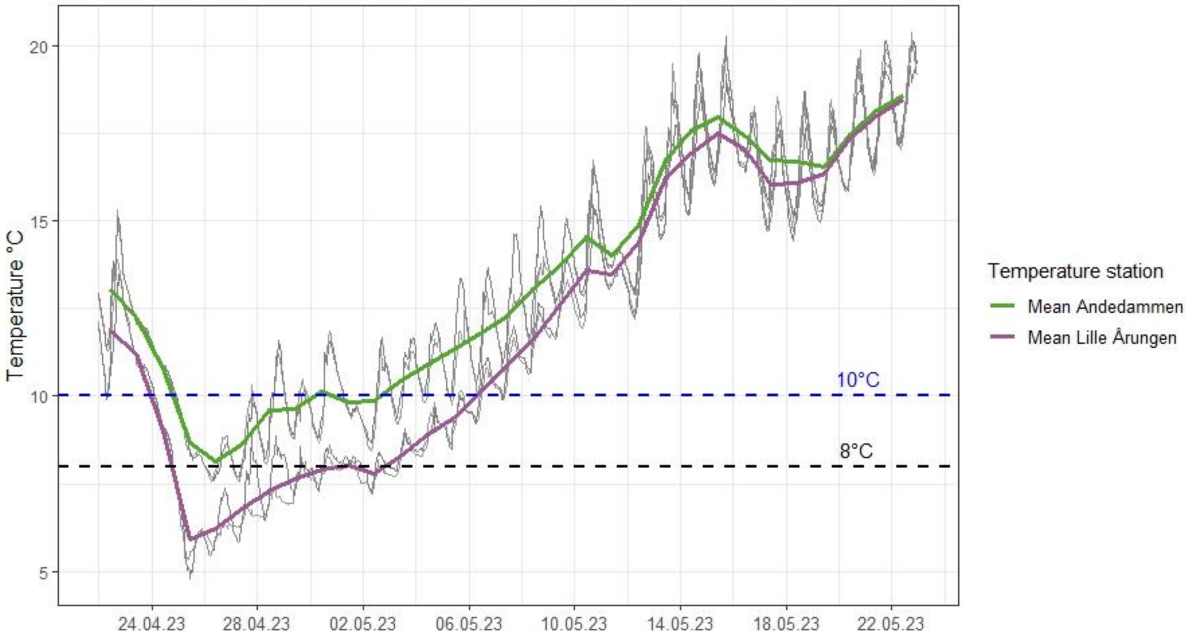

Figure 7: Excerpt from the temperature graph showing the start of the fieldwork period, from 22.04.23 to 21.04.23. A daily mean was calculated for Andedammen and Lille Årungen and overlayed the hourly measurements from temperature stations (in grey). Andedammen is a mean of T1 and T2, and Lille Årungen is a mean of T3 and T4. Horizontal lines indicate the 10 and 8 ºC threshold for breeding and egg laying for the smooth newt and common toad respectively. All loggers were placed in a water depth of 30cm.

Initially, temperatures in both ponds exceeded 10 ºC, the threshold for newt breeding, before subsequently dropping. In Andedammen, temperatures briefly fell below 8 °C, the temperature at which the common toad starts egg laying, on April 26th and 27th, but the average temperature remained above 8 °C (Figure 7). Daytime temperatures in Andedammen rebounded above 10 °C by late April with brief fluctuations. An average of 10 °C was reached on April 30th and remained above from May 3rd onward (Figure 7). In Lille Årungen, the temperature dropped more significantly, reaching as low as 5 ºC. The average temperature in Lille Årungen briefly fell below 6 ºC, it increased to 8 ºC by May 1st and remained above 8 ºC from May 3rd onward. By May 6th, the temperature had steadily increased and reached 10 ºC (Figure 7).

At the end of April and beginning of May, temperatures in Lille Årungen were consistently a few degrees cooler than in Andedammen (Figure 8). Starting on April 23rd, the temperature difference between Andedammen and Lille Årungen ranged from 1.5 to 2 ºC. On April 25th this difference increased to between 2.5 to 3 ºC. Although T4 recorded lower temperatures, it exhibited the same daily variation pattern as the stations in Andedammen. T3 did not display the same daytime temperature spikes.

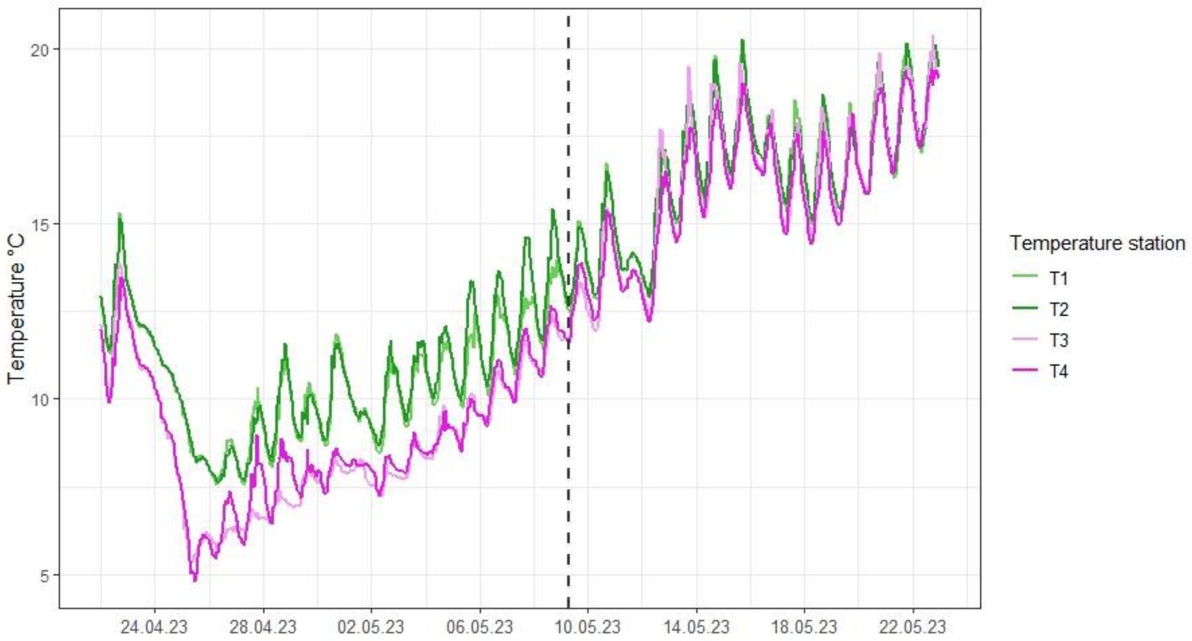

Figure 8: Excerpt from the temperature graph showing the start of the fieldwork period, from 22.04.23 to 23.04.23. A vertical line is added at 09.05.23 at 11:00 i.e. the date and time the waterlogged temperature stations in Lille Årungen were fixed. T1 and T2 was located in Andedammen, T3 and T4 in Lille Årungen.

3.2 Crustacean community

23 species were identified in the stream system (Table 4). Overall, the most abundant species were *Thermocyclops oithonoides*, *Daphnia longispina, Simosephalus vetulus*, *Alonella exigua*, and *Chydorus sphaericus*. In Andedammen, the most abundant species was *Thermocyclops oithonoides* (in July and August), but *Daphnia longispina* was also common in all samples (Figure 9). In Lille Årungen, the most abundant species was *Daphnia longispina* (dominant in August, common in June and July), while unidentified crustaceans of the *Calanoida* order were abundant in June and unidentified crustaceans of the *Cyclopidae* family were abundant in July and August (Figure 9). In the Lower Wetland Pond, the most abundant species were *Bosmina longirostris* (in July), *Alonella exigua* (in August), and *Chydorus sphaericus* (in June and July) (Figure 9). *Ceriodaphnia reticulata*, *Daphnia longispina,* and *Pleuroxus aduncus* were common in all samples from the Lower Wetland Pond.

Table 4: Species list for each study pond. The unique species for the pond are marked with a star (*). At the bottom, the number of species in the ponds are listed, with the addition of the number of unique species. Total number of species found in the stream system is 23.

	Andedammen	**Lille Årungen**	**Lower Wetland Pond**
	*Diaphanosoma brachyurum**	*Ceriodaphnia reticulata*	*Ceriodaphnia reticulata*
	Daphnia longispina	*Daphnia longispina*	*Daphnia longispina*
	Scapholeberis mucronata	*Simocephalus vetulus*	*Scapholeberis mucronata*
	Bosmina longirostris	*Bosmina longirostris*	*Simocephalus vetulus*
	Chydorus sphaericus	*Alona affinis**	*Alonella exigua**
	Pleuroxus aduncus	*Alonella excisa**	*Alonella nana**
	Pleuroxus truncatus	*Chydorus sphaericus*	*Chydorus sphaericus*
	Polyphemus pediculus	*Oxyurella tenuicaudis**	*Kurzia latissima**
	*Acanthodiaptomus denticornis**	*Polyphemus pediculus*	*Pleuroxus aduncus*
	*Acanthocyclops robustus**	*Mesocyclops leuckarti*	*Pleuroxus laevis**
	Mesocyclops leuckarti	*Thermocyclops oithonoides*	*Pleuroxus truncatus*
	Thermocyclops oithonoides		*Polyphemus pediculus*
			*Macrocyclops albidus**
			*Eucyclops serrulatus**
			Mesocyclops leuckarti
			Thermocyclops oithonoides
SUM	*12 (3 of which are unique)*	*11 (3 of which are unique)*	*16 (6 of which are unique)*

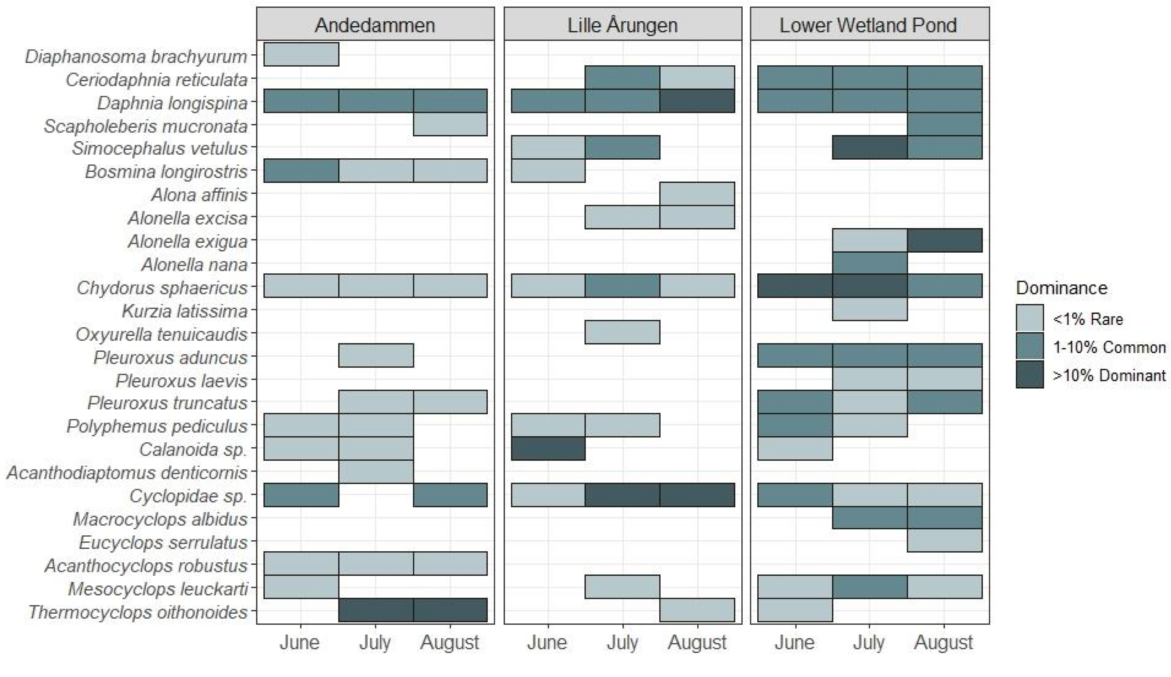

Figure 9: Tile-plot showing the relative dominance of various crustacean species, and two taxonomic groupings within the Calanoida order and the Cyclopidae family. The plot is based on 9 zooplankton samples taken in three study ponds (Andedammen, Lille Årungen and the Lower Wetland Pond), sampled in June, July, and August.

The highest species richness occurred in the Lower Wetland Pond, which had 16 species. Andedammen had 12 species, and Lille Årungen had 11 species (Table 4). Andedammen had three unique species (*Diaphanosoma brachyurum*, *Acanthodiaptomus denticornis*, and *Acanthocyclops robustus*). Lille Årungen also had three unique species (*Alona affinis*, *Alonella excise*, and *Oxyurella tenuicaudis*), while the Lower Wetland Pond had six unique species (*Alonella exigua*, *Alonella nana*, *Kurzia latissimi*, *Pleuroxus laevis*, *Macrocyclops albidus*, and *Eucyclops serrulatus*) (Table 4).

Andedammen and the Lower Wetland Pond had a more stable zooplankton composition than Lille Årungen, as shown by the NMDS analysis (Figure 10). In Lille Årungen the zooplankton composition in June differed from that of July and August (Figure 10). In June, the three study ponds were the most similar to each other, while the species composition was more different in July and August.

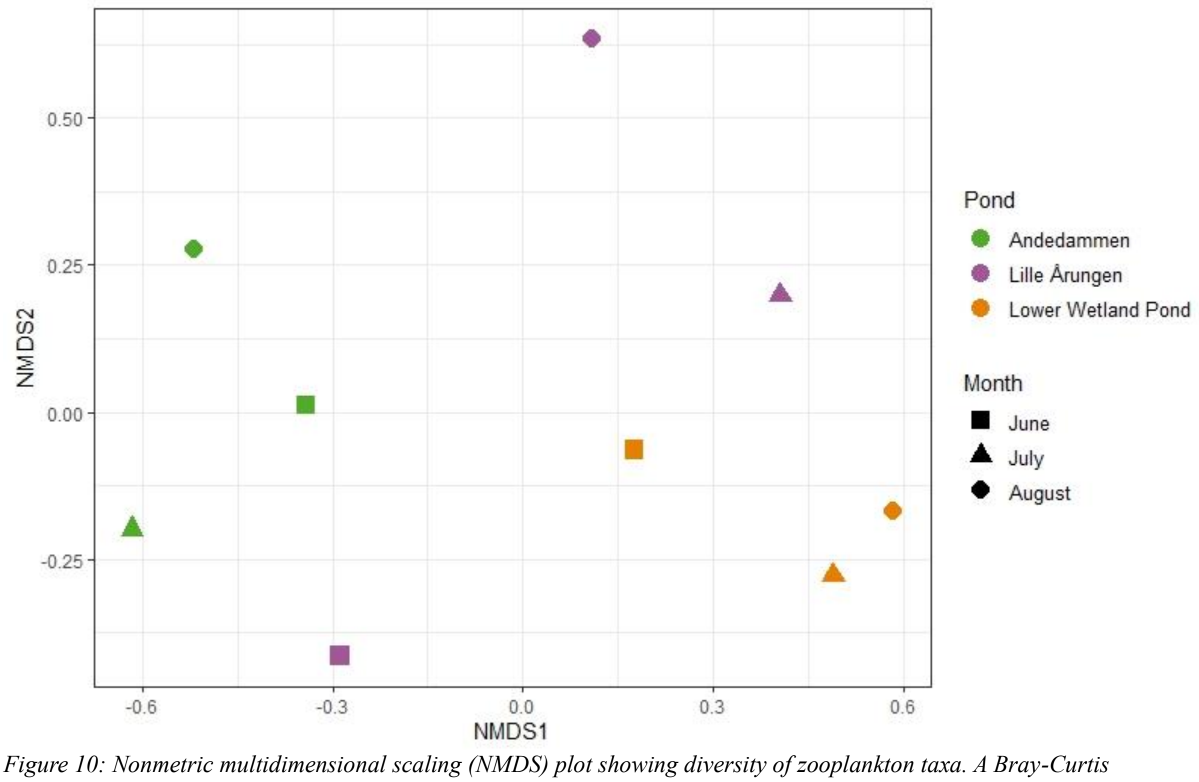

Figure 10: Nonmetric multidimensional scaling (NMDS) plot showing diversity of zooplankton taxa. A Bray-Curtis distance similarity matrix was calculated based on the taxonomic profiles of 9 zooplankton samples form three study ponds, sampled in June, July, and August. Shorter distances between two samples indicate higher similarities. The stress value of the NMDS analysis is 0.0997.

Crustacean counts peaked at 17,200 in Andedammen in June and reached a minimum of 251 in Lille Årungen during the same month (Table 5). The crustacean counts were most similar among the ponds in August (Figure 11b). In June, Andedammen had a higher number of zooplankton than the other two ponds, while in July, the Lower Wetland Pond had the highest abundance of zooplankton (Figure 11).

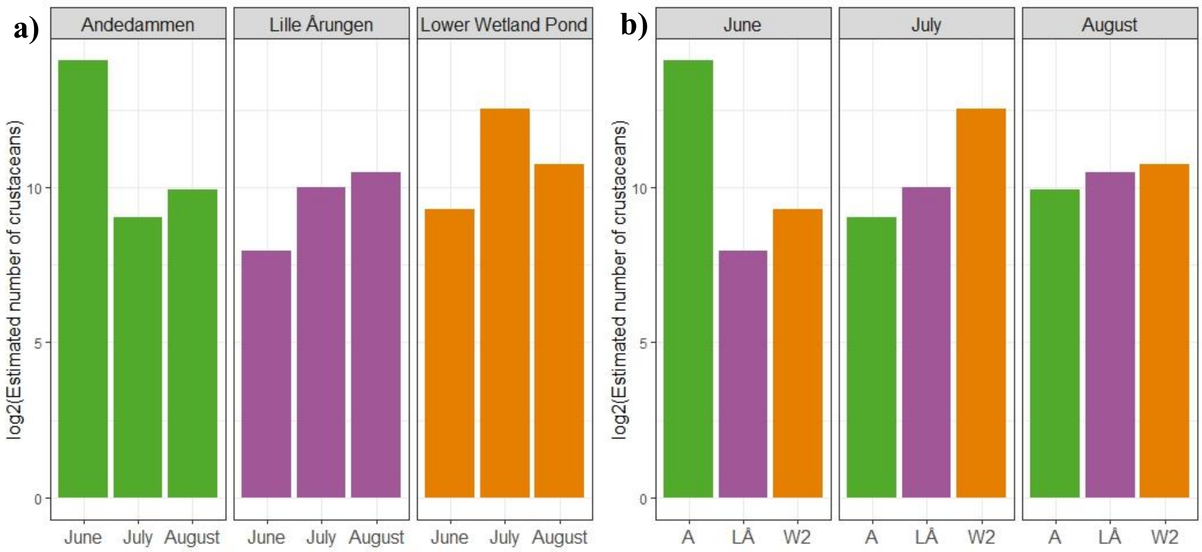

Figure 11: Barplot showing abundance of crustaceans 9 zooplankton samples from three study ponds sampled in June, July, and August, grouped by pond (a) and month (b). Pond abbreviations: A – Andedammen, LÅ – Lille Årungen, and W2 – Lower Wetland Pond.

Table 5: Number of crustaceans estimated in 9 zooplankton samples from 3 ponds sampled in June, July, and August.

Pond	Sample month	Estimated crustaceans
Andedammen	June	17200
	July	522
	August	970
Lille Årungen	June	251
	July	1030
	August	1415
Lower Wetland Pond	June	620
	July	5825
	August	1730

The size range of the crustacean species was 0.37–2.11 mm in Andedammen, 0.33–1.88 mm in Lille Årungen, and 0.23–1.88 mm in the Lower Wetland Pond. In Andedammen, sizes remained consistent for dominant and common species during July and August at 0.78 mm and 1.48 mm respectively (Figure 12), while June featured two common species at 0.37 mm nd 1.48 mm (Figure 12). Rare species spanned the entire size range. In Lille Årungen, no dominant species were recorded in June and July, while no common species were recorded in August. The size of the dominant species in August and the common species in June was the same; 1.48 mm (Figure 12). While the common and rare species covered the full size range in June and July respectively. The size range for rare species narrowed from 0.37–1.88 mm in June to 0.33–0.88 mm in August (Figure 12). In the Lower Wetland Pond, species sizes varied within each dominance level throughout the season. The size range for the common species first expanded from 0.53-1.48mm in June to 0.23-1.58mm in July, before shifting upward to 0.37-1.88mm in August (Figure 12). The dominant species were generally small (0.37 and 0.32mm) except in July when a larger species (1.88mm) occurred, in addition to the smaller one (0.37mm). The rare species in the Lower Wetland Pond ranged from 0.32mm to 1.07mm, with size densities varying between months. In June the two rare species were 0.70 and 1.00mm, in July the highest density was around 0.5 mm, and in August two species were close to 1.00mm, in addition to a species sized 0.51mm.

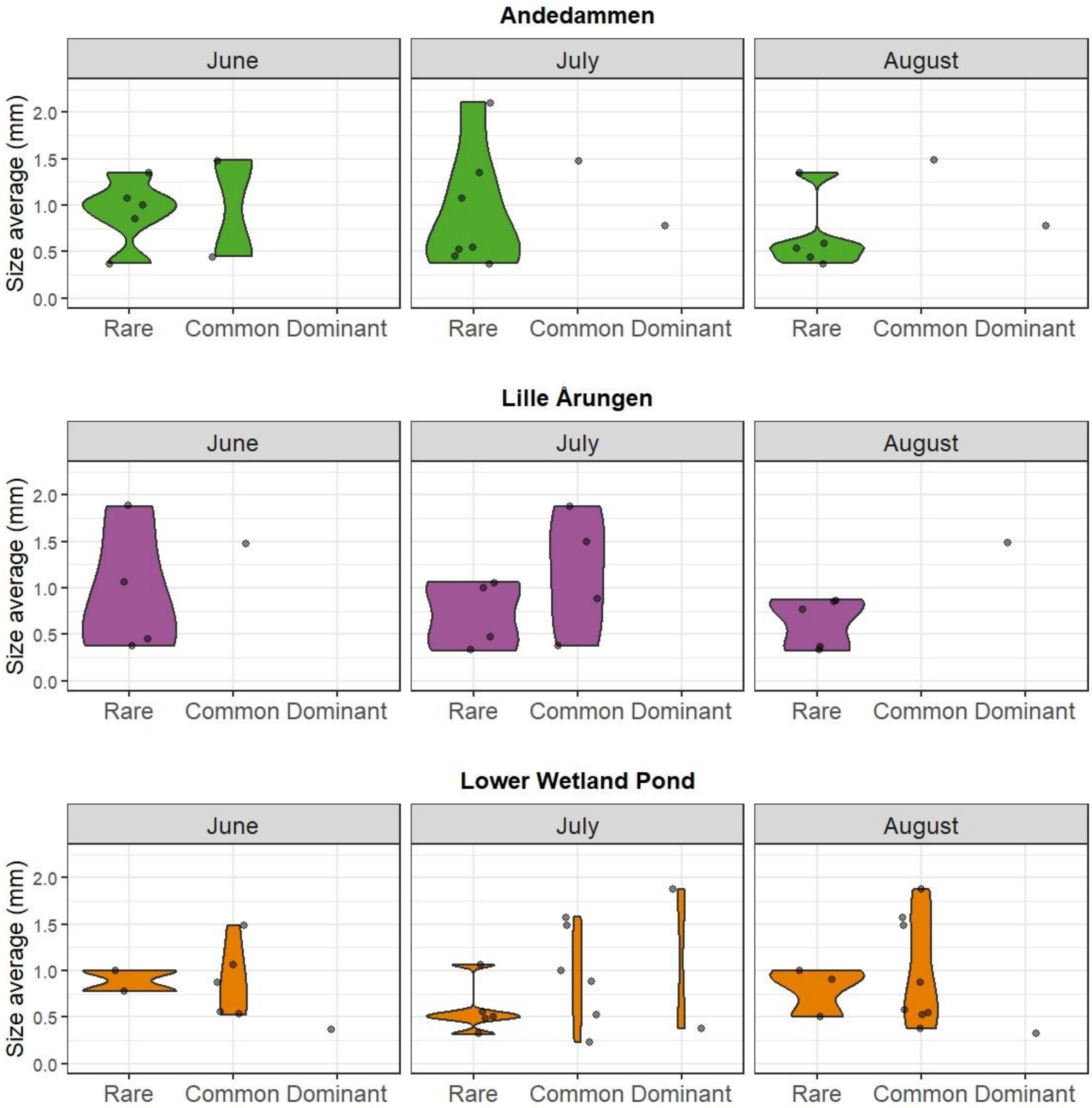

Figure 12: Violin plots showing distribution of average species size of crustacean species found in 9 zooplankton samples taken in June, July, and August in 3 study ponds; Andedammen, Lille Årungen, and the Lower Wetland Pond. The crustacean species have been sorted by relative dominance; <1% Rare, 1-10% Common, and >10% Dominant. The plots combine kernel density estimation with size data points to highlight size variations.

3.3 Artificial macrophytes

The artificial macrophytes were placed on May 9th three in Andedammen and two in Lille Årungen. Three checks were carried out on May 16th, 24th, and 31st, during which no eggs were found. Given the lack of egg presence, the artificial macrophytes were removed on May 31st, as it was deemed unlikely that the newts would utilise them if they had not already done so by that time.

3.4 Anuran presence in the stream system

The common frog and the common toad were identified within the stream system. Confirmed life stages of the common frog were eggs and tadpoles, eggs in Lille Årungen and tadpoles in both Lille Årungen and the Turbid Pond (Table 6). The confirmed life stages of the common toad were eggs, tadpoles, and adults, all of which were found in Andedammen (Table 6). Adult toads were also observed in Lille Årungen (Table 6).

Table 6: Overview of amphibian species and life stage observations in the campus stream. Letter explanation: (a) – adult, (e) – egg, (l) – larvae/tadpole

Pond	Common frog	Common toad	Smooth newt
Andedammen	(a)	(a), (e), (l)	(a)
Upper Niagara	-	-	-
Lille Årungen	(e), (l)	(a)	(a)
Turbid Pond	(l)	-	(a)
Wetland (W1 & W2)	-	-	(a), (l)

Table 7: An overview of anuran observations in the stream system during the fieldwork period starting 21.04 in the spring of 2023.

Species	Date	Life stage	Note	Pond
Common frog	21.04.2023	Eggs	One	Lille Årungen
	03.05.2023	Eggs	Two	Lille Årungen
	09.05.2023	Tadpole	Single	Lille Årungen
	10.05.2023	Tadpoles	Multiple	Lille Årungen
	31.05.2023	Tadpoles	Multiple	Turbid Pond
Common toad	21.04.2023	Adult	Multiple	Andedammen
	05.05.2023	Adult	Single	Lille Årungen
	10.05.2023	Egg strings		Andedammen
	16.05.2023	Adults	Two, breeding	Andedammen
	16.05.2023	Tadpoles	Multiple	Andedammen
	31.05.2023	Tadpole	Single	Andedammen

Frog eggs were discovered in the small bay that serves as an inlet in Lille Årungen on April 21st (Figure 13a; Table 7), this cluster was no longer present on May 5th. On May 3rd, two new egg clusters were discovered; one floating in the littoral zone along the southern edge of the pond, the other in the little bay where the first one was found (Figure 13b and 13d). All clusters are assumed to have been common frog. By May 5th the cluster in the middle of the pond had disappeared, presumably having hatched. The other cluster appeared somewhat damaged on May 5th (Figure 13c) but had disappeared by May 9th. Tadpoles were first observed in Lille Årungen on May 9th (Table 7). On May 10, multiple tadpoles were observed in the small bay where the first egg cluster had been laid (Figure 13e). On May 31st, tadpoles of the common frog were discovered in the Turbid Pond.

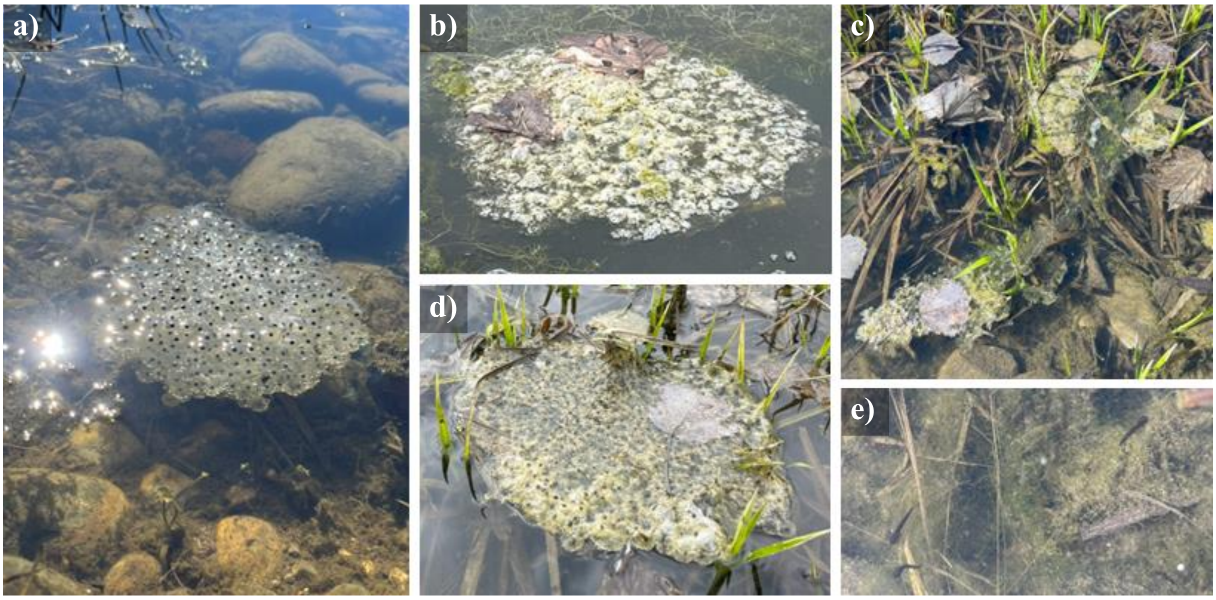

Figure 13: Pictures from the fieldwork of common frog eggs and tadpoles taken in Lille Årungen. (a) show the first egg cluster that was found 21.04.23. (b) and (d) show two egg clusters that were found 03.05.23. (c) show the same cluster as picture (d) but a few days later, the cluster appear damaged. (e) show tadpoles found 10.05.23. Photos: Haraldstad, I., 2023.

Toads were observed in large numbers in Andedammen on April 21st, and afterwards observed regularly in the pond until May 16th (Table 7). Toad eggs were difficult to detect, however, eggs were discovered on May 10th. The egg strings were suspended between the stalks of macrophytes and were covered with algae (Figure 14a and 14b). The eggs appeared to be partially developed (Figure 14c). On May 12th, the toad eggs seemed to have disappeared, potentially hatched. On May 16th, tadpoles, presumed to be common toad, were discovered in Andedammen (Figure 14d). On May 31st, a larger tadpole was observed in the water. Adult toads were also observed in Lille Årungen, although no eggs were found.

Figure 14: Pictures from the fieldwork of common toad eggs and tadpoles taken in Andedammen. (a) and (b) show the egg strings suspended between the waterlilies, the strings are covered in algae. (c) show a close-up of a common toad egg string, covered in algae, with partially developed eggs/tadpoles. (a) - (c) was taken 10.05.23. (d) show a group of tadpoles on a waterlily leaf in the pond taken 16.05.23. Photos: Haraldstad, I., 2023.

3.5 Newt presence in the stream system

Smooth newt was identified within the stream system, both with traps and with the net. Life stages found were adults and larvae (Table 6).

Traps were placed in six ponds across five dates (Table 8). A total of 18 smooth newts were captured using the traps: 17 males and one female (Figure 15). In Andedammen, one male was caught, no newts were captured in Upper Niagara, and one male was captured in Lille Årungen (Table 8). The only female newt was captured in the Turbid Pond (Figure 15c). The constructed wetland yielded the highest number of newts, with two males captured in the Upper Wetland Pond, and 13 males in the Lower Wetland Pond (Table 8; Figure 15d-r).

The net sweep was done on August 30th. Smooth newt larva was confirmed only in the Lower Wetland Pond (Table 6). The larva was caught after a few sweeps. While standing on the pond’s edge, other larvae were observed on the rocky bottom. The larvae density in the Lower Wetland Pond was evaluated as low to normal. 12 net sweeps were done in Andedammen, Upper Niagara, Lille Årungen and the Turbid Pond, but resulted in no capture. These ponds were evaluated as having no to low larvae density.

Table 8: Overview of the date and location of the smooth newt catch, as well as how many traps were used in the ponds. The sex of the trapped newts is also indicated as (m) - male and (f) – female.

Date	Pond	Catch
29.05.2023	Andedammen	1 (m)
30.05.2023	Lille Årungen	1 (m)
30.05.2023	Upper Niagara	0
01.06.2023	Lower Wetland Pond	13 (m)
01.06.2023	Turbid Pond	1 (f)
08.06.2023	Upper Frisbee Pond	2 (m)

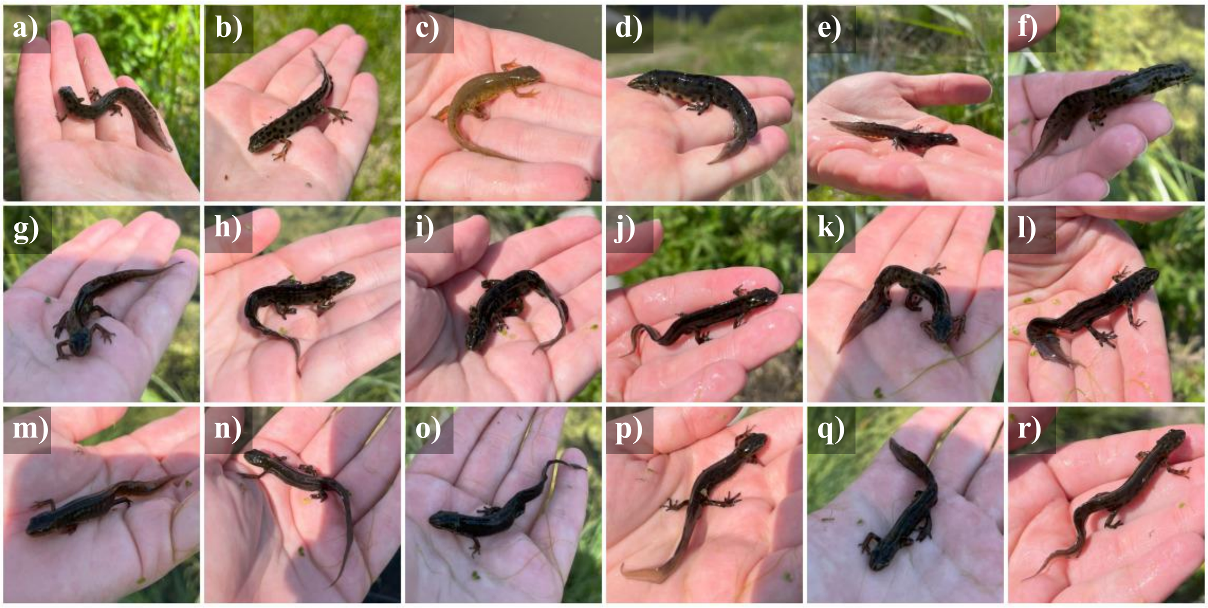

Figure 15: Collage of all the newts trapped in the campus stream between 28.05.23 and 07.06.23. (a) was caught in Andedammen, (b) in Lille Årungen, and (c) in the Turbid Pond. (e) and (d) were caught in the upper wetland pond, while (f) – (r) were caught in the Lower Wetland Pond. (c) was the only female caught, the rest were male. Photos: Haraldstad, I., 2023

4. Discussion

4.1 Which amphibians were present in the campus stream, how many species, and where?

Common toad

The common toad was only confirmed to be reproducing in Andedammen where adults, tadpoles and eggs of the species were found.

Toads generally seem to prefer larger and deeper ponds (Ahlén et al., 1995; Dolmen, 2008), and Nowakowski et al. (2011) found that vegetation cover in the littoral zone is important in habitat selection, which is likely a measure of available oviposition sites. The temperature in Andedammen was already above the toad egg-laying threshold of 8 ºC on April 22nd, and the mean temperature remained above this threshold all spring and summer. Andedammen's age is unknown, but it is at least 165 years old as it was made by the university sounding in 1859 (Norsk Landskapsarkitekters Forening, s.a.-b). The pond is also rather large, approximately 2850 m^2, and there is dense vegetation along the pond's western edge. Given its age, size, and vegetation, along with the water temperature, Andedammen offers a suitable habitat that includes favourable temperatures and oviposition sites, allowing sufficient time for a population to establish itself. Andedammen is also stocked with crucian carp. The fish species is an opportunistic omnivore and is likely to predate amphibian eggs (Sandlund et al., 2016). The common toad, however, commonly occurs in fish-stocked ponds (Elmberg, 2023). This is likely because, like the adult toad, both toad eggs and tadpoles are poisonous (Ahlén et al., 1995).

The absence of reproducing common toad in Lille Årungen was somewhat unexpected. Lille Årungen is approximately 450 m^2 and around 2 meters deep, it also has some tall emergent macrophytes in the outlet area. There could be different explanations for the absence of reproducing common toads in Lille Årungen; overlooked egg strands, lack of sufficient suitable vegetation, and pond age. Suitable vegetation is, as mentioned, important in habitat selection (Nowakowski et al., 2011), and the small patch of emergent macrophytes in the outlet area might not be enough. Also, the relatively young age of Lille Årungen might have played a role. Lille Årungen is only three years old and the tall emergent macrophytes have naturally colonised the pond after its construction (Fredriksen, 2023). Therefore, as the pond is relatively young and the macrophytes have only recently been established, there may not have been enough time for the toads to colonise the pond.

Common toads were not found on the frisbee golf course in the Turbid Pond or the Upper and Lower Wetland Ponds. Although I cannot exclude the possibility that eggs were overlooked, these ponds are small and shallow. The Species Map Service from Artsdatabanken (s.a) show that the majority of common toad locations are larger than 5000 m^2. Additionally, these ponds are typically deeper than 2-3 m (Dervo, 2024). Consequently, the small and shallow ponds on the frisbee golf course are unlikely to provide a suitable habitat for the common toad.

No toads were found in Upper Niagara either. The pond is small (ca. 45 m^2) and shallow (ca. 30 cm deep), which does not match the toad's preference for larger and deeper ponds. Due to its size and depth, the pond might be prone to drying out in warmer years. This could limit the establishment of a population, as tadpoles and eggs end up dying before undergoing metamorphosis (Dervo, 2024).

Common frog

The common frog was confirmed to be reproducing in Lille Årungen and in the Turbid Pond, which was unsurprising. The common frog is a habitat generalist and can be found in a variety of ponds and summer habitats (Elmberg, 2023). It is, however, sensitive to fish predation, and rarely co-exist with fish (Ahlén et al., 1995). Both Lille Årungen and the Turbid Pond are fish-free. Eggs are typically laid in shallow areas, which are likely warmer and heat up more quickly (Elmberg, 2023). This pattern is consistent with the observations in Lille Årungen where eggs were found in the shallow inlet and by the edge of the pond, and at the Turbid Pond, which is approximately 50 m^2 and is only up to about half a meter deep.

The lack of frogs in Andedammen was not surprising. Andedammen is stocked with crucian carp, an opportunistic omnivore, and the frog rarely co-exists with fish as they are sensitive to egg and larvae predation (Ahlén et al., 1995; Sandlund et al., 2016).

The common frog was also not present in the Upper and Lower Wetland Ponds, which is surprising as there appears to be no reason why the common frog would not breed in the ponds. The Upper and Lower Wetland Ponds are small (20 and 55 m^2), and around 1 m deep with rich vegetation. These conditions are typically preferred by the common frog, which favours shallow areas that heat quickly. However, the absence from these ponds does not necessarily indicate that they are unsuited for the common frog. The breeding and reproductive output in smaller ponds vary annually, and is dependent on different environmental factors (Dervo, 2024). During years with high water levels, the common frog may opt for a smaller, nearby pond over a larger one. Conversely, in drier years it may select a larger and more stable pond, despite presence of fish which would compromise its reproductive success and recruitment for that year (Dervo, 2024). April and May in 2023 were quite warm and dry, and the common frog may have opted out of using the Lower and Upper Wetland Ponds for this reason. However, the same should then apply to the Turbid Pond. This suggests that additional factors might explain the common frog's absence from the Upper and Lower Wetland Ponds. It is possible that eggs and tadpoles were overlooked. These ponds have also been showed to contain a population of smooth newt, which is known to prey on the common frog tadpoles and eggs (Griffiths & Mylotte, 1987). This would affect population size but should not limit occurrence in the ponds.

Common frog was not found in the Upper Niagara Pond. The pond is small and shallow, which is preferred. Despite the pond's considerable age of 80 years, giving ample time for colonisation, the common frog is not present. This absence likely stems from the pond drying out before tadpoles can complete metamorphosis, thus hindering population establishment (Dervo, 2024).

Smooth newt

Smooth newts were observed in all ponds, except for Upper Niagara. However, only in the constructed wetland, which includes the Upper and Lower Wetland Ponds considered as a single system, were a reproducing population confirmed. The Upper and Lower Wetland Ponds are small, about 20 and 55 m^2 respectively, and likely heating quickly, with riparian vegetation growing around the pond, providing oviposition sites and refuge from predators. In addition, the ponds become partially covered with duckweed in late spring and early summer, providing even more cover. The smooth newts managed to colonise the stream system despite its relatively young age. The closest known population is approximately 1600 m southwest of the constructed wetland, but there have been isolated finds on/near campus and in a pond near downstream Vollebekken, which the campus stream drains into (Artsdatabanken, s.a.-a). The area between the stream and this population is predominantly covered with forest and agricultural fields, extending up to the infrastructure surrounding NMBU. It is not unlikely that this population colonised the stream. The stream could also have been colonised by other unknown populations of smooth newt.

The absence of smooth newt in Upper Niagara might, as with the common frog, be due to a high likelihood of the pond drying out in warmer years. This would prevent establishment of a population by causing mortality of the eggs and larvae. The pond drying out every couple of years is enough to limit a population from establishing (Dervo, 2024).

Only one smooth newt was found in Andedammen, Lille Årungen, and the Turbid Pond. No eggs or larvae was found in the ponds, but as newts were caught in these ponds their presence cannot be ruled out completely. They could be present at a very low density. Andedammen is stocked with the crucian carp, which is an opportunistic omnivore and in direct dietary competition with the smooth newt as both eat crustaceans (Griffiths & Mylotte, 1987; Sandlund et al., 2016). This could either exclude or limit a population of smooth newt. Lille Årungen, which is free of fish and has vegetation crowding its edges, would present adequate habitat for the smooth newt. However, the low crustacean count in Lille Årungen (half of that in the Lower Wetland Pond in June) could limit establishment and persistence of a population there. The Turbid Pond is smaller, about 50 m^2 and max 0.5 m deep, and it might dry out during particularly warm seasons. This would limit establishment of smooth newt.

Species not found in the study area

The moor frog was not observed at any life stage within the stream system. Given that the species is red-listed and rare in Norway (Dervo et al., 2021c), its absence from the stream system is unsurprising.

The rarity of the moor frog may lead to the absence of a suitable source population for colonizing the stream. There have been a few registrations of moor frog near NMBU in Artsdatabankens Species Map Service. In 2022, 2 male frogs were found in Andedammen with no sign of a reproducing population, while recently in April of 2024 reproducing individuals was found in a small pond (named Smilehullet), behind the Student Society building in Ås (Artsdatabanken, s.a.-b). The pond is only around 600-700 m from the campus stream and might be able to colonise the campus stream given that the mean distance between occupied ponds for the moor frog is typically less than one kilometre (Vos & Chardon, 1998). However, the observation has not been validated yet and it might also be an isolated case. The pond 'Smilehullet' is shallow and can dry out in warmers years, which compromises recruitment as eggs and/or tadpoles dry out and die before they can undergo metamorphosis (Dervo, 2024). This can limit the establishment of a population with a sufficient surplus of migration-willing individuals to colonise the campus stream.

There also seems to be a lack of high-quality terrestrial moor frog habitat nearby. The moor frogs' summer habitats are more restricted to well-vegetated and damp habitats than the common frog (Elmberg, 2023). It prefers to spend summer in natural meadow-like areas close to a waterbody or in grassy forest clearings (Elmberg, 2023). While it is rarely encountered in coniferous forests, this species is often found in lush deciduous forests characterised by rich ground vegetation (Elmberg, 2023). There are no natural or semi-natural meadows on campus, along the stream or near the stream, and the closest forest is Nordskogen which consists of around 80% coniferous trees (NMBU, s.a.). The terrestrial habitat around NMBU simply isn't up to par with the moor frogs' requirements.

The absence of the great crested newt in the stream system is not surprising either. The species, along with the moor frog, is listed on the Norwegian Red List and has more specific habitat requirements than the smooth newt (Dervo et al., 2016b; Dervo et al., 2021d). The great crested newt prefer fish-free ponds (Dervo et al., 2016b), which limits occurrence in Andedammen. In Norway, the great crested newt requires ponds larger than at least 100 m^2 and deeper than 1m (Dervo, 2024). However, the mean size of the monitoring locations, in a report by Dervo et al. (2017), were larger than 1000 m^2, indicating a preference for larger ponds, at least in Norway. Upper Niagara, the Turbid Pond and the Upper and Lower Wetland Ponds are all below 100 m^2. Lille Årungen matches the requirement of 100 m^2 but, with its size of approximately 450 m^2, is smaller than the average location. Lille Årungen was also found to have a low crustacean count. This suggests that factors such as pond size and food availability, among others, might limit the occurrence of the great crested newt in the stream.

One limiting factor could be a lack of a suitable source population from which the great crested newt could have migrated to the study area (Dervo et al., 2016b; Dervo et al., 2021d). The nearest population is registered around 3 km southeast of the NMBU campus, while the second closest is around 3.5 km west of the campus (Dervo et al., 2019; Eldegard, 2024). There are considerable dispersal limitations between the closest registered populations and the campus stream. For dispersal from the population southeast of campus, the newts would need to cross roads and traverse considerable areas with housing developments. This would increase the risk of road mortalities and expose individuals to predators. The population is also small and may not be able to provide enough migratory animals (Dervo, 2024; Eldegard, 2024). The population west of campus, situated across the motorway (E6), faces even greater risks of road mortalities than those encountered on smaller, less trafficked roads.(Hels & Buchwald, 2001). Indicating that the species might be limited by infrastructure.

Importantly, the great crested newt also needs suitable terrestrial habitat, in addition to suitable spawning habitat. In Norway the crested newt is present in two main landscapes; cultural landscapes with a high density of small ponds, and continuous, semi-open mosaic forest landscapes rich in small fish-free ponds (Malmgren & Gustafson, 2002; Malmgren, 2007; Oldham et al., 2000). Adult individuals of the great crested newt are typically found less than 300 m from the breeding pond, however adults have been found as far away as 1300 m from the pond (Dervo et al., 2016b). The area surrounding the NMBU campus, within this range, does not fit this description. There are only a couple and rather small forests with few ponds, and the cultural landscape is also lacking in ponds, indicating a lack of suitable terrestrial habitat near the campus stream.

Migration may also be limited by the streams design particularly the stretch along the veterinary institute between Lille Årungen and the frisbee golf course. Here, the stream is channelled through a culvert beneath a road and a small parking lot, potentially obstructing movement. The great crested newt seems to have no problem utilising culverts designed as mitigation to road mortality (Helldin & Petrovan, 2019; Jarvis et al., 2019). However, such tunnels need to be accessible without barriers. The culvert inlet is a drop-down to the culvert tunnel, while the outlet has an unfortunate stone ledge that is near impossible for a newt to get over. The stream then runs along a rocky stream bed, with vertical stone walls. Therefore, as the newts move up the stream, they encounter a stretch of high exposure followed by a culvert that is impassable. The stretch above the culvert is also hard to pass due to length, high exposure, and asphalt-covered area.

The combination of limited dispersal due to infrastructure, a lack of terrestrial habitat, and potential unsuitability of the streams ponds, might make the stream difficult to colonise for the great crested newt.

The last threatened species that was not found in the stream system was the Norwegian pool frog. This was unsurprising. The Norwegian population of pool frog is small, with less than 50 individuals in Norway, and only present in 3-4 ponds in Agder county (Dervo et al., 2021a; Dolmen, 2008). Their location, approximately 180km southwest of the campus stream, and small population size suggests that colonisation of the stream is unlikely.

4.2 Can artificial macrophytes be used for oviposition?

Artificial macrophytes made up of egg strips were developed as an egg surveying method for the great crested newt by Hayward et al. (2000), and have since been shown to work (Charlton & Lewis, 2017; Skei et al., 2010). Artificial macrophytes might also facilitate newt oviposition in ponds with low vegetation cover. Charlton and Lewis (2017) found that the newts utilised the egg strips to a much higher extent in ponds with low macrophyte cover, indicating that artificial macrophytes might be able to provide oviposition sites for breeding populations of newts.

However, there was no newt oviposition on the artificial macrophytes placed in Andedammen and Lille Årungen, neither from the great crested newt, nor the smooth newt. Based on the temperature measurements it can be inferred that the newts would have started reproduction in early May, giving ample time for the newts to utilise the egg strips. Therefore, the most likely reason for the lack of oviposition is that Andedammen and Lille Årungen proved to have no great crested newt presence and no to very low presence of a smooth newt population.

Another reason for the absence of smooth newt oviposition on the egg strips could be that smooth newts in fact do not utilise artificial egg strips. The study by Charlton and Lewis (2017) took place in 10 ponds, all of which were confirmed palmate newt locations, while only 5 were confirmed smooth newt locations. The study therefore demonstrates that egg strips are viable as an egg surveying technique for the palmate newt. However, as the palmate and the smooth newt eggs cannot be differentiated in the field, the method's viability for surveying smooth newt eggs remains uncertain.

The design could also have affected the result. The egg strips used to create the artificial macrophytes in this study were white, 0.5 cm wide, 30-40 cm long, and 38 µm thick. The design of egg strips for the crested newt, and the smooth newt, varies across different sources in the literature (Charlton & Lewis, 2017; Hayward et al., 2000; Skei et al., 2010). Skei et al. (2010) described strips 0.5 cm thick, made with clear PVC, with no specified length. Hayward et al. (2000) used 2.5 cm wide strips of clear PVC that were about 80 cm long. While Charlton and Lewis (2017) used strips of plastic in a multitude of colours (black, green, red, and yellow), and lengths (50, 25, and 12.5 cm), as it was a study on newt preference for egg strip substrate. There is a lack of research regarding egg strips and how to improve effectiveness as a surveying method through design and placement, and a variety in design in published literature. It therefore is hard to say for certain whether the design used in this study impacted the result.

More study is needed to confirm artificial macrophytes as a viable option for facilitating smooth newt oviposition. It would have been interesting to see them placed in the Lower Wetland Pond where a reproducing smooth newt population was confirmed during the study.

4.3 Can food availability limit newt occurrence in the campus stream?

The crustacean communities in the three ponds were most similar in June, the ponds also exhibited similar crustacean size ranges in June, although Lille Årungen had a somewhat wider range. However, June had the most variety in crustacean count, with both the highest

(Andedammen, 17 200) and lowest (Lille Årungen, 251) crustacean counts registered. This indicates a similar baseline in crustacean diversity across the sites that should not affect newt occurrence, but the variations in crustacean counts between the ponds might affect newt presence.

In June both Lille Årungen and the Lower Wetland Pond recorded their lowest counts, 251 and 620 respectively, before increasing in July. It can be inferred that Lille Årungen contains around, or fewer than, half the number of crustaceans than the Lower Wetland Pond, despite the fact that smooth newts are present, at least to a larger extent, in the Lower Wetland Pond than in Lille Årungen. This indicates that the Lower Wetland Pond could have more available food in terms of crustaceans. This might affect the newt larvae to a larger extent than the adult newts. Both larvae and adult newts consume crustaceans, but adult newts also consume macroinvertebrates and can shift their diet or leave the pond when food becomes less available (Bell, 1975; Dervo, 2024; Griffiths, 1986; Semb-Johansson et al., 1992). It is also important to note that early development larvae are not active hunters and snap at food items within reach (Bell & Lawton, 1975). This suggests that a higher crustacean density might be more beneficial for larval development. Consequently, food availability might be a limiting factor for both smooth and great crested newt occurrence in the stream.

4.4 Was water temperature related to amphibian occurrence in the campus stream?

During April and the first two weeks of May, the temperature in Andedammen was higher than in Lille Årungen. The mean water temperature in Andedammen stayed above 8 ºC even after the temperature drop in late April, in contrast to Lille Årungen where the average temperature dropped to 6 ºC. This could explain why I found more toads and toad eggs in Andedammen than in Lille Årungen, although vegetation availability in, and the age of, Lille Årungen might have affected occurrence. The differences in mean water temperature could indicate that Andedammen is more attractive to the common toad and might explain the occurrence here.

Only a single smooth newt observation was made at both Andedammen and Lille Årungen, and no temperature measurements were taken in the Lower Wetland Pond where the reproducing smooth newt population was found. This limits the ability fully assess whether water temperature was a limiting factor for the smooth newt. And as no newt eggs were found, their occurrence cannot be coupled with the temperature data.

As Andedammen has fish as a limiting factor for the common frog it is hard to say whether temperature limited the common frog. However, since the common frog can sometimes lay eggs in temperatures only a few degrees above 0ºC (Dolmen, 2008; Semb-Johansson et al., 1992), it is unlikely that temperature limited occurrence.

4.5 Potential for amphibians in BGI

Amphibians seem to readily colonise urban and suburban ponds when possible. However, the resulting amphibian communities are made up of generalists and consist of a smaller number of species, compared to more rural reference wetlands (Knozowski et al., 2022; Lehtinen & Galatowitsch, 2001; Rubbo & Kiesecker, 2005). This is reflected in the current species composition of the campus stream. Although three species have been confirmed in the stream system, no single pond has shown evidence of more than one reproducing species. The three species that were found are common in Norway and can be considered generalists (Cirovic et al., 2008; Dervo et al., 2021e; Semb-Johansson et al., 1992).

Nevertheless, there is a lack of research on how rapidly amphibians colonise new habitats, likely because colonisation time is difficult to determine. An American study by Lehtinen and Galatowitsch (2001) observed that some amphibian species were able to colonise restored wetland ponds within just one year. Even so, several species were not found in these restored wetlands at all. The study suggested that this could be either because the habitats were not suitable or because the absent species lacked the necessary dispersal abilities to reach the restored areas. Colonisation of, and sustained reproductive success in, new ponds is complex. It is species-dependent and affected by multiple factors, such as the quality of aquatic and terrestrial habitats, the connectivity between and proximity of habitats, as well as inherent dispersal ability and nearby populations, which all interact and affect each other (Baker & Halliday, 1999; Birx-Raybuck et al., 2010; Hamer & McDonnell, 2008; Lehtinen & Galatowitsch, 2001; Rubbo & Kiesecker, 2005).

It is important to remember that amphibians depend on both terrestrial and aquatic habitats for survival. Both types of habitats must be of high enough quality to support the establishment and persistence of an amphibian population (Wells, 2007). However, even with optimal habitat quality, connectivity is crucial. If the habitats are too isolated and/or migration between them is too dangerous, it can negatively impact the survival of amphibian populations, through direct mortality from hazards such as road killings and indirect consequences like genetic isolation (Beebee, 2013). Furthermore, even if the habitats are perfect and well-connected, without established amphibian populations in the area, new habitats cannot be colonised (Hamer & McDonnell, 2008). Thus, habitat quality, connectivity, and existing population presence are all essential for amphibians' dispersal. This means that if all aforementioned factors are of suitable quality the amphibians should be able to colonise new ponds on their own, given a source population with a sufficient surplus of migration-willing individuals.

Multiple studies show how colonisation and amphibian persistence are affected by urbanisation through these factors, and how it reflects on the amphibian assemblages in urban ponds (Holtmann et al., 2017; Parris, 2006; Rubbo & Kiesecker, 2005). As BGI already aim to utilise green and blue areas to serve certain ecosystem services, their construction should be able to address or encompass these issues, with some planning, and become more successful for amphibians without impeded functioning.

Urban areas isolate habitats both through built-up areas and isolation by streets, which can be detrimental as increasing numbers of amphibians die with increasing traffic (Fahrig et al., 1995; Holtmann et al., 2017). Planning BGI with or near larger green areas, such as parks, could mitigate migration deaths and reduce migration barriers. Migration can also be aided in connecting multiple blue and green areas, creating migration corridors for easier colonisation and exchange of individuals between populations, which would aid survival by improving genetic diversity (Beebee, 2013). Considering amphibian habitat requirements, such as the absence of fish and the presence of permanent water, designing diverse terrestrial and aquatic habitats rich in vegetation with multiple microhabitats could significantly enhance amphibian persistence (Holtmann et al., 2017; Scheffers & Paszkowski, 2013).

When planning and implementing BGIs, "grey" infrastructures are of course necessary, for example, as culverts under roads. However, it is important to consider biology when merging grey and blue-green infrastructure to avoid creating limiting structures like tall ledges and large height drops. This would not only benefit amphibians but improve biodiversity in general (Filazzola et al., 2019; Nguyen et al., 2021).

Threatened species and their place in BGI

Research from Poland has demonstrated that the crested newt is generally more vulnerable to the impacts of urban development. According to Nowakowski et al. (2011), the crested newt exhibits heightened sensitivity to urbanisation stress, a finding that is supported by Knozowski et al. (2022), who noted a decline in colonisation by the great crested newt as urbanisation increased. Despite this, Konowalik et al. (2020) observed the presence of crested newts in urban areas, albeit rarely. Their study also shows that connectivity to habitats was crucial for the great crested newt. Based on this, the great crested newt may be able to persist in a blue-green designed stream system, but as they are more sensitive to urbanisation stress, they may require more planning and facilitating to be a success.

Similarly, the moor frog has shown increased sensitivity to urban stressors, as noted by Nowakowski et al. (2011). However, findings by Knozowski et al. (2022) contrast this, showing an increase in moor frog populations in both study settlements, despite increased urbanisation. Additionally, the study by Konowalik et al. (2020), from a Polish city, observed moor frogs in more ponds (22.5% of study ponds) than the smooth newt (19.9%) and in almost as many ponds as the common frog (25.1%). This suggests that the moor frog can persist in urban areas and should be able to persist in BGI, as long as both its terrestrial and aquatic habitat requirements are met through careful planning.

Holtmann et al. (2017) found pool frogs in urban stormwater ponds, and the pool frog might be able to persist in urban areas and BGI. However, as the Norwegian pool frog exist in such a small population in a small area in Norway (Dervo et al., 2021a; Dolmen, 2008), conservation efforts in its natural habitat should be prioritised before we start thinking about facilitating habitat in BGI.

4.6 Concluding remarks

The aim of my thesis was to investigate if it is possible that blue-green infrastructures can support amphibian populations by identifying amphibians in a blue-green stream on the NMBU campus. The common toad, common frog, and smooth newt were found to be reproducing in the stream, which shows that blue-green Infrastructure could support at least some amphibian species. Although no red-listed amphibian species were found in the stream system, their potential limitations underscore the need for more careful planning and design of BGI to meet more diverse habitat requirements. No newt eggs were found on the artificial macrophytes; however, the low newt presence makes it difficult to determine the reason for this. The differences in crustacean count between ponds with and without a confirmed population of smooth newt seems to indicate that food availability could be limiting in the stream system. Linking the water temperature measurements with amphibian occurrence is difficult due to other limitations likely affecting occurrence.

In conclusion, while generalist amphibian species currently utilise the BGI stream habitats, further enhancements in design could potentially promote greater biodiversity, including red-listed amphibian species. Such enhancements could be designing large and heterogeneous habitats, both aquatic and terrestrial, which would contain multiple microhabitats suitable for different species, and implementing a connectivity to aid in migration and colonisation.

Conducting a similar study in this stream system in a few years would be valuable, as the stream is young and changes are likely to occur. This would allow for tracking developments in the amphibian communities and better understanding of colonisation in a blue-green stream system. Once species composition stabilises, studies can focus on specific mitigation measures to enhance biodiversity, providing knowledge on how future BGIs can be made more suitable for amphibians. Additionally, temperature measurements in more ponds, especially the Lower Wetland Pond, would be beneficial to assess temperature effects on amphibian communities. Implementing artificial macrophytes could also be beneficial, as the method needs more research, both as a survey method for smooth newts and to promote oviposition in ponds with less vegetation.

More research is needed, especially in Norway, on amphibians in blue-green streams. Much of the research on species present in Norway is from central Europe and amphibian persistence, especially in urban areas or BGI, might be different in a more temperate zone such as Norway. By obtaining an overview of the amphibians typically found in blue-green streams and identifying what differentiates streams with varied species compositions, we can enhance urban and suburban planning to better facilitate habitat and dispersal opportunities for different species. Ultimately, these efforts may help conserve Norway's threatened amphibian species.

5. References

Ahlén, I., Andrén, C. & Nilsson, G. (1995). *Sveriges grodor, ödlor och ormar*. 2. rev. utg. ed. Stockholm: Naturskyddsföreningen.

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z. & Sanchez, A. (2019). Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management. *Journal of Environmental Management*, 239: 244-254. doi: 10.1016/j.jenvman.2019.03.036.

Artsdatabanken. (s.a). *Artskart - Funndata for Bufo bufo*. Available at: https://artskart.artsdatabanken.no/#map/456420,6906320/4/background/greyMap/filter/%7B%22TaxonIds%22%3A%5B1571%5D%2C%22IncludeSubTaxonIds%22%3Atrue%2C%22Found%22%3A%5B2%5D%2C%22NotRecovered%22%3A%5B2%5D%2C%22Style%22%3A1%7D (accessed: 13.05.2024).

Artsdatabanken. (s.a.-a). *Artskart - Funndata for Lissotriton vulgaris*. Available at: https://artskart.artsdatabanken.no/#map/262152,6621498/13/background/greyMap/filter/%7B%22TaxonIds%22%3A%5B92946%5D%2C%22IncludeSubTaxonIds%22%3Atrue%2C%22Found%22%3A%5B2%5D%2C%22NotRecovered%22%3A%5B2%5D%2C%22Style%22%3A1%2C%22YearFrom%22%3A2014%7D (accessed: 10.05.2024).

Artsdatabanken. (s.a.-b). *Artskart - Funndata for Rana arvalis*. Available at: https://artskart.artsdatabanken.no/#map/262361,6621854/12/background/greyMap/filter/%7B%22TaxonIds%22%3A%5B1576%5D%2C%22IncludeSubTaxonIds%22%3Atrue%2C%22Found%22%3A%5B2%5D%2C%22NotRecovered%22%3A%5B2%5D%2C%22Style%22%3A1%7D (accessed: 10.05.2024).

Auguie, B. (2017). *gridExtra: Miscellaneous Functions for "Grid" Graphics* (Version R package version 2.3). Available at: https://CRAN.R-project.org/package=gridExtra.

Baker, J. M. R. & Halliday, T. R. (1999). Amphibian colonization of new ponds in an agricultural landscape. *Herpetological journal*, 9: 55-63.

Beebee, T. J. C. (2013). Effects of Road Mortality and Mitigation Measureson Amphibian Populations. *Conservation Biology*, 27 (4): 657-668. doi: 10.1111/cobi.12063.

Bell, G. (1975). The diet and dentition of Smooth newt larvae (*Triturus vulgaris*). *Journal of Zoology*, 176 (3): 411-424. doi: 10.1111/j.1469-7998.1975.tb03212.x.

Bell, G. & Lawton, J. H. (1975). The Ecology of the Eggs and Larvae of the Smooth Newt (*Triturus vulgaris (Linn.)*). *Journal of Animal Ecology*, 44 (2): 393-423. doi: 10.2307/3604.

Bergen Kommune. (2019). *Kommunedelplan for overvann 2019-2029*. Available at: https://www.bergen.kommune.no/politikere-utvalg/api/fil/bk360/1860089/Kommunedelplan-for-overvann (accessed: 07.02.2024).

Birx-Raybuck, D. A., Price, S. J. & Dorcas, M. E. (2010). Pond age and riparian zone proximity influence anuran occupancy of urban retention ponds. *Urban ecosystems*, 13 (2): 181-190. doi: 10.1007/s11252-009-0116-9.

Brears, R. C. (2018). Blue-Green Infrastructure in Managing Urban Water Resources. In *Blue and Green Cities: The Role of Blue-Green Infrastructure in Managing Urban Water Resources*, pp. 43-61. London, United Kingdom: Palgrave Macmillan UK.

Broadhead, A. T., Horn, R. & Lerner, D. N. (2013). Captured streams and springs in combined sewers: A review of the evidence, consequences and opportunities. *Water Research*, 47 (13): 4752-4766. doi: 10.1016/j.watres.2013.05.020.

Charlton, O. & Lewis, T. R. (2017). Artificial egg-strip surveying for detection of pond-breeding newts: Does egg-strip substrate matter? *Salamandra*, 53 (4): 494-500.

Cirovic, R., Radovic, D. & Vukov, T. D. (2008). Breeding site traits of European newts (Tritururs macedonicus, Lissotriton vulgaris, and Mesotriton alpestris: Salamandridae) in the Montenegrin karst region. *Archives of Biological Sciences*, 60 (3): 459-468. doi: 10.2298/Abs0803459c.

Debele, S. E., Leo, L. S., Kumar, P., Sahani, J., Ommer, J., Bucchignani, E., Vranic, S., Kalas, M., Amirzada, Z., Pavlova, I., et al. (2023). Nature-based solutions can help reduce the impact of natural hazards: A global analysis of NBS case studies. *Science of the Total Environment*, 902: ARTN 165824. doi: 10.1016/j.scitotenv.2023.165824.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A. G., Mittal, N., Feliu, E. & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management*, 146: 107-115. doi: 10.1016/j.jenvman.2014.07.025.

Denis, E. (2020). More Urban Constructions for Whom? Drivers of Urban Built-Up Expansion Across the World from 1990 to 2015. In Lecture Notes in Morphogenesis, vol. Theories and Models of Urbanization, pp. 235-258. Switzerland: Switzerland: Springer International Publishing AG.

Dervo, B. K., Bærum, K. M., Skurdal, J. & Museth, J. (2016a). Effects of Temperature and Precipitation on Breeding Migrations of Amphibian Species in Southeastern Norway. *Scientifica (Cairo)*, 2016: 3174316-8. doi: 10.1155/2016/3174316.

Dervo, B. K., Pedersen, C. & Bærum, K. M. (2016b). *Tap av ynglelokaliteter for storsalamander i Norge*. NINA Rapport 1014: Norsk Institutt for Naturforskning. Available at: http://hdl.handle.net/11250/2383578 (accessed: 04.03.2024).

Dervo, B. K., Bærum, K. M. & Diserud, O. (2017). *Bruk av overvåkingsdata til beregning av bestandsutvikling hos storsalamander Triturus cristatus og småsalamander Lissotriton vulgaris i Norge.* NINA Rapport 1408: Norsk institutt for naturforskning. Available at: http://hdl.handle.net/11250/2469417 (accessed: 09.05.2024).

Dervo, B. K., Museth, J. & Skurdal, J. (2018). Assessing the Use of Artificial Hibernacula by the Great Crested Newt (Triturus cristatus) and Smooth Newt (Lissotriton vulgaris) in Cold Climate in Southeast Norway. *Diversity*, 10 (3): ARTN 56. doi: 10.3390/d10030056.

Dervo, B. K., Dokk, J. G. & Holter, T. (2019). *Rusefangst av stor- og småsalamander i Akershus 2019. En videreføring av den nasjonale overvåkningen av storsalamander i Norge*. NINA Rapport1730: Norsk institutt for naturforskning (NINA). Available at: http://hdl.handle.net/11250/2631657 (accessed: 08.05.2024).

Dervo, B. K. & van der Kooij, J. (2020). *Tiltakshåndbok for storsalamander - Erfaringer fra restaurerings- og skjøtselstiltak.* NINA Temahefte 73: Norsk Institutt for Naturforskning (NINA). Available at: https://hdl.handle.net/11250/2675363 (accessed: 09.04.2024).

Dervo, B. K., Strøm, B. S. & van der Kooij, J. (2021a). *Amfibier og reptiler: Vurdering av damfrosk Pelophylax lessonae for Norge*. Rødlista for arter 2021. Artsdatabanken Available at: http://www.artsdatabanken.no/lister/rodlisteforarter/2021/15708 (accessed: 09.01.2024).

Dervo, B. K., Strøm, B. S. & van der Kooij, J. (2021b). *Amfibier og reptiler: Vurdering av småsalamander Lissotriton vulgaris for Norge*. Rødlista for arter 2021. Artsdatabanken Artsdatabanken. Available at: http://www.artsdatabanken.no/lister/rodlisteforarter/2021/7789 (accessed: 09.01.2024).

Dervo, B. K., Strøm, B. S. & van der Kooij, J. (2021c). *Amfibier og reptiler: Vurdering av spissnutefrosk Rana (Rana) arvalis for Norge*. Rødlista for arter 2021. Artsdatabanken. Available at: http://www.artsdatabanken.no/lister/rodlisteforarter/2021/6630 (accessed: 09.01.2024).

Dervo, B. K., Strøm, B. S. & van der Kooij, J. (2021d). *Amfibier og reptiler: Vurdering av storsalamander Triturus (Triturus) cristatus for Norge*. Rødlista for arter 2021. Artsdatabanken. Available at: http://www.artsdatabanken.no/lister/rodlisteforarter/2021/785 (accessed: 09.01.2024).
Dervo, B. K., van der Kooji, J. & Johansen, B. S. (2021e). *Artsgruppeomtale amfibier og reptiler (Amphibia og Reptilia)*. Norsk rødliste for arter 2021. Artsdatabanken. Available at: https://artsdatabanken.no/rodlisteforarter2021/Artsgruppene/amfibierogreptiler (accessed: 09.01.2024).
Dervo, B. K. (2024). *Amphibian habitat requirements* (E-mail communication with Børre Dervo 11.05.2024).
Dolmen, D. (2008). *Norske amfibier og reptiler : (feltherpetologisk guide)*. Bli med ut! (trykt utg.), vol. 9. Trondheim: Tapir akademisk forl.
Donati, G. F. A., Bolliger, J., Psomas, A., Maurer, M. & Bach, P. M. (2022). Reconciling cities with nature: Identifying local Blue-Green Infrastructure interventions for regional biodiversity enhancement. *Journal of Environmental Management*, 316: ARTNR 115254. doi: 10.1016/j.jenvman.2022.115254.
Eldegard, K. (2024). *Great crested newt in garden pond* (E-mail to Katrine Eldegard 10.05.2023).
Elmberg, J. (2023). Amphibians and reptiles in North Sweeden: distribution, habitat affinities, and abundance (Classes: Amphibia and Reptilia). *Zootaxa*, 5301 (3): 301-335. doi: 10.11646/zootaxa.5301.3.1.
Elmore, A. J. & Kaushal, S. S. (2008). Disappearing headwaters: patterns of stream burial due to urbanization. *Frontiers in Ecology and the Environment*, 6 (6): 308-312. doi: 10.1890/070101.
Fahrig, L., Pedlar, J. H., Pope, S. E., Taylor, P. D. & Wegner, J. F. (1995). Effect of Road Traffic on Amphibian Density. *Biological Conservation*, 73 (3): 177-182. doi: 10.1016/0006-3207(94)00102-V.
Filazzola, A., Shrestha, N. & MacIvor, J. S. (2019). The contribution of constructed green infrastructure to urban biodiversity: A synthesis and meta-analysis. *Journal of Applied Ecology*, 56 (9): 2131-2143. doi: 10.1111/1365-2664.13475.
Fredriksen, B., A.,. (2023). *Interview with Professor Bjørn Anders Fredriksen, former Park Director at NMBU*. Ås (10.10.2023).
Grant, E. H. C., Miller, D. A. W. & Muths, E. (2020). A Synthesis of Evidence of Drivers of Amphibian Declines. *Herpetologica*, 76 (2): 101-107. doi: 10.1655/0018-0831-76.2.101.
Griffiths, R. A. (1986). Feeding Niche Overlap and Food Selection in Smooth and Palmate Newts, Triturus-Vulgaris and Triturus-Helveticus, at a Pond in Mid-Wales. *Journal of Animal Ecology*, 55 (1): 201-214. doi: 10.2307/4702.
Griffiths, R. A. & Mylotte, V. J. (1987). Microhabitat Selection and Feeding Relations of Smooth and Warty Newts, Triturus-Vulgaris and Triturus-Cristatus, at an Upland Pond in Mid-Wales. *Holarctic Ecology*, 10 (1): 1-7. doi: https://www.jstor.org/stable/3682117.
Grolemud, G. & Wickham, H. (2011). Dates and Times Made Easy with lubridate. *Journal of Statistical Software*, 40 (3): 1-25. doi: 10.18637/jss.v040.i03.
Hamer, A. J. & McDonnell, M. J. (2008). Amphibian ecology and conservation in the urbanising world: A review. *Biological Conservation*, 141 (10): 2432-2449. doi: 10.1016/j.biocon.2008.07.020.
Hayward, R., Oldham, R. S., Watt, P. J. & Head, S. M. (2000). Dispersion patterns of young great crested newts (*Triturus cristatus*). *Herpetological Journal*, 10 (4): 129-136.

Helldin, J. O. & Petrovan, S. O. (2019). Effectiveness of small road tunnels and fences in reducing amphibian roadkill and barrier effects at retrofitted roads in Sweden. *PeerJ*, 7: Artnr: e7518. doi: 10.7717/peerj.7518.

Hels, T. & Buchwald, E. (2001). The effect of road kills on amphibian populations. *Biological Conservation*, 99 (3): 331-340. doi: 10.1016/S0006-3207(00)00215-9.

Holtmann, L., Philipp, K., Becke, C. & Fartmann, T. (2017). Effects of habitat and landscape quality on amphibian assemblages of urban stormwater ponds. *Urban Ecosystems*, 20 (6): 1249-1259. doi: 10.1007/s11252-017-0677-y.

IUCN. (2023). *The IUCN Red List of Threatened Species. Version 2023-1.* . Available at: https://www.iucnredlist.org (accessed: 25.01.2024).

Jarvis, L. E., Hartup, M. & Petrovan, S. (2019). Road mitigation using tunnels and fences promotes site connectivity and population expansion for a protected amphibian. *European Journal of Wildlife Research*, 65: Artnr: 27. doi: 10.1007/s10344-019-1263-9.

Knozowski, P., Górski, A., Stawicka, A. M. & Nowakowski, J. J. (2022). Long-term changes in the diversity of amphibian communities inhabiting small water bodies in the urban area of Olsztyn (NE Poland). *European Zoological Journal*, 89 (1): 791-812. doi: 10.1080/24750263.2022.2087773.

Knutson, M. G., Sauer, J. R., Olsen, D. A., Mossman, M. J., Hemesath, L. M. & Lannoo, M. J. (1999). Effects of landscape composition and wetland fragmentation on frog and toad abundance and species richness in Iowa and Wisconsin, USA. *Conservation Biology*, 13 (6): 1437-1446. doi: 10.1046/j.1523-1739.1999.98445.x.

Konowalik, A., Najbar, A., Konowalik, K., Dylewski, L., Frydlewicz, M., Kisiel, P., Starzecka, A., Zalesna, A. & Kolenda, K. (2020). Amphibians in an urban environment: a case study from a central European city (Wroclaw, Poland). *Urban Ecosystems*, 23: 235-243. doi: 10.1007/s11252-019-00912-3.

Lehtinen, R. M. & Galatowitsch, S. M. (2001). Colonization of restored wetlands by amphibians in Minnesota. *American Midland Naturalist*, 145 (2): 388-396. doi: 10.1674/0003-0031(2001)145[0388:CORWBA]2.0.CO;2.

Li, X. C., Zhou, Y. Y., Eom, J., Yu, S. & Asrar, G. R. (2019). Projecting Global Urban Area Growth Through 2100 Based on Historical Time Series Data and Future Shared Socioeconomic Pathways. *Earths Future*, 7 (4): 351-362. doi: 10.1029/2019ef001152.

Luedtke, J. A., Chanson, J., Neam, K., Hobin, L., Maciel, A. O., Catenazzi, A., Borzée, A., Hamidy, A., Aowphol, A., Jean, A., et al. (2023). Ongoing declines for the world's amphibians in the face of emerging threats. *Nature*, 622: 308-314. doi: 10.1038/s41586-023-06578-4.

Madsen, H., Lawrence, D., Lang, M., Martinkova, M. & Kjeldsen, T. R. (2014). Review of trend analysis and climate change projections of extreme precipitation and floods in Europe. *Journal of Hydrology*, 519 (Part D): 3634-3650. doi: 10.1016/j.jhydrol.2014.11.003.

Magnussen, K., Wifstad, K., Seeberg, A. R., Stålhammar, K., Bakken, S. E., Banach, A., Hagen, D., Rusch, G., Aarrestad, P. A., Løset, F. & Sandsbråten, K. (2017). *Naturbaserte løsninger for klimatilpasning*. Norway: Miljødirektoratet. Available at: https://www.miljodirektoratet.no/globalassets/publikasjoner/m830/m830.pdf (accessed: 08.02.2024).

Malmgren, J. C. & Gustafson, D. (2002). *Inventering och övervakning av större vattensalamander (Triturus cristatus)*. publ nr 2002:2: Länsstyrelsen i Örebro län. Available at: https://www.diva-portal.org/smash/get/diva2:863494/FULLTEXT01.pdf (accessed: 08.04.2024).

Malmgren, J. C. (2007). *Åtgärdsprogram för bevarande av större vattensalamander och dess livsmiljöer*. Naturvårdsverket, Rapport 5636. Available at: https://naturvardsverket.diva-portal.org/smash/get/diva2:1632878/FULLTEXT01.pdf (accessed: 04.03.2024).

McCallum, M. L. (2007). Amphibian decline or extinction? Current declines dwarf background extinction rate. *Journal of Herpetology*, 41 (3): 483-491. doi: 10.1670/0022-1511(2007)41[483:Adoecd]2.0.Co;2.

Nguyen, T. T., Meurk, C., Benavidez, R., Jackson, B. & Pahlow, M. (2021). The Effect of Blue-Green Infrastructure on Habitat Connectivity and Biodiversity: A Case Study in the Otakaro/Avon River Catchment in Christchurch, New Zealand. *Sustainability*, 13 (12): ARTN 6732. doi: 10.3390/su13126732.

Norsk Landskapsarkitekters Forening. (s.a.-a). *Niagara - restaurering av verdens minste fossefall*. Available at: https://landskapsarkitektur.no/prosjekter/niagara-restaurering-av-verdens-minste-fossefall (accessed: 18.09.2023).

Norsk Landskapsarkitekters Forening. (s.a.-b). *Restaurering av Svanedammen på NMBU*. Available at: https://landskapsarkitektur.no/prosjekter/restaurering-av-svanedammen-pa-nmbu (accessed: 18.09.2023).

Nowakowski, J. J., Górski, A., Lewandowski, K. & Dulisz, B. (2011). Habitat selection of amphibians in water bodies in Olsztyn city (Poland). In Indykiewicz, P., Jerzak, L., Böhner, J. & Kavanagh, B. (eds) *Urban Fauna Studies of animal biology, ecology and conservation in European cities*, pp. 335-347. Poland: University of Technology and Life Sciences in Bydgoszcz.

Oertli, B. & Parris, K. M. (2019). Review: Toward management of urban ponds for freshwater biodiversity. *Ecosphere*, 10 (7): ARTNR e02810. doi: 10.1002/ecs2.2810.

Oksanen, J., Simpson, G., Blanchet, F., Kindt, R., Legendre, P., Minchin, P., O'Hara, R., Solymos, P., Stevens M, Szoecs, E., et al. (2022). *vegan: Community Ecology Package* (Version 2.6.4). Available at: https://CRAN.R-project.org/package=vegan.

Oldham, R. S., Keeble, J., Swan, M. J. S. & Jeffcote, M. (2000). Evaluating the suitability of habitat for the great crested newt (*Triturus cristatus*). *Herpetological journal*, 10 (4): 143-155.

Onset. (s.a.). *HOBO Pendant MX Temp (MX2201) and Temp/Light (MX2202) Logger Manual*.

Parris, K. M. (2006). Urban amphibian assemblages as metacommunities. *Journal of Animal Ecology*, 75 (3): 757-764. doi: 10.1111/j.1365-2656.2006.01096.x.

Paul, M. J. & Meyer, J. L. (2001). Streams in the urban landscape. *Annual Review of Ecology and Systematics*, 32: 333-365. doi: 10.1146/annurev.ecolsys.32.081501.114040.

Prudencio, L. & Null, S. E. (2018). Stormwater management and ecosystem services: a review. *Environmental Research Letters*, 13 (3): ARTNR 033002. doi: 10.1088/1748-9326/aaa81a.

R Core Team. (2022). *R: A Language and Environment for Statistical Computing* (Version 4.2.2). Vienna, Austria: R Foundation for Statistical Computing. Available at: https://www.R-project.org/.

Re:wild, Synchronicity Earth & IUCN SSC Amphibian Specielist Gorup. (2023). *State of the World's Amphibians: The Second Global Amphibian Assessment*. Available at: https://nc.iucnredlist.org/redlist/resources/files/1696400756-SOTWA_GAA2_04Oct2023.pdf (accessed: 29.01.2024).

Rubbo, M. J. & Kiesecker, J. M. (2005). Amphibian breeding distribution in an urbanized landscape. *Conservation Biology*, 19 (2): 504-511. doi: 10.1111/j.1523-1739.2005.000101.x.

Sandin, L., Seifert-Dähnn, I., Furuseth, I. S., Baattrup-Pedersen, A., Zak, D., Alkan Olsson, J., Hanson, H., Sadat Nickayin, S., Wilke, M., Koivula, M., et al. (2022). *Working with*

Nature-Based Solutions. Synthesis and mapping of status in the nordics. Nordic Council of Ministers. Denmark: Copenhagen. Available at: https://pub.norden.org/temanord2022-562/temanord2022-562.pdf (accessed: 08.02.2024).
Sandlund, O. T., Pettersen, O. & Hesthagen, T. (2016). *Effekter av spredning av karpefisk på biologisk mangfold. En litteratur gjennomgang*. NINA Kortrapport 35: Norsk institutt for naturforskning. Available at: http://hdl.handle.net/11250/2425638 (accessed: 09.05.2024).
Sauer, E. L., Cruz, J., Crone, E., Lewis, C., Plumier, E., Cwynar, B., Drake, D., Herrick, B. M. & Preston, D. L. (2022). Multiscale drivers of amphibian community occupancy in urban ponds. *Urban Ecosystems*, 25: 1469-1479. doi: 10.1007/s11252-022-01239-2.
Scheffers, B. R. & Paszkowski, C. A. (2013). Amphibian use of urban stormwater wetlands: The role of natural habitat features. *Landscape and Urban Planning*, 113: 139-149. doi: 10.1016/j.landurbplan.2013.01.001.
Semb-Johansson, A. & Frislid, R. (1981). *Norges dyr : 3 : Fisker, amfibier, krypdyr*. [2. utg.]. ed., vol. 3. Oslo: Cappelen.
Semb-Johansson, A., Jonsson, B. & Frislid, R. (1992). *Norges dyr : 1 : Fiskene Krypdyr, amfibier, ferskvannsfisker*. [3. utg.]. ed., vol. 1. Oslo: Cappelen.
Siehr, S. A., Sun, M. M. & Nucamendi, J. L. A. (2022). Blue-green infrastructure for climate resilience and urban multifunctionality in Chinese cities. *Wiley Interdisciplinary Reviews-Energy and Environment*, 11 (5): ARTNR e447. doi: 10.1002/wene.447.
Skei, J. K., Dervo, B. K., van der Kooij, J. & Kraabøl, M. (2010). *Evaluering av regestreringsmetoder for nasjonal overvåkning av storsalamander Triturus cristatus i Norge*. NINA Rapport 589: Norsk Institutt for Naturforskning. Available at: http://hdl.handle.net/11250/2642337 (accessed: 26.03.2024).
Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, 10: ARTNR 13768. doi: 10.1038/s41598-020-70816-2.
Tromsø Kommune. (2020). *Kommunedelplan for overvann 2019-2032*. Available at: https://tromso.kommune.no/sites/default/files/2022-02/Kommunedelplan_overvann_UU.pdf?v=31 (accessed: 07.02.2024).
Vos, C. C. & Chardon, J. P. (1998). Effects of habitat fragmentation and road density on the distribution pattern of the moor frog Rana arvalis. *Journal of Applied Ecology*, 35 (1): 44-56. doi: 10.1046/j.1365-2664.1998.00284.x.
Wake, D. B. & Vredenburg, V. T. (2008). Are We in the Midst of the Sixth Mass Extinction? A View from the World of Amphibians. *Proceedings of the National Academy of Sciences - PNAS*, 105 (supplement_1): 11466-11473. doi: 10.1073/pnas.0801921105.
Wells, K. D. (2007). *The Ecology and Behavior of Amphibians*. Chicago: University of Chicago Press.
Whitford, V., Ennos, A. R. & Handley, J. F. (2001). "City form and natural process" - indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape and Urban Planning*, 57 (2): 91-103. doi: 10.1016/S0169-2046(01)00192-X.
Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. 3.4.4 ed.: Springer-Verlag New York.
Wickham, H., François, R., Henry, L., Müller, K. & Vaughan, D. (2023a). *dplyr: A Grammar of Data Manipulation* (Version version 1.1.3). Available at: https://CRAN.R-project.org/package=dplyr.
Wickham, H., Vaughan, D. & Girlich, M. (2023b). *tidyr: Tidy Messy Data* (Version R package version 1.3.0). Available at: https://CRAN.R-project.org/package=tidyr.

Wild, T. C., Bernet, J. F., Westling, E. L. & Lerner, D. N. (2011). Deculverting: reviewing the evidence on the 'daylighting' and restoration of culverted rivers. *Water and Environment Journal*, 25 (3): 412-421. doi: 10.1111/j.1747-6593.2010.00236.x.

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