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DEPARTMENT OF ECOLOGY

BACHELOR THESIS

Detection probability in amphibian monitoring

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BACHELOR THESIS ASSIGNMENT

Anastasia Kuperberg

Environmental Sciences
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Thesis title

Detection probability in amphibian monitoring

Objectives of thesis

Monitoring of biodiversity is important for its conservation, because it can help to identify main conservation needs and to test the effectiveness of management actions. The main goal of my bachelor thesis is to deal with an issue of detection probability in amphibian monitoring, specifically: (i) to describe relevant terms as detection probability, site occupancy, imperfect detection related to species monitoring and its errors; (ii) to describe sources of errors of imperfect detection within species monitoring and faunistics; (iii) to provide information how to account for detection probability in abundance and site-occupancy assessment (different models and their use) including software used for that accounting; (iv) finally, to provide examples of studies considering imperfect detection and accounting for detection probability, mainly in amphibians.

Methodology

Work with relevant scientific papers and databases of these paper (WoS, Scopus, Science Direct), using key words, criticism and assessment of relevant papers.

The proposed extent of the thesis

cca 30 stran + přílohy

Keywords

amphibians, species monitoring, imperfect detection, site occupancy

Recommended information sources

Dorazio, Robert M. 2014. "Accounting for Imperfect Detection and Survey Bias in Statistical Analysis of Presence-Only Data." Global Ecology and Biogeography 23 (12): 1472–84.

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Declaration

I hereby declare that I have independently elaborated the bachelor/final thesis with the topic of: "Detection probability in amphibian monitoring" and that I have cited all of the information sources that I used in the thesis as listed at the end of the thesis in the list of used information sources. I am aware that my bachelor/final thesis is subject to Act No. 121/2000 Coll., on copyright, on rights related to copyright and on amendments of certain acts, as amended by later regulations, particularly the provisions of Section 35(3) of the act on the use of the thesis. I am aware that by submitting the bachelor/final thesis I agree with its publication under Act No. 111/1998 Coll., on universities and on the change and amendments of certain acts, as amended, regardless of the result of its defense. With my own signature, I also declare that the electronic version is identical to the printed version and the data stated in the thesis has been processed in relation to the GDPR.

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Abstract: The correct data resulting from the biodiversity monitoring are extremely important for conservation and appropriate management decisions. However, data are often biased for many different reasons. One of those is the imperfect detection, which means that individuals, populations or species are not always found even when they are present at a site. There are many causes for the detection to be imperfect, like species ecology, habitat features, weather conditions or even observers' skills. The way of accounting for the imperfect detection is to determine the detection probability for the species of interest. Even though the popularity of using the detection probability in studies and researches is growing, many biodiversity monitoring programs are still omitting it. This thesis deals with accounting for the imperfect detection and detection probability assessment in amphibian studies. In the literature review part, the theoretical background for this topic is presented. Terms connected with biodiversity monitoring are provided and different sources of error in it are listed. The imperfect detection and detection probability assessment are described deeply with examples in different species. The practical part of the thesis deals with the detection probability in amphibians and consists of two parts. The first part contains a simple meta-analysis of the available studies that account for the detection probability and deal with the amphibian species living in the Czech Republic. The second part includes the analysis of the abundance data of a population of fire salamanders (*Salamandra salamandra,* Linnaeus, 1758) in Prague, specifically the proportions of active salamanders per visit, and the suggestion for the further analysis of that data accounting for the detection probability.

Key words: Amphibians, species monitoring, imperfect detection, site occupancy

Abstrakt: Přesnost dat, která jsou zjišťována při monitoringu organismů je velice důležitá pro ochranu biodiverzity a stanovení vhodného managementu. Nicméně získávaná data jsou často z různých důvodů zkreslená a nedopovídají realitě. Jednou z příčin je fakt, že detekce daného druhu je prakticky vždy zatížena chybou a téměř nikdy není stoprocentní. Jinými slovy, jedinci, ale i populace nebo druhy nejsou vždy v průběhu monitoringu nebo mapování nalezeny, i přesto, že jsou na daném místě přítomní. Nedokonalá detekce může být způsobena různými příčinami, například ekologií druhů (skrytý způsob života, mimikry), charakteristikami habitatu, ale i schopnostmi pozorovatele. Zohlednění nedokonalé detekce v rámci monitoringu se děje stanovením pravděpodobnosti detekce pro určitý druh. Ve vědeckých výzkumech je pravděpodobnost detekce druhu stále častěji brána v potaz, nicméně při monitoringu nebo mapování je často stále opomíjená. Předkládaná bakalářská práce se zabývá problematikou nedokonalé detekce druhů a způsobům určení pravděpodobnosti detekce, zejména v případě obojživelníků. V rešeršní části je popsaná teorie týkající se daného tématu. Nejprve jsou definovány relevantní pojmy spojené s monitoringem druhů a popsány různé zdroje chyb. Dále je věnována značná pozornost nedokonalé detekci a způsobům určení pravděpodobnosti detekce. Praktická část této práce se skládá ze dvou oddílů. První obsahuje jednoduchou metaanalýzu dostupných studii, které zohledňují pravděpodobnost detekce a současně se zabývají obojživelníky žijícími v České republice. Cílem je vyhledat konkrétní hodnoty pravděpodobnosti detekce a faktory ji ovlivňující, pro naše jednotlivé druhy. Druhá část zahrnuje analýzu početnosti jedné pražské populace mloka skvrnitého (*Salamandra salamandra*, Linnaeus, 1758). Konkrétně jde o stanovení podílu aktivních jedinců během jednotlivých návštěv a dále konkrétní návrh stanovení pravděpodobnosti detekce pro tuto populaci.

Klíčová slova: Obojživelníci, monitoring druhů, nedokonalá detekce druhů, osídlení biotopů

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1. Introduction

Biodiversity is the variety within and among living organisms (Swingland 2001). It can be measured on three levels: genetic, ecosystem (Berwald 2020) and species diversity (Kéry & Schmidt 2008). It can be observed and measured at any spatial scale: from small sites and habitat patches to the entire biosphere (Swingland 2001). Species diversity or species richness, is the number of different species in a certain area (Kéry & Schmidt 2008). It can be calculated using different indices or simple counting of animals with the help of abundance or site occupancy estimation (Thukral 2017). Abundance is the number of individuals in a population (Kéry & Schmidt 2008) and site occupancy is the number of populations of the species within a larger area or collection of sites (Mazerolle et al. 2007). Gaining the information on the state of biodiversity helps determining main issues for policy and management goals, setting priorities for conservation and detecting the important changes (Niemelä 2000). One of the main ways of studying biodiversity is monitoring. Monitoring of biodiversity focuses on the gathering of information about ecosystems and their components, like communities, species and populations at different times. It can help assessing their state and reaching conclusions about the changes over time (Yoccoz, Nichols & Boulinier 2001).

However, the data collected by biodiversity monitoring are often biased for different reasons. One of the sources of error is the imperfect detection of species. The imperfect detection means that individuals, populations or species are not always detected even when they are present at a site (Tanadini & Schmidt 2011), so nondetection is not always equal to species absence (MacKenzie et al. 2003). If the imperfect detection is not accounted for, it will then cause bias in estimates of abundance, site occupancy (Tanadini & Schmidt 2011) or biased estimates of local colonization and extinction probabilities (Petitot et al. 2014). There are different causes of the imperfect detection, such as unfavorable weather conditions (Tanadini & Schmidt 2011), cryptic behavior (Kéry 2002) and color patterns of animals (Mazerolle et al. 2007) or even observer's motivation (Farmer, Leonard & Horn 2012). Not accounting for the imperfect detection can lead to incorrect management decisions (Schmidt et al. 2013). An efficient way of accounting for it is the detection probability assessment. The detection probability is the probability of detecting a species when it is present (Edwards, Pauley & Waldron 2016). There are two main types of studies accounting for the detection probability: estimating abundance or site occupancy. The value of the detection probability (p) is always placed between 0 and 1 (Kéry & Schmidt 2008), so that $p = 1$ means that detection is perfect (Kissling & Garton 2006), which happens rarely (Kéry & Schmidt 2008). When p < 1, expected counts E(C) are smaller than true abundance N in abundance studies or average observed occurrence $E(\eta)$ is smaller than true site occupancy ψ in site occupancy studies (Kéry & Schmidt 2008). To determine a detection probability, species have to be repeatedly recorded being present in site occupancy studies or repeatedly counted in abundance studies and then their

real abundance or site occupancy can be established using various statistical models. In case of abundance assessments, capture-mark-recapture (CMR) models are used the most. Those models are based on CMR approach, when individuals during the study are captured, counted, marked and released in the habitat (Pesarakloo, Najibzadeh & Mirkamali 2020) to be recaptured or resighted on a later occasion (Tanadini & Schmidt 2011). The CMR models are divided into the three classes of models according to the character of the estimated population, so that there are closed population models, open population models and robust design models, which are the combination of open and closed models (Mazerolle et al. 2007). Besides CMR models, there are models for populations that cannot be marked (Iijima 2020). In case of site occupancy assessment, the models are based on data of repeated surveys at a number of sites (Mazerolle et al. 2007) and are recorded as a vector of 1's and 0's meaning detection and nondetection respectively (MacKenzie et al. 2002). The site occupancy models are divided according to the length of study into single-season or multiseason models and by the number of species of interest into single-species or multispecies models (MacKenzie et al. 2003). To perform difficult calculations of detection probabilities, true abundances and site occupancies different software is used.

Accounting for detection probability in monitoring is very important for receiving the true and reliable data, because in most of groups of plants and animals the detection probability is less than 1. For example, in plants, the detectability of the species can be dependent on their size (Roth et al. 2018); in stream fish species detection probability can be determined by the water depth or water temperature (Mollenhauer, Logue & Brewer 2018); in reptiles the detectability correlates with how cryptic their coloration is (Kery 2002), their body size and behavior (Ruiz De Infante Anton et al. 2013). Even in studies of huge African elephants (*Loxodonta africana,* Blumenbach, 1797), the detection is not perfect, because it can be affected by tall trees (Schlossberg, Chase & Griffin 2016). However, still not all of the scientific studies and monitoring programs take into account the detection probability.

The detection probabilities of amphibians are also usually less than one (Petitot et al. 2014), as most amphibian species are nocturnal (Eekhout 2010), have cryptic color patterns or live underground or in muddy waters (Tanadini & Schmidt 2011). So that their detectability can be dependent on the sampling methods, the period of the year, the weather, habitat types and skill of the observer (Petitot et al. 2014). For instance, the detection probability of the common tree frog (*Hyla arborea*, Linnaeus, 1758) is 0.3 when the temperature is around 5°C, whereas when the temperature is 25°C, the detectability is close to 1 (Pellet & Schmidt 2005). In case of the palmate newt (*Lissotriton helveticus*, Razoumovsky, 1789), the visual encounter sampling method provides a detection probability higher than 0.8 for a single visit from the end of February till the beginning of April (Petitot et al. 2014). The yellow-bellied toad's (*Bombina variegata*, Linnaeus, 1758) detection probability is dependent on the wind speed, so when the wind speed is 5 km/h, the detectability of this species is around 0.8, however if the wind speed is 20km/h, the detection probability is around 0.6 (Tanadini & Schmidt 2011).

As it is clear that the detection probability is important to account for in studies, in my bachelor thesis I focus on the detectability of amphibians, especially species living in the Czech Republic. In terms of the practical part of my thesis:

1. I created a simple meta-analysis of available studies, researches, articles and theses that account for detection probability in abundance and site occupancy assessment of amphibian species living in the Czech Republic.

2. I analyzed the abundance data from the long-term monitorng of the target population of fire salamanders (*Salamandra salamandra*, Linnaeus, 1758), which inhabits the northern part of Prague (Filousová 2019). Specifically, I calculated the proportions of active salamander numbers per visit and the suggested the further analysis of that data accounting for the detection probability.

The results of my thesis can be used for amphibian monitoring and conservation in practice.

2. Goals

Monitoring of biodiversity is important for its conservation, because it can help to identify main conservation needs and test the effectiveness of management actions. The main goal of my bachelor thesis is to deal with an issue of imperfect detection and detection probability in amphibian monitoring, specifically:

1. To describe relevant terms related to species monitoring and its errors, such as detection probability, imperfect detection, site occupancy and abundance;

2. To describe sources of errors and especially sources of imperfect detection within species monitoring;

3. To provide information on how to account for detection probability in abundance and site occupancy assessment using different statistical models. Also, to describe different software that is used for the calculation of these models;

4. To show examples of studies considering imperfect detection and accounting for detection probabilities in different species;

5. To analyze examples of studies considering imperfect detection in amphibians living in the Czech Republic. To draw inferences from the data received and answer the study questions about the most frequent type of studies accounting for detection probabilities, the most used models and software for each type of studies and the most used covariates. Also, to provide the information like what influences the detection probability of each selected species and for some species to show the exact values of detection probabilities.

6. To analyze the abundance data from long-term monitorng of the target population of *Salamandra salamandra* and calculate the proportions of active salamander numbers per visit, mean number of active salamanders per visit, and minimum and maximum of active salamanders during a visit.

7. To suggest the further analysis of that abundance data accounting for the detection probability.

3. Literature review

Within this literature review I deal with the imperfect detection and detection probability in biodiversity monitoring. In the chapter 3.1, the definition of biodiversity monitoring is explained and the reasons of its importance for the nature conservation are highlighted, and also different biodiversity levels and its components are described. The main attention is paid to species diversity and sources of error in its monitoring. As one of the sources of error is imperfect detection, in the chapter 3.2 its definition is explained and the reasons of its occurrence are listed. To reduce the effect of imperfect detection on the monitoring results it is important to know the detection probability of species. So that, in the chapter 3.3 the definition of detection probability is clarified and the ways of measuring and implementing it into the surveys are described. In the chapter 3.4, the examples of studies on different species accounting for detection probability are listed.

3.1 Biodiversity monitoring and its errors

Monitoring of biodiversity is important for its conservation, because it can help to identify main conservation needs and to test the effectiveness of management actions (Kéry & Schmidt 2008). There are different types of biodiversity monitoring, like short-term and long-term monitoring. Long-term monitoring provides more reliable data, enables to watch population trends and helps measuring to what extent populations are endangered. Conservationists from different fields initiate long-term monitoring programs (Tanadini & Schmidt 2011), and one of the primary purposes of such programs is to collect data that can be used to examine the outcomes of management actions and to guide management decisions (Hunter & Heywood 2010).

3.1.1 Main terms and definitions

Biodiversity monitoring

Monitoring is the process of gathering information about some system at different points in time for the purpose of assessing system state and drawing inferences about state changes over time (Yoccoz, Nichols & Boulinier 2001). Monitoring of biodiversity typically focuses on ecosystems and their components, like communities, species and populations (Yoccoz, Nichols & Boulinier 2001). Monitoring consists of

two parts: making reliable observations from nature and detecting, measuring and drawing conclusions about how much species and ecosystems are changing. Monitoring of biodiversity can focus on different aims, like genetic diversity changes, control of invasive species or changes in vegetation cover or soil condition (Hunter & Heywood 2010), but often the main purpose is the assessment of population trends.

Biodiversity levels

There are three levels of biodiversity: ecosystem, genetic and species biodiversity. **Genetic diversity** is the variability of the individuals' genetic material in a certain population or community. This type of biodiversity influences how well a species can adapt to environmental pressures, like droughts, fires, climate changes, parasites, diseases or predators. **Ecosystem diversity** can refer either to the number of ecosystems or habitats found in a certain area, or to the extent of complexity and diversity of an ecosystem (Berwald 2020).

Species diversity

Species diversity or species richness is the number of different species in a certain area (Kéry & Schmidt 2008). It can be either measured by simple counting of species or using the diversity indices (Thukral 2017). Calculating methods of different indices vary, so that different indices from the same original data, the outcome of calculations will be different for each index. Indices are often based not only on abundance of species, but also on the species evenness, which describes how relative abundance or biomass is distributed among species (Wilsey & Stirling 2007) . Which means that a community, in which the species have equal number of individuals of different species, will have a higher diversity index than a community dominated by one or few species (Bynum 2021). The Shannon-Wiener index (H') is one of the most used indices. It can be calculated as: $H' = \frac{N \ln N - \sum n_i \ln n_i}{N}$, where N is the total number of species and n_i is the number of individuals in species i (Kiernan 2020). The Shannon-Wiener index is high when there are a lot of rare species in a surveyed community. Also, the Simpson's index (D) is used a lot and is calculated as: $D = \sum_{i=1}^{R} p_i^2$, where p_i is the proportional abundance for each species and R is the total number of species in the sample (Kiernan 2020). The Simpson's index is high when there are a lot of individuals within some species in a surveyed community. Also, the Brillouin index (HB) can be used in the situations when the sampling might not be random. It is calculated as: $HB = \frac{\ln N! - \sum_{i=1}^{S} \ln n_i!}{N}$, where n_i is the number of individuals in the ith species and N the total number of individuals in the sample (Beaugrand & Edwards 2001).

Species biodiversity can be also measured on the spatial scales: alpha, beta, and gamma diversity (Whittaker 1972). Alpha diversity is a diversity within community, the richness of taxa at a single locality or in a certain community. Beta diversity is a diversity between communities, which reflects taxonomic differences of fauna or flora between sites or communities. Gamma diversity is a diversity between regions, which shows the taxonomic differences between geographic regions (Sepkoski 1988).

Abundance is the number of individuals (Kéry & Schmidt 2008) in the population. Absolute abundance is the total number of individuals in the population. Relative abundance refers to how even the distribution of individuals is among species in a community (Groves 2017) or how common or rare is the species comparing to other species in the certain location (Hubbell 2001). Absolute abundance is very hard to measure, so that the estimation of relative abundance is used more often. Methods of estimating species abundance are different. The easiest methods are based on counting signs of individuals (like bird calls or animal droppings), which results to the number per unit area which can be converted into a population count by multiplying by the population area (Schwarz & Seber 1999). The widely used method of estimating the population abundance is by tagging or marking, used in capture-mark-recapture (CMR) approach. The principle of CMR approach is that during the study individuals are captured, counted, marked and released in the habitat (Pesarakloo, Najibzadeh & Mirkamali 2020) to be recaptured or resighted on a later occasion (Tanadini & Schmidt 2011). The samplings are conducted the following way: the observer takes series of samples, the first sampling is used for tagging and releasing animals, the animals encountered in the second sampling can be either tagged or untagged, the untagged animals are then tagged, and all the animals are released and that process is repeated several times. In the end of the survey, each caught has a certain capture history. For example, the history 10101 of an individual means that the individual was caught in the first, third and fifth samples (Schwarz & Seber 1999). Marks are usually individual-specific, and can be metal bands for birds or bats), color bands for birds, ear tags for mammals and pen markings for lizards and invertebrates (Lettink & Armstrong 2003). Toe clip combinations for frogs, lizards and small mammals were used (Lettink & Armstrong 2003) before, but nowadays the use of this method decreased because of the ethical issues, as it causes discomfort and pain to the animals.

Fig. 1: Cope's Gray Treefrog (*Dryophytes chrysoscelis*, Cope, 1880) with the orange alphanumeric tag A13 inserted into the thigh (by Brad M. Glorioso, 2019)

Species distribution is the spatial distribution of a species (Dorazio 2014) or how the individuals in a population are distributed in space at a given time (Rye et al. 2016). The distribution can be based on biotic factors, like agriculture, vegetation cover or carnivore richness and abiotic factors (Clark, Choi & Douglas 2018), like precipitation and potential evapotranspiration (Lewis et al. 2017) . The distribution or dispersion of individuals in the certain area can be of three different types. Clumped dispersion means that individuals are clustered in groups (Rye et al. 2016). This type of dispersion usually occurs in a situation when resources are concentrated in small areas within a larger habitat or if individuals form social groups (Walker 2011). In uniform dispersion, individuals are spaced more or less evenly (Rye et al. 2016), which could be the result of territoriality and competition (Walker 2011). Random dispersion means that individuals are distributed randomly, without a pattern (Rye et al. 2016). This type of dispersion is not typical in nature (Walker 2011) and could indicate that the environment is favorable (Rye et al. 2016) or that there is a lack of interactions among individuals in the population (Walker 2011).

Site occupancy is the number of populations of the species within a larger area or collection of sites (Mazerolle et al. 2007). Site occupancy is a very important characteristic, as the its probabilities may be used as a metric reflecting the current state of the population (MacKenzie et al. 2003). The site occupancy and abundance are linked with abundance-occupancy relationship, which means that species declining in abundance often tends to decline in the number of sites it occupies, while species whose abundance increases also increases in site occupancy (Gaston et al. 2000).

Aims of species and population monitoring are the observation and recording of changes in status and trends of species or their populations in a certain territory (Hunter & Heywood 2010). Accurate monitoring data are very important for conservation and management decisions. For instance, some of the criteria for classifying the species into one of the categories of IUCN Red list are abundance, site occupancy and species distribution (IUCN 2020).

3.1.2 Error sources in monitoring

There are various sources of error in species monitoring that can cause distortion and misinterpretation of the collected data (Tanadini & Schmidt 2011). The bias causes may be different and are shown in the following paragraphs:

The samples might **not be representative** (Archaux 2011). The representativeness of the sample is judged by several criteria. It should provide the answer the certain question, and the question should refer to the certain population. Samples have to be collected randomly. Furthermore, a sample should adequately represent the population, which means, ideally, it should be a miniature of the target population (Ramsey & Hewitt 2005). The example of representative sampling could be the data set consisting of data from 30 plots selected randomly and located using a GPS device, plots being declined only for the reason of inaccessibility (Diekmann, Kiihne &

Isermann 2007). Not representative is the method of **convenience sampling.** That method is very often used by biologists and conservationists in the field work because of its simplicity. However, data collected that way in most cases are not representative of populations of interest (Anderson 2001). Convenience sampling is a type of nonrandom sampling. In that type of sampling, sampled organisms meet certain criteria, like easy accessibility, geographical proximity, availability at a given time or easy accessibility to the researcher (Etikan, Musa & Alkassim 2016). Samples can be collected along roads, trails, utility corridors or taken subjectively near camp, around parking areas, or on areas where density is known to be high. (Anderson 2001). For example, in the field work estimating size and condition of trees in urban conditions, where field personnel while walking through the urban landscape, chose trees situated next to the route, the data sampling can be classified as convenient (Speak et al. 2018).

Imperfect detection of species can be an important source of error. Imperfect detection means that individuals, populations or species are not always found even when they are present at a site, so nondetection does not equate to species absence (MacKenzie et al. 2003). As it is shown below, many factors can cause the imperfect detection.

3.2 Imperfect detection

Detecting individuals during the biodiversity monitoring can be a hard task, the detection of some species can be more daunting than the detection of other, but few species are likely to be so evident that they will always be detected when present. One of the reasons of that is the occurrence of the imperfect detection (MacKenzie et al. 2003).

3.2.1 Term definition

Imperfect detection means that individuals, populations or species are not always found even when they are present at a site. Imperfect detection will then cause bias in estimates of abundance, site occupancy, species richness (Tanadini & Schmidt 2011) or biased estimates of local colonization and extinction probabilities (Petitot et al. 2014), unless it is accounted for (Tanadini & Schmidt 2011). Errors caused by imperfect detection can be divided into two main types: false negatives (Farmer, Leonard & Horn 2012), also called errors of omission or nondetection (Chen et al. 2013) and false positives (Farmer, Leonard & Horn 2012), also called errors of commission or misclassification (Chen et al. 2013). False negatives occur when a species is present but is not recorded and false positives happen when a species is absent but is recorded. False positives are more serious errors because they usually result from the misidentification of a species that is actually present, so that they are often accompanied by simultaneous false negative outcome. The problem of false negatives in animal surveys has been studied for a long time, while false positives are often assumed to be insignificant and have received less attention (Farmer, Leonard & Horn 2012).

If variation in detectability is not accounted for, unreliable data are generated (Petitot et al. 2014). Furthermore, if imperfect detection varies spatially or temporally, then spatial or temporal patterns in abundance and distribution can appear, even though in reality they are not important (Tanadini & Schmidt 2011). The species turnover rate can also be biased, as a seeming recolonization of a site may be due to nondetection of the species at a previous sampling period (MacKenzie et al. 2003). Imperfect detection generally is an issue for all wildlife studies, but is particularly severe for rare and elusive species (Metz et al. 2020).

3.2.2 Reasons and sources of imperfect detection

There are several sources of imperfect detection, which are:

Weather and environmental conditions

If the weather conditions are unfavorable, then few animals may be active and detectable, so that the counts of abundance might be biased. For instance, the yellow-bellied toad (*Bombina variegata*) hides during windy nights. So that this species is only active and available for detection when there is no wind (Tanadini & Schmidt 2011). Animals also may be conspicuous only under certain weather conditions (Mazerolle et al. 2007), for example during warm and moist nights more male amphibians may be heard calling and this would make the population more easily detectable (Tanadini & Schmidt 2011). Also, the barometric pressure can have an impact on detectability. Barometric pressure lowering helps animals like coyotes (*Canis latrans*, Say, 1823) to predict rain, and that can lead to less activity (Madsen, Corral & Fontaine 2020).

Species ecology

Different species vary in their ecological requirements. The detectability of the species can depend on the time of the year. Some species are inactive for the certain period of the year, for example black bears hibernate from 5 to 7 months every year (Toien et al. 2011), so that period of time is not suitable for monitoring of those animals. Also population changes happen at the certain time of the year, like addition of the young fishers into the population, can cause variation in the detectability (Slauson et al. 2009). Imperfect detection can be also caused by the fact that different species are active during different time of the day. Some species can be nocturnal (Mazerolle et al. 2007), which means that they are most active at night (Smale & Nunez 2009). For instance, *Bombina variegata* is mostly active during the night (Tournier 2017). So naturally, species like this should be monitored at night. Some species detection can be complicated because of their cryptic behavior (Kéry 2002) or color patterns (Mazerolle et al. 2007). For example, Burmese python (*Python molurus bivittatus*, Kuhl, 1820) is one of the largest snake species in the world, with adults exceeding 5 m in length. However, Burmese python is difficult to detect, because of its coloration and cryptic behavior (Nafus, Mazzotti & Reed 2020).

Fig. 2: Burmese Python (*Python molurus bivittatus*) in Sauraha, Nepal. (by Paul Freed & Barbara Lester)

Detection of animals can depend on the type of habitat. Some animals spend some time or even live underground (Mazerolle et al. 2007). For instance, terrestrial salamanders are active on the surface during the day only if it can provide the moist conditions, because salamanders lack lungs and respire cutaneously. A surface can provide moisture for some time after rain, but terrestrial salamanders eventually go underground when a surface becomes too dry. (O'Donnell & Semlitsch 2015). Studies of aquatic species also come across the imperfect detection issues. For instance, whales and other marine mammals spend most of their time underwater, rarely appearing on the surface and that affects their detectability during monitoring (Metz et al. 2020). Also the imperfect detection is a big issue for monitoring rare freshwater fishes, because they are small-bodied, cryptic, occur in low abundances and inhabit heavily vegetated sites (Wedderburn 2018). Imperfect detection can be caused by the life cycle of animals. For example, the indirect development is very typical for amphibians, most of them go through three life stages: embryonic, larval and adult. Even though, larval stages of amphibians often look just like a small versions of adults (for example larvae of salamanders) (Zug & Duellman 2020), it can still be harder to detect them because of the smaller size. Which can lead to the situation that there are a lot more individuals of the certain species than it was detected.

Population size

It is a potentially important source of variation in detection probabilities (Kéry 2002). Small populations are more likely to be unnoticed during surveys. Which can have consequences like going extinct, because they cannot be the focus of conservation action (Alpizar-Jara et al. 2004). Or conservation managers may stop species-specific management actions, so the species may go locally extinct. (Tanadini & Schmidt 2011).

Observers' skills, experience and motivation

This type of error is linked only to an observer as a person. Skills, abilities, motivation and experience can vary between observers. For instance, in surveys of birds and anurans, a great proportion of detections are made by ear, without visual confirmation of a species' identity. So that accurate auditory identifications can be difficult because many species sound alike and also background noises can affect detection probability (Farmer, Leonard & Horn 2012). Species that are more rare and call less often tend to be associated with greater numbers of detection errors than frequently calling and less rare species (Rempel et al. 2005). So that observer experience might be an important factor, as more experienced observers are more successful in spotting animals (O'Donnell & Semlitsch 2015), especially more rare species. Visual and aural acuity and or also fatigue of the observers can affect the results of the research (Mazerolle et al. 2007), for example in call-count monitoring the hearing sharpness is very important. Also, the motivation of observers can affect detectability (O'Donnell & Semlitsch 2015) , as motivated and interested observer will pay more attention to the surroundings and detect more animals.

Habitat features

Detectability of the species is also dependent on different characteristics of the habitat. In case of terrestrial habitats, the characteristics are the area of the habitat, its viewshed, openness and segmentation. In case of aquatic habitats, the detectability depends on the size of the habitat, its segmentation, depth, water transparency and whether plants are present. Viewshed is a topographic nature of where animals are in relation to observer locations or whether the location is viewable. For instance, viewshed had a very strong effect on the probability of observing gray wolves (*Canis lupus*, Linnaeus, 1758) in northern Yellowstone National Park, Wyoming, USA. Detection of wolves was four times more likely when wolves were in the predicted viewshed. Also, the results were negatively affected by distance from observer locations, meaning the larger was the distance, the less likely was to observe a wolf. Openness or how forested are areas where species of interest live, can also play a great role in species' detectability (Metz et al. 2020). Trees, shadows and ground cover coloration can make it difficult to count elks (*Cervus canadensis*, Erxleben, 1777) after a group is detected by aerial survey (Clement, Converse & Royle 2017).

Survey duration

Imperfect detection can be dependent on the survey duration. Detection increases when the survey lasts longer (Albergoni et al. 2016) and longer survey duration plays a big role in detecting species that are inconspicuous or have large home ranges (Galbraith et al. 2011).

Sampling method used

There are a lot of different sampling methods with different efficiency. It is very important to choose the right method, as every species, sometimes even individuals of

different life stages within the same species can require different sampling methods. The right timing of sampling is also crucial, as was written above. The sampling methods can be observational: avian point counts, visual searches, foot track surveys (looking for animal signs) or audio monitoring. Methods can be based on passive capturing, like pitfalls and snap traps6 or on active capturing, like cannon nets or hand capture. There are also methods based on marking, for example mutilation or pigments (McComb et al. 2010). Those methods can be also combined, for instance in case of capture-mark-recapture method, capturing and marking are combined. Sampling methods fall into two groups: ad hoc methods and standardized methods. **Ad hoc methods** use raw data uncorrected for detectability: raw counts, trap rates, return rates. Ad hoc methods can be defined as methods without any plan for repetition (OECD Glossary of Statistical Terms 2013) and are planned on a case by case basis (Cardoso et al. 2009). Those methods assume that individuals or species are detected perfectly (Mazerolle et al. 2007). A typical example of this method can be a checklist of encountered species, and if no individuals of a certain species are found in the studied area, it is considered that the species is absent (Petitot et al. 2014). This approach is often used for obtaining the maximum information about areas in a minimum amount of time (Cardoso et al. 2009). However, using those methods can lead to making limiting assumptions (Mazerolle et al. 2007). **Standardized methods** are those suitable for dealing with imperfect detection, because sampling occasions are repeated and it is not assumed that species are detected perfectly. Those methods are not widely used among conservationists and researchers (Petitot et al. 2014), because they are thought to require big amounts of resources, like time, personnel, labor or funds (Mazerolle et al. 2007). However, the popularity of standardized methods is rapidly increasing (Petitot et al. 2014).

As in the practical part of this thesis, the target species is the specimen of amphibians, in the following paragraph, the most used survey methods for amphibians are described. Those are visual encounter surveys, dipnetting, auditory surveys, leaf-litterbag surveys and funnel trapping (Eekhout 2010). Visual encounter survey is the most commonly used sampling technique for amphibians, but it only can be used for the amphibians that can be seen while the observer walks through the habitat (Heyer et al. 1994). Dipnetting is a technique when a dipnet is swept through an aquatic habitat to capture amphibians (Eekhout 2010). This method is necessary for locating and catching amphibian larvae (Fellers & Freel 1995). Auditory survey uses the frogs calling to estimate relative abundances of calling males, relative abundances of all adults or species composition. This technique is good for species that are difficult to see (Heyer et al. 1994). Leaf-litterbag surveys are typically used for salamanders sampling. Litterbags are placed in the aquatic habitat at regular intervals and after couple of weeks, each bag is checked using a dip net. This technique is good for detecting the presence of salamander species, but it cannot index populations sizes, so it cannot be applied as the only technique in monitoring programs (Eekhout 2010). Funnel trapping is one of the most effective methods for sampling of salamanders (Farmer et al. 2009). The principle of this method is that the individual is directed

through a small opening in the trap through a funnel, and when it is inside, it is impossible to find the way out (Eekhout 2010).

Fig. 3: Funnel trap at Mayslake Forest Preserve (by Carl Strang, 2013).

3.3 Detection probability

As it was shown above, many errors from different sources can arise during species monitoring. Over the years, there have been developed more methods of eliminating those errors. The calculation of detection probability can eliminate errors arising from the imperfect detection, because the knowledge of the error probability or, vice versa, the probability of the error not happening, can be very useful for getting a lot more accurate data. In this chapter, the definition of detection probability is explained, ways of assessment listed and examples on different taxa are given.

3.3.1 Term definition

Detecting a species even when it is present is not always achievable because of different issues that are listed in the chapter 3.2., so that the nondetection of a species does not mean it is absent (MacKenzie et al. 2002). Detection probability is the probability of detecting a species when it is present (Edwards, Pauley & Waldron 2016). Detection probability (p) is always situated between 0 and 1. When detection probability (p) = 1, that means the detection is perfect (Kissling & Garton 2006), which is possible in principle, but happens rarely (Kéry & Schmidt 2008). Whereas when p = 0, it means that for some reason no individuals can be found.

There are two main types of studies. One is aimed on the estimation of abundances and another assesses site occupancies. In **abundance** studies, the expected value of the total number of individuals is expressed with the equation $E(C) = N * p$, where E is the statistical expectation (Schmidt & Pellet 2009), C is the total number of individuals counted/observed/heard/captured during a sampling period, $E(C)$ is the expected counts of individuals, p is the detection probability and N is the true unknown total number of individuals (true abundance) (Mazerolle et al. 2007). When $p < 1$, expected counts $E(C)$ are smaller than true abundance N (Kéry & Schmidt 2008). Without any knowledge of the probability of detection, it is almost impossible to evaluate N, because there can be an infinite number of combinations of $p * N$ (Mazerolle et al. 2007). While accounting for p, the true abundance can be calculated as: $N = \frac{E(C)}{p}$. For example, during the sampling of a forest quadrat an observer encounters 60 fire salamanders (*Salamandra salamandra*), which means that $N * p = 60$ or that $N = \frac{60}{p}$. Without any knowledge of p, it is impossible to calculate N, because there are innumerable combinations of $p * N$, returning 60 (Mazerolle et al. 2007). Although, if know that p is for instance 0.5, we can easily calculate that $N = 120$.

In **site occupancy** studies the detection probability is calculated using the model likelihood (MacKenzie et al. 2002). This model incorporates probabilities of certain detection histories of the target species (*Pr*). The detection history is a record of the

target species being encountered or not during each survey at each site (MacKenzie et al. 2003). The site can be either occupied (ψ) or unoccupied ($1 - \psi$), so the detection history is composed of those two units. The equation of the probability of the certain detection history is: $\text{Pr} = \psi *$ detection history of a certain site. So that, if the site was sampled 4 times, and on the 1st and 4th try the species was detected, and on the 2nd and 3rd try the species wasn't detected, the detection history of this site will be 1001. So that the probability of this detection history will be: $\text{Pr}(H_i = 1001) = \psi * p_1(1 - p_2)(1 - p_3)p_4$. The detection histories of all the sites estimated are then combined into the model likelihood, from which the estimates of site occupancy and detectability can be obtained. For example if there were 30 samplings in total, the model likelihood will be calculated as: $L(\psi, p | H_1, \ldots, H_{30}) = \prod_{j=1}^{30} \text{Pr}(H_i)$. (Bailey & Adams 2005). When $p < 1$, average observed occurrence $E(\eta)$ is smaller than true site occupancy ψ (Kéry & Schmidt 2008).

Multiple approaches have been developed to account for the probability of detection in both small scale single-site population studies and large scale community level studies (Mazerolle et al. 2007).

3.3.2 Ways of detection probability assessment

For the detection probability to be determined, it is necessary to repeatedly record the species presence in case of site occupancy assessment or repeatedly count the species in case of abundance assessment. In the first part of this chapter, the abundance assessment and accounting for detection probabilities will be described. In the second part the site occupancy estimation and accounting for detection probabilities will be illustrated. In the third part, methods of model selection both in abundance and site occupancy assessment will be listed.

a) Abundance assessment

Capture-mark-recapture models

Most abundance models accounting for detection probability are based on capture-mark-recapture analysis, as it is common and well-tested. This method is based on the recapture patterns of previously captured and marked animals (O'Donnell & Semlitsch 2015). More about CMR approach can be found in the chapter 3.1.1. CMR models are divided according to the character of population estimated, so that in total 3 classes of CMR models exist, which are: closed population models, open population models and robust design models (the combination of open and closed models) (Mazerolle et al. 2007).

Closed population abundance models

This class of models focuses on the populations that remain constant in size and composition (Lettink & Armstrong 2003), which means that there are no births, deaths and migrations during the study period. So that target population should be sampled over a short time period (Mazerolle et al. 2007). All of the CMR methods of abundance

estimation in closed populations are based on the Peterson-Lincoln estimate (Powell & Gale 2015), which is the simplest form of a closed capture-mark-recapture analysis. It is an estimate for two visits, which is calculated as: $\widehat{N} = \frac{n_1 n_2}{m_2}$, where $\widehat{N}$ is the estimated population size, n_1 is the number of animals caught in the first capture session, n_2 is number of animals caught in the second capture session and m_2 is number of animals caught in both sessions (recaptures) (Lettink & Armstrong 2003). The detection probability (p) can be defined as a proportion of the population that was marked during the first time period. As it is unknown, it can also be said that the proportion of the animals with marks in the sample are the same as proportion of the captured and marked population during time 1, which means that $p = \frac{n_1}{\widehat{N}} = \frac{m_2}{n_2}$. The Schnabel method expanded the Lincoln-Petersen method to be used when more than two visits were conducted (Powell & Gale 2015). The multiple samples are considered as series of Petersen samples and the population estimate is calculated as a weighted average of Petersen estimates: $\widehat{N} = \frac{\sum_t (C_t * M_t)}{\sum_t (R_t)}$ (Krebs 2009), where $\widehat{N}$ is estimated population size, C_t is the number of captures during time t, R_t is the number of recaptures (marked animals, which were captured again) captured during time t and M_t is the number of animals marked in the population, at time t. Modern methods estimating abundance in closed populations use individual marks and it helps developing individual capture histories and building models (Powell & Gale 2015).

Open population abundance models

This class of models is usually focused on the studies of longer duration (Powell & Gale 2015), where births, deaths, immigration, or emigration can occur. Those studies can also be designed to estimate demographic rates such as survival or population trends. The study design for this type of models consists of three or more capture occasions (Mazerolle et al. 2007). Although, the issue is that as the study lasts the longer time, it can be mistakenly assumed that the animal that wasn't detected on the first visits, came later by birth or immigration. Also, it can be wrongly thought that animal which was previously detected and wasn't detected on the later visits, died or emigrated (Lettink & Armstrong 2003). So, the solution for that problem is to estimate the survival probability (ϕ), which is the probability that an individual alive at time t survives to time $t + 1$ and does not permanently emigrate, and also the capture probability (p) (Mazerolle et al. 2007). If p is known, population sizes for each capture occasion can be calculated as $\widehat{N} = \frac{n_i}{\hat{p}_i}$, where $\widehat{N}$ is the population size for capture occasion i, n_i is the number of animals captured on occasion i and $\hat{p}_i$ is the capture probability on occasion i. The recruitment between capture sessions is calculated as: $\hat{B}_i = \widehat{N}_i - \phi_i \widehat{N}_{i-1}$, where $\hat{B}_i$ is the recruitment for occasion i, $\widehat{N}_i$ is the population size for capture occasion i, ϕ_i is the survival probability on occasion i (Powell & Gale 2015). There are two main open population CMR models frameworks: Jolly-Seber (JS) model and Cormack-Jolly-Seber (CJS) model, which is a simplified form of JS model (Mazerolle et al. 2007). CJS model is aimed to estimate the survival, while JS model is more focused on estimating the abundance (Schwarz & Seber 1999). The

initial JS and CJS models required all animals to have the same survival and capture probabilities, but modern developments to those models have relaxed that condition It is also possible to fit individual covariates to the models, for instance, to determine if survival or capture probability of individuals of certain species depend on the body weight (Lettink & Armstrong 2003). The issue with the open design frameworks is that it is assumed that the animals from the same group have the same survival and capture probabilities, which is not always true (Mazerolle et al. 2007).

Robust design models

Multistate mark-recapture models (MSMR) are a class of models, that mix open and closed population models and allow to account for temporary emigration and immigration and for different survival and capture probabilities. (Mazerolle et al. 2007). The robust design allows the estimation of many key parameters that describe dynamics of populations, like movement patterns (Powell & Gale 2015), as closed models can be used for the estimation of abundance and open models can be used for the estimation of true survival, temporary emigration, and immigration of animals over the longer sampling periods. So that, the basic design of this type of models is sampling over two scales (Grand 2020). The Pollock's robust design is the original and basic version of the MSMR. It is represented by the series of closed population model analyses, one for each primary period, which are then included into an open population analysis (Mazerolle et al. 2007). The capture history is divided into primary and secondary sampling periods. The secondary sampling periods are considered closed, the primary periods are created by grouping the secondary periods. The population is considered open between the primary periods. There are two types of capture probabilities: p_{ij}, which is a capture probability during the secondary sampling in the primary sampling period i, and p_i^*, which is the overall capture probability during the primary sampling i. It can be calculated as $p_i^* = 1 - ((1 - p_{i1})(1 - p_{i2})(1 - p_{i3})(1 - p_{i4})$ (Powell & Gale 2015). The recruitment can also be estimated using the equation: $\hat{B}_i = \hat{N}_{t+1} - \phi_i(N_t - n_i + R_i)$, where $\hat{B}_i$ is the number of births during time between i and $i+1$, ϕ_i is the survival rate during the period between i and $i+1$, $\hat{N}_{t+1}$ is the population size at the time $t+1$, N_t is the population size at time t, n_i is the number of animals caught at i sampling period and R_i is the number of animals released at i sampling period (Grand 2020).

Abundance models for populations that cannot be marked

Marking of animals is sometimes impossible or practically difficult. (Iijima 2020). It can be, for example, too expensive or species ecology might not allow marking. So that there are methods for estimating populations that cannot be marked and those are double sampling method and distance sampling method.

Double sampling method

Double sampling methods are used to estimate abundance as only one method used or in a combination with capture-mark-recapture method (Loehle 2010), That sampling method can be conducted with independent or dependent observers. The **independent**

observer method consists of two observers counting animals independently within a very short time period so that the population can be considered closed. (Mazerolle et al. 2007). Two observers detect animals independently of each other. A third person acts as a coordinator to determine which animals are detected by both of the observers, and which by only one of them (Chen 2000). This method could be useful in the salamander burrows estimation, where each observer would take the position of each animal of interest with a GPS receiver. In a **dependent observer** method, there is always a primary observer and a secondary observer. The primary observer signals to the secondary observer each time an animal is detected, while secondary observer notes all animals seen and missed by the primary observer. For example, in the study of birds, at each point, a primary observer indicates to a secondary observer all birds detected. The secondary observer records all detections of the primary observer as well as any birds not detected by the primary observer. At the end of each point, the data are the number of birds of each species detected by the primary observer and also the number of birds missed by the primary observer but detected by the secondary observer. Observers change primary and secondary roles during the course of the survey (Nichols et al. 2000).

Distance sampling method

This method is dependent on distance – to – transect data for each observed group, and the assumption that detection declines with distance (Clement, Converse & Royle 2017). The goal is to estimate density, which is performed using line or point transects after accounting for detectability. In case of the **line transect technique** of the distance sampling, the observer walks along a line, notes all detected individuals on one or both sides to some specified width, and measures the perpendicular distance of each to the center line. The basic equation for the density estimation in the line transect technique is: $\widehat{D} = \frac{n}{2wL\hat{P}_a}$, where $\widehat{D}$ is the estimator of wildlife density, n is the total number of counted wildlife from a line of L length within w distance from the line and $\hat{P}_a$ is the probability of detection for an object within an area a (Iijima 2020). In the **point transect technique** the observer stands at a point, notes all individuals detected around that point, and measures the distance of each individual from the point (Mazerolle et al. 2007). The equation for the density estimation in point transect technique is $\widehat{D} = \frac{n}{\alpha\hat{P}}$, where $\widehat{D}$ is the estimator of wildlife density, n is the number of animals detected, $\hat{P}$ is the probability of detecting an individual if it is in the covered area a (Marques et al. 2010).

b) Site occupancy assessment

The survey technique for estimating site occupancy is very similar to CMR approach for estimating abundance. However, it does not require any marking of animals, only repeated observations (Bailey & Adams 2005). Typical data in the site occupancy framework consist of repeated surveys at a collection of sites, such as anuran call surveys conducted at breeding sites, dipnetting for overwintering tadpoles in ponds, or observing lizards in forest quadrats (Mazerolle et al. 2007) and are recorded as a vector

of 1's and 0's meaning detection and nondetection respectively, for the occasions on which the site was sampled. Site occupancy models are rapidly gaining popularity, because they are less expensive and require less time and effort than abundance analysis, hence are more used in large scale monitoring programs (MacKenzie et al. 2002). To estimate site occupancy, the signs of species presence across sites are investigated (Mazerolle et al. 2007). The occupancy models can be differentiated by the length of study into single-season or multiseason models and by the number of species of interest into single-species or multispecies models (MacKenzie et al. 2003).

Single-season models

This type of models is used for shorter studies (MacKenzie et al. 2003) and is similar to closed populations models that estimate the abundance, except that in the site occupancy models, the site is the sampling unit and the total number of sites sampled is known (Mazerolle et al. 2007). The detection history for the site visited three times could be 1 1 0 (i.e., the species was detected during the first two surveys but not during the third), and the corresponding probability for the detection history would be defined as $\psi = p_1 p_2 (1 - p_3)$, where ψ is the probability of site occupancy and p_i is the detection probability for visit i. The product of all probabilities forms a model likelihood for the observed data set. Estimates of the probability of site occupancy and detection probability can be obtained by maximizing the likelihood function. If both occupancy and detection probabilities are constant, the model likelihood can be written as:

$$L(\psi, p) = \left[\psi^{n \cdot} \prod_{t=1}^{T} p_1^{n_1} (1 - p_1)^{n - n_1} \right] \times \left[\psi \prod_{t=1}^{T} (1 - p_t) + (1 - \psi) \right]^{N - n}$$

where ψ is the probability that a species is present, p_{it} is the probability will be detected at site i at time t, given presence, N is the total number of surveyed sites, T the number of distinct sampling occasions, n_t the number of sites where the species was detected at time t and n is the total number of sites at which then species was detected at least once (Tanadini & Schmidt 2011). Using likelihood function in this form, the model can be easily implemented, because only N and n are required. Site occupancy depends on some site characteristics, such as habitat type or patch size. Those characteristics should be site specific and time constant, because the occupancy does not change through time. Also, detectability may differ with variables like air or water temperature. Those variables should be time varying and site specific. Those variables can easily be introduced to the model as covariates using a logistic model: $\theta = \frac{\exp(XB)}{1 + \exp(XB)}$, where θ is site occupancy or detection probability, X is the covariate information and B is the vector of model parameters. There is always a possibility of missing observations happening for a number of reasons. However, it can be easily accommodated using the likelihood model. If sampling does not take place at the site i at time t, then that occasion does not contribute anyhow to the model likelihood for that site. So that if no sampling occurred at time 3 at the site, the likelihood for this site would be: $\psi p_1 (1 - p_2) p_4 p_5$ (MacKenzie et al. 2003).

Multiseason models

Multiseason models are used for longer studies, for example across multiple years, where the rate of change in site occupancies may be more interesting than the overall proportion of sites occupied at any given time (MacKenzie et al. 2003), so that it can provide inferences about occupancy dynamics (Hines, Nichols & Collazo 2014). The approach is to combine single-season models with the robust design mark–recapture approach (MacKenzie et al. 2002). This model requires two kinds of parameters in addition to the single-season model, which are probabilities of local extinction and local colonization. The data needed for this model are detection histories for multiple seasons. The process of community dynamics can be calculated as: $\psi_{i,t+1} = \psi_{i,t}(1 - \varepsilon_{i,t}) + (1 - \psi_{i,t})\gamma_{i,t}$, where $\varepsilon_{i,t}$ is a probability a sample unit i not occupied in season $t+1$ | occupied in season t, $\gamma_{i,t}$ is a probability sample unit i occupied in season $t+1$ | not occupied in season t (Hines, Nichols & Collazo 2014).

Model selection

Selecting the better model(s) from the candidate set can be done either using hypothesis testing or information-theoretic methods (MacKenzie et al. 2003).

Hypothesis testing

This method is based on testing the null and alternative hypothesis and it can lead to either rejecting the null hypothesis or not.

Likelihood ratio tests

The model m_0 is compared with the model m_a. m_0 is the less general model, representing the null hypothesis. m_a is the more general model, representing the alternative hypothesis (MacKenzie et al. 2017).

Information-theoretic methods

Akaike Information Criterion (AIC)

This approach is really different from other older methods and is used very often nowadays (MacKenzie et al. 2017). It is a framework that identifies which potential models can explain the process of interest in the best way and selects models that fit the data well with a minimum number of variables (Mazerolle et al. 2007). It is based on information theory and estimates relative expected Kullback–Leibler distance (Schmidt 2005), which is a relative measure of how much information is lost by using a model to represent a true information. However, the true information is unknown and the candidates sets of models can be compared and ranked in terms of which model have lost more or less information (MacKenzie et al. 2017) or which model offers a compromise between bias and variance (Mazerolle et al. 2007). AIC can be calculated as: $AIC = -2\ln\left(L\left(\hat{\theta}|x\right)\right) + 2\delta$, where $-2\ln\left(L\left(\hat{\theta}|x\right)\right)$ is the log of the likelihood function evaluated at the maximum likelihood estimators (MLEs) and δ is the number of parameters estimated in the model. Usually, all the models are compared to the model with the minimum AIC achieved. So that, the AIC for the certain model k can

be calculated by the following equation: $\Delta AIC_k = AIC_k - AIC_{min}$ (MacKenzie et al. 2017). Advantage of this approach is that the evidence in favor of a model, out of the set of candidate models, can be weighed, using Akaike weights (ω) (Mazerolle et al. 2007), which can be calculated by the equation: $\omega_k = \frac{\exp(-0.5\Delta AIC_k)}{\sum_{r=1}^{R} \exp(-0.5\Delta AIC_r)}$, where R is a suite of models and ω_k is the Akaike weight or the weight of evidence in favor of model k. Akaike weights can be interpreted using evidence ratios (ER), which indicate how much support there is for that certain model compared to other models. ER<1 indicates less support, ER=1 indicates equal support and ER>1 means more support. ER can be calculated as: $ER = \frac{\omega}{1-\omega}$ (MacKenzie et al. 2017). In cases where several models have similar Akaike weight, inferences can be based on the whole set of candidate models, using the procedure called model averaging or multimodel inference. This consists of using the information available, for example estimate of a parameter of interest or predicted value, from the whole set of models to calculate a mean weighted by the Akaike weight of each model (Mazerolle et al. 2007).

3.3.3 Software

Estimations of detection probabilities, true abundances and site occupancies are in most cases difficult calculations with a lot of parameters. So, to perform those calculations different software is used. In this chapter the most used software for abundance and site occupancy estimation is shown.

Software for abundance data processing

Program CAPTURE (Rexstad & Burnham 1992)

CAPTURE is the program for estimating abundance of the closed populations (Mazerolle et al. 2007). It takes into account aspects of unequal capture probability. The maximum size of data that are able to be handled by CAPTURE in is 18 capture occasions and 1000 animals in simulation experiments. This software is designed to run on any IBM-PC compatible computers (Rexstad & Burnham 1992), is free and can be downloaded from the following link: https://www.usgs.gov/software/capture. The program consists of two components: an analytical component that performs abundance and density estimation from the data provided by the user and data entry field (Rexstad & Burnham 1992). The simplest form of data input is in the form of a matrix. The rows of the matrix stand for the individuals captured during the study, and the columns of the matrix represent the time of capture. In each column a "0" means that the individual in was not captured during this sampling occasion, and a "1" indicates that the individual was captured. From that matrix of "0"s and "1"s the probability theory can be used to build different models. The simplest model is the null model in which the captures occur randomly and all individuals have equal chances of being caught at any time. If the null model does not fit, the models accounting for variation should be built (Krebs 2009). The model selection is conducted in the testing menu using the selection algorithm (Rexstad & Burnham 1992).

Program MARK (White & Burnham 1999)

MARK is the software developed for estimating abundance, it can provide estimates from marked animals when they are re-encountered at a later time as dead recoveries, or live recaptures or re-sightings, so it is suitable for open and closed populations and robust design models (White et Burnham 1999). The software can be downloaded from the following link: http://www.phidot.org/software/mark/downloads/ and is free. It is a Windows application, but can be successfully run on other platforms like Mac or Linux (White n.d.). All analyses in the software are based on encounter histories of individuals. To construct the set of models for a data set, the encounter histories file must be downloaded, which contains the raw data on encounter histories. Those data consist of "1"s indicating a live capture or recapture and "0"s meaning the individual was not captured. Negative values indicate animals that were not released again. Also, there is a possibility of estimating the parameters like apparent survival or recapture probability using the parameter index matrices. All the parameters should be defined in the Run window (G. C. White & Burnham 1999). Program computes the estimates of model parameters using numerical maximum likelihood techniques (White n.d.).

Software for site occupancy data processing

Software PRESENCE (Hines 2006)

PRESENCE is the software developed for analyzing site-occupancy data (MacKenzie & Bailey 2004), which allows the estimation of the detection probability, site occupancy in relation to different covariates (Tanadini & Schmidt 2011) There are 6 predefined models that users can run, like for example single-season or multiseason models or also custom models can be defined by users (Hines & MacKenzie n.d.). The program can be downloaded from the following link: https://www.mbr-pwrc.usgs.gov/software/presence.html and is free. The software consists of two parts: an interactive piece where input data are entered, and models are specified and run; and a computational piece, where the estimates of the specified model are computed. The data can be input in different ways: directly into a spreadsheet-like interface in the program, copied from the spreadsheet program like Excel or downloaded from an ascii text file. The covariate data can be entered by changing the number of covariates in the appropriate box. (Hines & MacKenzie n.d.).

R (R Core Team 2020) programming environment for abundance and site occupancy estimation

The R (R Core Team 2020) programming environment is becoming more popular for the analysis connected with detection probabilities. It is an open-source project, runs on most of the operating systems and is well maintained, so that many statisticians code the new approaches straight away in R and also R language is often taught in undergraduate classes (Mazerolle 2015). Using R is also a way to make a research reproducible, which means that all the calculations and statistical analysis are available and it allows others to reproduce the results (Donoho 2010). R has a wide range of functions and using it quality graphics can be created and numerous analysis can be

executed. R can be downloaded for free through mirror site at https://cran.r-project.org. As R programming environment has minimal graphical user interface and is just a terminal where the commands should be typed in (Mazerolle 2015), the intelligent text editor like RStudio (RStudio Team 2020) can be useful. Functions in R are available through packages, some of the packages with most common functions are already installed when the program is started, however other should be downloaded. There are packages that can help to account for detection probability in abundance or site occupancy assessment. Those packages might be developed independently (Mazerolle 2015) or as the integration from the stand-alone programs like MARK (White & Burnham 1999) or CAPTURE (Rexstad & Burnham 1992). Packages helping to account for detection probabilities in abundance analyses are, for example *RMark* (Laake 2013) or *RCapture* (Baillargeon & Rivest 2007) and packages for site occupancy analyses accounting for detection probabilities are, for instance *unmarked* (Fiske & Chandler 2011) or *stocc* (Johnson 2015). *RMark* (Laake 2013) supports a variety of models, like robust design models, closed and open population models and even some site occupancy models (Mazerolle 2015). The *unmarked* (Fiske & Chandler 2011) package presents a lot of site occupancy models, like multiseason models (Mazerolle 2015).

3.4 Examples in different taxa

In this chapter the different studies that consider imperfect detection and account for detection probabilities are presented. In the first chapter (3.4.1) the plants study is described, as the issue of imperfect detection also exists in botanical research. After that, examples of using detection probabilities in studies of different animal groups are described: fish in the chapter 3.4.2, reptiles in the chapter 3.4.3, birds in the chapter 3.4.4 and mammals in the chapter 3.4.5. The animal class of amphibians is not presented here, as the practical part of this thesis deals with the amphibian studies.

3.4.1 Plants

In botanical research, imperfect detection plays a big role in the probability of species detection and has the potential to bias measures of functional composition. Tiny species with small seeds and high specific leaf area are less likely to be detected, but certainly the detectability also depends on the type of community: in a heavily grazed grassland, where all species are low growing, small species are more likely to be detected than in an ungrazed system. Also monitoring of rare species and species occurring mainly at low elevations tend to be more affected by imperfect detection (Roth et al. 2018). However, the plant detection is not perfect even for large and highly visible plants, because the detection in those cases can be also dependent on how long was the search, on the observers fatigue or difficulty of the search (Moore et al. 2011).

Imperfect detection in plant distribution studies (Chen et al. 2013)

In this study, the detection probability and study patterns in detection depending on life-form (LF), space and time were estimated for a big random sample. The data from the Swiss Biodiversity Monitoring (BDM) were used. The BDM was designed to measure changes in Swiss biodiversity. In this monitoring program the detection/nondetection data were collected by surveying transects twice a year: once in spring and once in late summer. For the purpose of study, the multispecies site-occupancy model was used, with covariates representing life form, species, elevation, survey date and their interactions and two analyses were conducted. In the first one, 100 plant species were randomly sampled from among all the 1700 species that were detected, to collect estimates of average detection probability in the entire flora. The effect of life form covariate was not included. In the second one, 25 species were randomly chosen from each of four life forms: grass, forb, shrub and tree to understand the factors affecting detection probability of more common species. In that case, effects of covariates like life form, species, elevation, survey date and their interactions on detection probability were included. The Bayesian analysis of the model was conducted in the program WINBUGS (Spiegelhalter et al. 2003). Also, the minimal number of surveys needed to detect a species with a 95% probability during the

appropriate survey season, was estimated using the maximum per-visit detection probability of each species or the higher value of detection probability for the first and the second surveys. As a result, detection probabilities were not much different among forbs, shrubs and trees, nor between grasses and forbs, however it differed significantly between grasses and shrubs and also grasses and trees. It can be explained by the fact that observers are most likely to overlook grasses, rather than trees and shrubs, because the large size make trees and shrubs more distinctive. Also, even though shrubs might also be small sized, they might have distinctive flowers. Elevation and survey season had effects on detection probability of 60 of the 100 studied species. The effect of survey season can be explained by plants being in different life stages (like flowering or wilted to the ground) during two observations. For 92 out of the 100 common species, the maximum per-visit detection probability was higher than 0.7, which means two surveys would be enough for their detection in a quadrat with a probability of 95% (Chen et al. 2013).

3.4.2 Fish

Occupancy modelling of fish is rare, because the replicate samples are required by these models to account for imperfect detection, but it is often impractical to obtain them in the aquatic environment (Coggins, Bacheler & Gwinn 2014). However, fish surveys are affected by issues of imperfect detection. Freshwater fishes can be overlooked in monitoring (Wedderburn 2018), because most of them are small-bodied and cryptobenthic (Albanese et al. 2011). Stream fish detectability can depend on multiple characteristics such as water depth, water temperature, conductivity, water clarity, and flow, as streams are dynamic systems (Mollenhauer, Logue & Brewer 2018).

Estimating occupancy of fish (Wedderburn 2018)

The study took place in Lake Alexandrina, in south-eastern Australia. The target fishes were ecological specialists that are now considered rare due to population decline: murray hardyhead (*Craterocephalus fluviatili*, McCulloch, 1912), yarra pygmy perch (*Nannoperca obscura*, Klunzinger, 1872)) and southern pygmy perch (*Nannoperca australis*, Günther, 1861). Two contrasting sampling techniques were chosen: fyke netting and seining (fine mesh).

Fig. 4: The fyke net (https://www.seafish.org/)
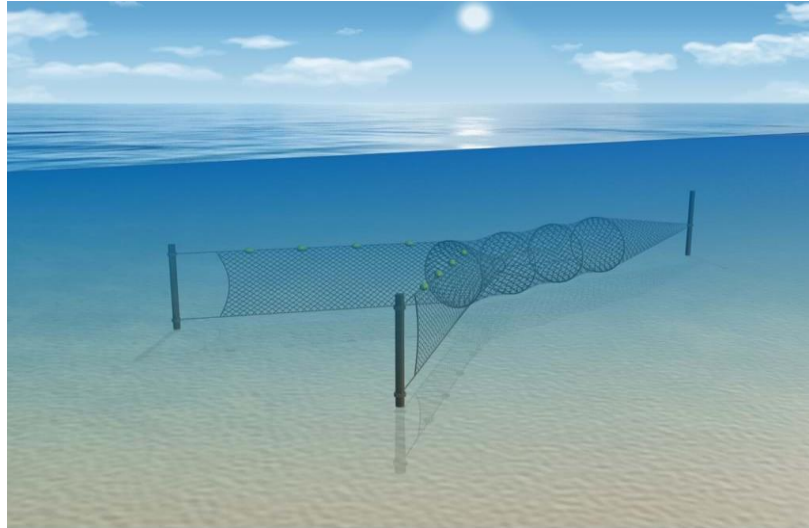
Fig. 5: Seine net (Florida Marine Science Educators Association)

Surveys were conducted by the same two observers and, at 17 sites over 3 weeks in March 2016 (two fyke surveys and two seine surveys) and over 4 weeks in March 2017 (three fyke surveys and two seine surveys). Sites were selected depending on habitat preferences of the target fishes. Sampling occurred when all target fishes had grown large enough to be detected. Salinity, pH and temperature were recorded 30 cm below the surface of the water at each site and also Secchi depth was measured. A single-season multi-method model was used, which was processed using program PRESENCE (Hines 2006). The study has shown that the use of multiple sampling techniques is a great approach in multi-species monitoring. For instance, three replicate fyke net surveys provided a reliable detection probability and occupancy data of *Nannoperca australis*, while that species was mostly undetected with seine. Four surveys with both devices accounted well for detection probability of *Craterocephalus fluviatili*. The number of replicate surveys influenced the reliability of an occupancy

model. In 2017, the additional fyke survey improved the detection probability estimate for *Nannoperca australis* (Wedderburn 2018)

3.4.3 Reptiles

There are not enough data on the fifth of the reptiles, which causes not understanding the reasons of the reptile decline (Ward et al. 2017). Reptile species are very difficult to detect because of the small body size of the animals, secretive behavior and fast unpredictable activity (Ruiz De Infante Anton et al. 2013). Some reptiles, such as lizards, may be unavailable for sampling during certain periods of the day or year, because of their sensitivity to temperature (Furnas et al. 2019). Snakes have some of the lowest detection rates among reptiles. They occur at low densities, have wide ranges (Ward et al. 2017) and cryptic color patterns (Kery 2002) and use fossorial and arboreal habitats (Nafus, Mazzotti & Reed 2020).

Estimating detection probability and site occupancy of aquatic snakes as a case study for monitoring of rare and cryptic reptiles (Durso, Willson & Winne 2011)

Between 30 May and 20 July 2006, seven aquatic snake species were sampled: banded water snake (*Nerodia fasciata*, Linnaeus, 1766), Florida green watersnake (*Nerodia floridana*, Goff, 1936), glossy crayfish snake (*Regina rigida*, Baird & Girard, 1853), black swamp snake (*Seminatrix pygaea*, Cope, 1895), mud snake (*Farancia abacura*, Holbrook, 1836), rainbow snake (*Farancia erytrogramma*, Palissot De Beauvois, 1802), and cottonmouth (*Agkistrodon piscivorus,* Lacépède, 1789). Study sites were 20 freshwater wetlands in the upper Coastal Plain of South Carolina, USA. The majority of sites surveyed were semi-permanent, open-water and depressional wetlands. The sites were visited repeatedly, passive plastic minnow traps were used to catch the snakes for five consecutive nights. Every morning the traps were examined and captured snakes were removed.

Fig. 6: Minnow trap (https://btycc.org/)

The captured snakes were transported then to the laboratory and on the next day, snakes were released into the wetland within 10 m of their original capture location. Recaptured individuals were recorded and released immediately at their capture location. The covariates were: permanence (hydroperiod length) of wetlands, their distance from the Savannah River floodplain, and their abundance of prey. The abundance of snakes' prey was measured by counting the number of fishes, crayfish, large aquatic salamanders and larval or paedomorphic mole salamanders (*Ambystoma talpoideum* (Holbrook, 1838)) caught on the first day of sampling at each wetland. For the most wetlands, the permanence was calculated as the proportion of each year a wetland held standing water, which was then averaged over 5–12 years of available data. Detection probability and site occupancy for all wetlands were computed using program PRESENCE (Hines 2006). As a result, across all species and models, detection probability estimates were between 0.03 and 0.46. *Nerodia fasciata* had the highest overall estimates of detection probability and site occupancy, and overall represented 63% of all captures, but mostly detectability for aquatic snakes was low in comparison to other animals. Detection probability of snakes was lower in more permanent wetlands with denser populations of fish and large aquatic salamanders and was higher in wetlands that were far from the floodplain and had large populations of *Ambystoma talpoideum* (Durso, Willson & Winne 2011).

Fig. 7: Banded water snake (*Nerodia fasciata*) (by David Scott)

3.4.4 Birds

Unlike most animals, birds are typically surveyed without capturing or marking individuals, but with passive sampling techniques, like line transects or point counts (Olenev & Grigorkina 2014). The detection probability of birds depends on many aspects: behavioral factors, like singing rate, volume, bird movements; environmental factors, like wind speed or time of day; and observer effects, such as hearing ability, skills or the observers distance from the bird (Rigby & Johnson 2019). Some birds are

nocturnal, so the detection probability can be dependent on the survey timing (Zuberogoitia et al. 2020).

Analysis of territories occupied by the Northern spotted owl (_Strix occidentalis caurina_, Merriam, 1898) (MacKenzie et al. 2003)

Data for this study were taken from the monitoring program of Northern spotted owls' (_Strix occidentalis caurina_) breeding pairs presence in northern California. The monitoring program has begun in 1985. Each site was surveyed up to eight times during a breeding season to determine whether the territory was occupied by a breeding pair. For this study the analysis was restricted to a group of 55 sites surveyed annually between 1997 and 2001. It was assumed that colonization, local extinction or detection probabilities are constant across years. With the help of Akaike weights, it was found that detection probabilities and colonization probabilities should be modeled as year specific and local extinction probabilities are constant. Another conclusion was that if the detectability was not explicitly accounted for, a higher turnover rate in territory use would have been concluded (MacKenzie et al. 2003).

Fig. 8: Northern spotted owl (_Strix occidentalis caurina_) in the Olympic Mountains (by Rod Gilbert)

3.4.5 Mammals

Mammals is an extremely diverse group of animals, which includes the world's smallest mammal, Kitti's hog-nosed bat (_Craseonycteris thonglongyai_, Hill, 1974) (Pereira et al. 2006) or little shrews (_Sorex_ spp. ,Linnaeus, 1758), as well as such large animals like blue whale (_Balaenoptera musculus_, Linnaeus, 1758) or African elephant (_Loxodonta africana_) (Strauss 2021). All these animals are very distinct, but all of them have the similar feature: for different reasons, their detection is not perfect. The

detection of *Loxodonta africana* can be negatively affected by tall trees or smaller herd sizes (Schlossberg, Chase & Griffin 2016), as well as the detection of *Sorex* spp. can be influenced by seasonality or weather (Otto & Roloff 2011).

Status and habitat preferences of wild cattle and large carnivores in Eastern Cambodia (Gray 2012)

Monitoring of large mammal species in tropical forests is a challenge, because many species living there are shy, solitary or nocturnal, so that nondetection of those species during surveys is likely. For monitoring that species and understanding their habitat preferences, the analysis of camera-trap data in an occupancy framework is used, because it accounts for imperfect detection at sampling sites. The study was conducted in Mondulkiri Protected Forest, located in eastern Cambodia and consisting of a mosaic of dominant deciduous dipterocarp forest with smaller parts of mixed deciduous/semi-evergreen forest on hilltops and along rivers. The aims of this study were to analyze camera trapping data of four large mammals: banteng (*Bos javanicus*, d'Alton, 1823), gaur (*Bos gaurus*, Smith, 1827), dhole (*Cuon alpinus*, Pallas, 1811) and leopard (*Panthera pardus*, Linnaeus, 1758). Camera trapping was conducted between March and June 2009 (late dry-season), in which all photographs are digitally stamped with date and time. Camera traps were placed at 50 locations. The habitat at photographs was defined post hoc in ArcGIS (ESRI 2010). Sampling occasions lasted 10 nights, starting from the date camera traps were set and finishing when the camera trap was brought back. Occupancy models were used that implemented likelihood-based methods and were developed in software PRESENCE (Hines 2006). Histories of encounters of each species were then transferred into a "X-matrix format" with rows representing encounter histories at each camera-trap location and columns representing captures on each sampling. Two occupancy models were built for each species with camera-trap location included as a covariate affecting occupancy. Also, the null model was built, in which detection probability was constant for each species between habitats. These two were compared and as a result the null model was strongly supported by AIC. Finally, two more models were built. In the first model, the detection probability was set as constant between habitats for each species and occupancy differed between habitat types and in the second model occupancy was set as constant across habitats. As a result, for *Bos gaurus* and *Cuon alpinus* the first model was strongly supported by AIC, and in case of *Bos javanicus* and *Panthera pardus* the second model appeared appropriate. *Panthera pardus* was the most frequently encountered species recorded, summed across all camera-trap locations, followed by *Bos javanicus*, *Cuon alpinus* and *Bos gaurus*. Overall detectability across the survey period was high for *Bos javanicus* and *Panthera pardus*, but much lower for *Cuon alpinus* and *Bos gaurus*. That could be explained by the fact that at higher abundances more individuals are available to be detected and so that detection probabilities are higher (Gray 2012).

4. Methods

The following section of the thesis is divided into two parts: in chapter 4.1 I describe a simple meta-analysis of studies that deal with site occupancy and abundance of different amphibian species, accounting for the detection probability. In that review, I mostly focus on the amphibian species that are found in the Czech Republic. In the chapter 4.2 I focus on the target population of fire salamanders (*Salamandra salamandra*) from Prague, abundance data of which were collected using CMR methods during several years (Filousová 2019). Firstly, I analyze numbers of encountered salamanders during every visit and secondly, I propose the exact approach of estimating those abundance data accounting for the detection probability.

4.1 Meta-analysis

4.1.1 Target species

In the following analysis, I concentrate on different studies, researches, articles and theses that deal with amphibians living in the Czech Republic. The species about which inhabit the Czech Republic and about which I found the relevant information are: common toad (*Bufo bufo*, Linnaeus, 1758), natterjack toad (*Epidalea calamita*, Laurenti, 1768)), yellow-bellied toad (*Bombina variegata*), water frogs (*Pelophylax* spp., Fitzinger, 1843), common tree frog (*Hyla arborea*), smooth newt (*Lissotriton vulgaris*, Linnaeus, 1758), palmate newt (*Lissotriton helveticus*), great crested newt (*Triturus cristatus*, Laurenti, 1768)) and fire salamander (*Salamandra salamandra*).

4.1.2 Literature sources and key words

The sources for finding the literature to conduct the meta-analysis were:

- https://www.sciencedirect.com/

- https://www.researchgate.net/

- https://webofknowledge.com/

- https://link.springer.com/

- https://academic.oup.com/journals

- https://journals.plos.org/plosone/

The key words used to find the suitable literature were:

- detection probability

- amphibian monitoring

- site occupancy

- abundance

- occupancy modelling

- amphibian detection probability

4.1.3 Data visualization and parameters of interest

Data are presented in a table originally made in the Microsoft Excel (Microsoft Corporation 2018) program. That table is placed in Appendix. It includes three sections: the reference section, which shows the source of the study; the study description section, which includes subsections like study area, target species and number of sites; the methodology section, which includes subsections like whether the study was on abundance or site occupancy, types of models used, covariates and software used.

4.1.4 Data analysis

The results of the meta-analysis are placed in the chapter 5.1. With the data received I answer the several study questions:

1. Which type of studies was more frequent: site occupancy or abundance?

2. What was the mean number of sites in site occupancy and abundance studies?

3. What was the most used type of models in site occupancy and abundance studies?

4. What were the most frequently used covariates?

5. What was the most used software for studies on site occupancy and abundance?

I also sum up the useful information from the analyzed studies for every single species of interest, like which sampling methods have higher detection probabilities and what are the reasons of that or what habitat or weather features influence detection probabilities of different species. I also show the detection probability values for different cases, when they are available. The results can be taken into account by the Nature Conservation Agency of the Czech Republic (NCA CR) when planning the monitoring of amphibians of the Czech Republic.

4.2 Assessment of the data on the target population's abundance

4.2.1 Study species

<u>Basic description</u>

The fire salamander (*Salamandra salamandra*) is the specimen of the Salamandridae family (Griffiths 1996) of Amphibia class and order Caudata (Kuzmin et al. 2009). Salamandridae family is one of the most diverse groups of salamanders and is divided into two subgroups: true salamanders and newts. *Salamandra salamandra* represents the true salamanders subgroup and differs from newts by being smooth-skinned (Zhang et al. 2008). The fire salamanders' size ranges from 15 to 25 cm long, their body is longer than the tail (Griffiths 1996). They have of a highly contrasted black and yellow coloration, even though the color patterns can differ within subspecies (Lüddecke et al. 2018). The bottom of fire salamanders' body is dark grey with some spots (Griffiths 1996).

Fig. 9: *Salamandra salamandra* close up (by Petar Milošević, 2020)

Females of fire salamanders are larger than male individuals (Griffiths 1996), whereas males have a slimmer body, long tail and limbs. Also, during the breeding period, males have a more swollen cloaca (Labus, Cvijanović & Vukov 2013). *Salamandra salamandra* produces the cutaneous poisonous secretions (Lüddecke et al. 2018), consisting of three neurotoxic components (samandarine, samandaridine and samandarone) (Meikl et al. 2010). Those secretions are a part of fire salamanders' immune system, protect it from bacterial and fungal infections (Lüddecke et al. 2018) and also against predators. Fire salamanders can live up to 20 years (Meikl et al. 2010).

Habitat and ecology

Salamandra salamandra prefers wet cool deciduous or mixed forests (Kuzmin et al. 2009) with shade and nearby ponds or streams (Griffiths 1996) at a altitudinal range from 200 to 1000 m (Balogová et al. 2015). Fire salamanders are active during the night (AmphibiaWeb 2020), whereas during the day they hide under the rocks, tree trunks and foliage (Patočka & Patočka 2014) to stay moist (Griffiths 1996) and protected from the direct sunlight (Patočka & Patočka 2014). However, during rainy weather *Salamandra salamandra* leaves its hiding places even during the day (AmphibiaWeb 2020). Hibernation of fire salamanders in the northern part of their range starts from the end of October or beginning of November and finishes around the start of April (Patočka & Patočka 2014). *Salamandra salamandra* hibernates in groups (AmphibiaWeb 2020) in underground shelters (Balogová et al. 2015) with constant temperatures and air humidity, like crevices, caves or mine tunnels (Meikl et al. 2010), In the southern part of fire salamanders' range, activity stops during hot summer period (AmphibiaWeb 2020). *Salamandra salamandra* often shows fidelity to its hibernation place (Balogová et al. 2015). Fire salamanders are opportunistic predators, hunting the most accessible prey from their habitat (Balogová et al. 2015), like soft-bodied prey such as earthworms and slugs, and harder-bodied prey such as flies, millipedes, centipedes, and beetles (Griffiths 1996).

Reproduction

Salamandra salamandra is an ovoviviparous amphibian, which means females carry eggs within their body (Stoltz 2013), the development of the larvae takes place in an uterus (Meikl et al. 2010) and the embryos are nourished from the yolk (Griffiths 1996). During mating, female receives a spermatophore into her cloaca, then the packet dissolves and the individual sperm cells are released. Fertilization occurs internally and the gestation period lasts from 2 to 5 months and usually takes place during hibernation (Stoltz 2013). The sperms can be stored in the spermatheka, which allows the sperms storage for up to two years (Meikl et al. 2010). Salamanders require small springs or ponds in their habitats for their 30 to 60 larvae to develop. The reproduction cycle is annual (Meikl et al. 2010). Females give birth to aquatic larvae (Alcobendas, Buckley & Tejedo 2004), which are already quite advanced (Griffiths 1996). Larvae are carnivorous and eat fish spawn, small crustaceans and arthropods. Cannibalism is also quite common (Patočka & Patočka 2014). Larvae metamorphose into a juvenile salamander a few months later (Meikl et al. 2010). *Salamandra salamandra* attains sexual maturity at the age of 3-4 years (Patočka & Patočka 2014).

Fig. 10: *Salamandra salamandra* larvae (by Jaromír Maštera, 2010)

Distribution, conservation and threats

a) Europe

Salamandra salamandra is distributed across central, eastern and southern Europe. Some populations occur in the Middle East (Kuzmin et al. 2009) and northern Africa (Griffiths 1996).
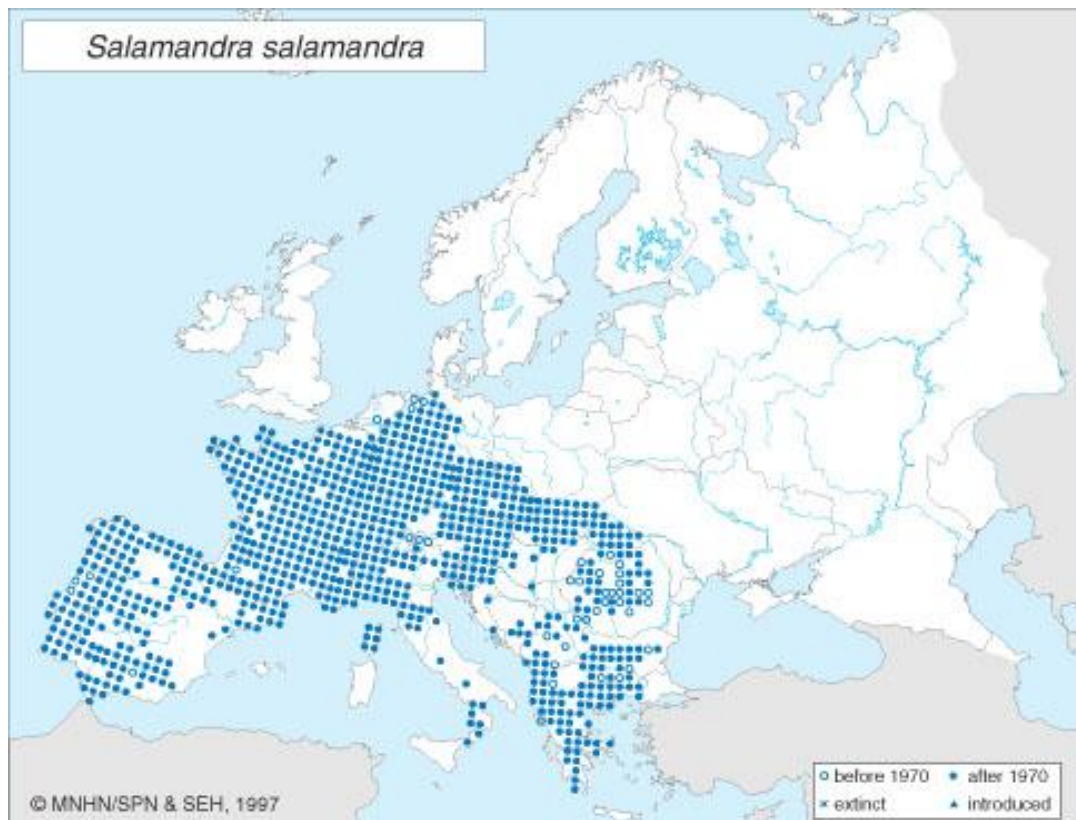
Fig. 11: Distribution of *Salamandra salamandra* in Europe (Gasc et al. 2004)

Red List (IUCN) status of *Salamandra salamandra* is the Least Concern (LC), however there has been a steep decline in the number of species (AmphibiaWeb 2020), mostly because of the parasitic amphibian chytrid fungus *Batrachochytrium salamandrivorans (Bsal)*. The fire salamanders are highly sensitive to that pathogen and it is usually lethal for individuals within two weeks after infection, which results in high local mortality rates (Wagner, Pfrommer et al. 2020). The other main threats for *Salamandra salamandra* are: habitat destruction, pollution of breeding sites by agrochemicals, collection for commercial purposes, introduction of predatory species and population fragmentation. Also, the localized threat in some parts of its range is the mortality on roads (Kuzmin et al. 2009).

b) Czech Republic

In the Czech Republic *Salamandra salamandra* is present all over the country mostly in beech forests, except some parts of Southern Bohemia and South Moravian Region (Česká divočina 2017).
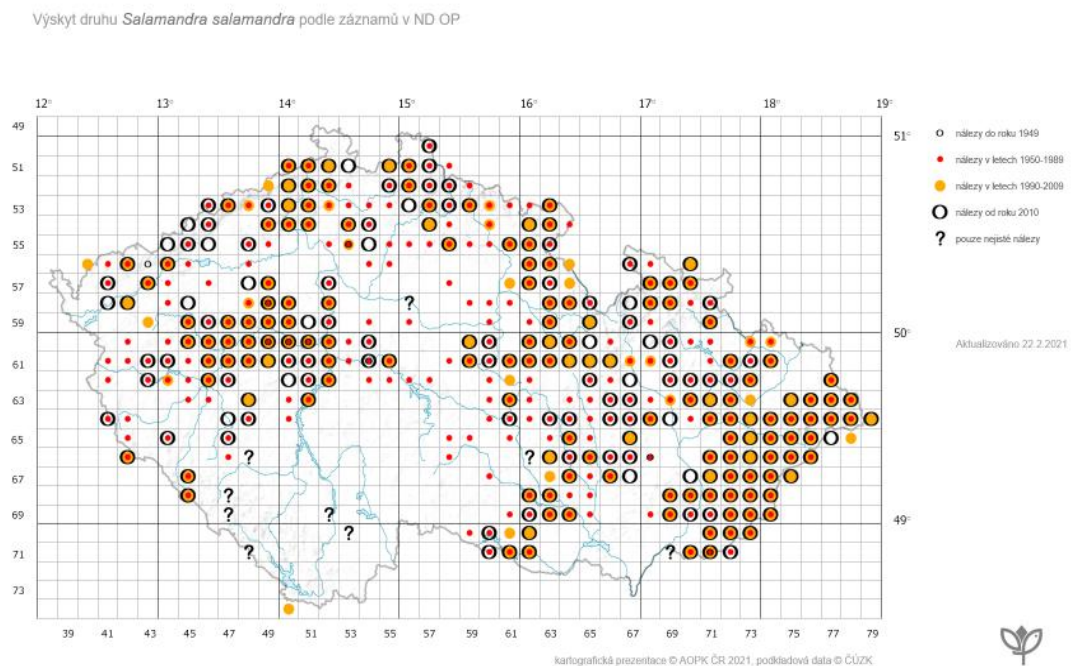
Fig. 12: Records of *Salamandra salamandra* presence in the Czech Republic: before year 1949; in the years 1950-1989; in the years 1990-2009; from year 2010 till present and unclear records (https://portal.nature.cz/)

Salamandra salamandra according to the legal notice 395/1992 Sb. (MŽP 1992) is a critically endangered species in the Czech Republic. The reason of such state is the

long-term pollution and destruction of the natural watercourses, lakes and springs (Patočka & Patočka 2014).

4.2.2 Study area and target population

The location that target population of *Salamandra salamandra* inhabits is a small narrow valley in the northern part of Prague. That valley is situated in the Prague municipal district Suchdol, on the border of nature rezerve Roztocký háj – Tiché údolí, and is only 180 m long. The elevation of the valley starts in 216 m a. s. l. and rises steeply up to 310 m a. s. l. *Salamandra salamandra* occurs only inside and around the brook that falls into a larger creek named Únětický, which then flows into the Vltava river. In the pools around the brook larvae of *Salamandra salamandra* have been found. The watercourse is surrounded by semi-deciduous forests and bushes, in the upper part of the brook private properties with gardens are situated. Some gardens' fences are old with a lot of cracks and holes, that serve as salamanders' hiding places, just as natural refuges between stones, underground or under tree stumps (Filousová 2019).
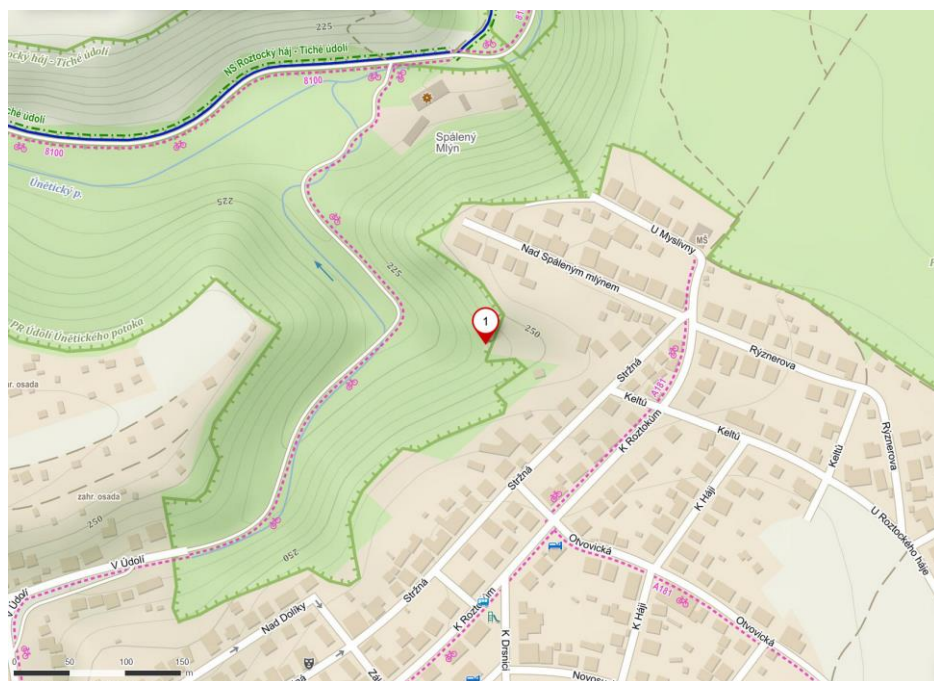
Fig. 13: The exact location of the target *Salamandra salamandra* population (https://mapy.cz/)

The monitoring of the local population of fire salamanders started in the autumn of 2015 and lasted till 2019. 32 visits were conducted to assess the population abundance and vitality using the CMR method. Visits were conducted in rainy weather or after the rain, when the air temperature was higher than 5°C, however during the winter, the location was visited at even lower temperatures (Filousová 2019). As *Salamandra*

salamandra is a nocturnal animal (AmphibiaWeb 2020), sampling was run mostly after 7 pm, during the dusk. During the increased activity of salamanders, like eggs laying or reproduction, visits were performed more often.

Every visit, before performing the monitoring, air and soil temperatures were written down. Monitoring was executed by slowly walking along the path from the bottom to the top of the valley and sampling salamanders on each side in a visible distance. After reaching the top, the sampling was conducted in the opposite way, from the top to the bottom, excluding the individuals already sampled. The whole monitoring in one visit was performed by the same persons (Filousová 2019). During the sampling, salamanders were photographed from above for the colour pattern to be seen, as it is important for the individual identification. After each visit, the photographs were compared in order to find out if the new individual was captured or the individual was seen repeatedly (Filousová 2019). To find out the proportion of sexes in the population, the sexes of captured salamanders were determined by the assessment of cloaca, as the male cloaca is large, swollen and round compared to the female cloaca which is smaller (Labus, Cvijanović & Vukov 2013). Handling of each individual was done with the new rubber gloves, to avoid spreading the amphibian pathogens (Filousová 2019).

I personally did not participate in the data collection. However, I was involved in the data analysis.

4.2.3 Data analysis

Firstly, I work with the data on abundance of the target population of fire salamanders that were collected using the CMR method to determine the proportions of active salamanders during visits. Data collected in the monitoring can be found in the Appendix 4, in a table consisting of the IDs of individuals that were encountered at some time or several times during the monitoring, the exact dates when the visits were held and the matrix of "0"s and "1"s, "0" meaning the individual was not found in that exact date, and "1" meaning it was encountered. On the basis of that data, I calculate the number of active salamanders during each visit and the proportion of those numbers to the estimated abundance. That numbers and proportions are placed in the table in Fig.20. The mean number of salamanders encountered during a visit, the minimum and maximum number of individuals found during a session also are calculated. The table was created and the calculations were performed in Microsoft Excel (Microsoft Corporation 2018). The results are put in the chapter 5.2.1.

Secondly, I suggest the exact way of analyzing that data accounting for the detection probability. I propose the models and the software that should be used and explain that choice. The suggestion is based on the literature review, especially chapter 3.3, and known data about the target population. The proposed way of analysis will be used in my master's thesis, where I will conduct a more complex detection probability assessment. As the data collected using the CMR method were on abundance, I choose between three abundance models: closed population models, open population models and robust design models. Regarding the software, as I analyze the abundance data, I

choose from the software like CAPTURE (Rexstad & Burnham 1992), MARK (White & Burnham 1999) or R (R Core Team 2020) packages that are oriented on abundance and detection probability estimation. The results are put in the chapter 5.2.2.

5. Results

In the chapter 5.1 I present the results of the analysis of studies that deal with the amphibians living in the Czech Republic and involve assessments of detection probabilities. I answer the study questions that I define in chapter 4.1.4 and summarize the useful information for every single species, like which sampling methods have higher detection probabilities and what are the reasons of that or what habitat or weather features influence detection probabilities of different species. I also show the detection probability values for different cases, when they are available. In the chapter 5.2 I analyze the proportions of active salamanders during each visit throughout the monitoring of the target population of *Salamandra salamandra* and also suggest the way of analyzing data accounting for the detection probability.

5.1 Meta-analysis

<u>Summary</u>

In total, I analyzed 18 studies. The data used in analysis can be found in the table in Appendix 1. Using the data obtained, I will answer the study questions.

1. Which type of studies was more frequent: on site occupancy or abundance?

Site occupancy studies were more frequent. In 2 studies, both abundance and site occupancy were estimated, so out of 18 studies, 16 were on site occupancy and 4 on abundance.
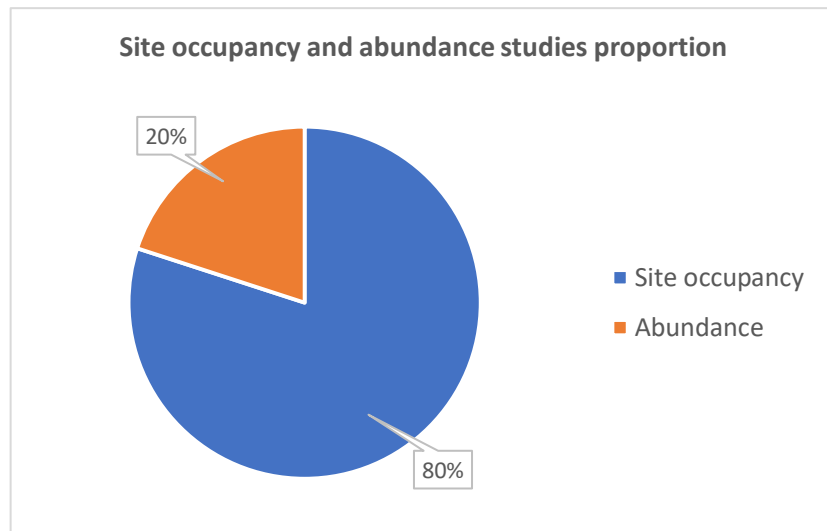
Fig. 14: Site occupancy and abundance studies proportion within analyzed studies accounting for detection probability on amphibians living in the Czech Republic

2. What was the mean number of sites in site occupancy and abundance studies?

Using R (R Core Team 2020), I calculated the mean number of sites for each type of studies, using the function mean(). For site occupancy studies, the mean number of sites was 159.6 (out of 16 studies). For abundance studies, the mean number of sites was 45.5 (out of 4 studies).

3. What was the most used type of models in site occupancy and abundance studies?

In the site occupancy studies, the model used the most frequently was a single-season occupancy model, it was used in 9 studies. In all 4 studies on abundance, different models were used, which are multinomial mixture models, robust design model, N-mixture models and hierarchical design models.

4. What were the most frequently used covariates?

The most frequently used type of covariates was connected with habitat. Those were the covariates such as pond size, percentage of pond surface covered by vegetation, geographical location etc. This type of covariates was used in 11 studies. The second used type of covariates was the covariates connected with the date of the survey, like the day or season. This type of covariates was used in 5 studies. The third used types of covariates were the covariates connected with the water characteristics and with the weather. The covariates connected with water characteristics were: the water temperature, conductivity, mean water level etc. The covariates connected with the weather were: the wind speed, the amount of rainfall during the day in millimeters, air temperature, moon phase etc. Those 2 types of covariates were used in 4 studies.
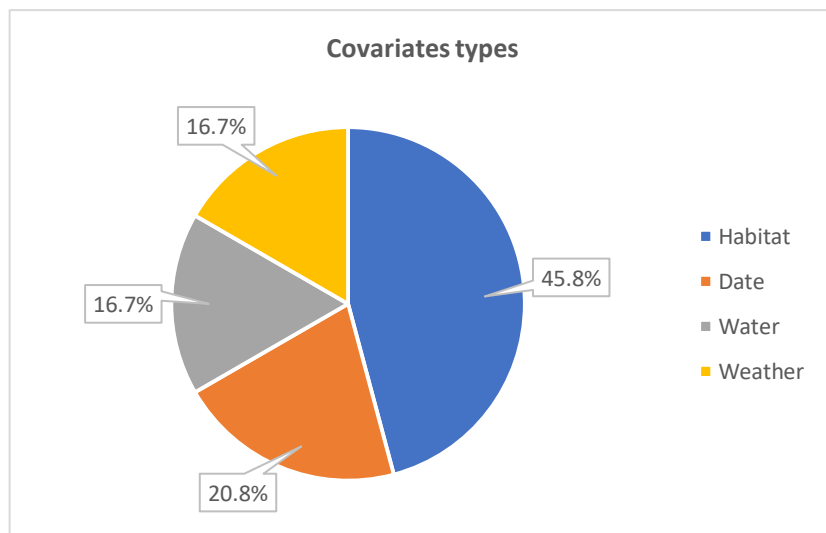
Fig. 15: Covariates types used within analyzed studies accounting for detection probability on amphibians living in the Czech Republic

5. What was the most used software?

For the site occupancy studies, the most used software was the program PRESENCE, which was used in 8 studies. The second used software was R (R Core Team 2020) , used in 7 studies. For the abundance studies, the most used software was R software and program MARK (White & Burnham 1999). R was used in 3 studies and MARK in 1 case.
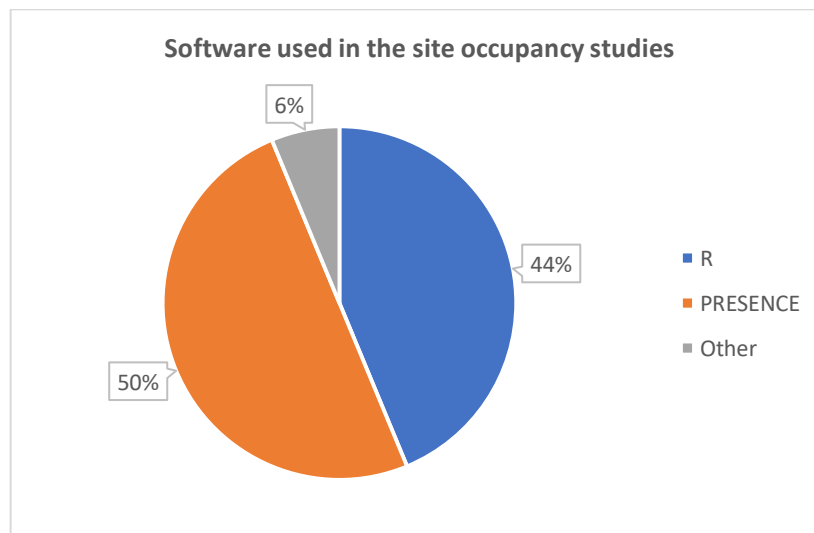
Fig. 16: Software used in the site occupancy studies within analyzed studies accounting for detection probability on amphibians living in the Czech Republic
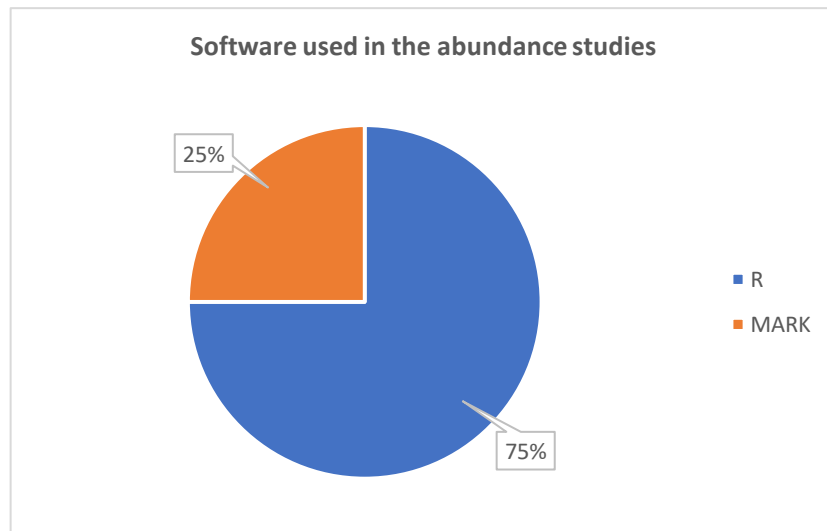
Fig. 17: Software used in the abundance studies within analyzed studies accounting for detection probability on amphibians living in the Czech Republic

Species notes

Common toad (*Bufo bufo*)

The nighttime visual encounter survey method provides a higher detection probability than the call count method for this species. However, after April, the detection probability obtained by visual encounter decreases, and the addition of netting might be required, because for example if netting, nighttime visual encounter and call count survey are combined, two visits between March and June are necessary to detect this species, and if netting is not used, more than four visits are required between April and June (see the table in Appendix 2). Detectability of this species also depends on the water temperature, as very low water temperature is required to detect it by call or visually (see the table in Appendix 3) (Petitot et al. 2014). Distribution of the this species is influenced positively by riparian vegetation (Cinquegranelli, Salvi & Vignoli 2015).

Natterjack toad (*Epidalea calamita*)

The nighttime visual encounter survey method provides a higher detection probability than the call count method for this species. However, using the combination of those two methods, a relatively high detection probability between 0.5 and 0.7 can be reached in a single visit. Moreover, if the netting is added, even higher detection probability, between 0.7 and 0.8 can be accomplished, and two visits are required between March and June if the three methods are combined (see the table in Appendix 2). Detectability of this species also depends on the water temperature, it is more often detected when water temperature is between 15°C and 20°C (see the table in Appendix 3) (Petitot et al. 2014). Anuran call survey is a detection method, using which this species can be overlooked (Pellet & Schmidt 2005).

Yellow-bellied toad (*Bombina variegata*)

Wind speed had a negative impact on the detection probability of this species, if visual encounter method or call count is used. Which means in the conditions with the strong wind, the detection probability will be low (Tanadini & Schmidt 2011).
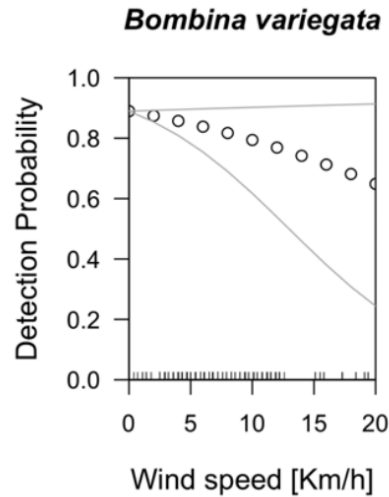
Fig. 18: The relationship between wind and detection probability in *Bombina variegata*. Thin gray lines are 95% confidence intervals. Small ticks inside the box indicate observed wind speeds (Tanadini & Schmidt 2011)

Water frogs (*Pelophylax spp.*)

For this species the nighttime visual encounter survey is an efficient method. Using this method from early March to mid-June for a single visit a high detection probability > 0.8 can be achieved. From mid-May to June the nighttime call count is useful. From mid-March to June the combination of nighttime call count and visual encounter can provide a detection probability of 1 for a single visit (see the table in Appendix 2). For the visual detection of this species the water temperature above 10°C is required and to detect it by call above 20°C (see the table in Appendix 3) (Petitot et al. 2014). This species detection probability increases with the population size (Tanadini & Schmidt 2011).

Common tree frog (*Hyla arborea*)

Maximum chorus counts estimation is an inaccurate method for surveying abundance of this species (Pellet, Helfer & Yannic 2007), however an anuran call survey is a good detection method for *Hyla arborea* site occupancy (Pellet & Schmidt 2005). When the air temperature is higher than 20°C, the probability of detection of this species is higher (Pellet & Schmidt 2005). Per-visit detection probability for this species using the combination of visual encounter surveys, call surveys and dip netting is 0.85. For the detection to almost reach 1, two visits are enough (Cruickshank et al. 2016).
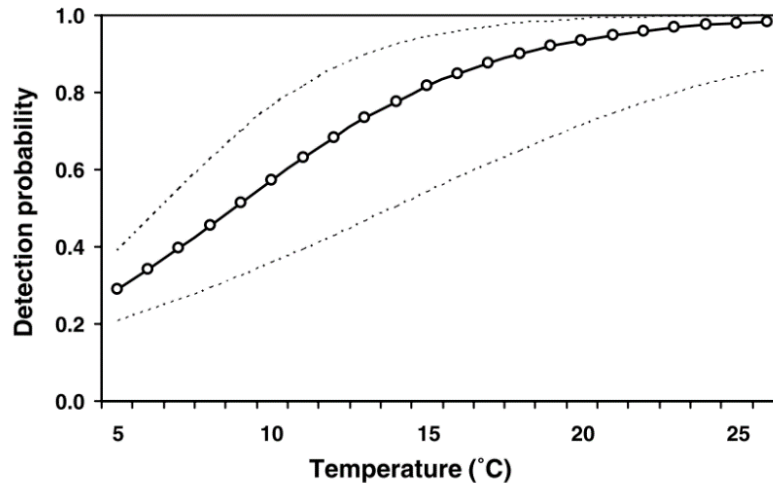
Fig. 19: The relationship between air temperature and detection probability for *Hyla arborea* (Pellet & Schmidt 2005)

Smooth newt (*Lissotriton vulgaris*)

Per-visit detection probability for this species using the combination of visual encounter surveys, call surveys and dip netting is 0.5. Four visits are not enough for the detection probability to reach 1 (Cruickshank et al. 2016). Occupancy of *Lissotriton vulgaris* is the highest at the lower elevations (Foresti 2012).

Palmate newt (*Lissotriton helveticus*)

The visual encounter method provides a high detection probability ($p \geq 0.8$) for a single visit for this species from the end of February till the beginning of April. After that, the use of netting is necessary to keep the detection probability high. Also, if those two methods are combined, one to two visits between March and June are necessary to detect these two species, while more than three visits are required between the end of April and June if netting is not used (see the table in Appendix 2) (Petitot et al. 2014).

Great crested newt (*Triturus cristatus*)

This species detection probability increases with the population size (Tanadini & Schmidt 2011). Shading and density of submerged vegetation affect occupancy of those species. Occupancy is higher in the sites with the shading up to 60% and denser submerged vegetation (Maletzky, Kyek & Goldschmid 2007). Fish in the ponds negatively affects the distribution and abundance of this species (Unglaub et al. 2015). Occupancy of this species is the highest at the lower elevations (Foresti 2012). High detection probability can be achieved with the combination of night counting and bottle traps (Maletzky, Kyek & Goldschmid 2007). Flashlight surveys is also a reliable detection method for this species; however, the detectability decreases with increasing water temperature and with denser pond vegetation if this method is used. Season of the survey has an effect on detection probability if flashlight surveys are used.

Trapping is a slightly better method for this species, as fewer sampling sessions are needed using traps than using flashlight surveys. However, it is a more expensive method. (Kröpfli, Heer & Pellet 2010).

Fire salamander (*Salamandra salamandra*)

In case of larvae of this species living in the creek, the number of pools within a creek positively affected larval abundance and detection probability. Which means, the more pools there are in the creek, the more larvae can be found. Elevation has a negative effect on the larvae presence, which means there are less larvae in the higher elevations. The higher is the amount of prey, the more likely species is present. If there are higher proportions of forest around the creeks, that leads to higher presence of the larvae, except the coniferous forests that, on the contrary, have a negative effect. Agricultural land-use near creeks lessens larval abundance and detection probability (Wagner, Harms et al. 2020).

5.2 Assessment of the data on the target population's abundance

5.2.1 Proportion of active fire salamanders during visits

Abundance of the target population determined after 32 visits was 180 individuals. Confidence intervals are relatively narrow: 164.08–198.58, which proves that the abundance assessment was correct (Filousová 2019).

Date	15.10.2015	19.10.2015	27.10.2015	06.11.2015	07.11.2015	15.11.2015	15.2. 2016	03.10.2016	04.10.2016	16.11.2016	19.11.2016	28.12.2016	09.3.2017	07.10.2017	08.10.2017	06.11.2017	08.11.2017	25.11.2017	29.11.2017	05.1. 2018	28.3.2018	24.10.2018	28.10.2018	24.11.2018	21.12.2018	23.12.2018	02.12.2018	03.12.2018	07.12.2018	9.12.2018	01.3.2019	01.1.2019	08.1.2019
Number	17	8	9	21	19	16	4	4	7	20	19	16	11	6	7	12	15	7	1	3	21	7	21	15	33	11	7	34	17	10	39	11	13
Proportion	9%	4%	5%	12%	11%	9%	2%	2%	4%	11%	11%	9%	6%	3%	4%	7%	8%	4%	1%	2%	12%	4%	12%	8%	18%	6%	4%	19%	9%	6%	22%	6%	7%

Fig. 20: The numbers of active fire salamanders during each visit in monitoring and the proportions of those numbers to the estimated abundance

In the table above the numbers of active salamanders during each visit and the proportions of those numbers to the estimated size of local population (180 salamanders) are presented. The mean number of active salamanders during visits is 14, which is the 8% of the estimated size of the population. The minimum number of active salamanders is 1 or 0.6% of abundance and the maximum is 39, which is 22%.

5.2.2 Suggested way of detection probability analysis

As it is already known, that the data were collected using CMR method, for the further advanced analysis of the data accounting for detection probability, which will be one of the tasks of my master's thesis, I have to choose between the abundance CMR models. I would suggest using a robust model design, because the data were collected during a long period of time (years 2015–2019) and the model should account for temporary immigration or emigration. Multistate robust models can do that (Mazerolle et al. 2007), so using this type of models survival and abundance can be estimated while accounting for the temporary emigration (Santostasi et al. 2016). Regarding the software used for the data processing, I would suggest using the program MARK (White & Burnham 1999), as it is well suited for processing the robust design models, is able to model parameters as functions of covariates, and also fit testing, model selection, and model averaging can be conducted inside the program (Kendall 2001).

6. Discussion

6.1 Meta-analysis

Summary

The higher frequency of site occupancy studies rather than abundance studies can be explained by the fact that the abundance studies can be time-consuming and expensive to implement (Petitot et al. 2014), because they might require massive amounts of resources, such as time, personnel, labor and funds (Mazerolle et al. 2007). For example, in CMR methods repeated efforts to capture or observe animals are needed (Royle, Andrew & Nichols 2003). On the other hand, the collection of detection/non-detection data needed for site occupancy studies is simple and inexpensive (Bailey & Adams 2005), so that estimating occupancy even in geographically extensive study can be affordable (Mazerolle et al. 2007). The lower mean number of sites in abundance studies than in site occupancy studies can be also explained by the larger effort needed to survey the sites in abundance studies. The popularity of single-season models can be explained by their suitability for shorter studies (MacKenzie et al. 2003), because in this type of models there is a closure assumption, which means sites are assumed to be closed to changes in occupancy (Bailey et al. 2007). As shorter studies are cheaper and faster, single-season models are used the most.

The most frequent covariates were those connected with the habitat characteristics. That can be explained by the fact that habitat features influence not only detection probability as it was explained in the chapter 3.2.2, but also site occupancy (Fred & Brommer 2003) and abundance (Fahrig & Jonsen 1998) a lot. So, in case of detection probability it is important to know how habitat features influence it, because it can help to determine the real number of animals in the given habitat conditions. The most used software for site occupancy studies was the program PRESENCE (Hines 2006) and the second used was the software R (R Core Team 2020). However, in the newer studies, there is a tendency to use R software rather than PRESENCE. One reason for that could be that it might be more convenient, as the popularity of software R grows rapidly (Eduonix.com 2019), so more and more people have it downloaded, so it is easier, faster and more efficient to install the R package needed, such as for example the package *unmarked* (Fiske & Chandler 2011), rather than downloading the program PRESENCE. In the occupancy studies the software R is used more than software MARK (White & Burnham 1999), probably for the same reason.

Species

The nighttime visual encounter method is suitable (Petitot et al. 2014) for *Bufo bufo* (AmphibiaWeb 2021a), *Epidalea calamita* (Beja et al. 2009), *Lissotriton helveticus* (AmphibiaWeb 2021b) and *Triturus cristatus* (Dolmen 1983), because those are nocturnal species. However, after April there is a need of adding other methods to detect *Bufo bufo* (Petitot et al. 2014). The reason for that could be the start of the reproduction period (AmphibiaWeb 2021a). For *Epidalea calamita*, using only the anuran call survey can be unreliable for detection, because its calls are infrequent during the breeding season (Pellet & Schmidt 2005). Flashlight survey is a reliable method for detecting *Triturus cristatus* if the surface cover is not too dense. The date of the flashlight survey also affects the detectability of *Triturus cristatus*, because during some seasons there is more vegetation in the pond (Kröpfli, Heer & Pellet 2010).

Detectability of *Epidalea calamita* is better when water temperature is between 15°C and 20°C (Petitot et al. 2014), because that species prefers warm aquatic habitats for reproduction (Beebee 2002). Higher wind speed lowers the detectability of *Bombina variegata*, because during those conditions less animals are active (Tanadini & Schmidt 2011). Species like *Lissotriton vulgaris* (O'Reilly 1997) and *Triturus cristatus* (Edgar & Bird 2006) prefer lowland ponds, so they occur the most at the lower elevations (Foresti 2012). Also, *Salamandra salamandra* prefers lowlands (Wagner, Harms et al. 2020). Coniferous forests have a negative effect on *Salamandra salamandra* presence (Wagner, Harms et al. 2020), because it prefers deciduous or mixed forests over coniferous (Kuzmin et al. 2009). The presence of vegetated and open areas in the same place allows *Bufo bufo* keep a suitable body temperature and prolong the daily and seasonal activity, which can explain the positive influence of riparian vegetation on its distribution (Cinquegranelli, Salvi & Vignoli 2015).

6.2 Assessment of the data on the target population's abundance

Proportion of active fire salamanders during visits

As it can be seen from the data in the table in Fig.20, the numbers of active salamanders during each visit are just a fraction of the total abundance estimated. Even the maximum number of salamanders seen during one visit was 39, which is still only 22% of all the salamanders inhabiting the location. This can be explained by the fact that fire salamanders as all terrestrial salamanders have a low availability for sampling. Availability is an important component of the detection probability (McCallum 2005) and it is the probability that the individual is present in the sampling area and is available for sampling (O'Donnell & Semlitsch 2015). Availability is also dependent on the capacity of the survey method to detect the targeted animals. Most survey methods for terrestrial salamanders require individuals to be active on the surface to be considered available. However, salamanders do not spend a lot of time on the surface (O'Donnell & Semlitsch 2015), because they are active during the night (AmphibiaWeb 2020) and during the day they hide (Patočka & Patočka 2014), leaving its hiding places only during rainy weather (AmphibiaWeb 2020). Although, it was also proved that not only the time of the day and weather determines the availability of terrestrial salamanders, but also the characteristics of habitat, meaning that salamanders are less available in disturbed, low-elevation habitats (Bailey et al 2016). This information highlights the importance of carrying out the repeated visits to the location of interest during the monitoring and accounting for the detection probability, because otherwise the resulting data can be biased a lot.

7. Conclusions

- The accurate and unbiased data from biodiversity monitoring are very important for making the correct management decisions and for conservation of biodiversity. However, many factors can cause the bias in those data. That are, for example, usage of convenience sampling (Anderson 2001) or the samples not being representative (Archaux 2011). One of the most important factors is the imperfect detection, which means that individuals, populations or species are not always found even when they are present at a site (Tanadini & Schmidt 2011). There are different sources of imperfect detection, like weather and environmental conditions, species ecology, population size, observer's skills and motivation, habitat features or sampling method selected. Even though imperfect detection is an important source of error, still not many studies account for it. The way of dealing with the imperfect detection is using the standardized sampling methods (Petitot et al. 2014), repeating the samplings and accounting for the detection probability. The first part of the literature review in my thesis deals with the necessary definitions and an explanation of the imperfect detection.

- The way of accounting for imperfect detection is to assess the detection probability in studies. Detection probability is the probability of detecting a species when it is present (Edwards, Pauley & Waldron 2016). A large part of the literature review in my thesis describes the detection probability and the way of dealing with it using statistical models with the examples of different species and studies. The models described in this thesis are those for the abundance studies based on capture-mark-recapture surveys, for the abundance studies in which individuals cannot be marked and for site occupancy studies. All those models are then differentiated by the characteristics of the population of interest. I also describe the process of the model selection from the candidate set. As building models accounting for detection probabilities requires difficult statistical analyses, it is done using different software. That software differentiates by the models it can analyze. Some of the most used software was shown in my thesis.

- The aim of the practical part of my thesis was to show by the examples that the accounting for imperfect detection in studies is very important, detection probability can depend on many different factors and also to provide some information that can be taken into account during the planning of the amphibian monitoring in the Czech Republic.

- The first section of the practical part consists of the simple meta-analysis of available studies of amphibian species inhabiting the Czech Republic, that deal with detection probabilities. I analyzed 18 studies and answered study questions about which type of studies was the most frequent, what was the mean number of sites for abundance and site occupancy studies and what type of models, covariates and software was the most used. As an example of final data, the site occupancy

single-season model was the most used and also site occupancy studies had a higher mean number of sites surveyed. That can be explained by site occupancy studies being much cheaper and easier to conduct. I also analyzed the information from those studies connected with detection probabilities of species of the Czech Republic, that can be useful for the monitoring planning, like what and how weather conditions, date, water temperature or other covariates influence the detection probabilities of some species and which sampling techniques are successful for some species.

- The second section of the practical part contains the analysis of already collected data on abundance of fire salamanders' (*Salamandra salamandra*) population from the Prague district Suchdol. Data were collected from the year 2015 till the year 2019 using CMR method. 32 visits to the location were carried out and the abundance was defined as 180 individuals (Filousová 2019). From the data on individuals captured during each visit, I set a number of active salamanders during each visit and the proportion of those numbers to the estimated abundance. I also calculated the mean number of salamanders encountered during a visit and the minimum and maximum number of individuals found during a session. The result shown that the percentage of active salamanders to the abundance was very small, the mean percentage was only 8% and the maximum out of all visits was 22%. That output has shown that *Salamandra salamandra*, as most terrestrial salamanders because of their ecology, has a low availability or the probability that the individual is present in the sampling area and available for sampling (O'Donnell & Semlitsch 2015). Availability is a very important component of the detection probability (McCallum 2005). So that shows that accounting for the detection probability in studies is very important and that the repeated sampling is needed. As a next step in that section of the practical part I suggested the way of analyzing the data on fire salamanders accounting for the detection probability, so I will implement that suggestion in my future master's thesis. So, I proposed the abundance robust design model, as it can account for the temporary emigration and the data analysis using MARK (White & Burnham 1999) program.

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9. Appendices

9.1 Appendix 1

Appendix 1: Data for the meta-analysis conducted in the chapter 5.1

| Reference | Study description | | | Methodology | | | |
	Study area	Target species	Number of sites	Abundance or site occupancy estimation	Type of models used	Covariates	Software used
Petitot et al. 2014	Languedoc region, Southern France	*Alytes obstetricans, Bufo bufo, Epidalea calamita, Discoglossus pictus, Hyla meridionalis, Pelobates cultripes, Pelodytes punctatus, Pelophylax* sp, *Lissotriton helveticus, Triturus marmoratus*	49	Site occupancy	Single-season occupancy models	Detection method, date, water temperature	R
Tanadini & Schmidt 2011	Canton Aargau, Switzerland	*Alytes obstetricans, Bombina variegata, Epidalea calamita, Pelophylax esculentus-*complex, *Mesotriton alpestris, Triturus cristatus*	165	Site occupancy	Single-season occupancy models	Pond characteristics, phenology, wind speed, index to past population size	PRESENCE
Scmidt 2005	Mittleres Aareta, Canton Aargau, Switzerland	*Alytes obstetricans, Bombina variegata, Bufo calamita*	32	Site occupancy	Single-season occupancy models	Whether the site is a gravel pit, the amount of rainfall during the day in mm, the temperature in °C at 19:00 hours, day since April 30	PRESENCE
Wagner, Lötters et al. 2020	Eifel Mountains, Germany	*Salamandra salamandra* larvae	61	Abundance	Multinomial mixture models	Capture occasion (date), number of pools, creek width, *Bsal* presence/absence in some models	R

Gómez-Rodríguez et al. 2010	Doñana Biological Reserve, Southwestern Spain	*Bufo bufo, Bufo calamita, Pelobates cultripes, Discoglossus galganoi, Pelophylax perezi, Hyla meridionalis, Pleurodeles waltl, Triturus pygmaeus, Lissotriton boscai, Alytes cisternasii, Pelodytes ibericus*	21	Site occupancy	Single-species occupancy models	Pond size, hydroperiod	PRESENCE
Kröpfli, Heer & Pellet 2010	Nature reserves around Bern, Switzerland	*Triturus cristatus*	12	Site occupancy	Single-season occupancy models	Flashlight survey covariates: shape index of the pond, water temperature, accessibility of the pond, percentage of vegetation, survey date and season, percentage of pond surface covered by vegetation. Trapping covariates: water temperature, pond area, moon phase, position of the traps in the pond, survey date and season	PRESENCE
Pellet, Helfer & Yannic 2007	Western Switzerland	*Hyla arborea*	2	Abundance	Robust design models	No covariates included	MARK
Schmidt & Pellet 2009	Western Switzerland	*Hyla arborea, Epidalea calamita, Bombina variegata, Alytes obstetricans*	27	Site occupancy	Single-season occupancy models	Distance to nearest road; whether a site is man-made, natural or originally man-made, but left undisturbed for many years	PRESENCE
Cruickshank et al. 2016	Switzerland	*Hyla arborea, Hyla intermedia, Bufo bufo, Triturus carnifex, Triturus cristatus, Lissotriton vulgaris, Rana dalmatina, Epidalea calamita*	20 sites for 9 species with >400 known breeding sites, 25 sites for 3 species with <400 known breeding sites, and 12 sites for 2 species that occur only in the southern region of Switzerland	Site occupancy	Single-season occupancy models	No covariates included	R

Steiner 2014	Western Switzerland	*Alytes obstetricans, Bombina variegata, Lissotriton helveticus*	34	Site occupancy and abundance	Single-season occupancy models, N-mixture models	Site occupancy: habitat type, the year of last observation and the year of last observation of other amphibian species. Abundance: air temperature, rain, wind, moon state	R
Wagner, Harms et al. 2020	Western Germany	*Salamandra salamandra larvae*	Site-occupancy - 135, abundance - 85	Site occupancy and abundance	Hierarchical models	Date, elevation, number of pools, creek width, presence of predatory fish, terrestrial habitat	R
Maletzky, Kyek & Goldschmid 2007	Salzburg, Austria	*Triturus cristatus*	39	Site occupancy	Single-season occupancy models	Pond area, maximum depth in three classes (<30 cm, 30-100 cm, >100 cm), fish presence or absence, natural or artificial origin, presence or absence of human use, density of submerged vegetation and proportion of shade	PRESENCE
Unglaub et al. 2015	Krefeld, Germany	*Triturus cristatus*	22	Site occupancy	Multiseason-multistate hierarhical models	Habitat suitability index	MARK
Foresti 2012	Switzerland	*Ichtyosaura alpestris, Lissotriton helveticus, Lissotriton vulgaris, Lissotriton vulgraris meridionalis,Triturus cristatus, Triturus carnifex*	No data	Site occupancy	Hierarchical site occupancy model	Detection probability covariates: the number of records within a quadrat in a year, the number of distinguishable visits per quadrat and year, the number of different visitors per quadrat and year Environmental covariates of the occupancy dynamics: elevation, urbanization and connectivity	R

Miró, Sabás & Ventura 2018	Pyrenean mountain range	*Rana temporaria, Alytes obstetricans, Bufo spinosus, Lissotriton helveticus, Salamandra salamandra, Calotriton asper*	1739	Site occupancy	Semiparametric generalized additive models	Existence of refuge areas from fish predation, coverage of the littoral occupied by aquatic vegetation in percentage, conductivity, existence of cold sites with cold water inflow during the summer, existence of temporary ponds that dry up most of the ice-free seasons, geographical location, altitude and surface area of the water body, littoral and shore habitat characteristics	PRESENCE
Cinquegranelli, Salvi & Vignoli 2015	Circeo National Park, Central Italy	*Bufo bufo, Bufotes balearicus, Hyla intermedia, Pelophylax* spp, *Rana dalmatina, Lissotriton vulgaris, Triturus carnifex*	15	Site occupancy	Principal component analysis, logistic regression analysis	Riparian vegetation, aquatic vegetation, shore slope, bottom substratum, water flow, water permanence, depth, leaf litter, water turbidity, predators	PRESENCE
Lupi 2015	Southern Switzerland	*Bufo bufo*	49	Site occupancy	Multi-season site occupancy models	Urbanization rate, rate of forest cover, whether the site is favorable or not	R
Băncilă et al. 2017	Southern Carpathians, Romania	*Rana temporaria*	97	Site occupancy	Single season multistate occupancy models	Location, altitude (m), habitat type (permanent or temporary, 0), surface area, sinuosity, presence of invertebrates, whether the grazing along the banks and in the vicinity is present	R, WinBUGS

9.2 Appendix 2

Appendix 2: Estimated detection probability of the different survey methods: nighttime call count, nighttime visual encounter and netting for different species: (A) *Alytes obstetricans*, (B) *Epidalea calamita*, (C) *Bufo bufo*, (D) *Pelophylax spp.*, (E) *Hyla meridionalis*, (F) *Pelodytes punctatus*, (G) *Triturus marmoratus*, (H) *Lissotriton helveticus* (Petitot et al. 2014)
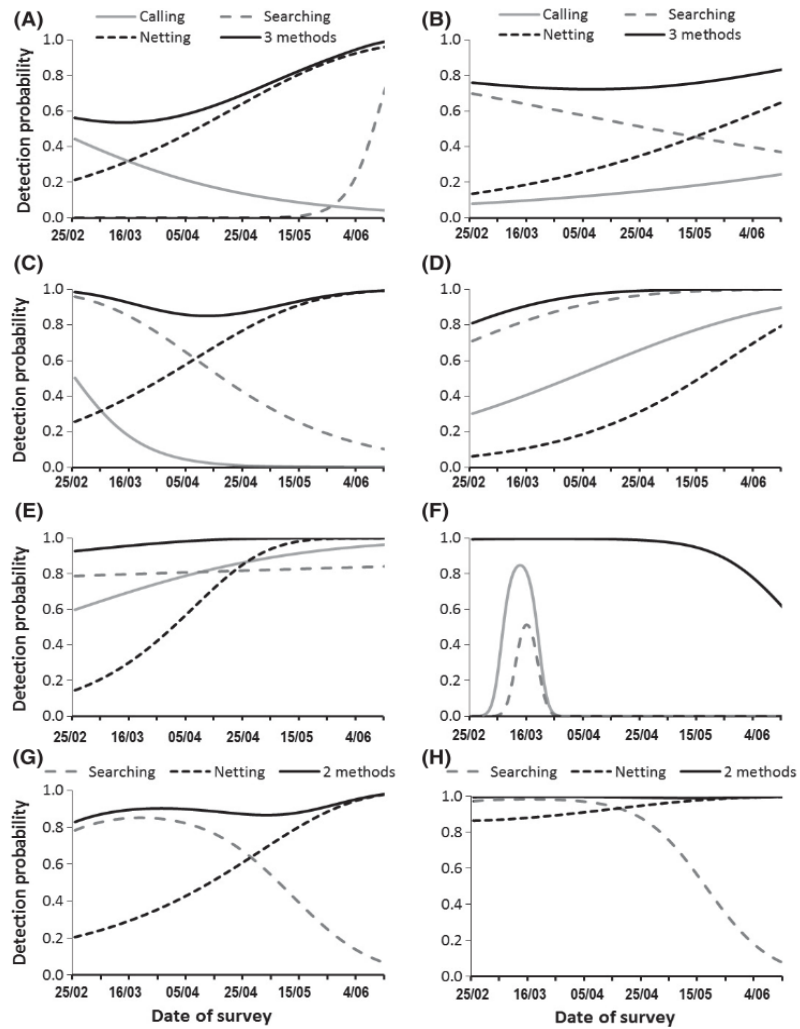
9.3 Appendix 3

Appendix 3: Relationship between water temperature and detection probability for (A) *Hyla meridionalis*, (B) *Pelophylax* spp., (C) *Bufo bufo*, and (D) *Epidalea calamita* (Petitot et al. 2014)
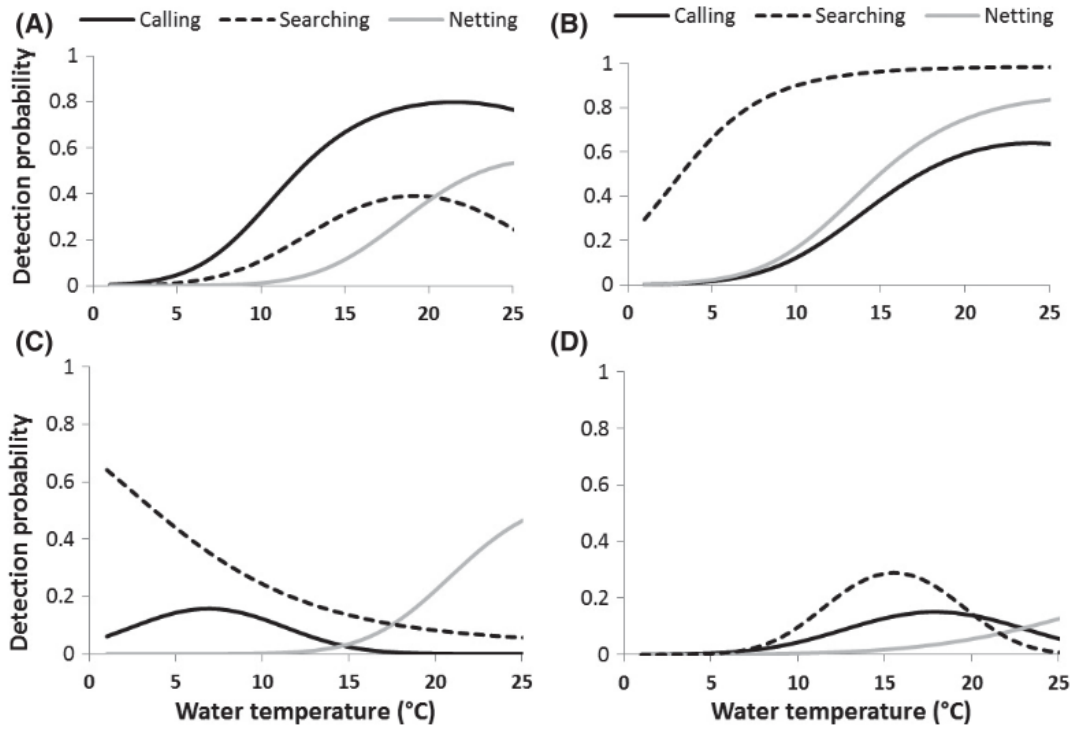
Appendix 4: Data from the monitoring of a Prague-based fire salamander (*Salamandra salamandra*) population.

ID	15.10.2015	19.10.2015	27.10.2015	06.11.2015	07.11.2015	15.11.2015	15.2.2016	03.10.2016	04.10.2016	16.11.2016	19.11.2016	28.12.2016	09.3.2017	07.10.2017	08.10.2017	06.11.2017	08.11.2017	25.11.2017	29.11.2017	05.1.2018	28.3.2018	24.10.2018	28.10.2018	24.11.2018	21.12.2018	23.12.2018	02.12.2018	03.12.2018	07.12.2018	9.12.2018	01.3.2019	01.1.2019	08.1.2019
SCH 001	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0
SCH 002	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
SCH 003	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
SCH 004	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
SCH 005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
SCH 006	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
SCH 007	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 008	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	1	0	0	1	0	0	0	1	0	0
SCH 009	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 010	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
SCH 011	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 012	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 013	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 014	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 015	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
SCH 016	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0
SCH 017	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 018	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 019	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
SCH 020	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 021	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
SCH 022	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0
SCH 023	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 024	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
SCH 025	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SCH 026	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0	1	1	0	0	0	0
SCH 027	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 028	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
SCH 029	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 030	0	0	1	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
SCH 031	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 032	0	0	1	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
SCH 033	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
SCH 034	0	0	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 035	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 036	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 037	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 038	0	0	0	1	1	1	0	1	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SCH 039	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 040	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 041	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 042	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 043	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 044	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SCH 045	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
SCH 046	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 047	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
SCH 048	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 049	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	1	0	1	0	0
SCH 050	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 051	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
SCH 052	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	1
SCH 053	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	1	1	1	0	0	1	0	1	1	0	0
SCH 054	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 055	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0
SCH 056	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 057	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0
SCH 058	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	1	0	0
SCH 059	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 060	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 061	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 063	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	1	1	0	0
SCH 064	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0
SCH 065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	1	1	0	0
SCH 066	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 067	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
SCH 068	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
SCH 069	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
SCH 070	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 071	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
SCH 073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
SCH 074	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 075	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 076	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 077	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 078	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0
SCH 079	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 080	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	1	
SCH 081	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1			
SCH 082	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0		
SCH 083	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0			
SCH 084	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
SCH 085	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	
SCH 086	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
SCH 087	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	1	0	1	1	1	0	
SCH 088	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0			
SCH 089	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	
SCH 090	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 091	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 092	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 093	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 094	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 095	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 096	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 097	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 098	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 099	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 100	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
SCH 102	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 103	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 104	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	
SCH 105	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	0	1	0	1	0	
SCH 106	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 107	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	0	1	0	0	
SCH 108	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	
SCH 109	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	
SCH 110	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCH 111	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	1	0	0	
SCH 112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
SCH 113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	1	

SCH 114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0
SCH 115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
SCH 116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0
SCH 117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	1
SCH 118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0
SCH 119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0
SCH 120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
SCH 121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
SCH 122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
SCH 123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
SCH 124	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1
SCH 125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
SCH 126	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1
SCH 127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1
SCH 128	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
SCH1 29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
SCH1 30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
SCH 131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
SCH 132	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
SCH 133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0
SCH 134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
SCH 135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
SCH 136	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
SCH 137	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
SCH 138	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
SCH 139	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
SCH 140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
SCH 141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
SCH 142	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
SCH 143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SCH 144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SCH 145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
SCH 146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SCH 147	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SCH 148	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SCH 149	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SCH 150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1