Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands

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Abstract

The muskrat (*Ondatra zibethicus*) is considered as an invasive species in the Netherlands. A muskrat control program is now conducted nation wide with the aim of eradicating the species. In the field, there are 10 trap types used to capture muskrats, which is sorted into body-grip trap, cage, fyke and others by their characteristics or active and passive traps depending on how professional trappers use them.

The study aims to investigate the trap efficiency in muskrat control program, based on field data from Flevoland, the Netherlands. The efficiency is discussed in three aspects namely catch efficiency, cost efficiency and target specificity. The relative catch number (number of catches/ km of waterway) in an atlas block in one period of four weeks is modeled based on trap densities of different trap types and external conditions. The best model contains trap densities of five most used trap types, year, historical catch (relative catch number of last year in same period) and their interaction with season. Within the best model, Duikerafzetting has the highest coefficient estimates in all seasons except spring. Schijnduiker has the lowest significant coefficient estimates throughout the year. Conibear has relatively similar coefficients in different seasons. Coefficient estimates for Lokaasklem and Lokaaskooi vary largely through seasons. Active traps have higher contribution to relative catch in summer and autumn and have similar coefficient with passive traps in winter. Fyke works most stable during the year. Cage has the highest coefficients in spring and winter and insignificant coefficients in other seasons. Body-grip trap contributes the most to relative catch in summer and autumn. In all models, the year 2017 has higher catches in all seasons. The historical catch only significantly positively related to relative catch in winter.

According to questionnaire about time spent on different traps, the Levend vangende kooi is checked most frequently by professional trappers (checked everyday). Conibear is mostly checked 2-3 times per week. Schijnduiker is usually checked once per three weeks or less. The other traps are checked in a relatively similar frequency. And it usually takes a trapper less than 10 minutes to check a trap. Total cost of using different type of trap was
estimated against time spent in the field. Levend vangende kooi costs the most through time, followed by Conibear, Grondklem and Lokaasklem. The rest of trap types have relatively similar low cost with Schijnduiker having the lowest. Considering the total number of catches made by different trap types through the whole study period and corresponding checking cost estimate, Duikerafzetting has the highest catch and cost ratio. Overall most of trap types have similar catch and cost ratios.

Only four out of ten trap types caught non-target animals namely Schijnduiker, Lokaasklem, Duikerafzetting and Conibear. Lokaasklem has the highest by-catch rate of 0.2 (one non-target animal caught when capturing every 5 muskrats). Most of the by-catches are widely accepted by social public such as brown rat and European water vole. However, Duikerafzetting only caught fish as by-catch which is less accepted by the public. Moreover, Different trap types have selective trends on species of by-catches they made, as they usually have different working scenario and environment.

The field experiment shows that Conibear trap has higher catch ability than two passive traps: Lokaasklem and Lokaaskooi. The result of simulated experiments suggests the catch probability of Lokaaskooi is statistically significantly higher than the catch probability of Lokaasklem.

To conclude, Duikerafzetting is considered the most efficient among 5 most used trap types. Yet it is also found to have less ability to specify the target species. Catch efficiency varies among different trap types, years, historical population conditions and these factors perform differently among seasons. However, clear pattern of efficiency changes in migration season is not found.

It is suggested that the seasonal variation of catch efficiency for trap types and potential danger traps may cause to non-target animals can be taken into account when making trapping strategies. Also the data collecting and storage system needs to be upgraded. The status change is recommended to be recorded and the by-catches should not be removed when the corresponding trap is deleted. More precise and detailed analysis can be
conducted in the future if these improvements are made and the performances of different traps, muskrat population can be further monitored using the data.
Introduction

The Muskrat (*Ondatra zibethicus*) is a semi-aquatic rodent. Originally inhabiting North America, it has been introduced to Europe, Asia and South America. Muskrats favor wetlands, brackish and fresh-water lakes, ponds and marshlands. They build their nests either by cutting down and assembling vegetation within wetlands or digging burrows into banks or dikes (Cassola, 2016; Kadlec, Pries, & Mustard, 2007). Muskrats are mainly herbivorous. They eat roots, bulbs and shoots of aquatic vegetation (Gross, 2015). The most favored vegetation is cattail (*Typha spp.*). Muskrats also consume small animals such as frogs when lacking in food supply (Cassola, 2016). The species has high ability of reproduction: on average, a pair of muskrats can give birth to three litters annually with three to nine young muskrats per litter (Association of Fish and Wildlife Agencies, 2014).

The Muskrat was first introduced to Europe as a furbearer in the early 20th century. Soon the species began to spread all over the lowlands in Europe (van Troostwijk, 1978). Around the year 1941, the muskrat first migrated into the Netherlands (van Loon et al., 2016). Here, the population of muskrats grew dramatically because of the moderate climate and adequate vegetation. More importantly, the large scale of waterways and precisely controlled water level provide the animal with a suitable living habitat (van Loon, Bos, van Hellenberg Hubar, & Ydenberg, 2016; van Troostwijk, 1978). In the Netherlands, most muskrats live in burrows which are dug into banks, dykes and other water infrastructures. These burrows often consist of several entrances, which are buried under water to prevent from predators, and chambers connected by tunnels (van der Steen, 2014). The burrowing activity of muskrats poses a serious threat to the stability of the water retaining structures and may eventually cause a breach (van Hemert & Bos, 2016). As a result, muskrat is considered an invasive species in the Netherlands.

In 1945, the first muskrat control organization was established in the Netherlands (van der Steen, 2014). The muskrat control program aims to minimize the population size of muskrats and further eradicate the species. Over time, the responsible organizations for the muskrat control program have shifted. Currently, the nationwide control program is...
coordinated by Dutch Muskrat Control Committee (LCCM) (Bos et al., 2009). There are eight management organizations responsible for different areas around the country. Over 400 professional trappers work in the country to catch muskrats (Bos, van Loon, Klop, & Ydenbreg, 2016). The program is carried out throughout the year and all over the country except for the nature reserve Oostvaardersplassen (Bos & Ydenbeg, 2011). Traps, mainly drowning cages and Conibear traps, are set in the field to catch muskrats. Since [year] the country-wide number of catches in the country has been declining and, analogous to that the population level is believed to be at a relatively low level. [reference] However, there are still some non-target animals, such as water birds, are captured as a side effect of the control program. From an annual report of Unie van waterschappen (2017), in the year 2016, there are 81,125 muskrats caught throughout the country, which is decreased by 9% comparing to 2015. In the meanwhile, over 7,000 non-target animals are caught by muskrat traps, including mammals, birds and fish. In addition, significant resources are invested to operate the management program every year (Bos et al., 2009). As a consequence, there is an ongoing debate concerning the effectiveness of this control program (van Loon et al., 2016).

Independent researches have been carried out from different aspects related to muskrat control, such as economic losses caused by burrowing and feeding (Gaaff, de Graaff, Michels, Reinhard, & Vrolijk, 2007), muskrat population dynamics (Bos et al., 2009), by-catch in the trapping processes (Klop, van der Heide, & Schoppers, 2011), etc. Large-scale field experiments have been held in the Netherlands to investigate the relationship between the effort and the harvest. It is commonly believed that more effort invested in trapping can result in more muskrats caught (Bos et al., 2016). However, with population size decreasing, more effort will generally be needed to capture the same amount of muskrats. But geographical contrasts do suggest that additional factors play a role. In Flanders (Belgium), for instance, the intensive muskrat management plan resulted in higher harvest proportion (number of catch per kilometer of shorelength) and a probably much lower population density than in the Netherlands, while the investment in field hour remains similar (Bos & Ydenberg, 2011). This indicates that it may be possible to further reduce the current population level by increasing harvest proportion while maintaining the current investment.
level in the Netherlands (Bos & Ydenberg, 2011). In this case, a catch-efficient, target-specified, low-cost trapping plan is needed to increase efficiency.

Several alternative management plans were proposed and investigated through field experiments, such as “space-differentiated harvesting” and “time-differentiated harvesting”. However, neither of the plans were shown to be more effective than current year-round plan (Bos & Ydenberg, 2011; Haye, Bos, Hollander, Klop, & Roodbergen, 2016). While most of the researches look into the evaluation and improvement of general management plans, only few studies focus on detailed trapping methods. For example, a study carried out by Landelijke Coördinatiecommissie Muskusrattenbestrijding (LCCM) looks into non-target animals caught in muskrat trapping process by different traps, seasons and geographical distribution. The study shows that use of different types of traps in the field is one of the factors directly influencing the result of trapping.

For the reasons mentioned above, this study aims to compare the efficiency among different types of traps used in the Netherlands and provide suggestions to adjust the current management plan towards a more effective control program. Based on the study, a systematic way can be proposed to evaluate the efficiency of animal trapping method, which provides insights for other cases of invasive species control. For example, coypu (*Myocastor coypus*) is also considered as an invasive species in Europe. A large number of coypu are still entering the Netherlands from Germany every year, and the annual catch has been increasing in recent years (Unie van Waterschappen, 2017; van der Steen, 2014). The study provides a way to evaluate trap efficiency which can also be applied to coypu control. Moreover, the study can reflect on the current data collection system in the field. Suggestions will be given to improve the logic of the system and accessibility of relevant data.

Warburton (1982) summarized eight criteria when evaluating possum traps, which contains most of the criteria used to evaluate a small mammal trap. To capture an animal, catch ability is commonly believed to be the most important quality for a trap. Catch-efficient traps can harvest more target animals within a time period. The cost for different traps also
needs to be taken into account. A trap with high catch ability can still turn out to be less efficient due to relatively high costs in terms of time and money. Also, it is important for a trap to show high selectivity on the animal caught. For different types of traps, the ability to target wanted animals may differ. As a result, catch efficiency, cost efficiency and target specificity are chosen from the list of Warbuton (1982) to compare working efficiency between different traps in this study.

The aim of this research is to determine which kind of trap, currently used in the field, can be considered most efficient. To answer it, the following research questions are used:

How does catch efficiency differ between different traps?
How do the external factors season (winter, spring, summer and autumn) and spatial distribution of traps influence catch efficiency?
How does the relationship between catch and effort differ for different traps?
Is there any difference on by-catch rate among different traps?

In the following sections the study area and methods are described, followed by a result and a conclusion section.

**Study Area**

The study area is located in the east of Flevoland, Netherlands (Fig.1). Flevoland is a province located in the middle of the Netherlands, which was reclaimed during 1950s to 1960s. The main study area is in the eastern part of working area of the local muskrat control organization: Waterschap Zuiderzeeland. The study area is approximately 450 km² and is mainly used as agricultural land.

The nature reserve Oostvaardersplassen is located in the southwest of the study area, where no muskrat trapping is taking place. As a result, there are muskrats continuously coming into the study area from the nature reserve. As the whole area is a reclaimed land area, located beneath sea level, the water level is carefully monitored and controlled by the local
water board. The water level remains almost the same throughout the year, creating a suitable living condition for muskrats.

The muskrat trapping in the area is managed by Waterschap Zuiderzeeland. There are around 12 professional trappers working in the area. In 2016, the total number of catch in the area is 844 with 36 non-target animals caught within 3317 hours of field work. Most non-target animals caught are brown rats (*Rattus norvegicus*) and European water voles (*Arvicola amphibius*). But also water birds like Eurasian coot and a beaver were caught by accident. The most frequently used traps in the area are Conibear, Schijnduiker and Lokaasklem in recent years.

![Figure 1. map of the study area](image-url)
Methods

To compare the efficiency between trap types, three aspects were evaluated, namely catch efficiency, cost efficiency and target specificity. The study of catch efficiency and target specificity were based on field data from 2013/8/14 until 2017/12/25 in the study area (east Flevoland). Statistical models were built to analyze catch efficiency using different predictors. Cost efficiency describes the cost to catch muskrat using a certain type of trap and ratio between catch and cost. A questionnaire concerning field time invested on different traps was made and handed out to trappers in the area to help estimate the cost. The target specificity is based on the by-catch rate in the study meaning the ratio between number of non-target animals caught and number of muskrats caught. In addition, a small-scale field experiment was held near Lepelaarsplassen. The results acted as a complement and comparison to the results gained from the field data. In the next sections, the different methods are elaborated further.

Field work details

For muskrat control, professional trappers are responsible to search for possible trap locations, set or remove traps, regularly check traps in the field, record catches and other related work. Normally, a trapper is responsible for the trapping in a certain area for years and the result of catch per hour of fieldwork mainly depends on one's understanding of the muskrat behavior and experience.

Trappers work with a collector application in their mobile phone in the field. The application shows a map with all the traps currently set in the field with different colored symbols representing trap types. When a new trap is set in the field, a new location point is added into the trap location dataset with information including trap location, date, user, trap type, number of traps. Trappers regularly visit a trap to check whether it catches an animal and replace baits. The checking frequency varies between trap types, from approximately every day to every several weeks. During these visits, harvest information, if any, is uploaded by selecting the trap and adding catch description on the same point in
the map in the catch data. Usually, a trap is removed from the field if trapper finds it less efficient. In the collector application, the status of this trap can be changed from active in the field to temporarily removed or permanently deleted. Consequently, the corresponding data row is overwritten to the destination dataset. Whereas records of catch stay in the catch dataset. The same trap location can be changed from removed to activated again if a trap is set in the same place.

There are twelve trap types used in this area, which fall in the categories of fykes, body-grip traps and cages (Table 1). Trappers usually choose a certain type of trap based on the habitat, environmental condition and their experiences. Fykes are set where there is a culvert. Conibear traps are usually set in front of the entrance of a burrow or places very likely to be passed through (in a rack - ‘klemmenrekje’). Cages, like Lokaaskooi, are usually set near the trace of muskrats. There are fewer occasions a muskrat is killed by a car or found dead naturally or found and knocked to death in the field, which are all recorded as ‘Slaan en delven’ in the dataset. Trappers wait at the location and shoot the muskrat by gun is recorded as Geweer (a method applied rarely, only when a Conibear trap does not work). These latter two techniques (categorized as ‘Others’ under trap type) will not be discussed in this study as they are rarely applied and unplanned. Traps that requires trappers to actively search for burrows and be placed in front of entrance of burrows are usually considered as Active traps. Passive traps, usually cages, usually set at locations potentially visited and wait to kill or catch animals (Klop et al, 2011). According to general usage scenarios, the Conibear, Grondklem and Geweer are considered as active traps, all trap types other than which are considered as passive trap in this study. Pictures of several trap types are shown in Appendix A.

<table>
<thead>
<tr>
<th>Trap Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fykes</td>
<td>Schijnduiker, Duikerafzetting</td>
</tr>
<tr>
<td>Body-grip traps</td>
<td>Conibear, Lokaasklem, Klemmenrekje, Grondklem, Postklem</td>
</tr>
<tr>
<td>Cages</td>
<td>Lokaaskooi, Slootafzettingmetkooi, Levend vangende kooi</td>
</tr>
<tr>
<td>Others</td>
<td>Geweer, Slaan en delven</td>
</tr>
</tbody>
</table>
Data collection

Field data
The field data of the study area was downloaded from the supporting website (https://vangstregistratiemobiel.nieuwland.nl/). The data within the study area is available from August 2013 and it is continuously being updated. In the dataset, the trap location data and the catch data of muskrat and the catch data of non-target animals are stored separately. Trap information are stored in three files according to their status, namely active in the field, temporarily removed and deleted. The former two statuses can be changed. However, once a trap is deleted, it can not be activated again. Also, if a trap was deleted, the corresponding records of by-catch made by this trap will consequently be deleted in the data. The date when trapper changes the status of a trap is not recorded in the dataset. Therefore, specific daily trap arrangement in the field is unknown. All catch information of muskrats is stored in the catch dataset. Captures of non-target animals are recorded in the by-catch dataset. Overviews of catch data and trap location data are shown in Appendix B, C.

The field data were used to investigate the catch efficiency and target specificity in the study area. To evaluate the seasonal change of efficiency, the catch data were analyzed per season. For muskrat, a year can be divided into 13 periods of four weeks, within which winter contains four periods (from early December until end of March) and other seasons contains three periods. Spring begins at the end of March and ends at mid-June. Summer runs from middle of June till early September. And autumn starts at the mid of September and ends at the beginning of December.

Questionnaire
To investigate the working routine and working details in muskrat trapping, a questionnaire was made and handed out to professional trappers in January 2018. The questionnaire aims to collect information on the working hours that professional trappers spent on different traps and also the assessment of catch ability by different trap types. The results were used to estimate the cost of trapping muskrat using a certain type of trap.
The questionnaire included questions about the time spent on making traps, checking captures in the field as well as the checking frequency of each trap type. Also, a question concerning catch probability using different traps was listed. In the questionnaire, checking frequency is described in a situation when a trap has already been set in the field for some time and will stay in the field at least until next visit. The check time refers to the time trappers need to find the trap, remove the body, replace baits and reset the trap. And the catch probability is described as the empirical probability of catching a muskrat in a week, or a checking period for those checked longer than a week, after the trap was set ready to catch. The questions are mostly given with multiple choices. Multiple answers are accepted if more than one situations suit the question and a blank for brief explanation is provided at the end of each question.

The questionnaire was handed out online through a Google form. The responses were sorted into a sheet containing all answers. The original questionnaire and response sheet are shown in Appendix D and E.

Field experiment
In addition to the field information from the collector application, a field experiment was held near Lepelaarsplassen, Netherlands, where no year-round trapping program had been carried out during last few years. The experiment lasted 3 weeks in November, 2017. Two types of floating cages were put in pairs in one side of a ditch to compare the ability of catching muskrats, which were Lokaaskooi (Appelkooi) baited with apple and Lokaasklem baited with carrot. In total there were 10 pairs of passive traps. The intervals between two traps was 5 meters. And the intervals between pairs were around 50-100 meters. Several entrances of burrows had already been found along the bank indicating the availability of muskrats. The experiment was carefully monitored by professional trappers. All traps were visited every day. These floating cages were placed in the field for 10 days. During the second phase of the experiment, cages were removed in the field. Instead, the entrances of burrows were carefully searched and Conibear traps were set in front of these entrances. The results of phase II were compared with phase I to investigate the catch efficiency.
between passive and active traps. The overall results of the field experiment were compared with the analysis results from the field data.

The location of the traps and catch results of the field experiment were also recorded by the data collection app. The data was downloaded from the same supporting website as used for investigating catch efficiency and target specificity.

Data analysis

Catch efficiency
As the total number of trap nights is unknown, several assumptions were made based on the working detail of the study area to analyze catch efficiency. The general operational trapping procedures, including trapping method, the intensity of work and the trapping plan throughout the year were considered unchanged during the study period. As a consequence, it was assumed that the total number of traps set in the field are in a dynamic equilibrium state within the study time period in the study area, meaning the number of traps removed roughly equals to the number of traps newly set within each cell in a certain time period. The area and the time period can be further divided into smaller cells and time slices with the same assumption. However, the assumption is valid only with the precondition that the cell is sufficiently big and time period slice sufficiently long so that the stationary assumption holds. Further, a choice was made to take not the absolute number of traps as a response variable, but rather trap density: number of traps per unit of suitable habitat. This suitable habitat was expressed as length of water bank.

As the arrangement of traps is changing daily, trap location data was downloaded in 17 Oct, 28 Nov and 25 Dec 2017 as three example days in these three months. The average of trap numbers in these example days in each atlas blocks were used as daily trap arrangements within study period. The trap numbers in these example days were checked by Friedman test to test if the number is constant over time. As the example days were taken only from the year 2017, the number of newly set traps and the number of catch in
different years were also taken into consideration to evaluate the rationality of the assumption.

The daily working records from the study area were used to evaluate the catch efficiency among different trap types. The data were aggregated into four-week periods and different atlas blocks. The atlas blocks are 5 by 5km squares based on the national Dutch map projection, which are used in the muskrat control program (Bos et al., 2014). There are 28 atlas blocks within the study area, 27 of which have muskrat captures. The total catch was summed up by each block. According to the trappers' working habits and checking frequency, a four-week time period was chosen to aggregate the data. The total catch was divided by the amount of suitable habitat for muskrats based on the length of waterway in the atlas block. In each atlas block, the length of waterway was calculated by the sum of the linear waterways. For blocks covering areas out of the study area, only the waterway within the study area were calculated.

Apart from different trap type, factors including habitat conditions, environmental change and trap placement affect the result of catch in the field. In this study, several factors were used to estimate the catch number by a series of statistical models. The main factors of interest were trap densities of different trap type in the field (average number of trap in example days per km of waterway). The catch efficiency was discussed in three scales: specific trap type, general type and the type of working mechanism (active or passive). Three series of predictor variables representing trap density in different trap categories were successively used in the model in order to compare the catch efficiency in different scales (shown in Table 2). The trap density of different trap varied from 0.29 traps/km to 3.2e-4 traps/km, the latter of which means there is on average less than 1 trap set in the field in these days. For Levend vangende kooi, Klemmenrekje and Slootafzetting met kooi, there was in average a trap density smaller than 1 in the field in these example days (0.67, 1, 0.67 traps within study area). These values are relatively small and therefore was omitted from the models. For Conibear, Duikerafzetting, Lokaasklem, Lokaaskooi and Schijnduiker, they were in average set in more than one spot in the field and consequently retained in the model (8.8e-2, 3.5e-3, 1.7e-2, 8.5e-4, 0.29 traps/km of waterway). The
seasonal change can affect the behavior of muskrats and further affect the catch efficiency. With the ongoing trapping program, the number of muskrats may decline over the year. The number of catch would consequently decrease over the years. The historical relative catch of an atlas block can be seen as the variable representing the potential population size of muskrats, which may also influence the catch result. All predictor variables of interest for modeling relative catch (catch number /km of waterway) were listed in Table 2.

Table 2 Predictor variables of interest

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trap type</td>
<td>numeric</td>
<td>A series of variables describing trap density in certain atlas block (the amount of a certain trap type per length of waterway)</td>
</tr>
<tr>
<td>General type</td>
<td>numeric</td>
<td>A series of variables describing trap density in certain atlas block (the amount of a certain general trap type per length of waterway)</td>
</tr>
<tr>
<td>Active/Passive</td>
<td>numeric</td>
<td>Two variables describing trap density in certain atlas block (the amount of active/passive traps per length of waterway)</td>
</tr>
<tr>
<td>Season</td>
<td>Factor</td>
<td>The Season of the period</td>
</tr>
<tr>
<td>Year</td>
<td>Factor</td>
<td>The year when the catch happened</td>
</tr>
<tr>
<td>Historical catch</td>
<td>Numeric</td>
<td>The total number of catch per km of waterway in same atlas block in same period last year</td>
</tr>
<tr>
<td>BlokCode</td>
<td>Factor</td>
<td>The code suggesting each atlas block</td>
</tr>
</tbody>
</table>

The distribution of catch number was estimated using general linear regression model in R with a log link function and a Poisson error distribution. As Poisson regression only allows integer values to be response variable, in the model, the response variable was the catch number within an atlas block in a period and the length of waterway in each atlas block was set as an offset variable to represent the total amount of suitable habitat. The offset function in R program sets a known coefficient 1 in generalized linear model. In the study, natural logarithm of length of waterway was set as an offset variable which works mathematically the same as relative catch (number of catches/ km of waterway) being response variable and explained by other predictors. Several models (Table 3) were made and compared by Akaike Information Criterion (AIC). The most suitable model was selected to explain the contributions different variables made to the total relative number of catches. The errors of the model were evaluated to check if the assumptions underlying the model are met including if the model error would vary among atlas blocks. Additionally, the overall model fit was evaluated and shown by graph. The stability of the best model results was investigated by cross-validation, meaning all data except for one atlas block was used to predict that one.
were used in the same model and the predicted catches were compared with the real data. The model is considered stable if the coefficient estimates are similar in each model. The catch efficiency of different traps can be evaluated by comparing coefficient estimates of variables representing the number of traps set in the field. The whole modeling process was processed in R program. The script for data analysis is attached in Appendix F.

Table 3 Models made to explain the total number of catches

<table>
<thead>
<tr>
<th>Model</th>
<th>Offset expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1</td>
<td><code>offset(log(waterway)) + (Conibear + Duikerafzetting + Lokaasklem + lokaaskooi + Schijnduiker + year + his.catch + 0) * season</code></td>
</tr>
<tr>
<td>A.2</td>
<td><code>offset(log(waterway)) + (Conibear + Duikerafzetting + Lokaasklem + lokaaskooi + Schijnduiker)*season + year + his.catch + 0</code></td>
</tr>
<tr>
<td>A.3</td>
<td><code>offset(log(waterway)) + Conibear + Duikerafzetting + Lokaasklem + lokaaskooi + Schijnduiker + season + year + his.catch + 0</code></td>
</tr>
<tr>
<td>A.4</td>
<td><code>offset(log(waterway)) + (Conibear + Duikerafzetting + Lokaasklem + lokaaskooi + Schijnduiker)*BlokCode + year + his.catch + 0</code></td>
</tr>
<tr>
<td>B.1</td>
<td><code>offset(log(waterway)) + (klemmen + kooien + fuiken + year + his.catch + 0) * season</code></td>
</tr>
<tr>
<td>C.1</td>
<td><code>offset(log(waterway)) + (Active + Passive + year + his.catch + 0) * season</code></td>
</tr>
<tr>
<td>N</td>
<td><code>offset(log(waterway)) + season + year + his.catch + 0</code></td>
</tr>
</tbody>
</table>

Cost efficiency

The cost efficiency was evaluated by comparing cost against time between all trap types. Further, the cost was compared with catch results to search for traps that have high catch ability and low cost.

**Total Cost**

In the study, the cost spent on catching muskrats using different traps was defined as a combination of trap cost ($C_p$) and field cost ($C_f$). Trap cost was defined as one-time monetary cost for a certain trap. In the field, Fykes are made by the trappers using metal net, as they need to fit in culverts with specific diameters. Some floating cages are also made by trappers. In water board Zuiderzeeland, Schijnduiker, duikerafzetting and slootafzetting met kooi are hand-made by trappers. Other traps are purchased. As a result, for traps need to be made, the trap cost was estimated by time for making the trap ($T_m$) and average hourly wage of a professional trapper ($W_h$) (Eq.1). For traps that are purchased, trap cost referred to the average price of a single trap.

\[
C_p = T_m \times W_h \quad eq. 1
\]
The field cost was defined as the cost to regularly check the trap in the field. As trappers decide to use specific type of trap in the field only after they identify the trace of muskrats or entrances of a burrow, working time spent on finding suitable places to set traps can not be allocated to different trap types. Consequently, the field time cost on different traps only included the time used to find an existed trap, remove the body, replace baits and reset the trap. The frequency of checking a certain trap was also taken into consideration. As a result, an estimation of the field cost for one trap type was made based on checking frequency ($F$), checking time ($T$), hourly wage ($W_h$) and time ($t$) (Eq.2).

$$C_f = F \times T \times W_h \times t \quad eq. 2$$

The total cost ($C_t$) can be expressed as the sum of trap cost and field cost (Eq.3).

$$C_t = C_p + C_f \quad eq. 3$$

For each type of the trap, the total cost was estimated and compared against time. All the details of working hours and checking frequency were derived from the result sheet containing all answers from the responses of the questionnaire. The answers to the questions were averaged to make estimation of the cost. And the overall responses for each questions were given. The price of traps and average hourly wage were provided by staff from Waterschap Zuiderzeeland.

Cost vs. Catch

To compare the cost of different trap type and the catch ability, the catch data from last three years and estimates of cost during this period were used. The catch number using different traps in an atlas block within the study period was expressed by the cost estimates in a linear model. The catch data will be aggregated by different atlas blocks and different trap types. For each block, the number of different types of traps set in the field was estimated using average number derived from three example days. And the cost was calculated based on the total time interval as well as number of different traps. As the trap cost is minor, only field cost was taken into account. Therefore, the intercept of the linear model was set to 0. The trap with highest catch-cost ratio (coefficient estimates) can be considered to be most cost-efficient.
Target specificity
To evaluate the target specificity for different traps, by-catch rate was used, which refers to ratio between number of non-target animal caught and the number of muskrat caught within a time period. However, the social acceptance of by-catch species in muskrat trapping varies. According to a survey made by LCCM, the degree of social acceptance for different by-catch species in muskrat control processes is scaled from 0.25 (no acceptance) to 1 (full acceptance) (Klop et al., 2011). This result was used as a reference when comparing by-catch rate among trap types. The capture of endangered or less accepted by-catch species was considered less target-specific than capture of commonly accepted ones. Also, the selectivity of different traps was also compared by looking into the contribution each trap type made to a specific non-target species. Some species were only caught by certain trap types.

In the study area, the by-catch species includes American mink, brown rat, common toad, Eurasian coot, mole, northern pike, European water vole and tench. Among these species, tench is the least acceptable, followed by northern pike. The acceptances of other species are above average. The brown rat and European water vole are widely accepted, among which the brown rat is considered as a desirable by-catch species and will be killed if caught alive in a trap (Klop et al., 2011).

Field Experiment
In the field experiment, it is considered that the whole population of muskrat in this ditch were eradicated after the placement of Conibears. As the scale of field experiment is limited, the results were analyzed by simulating catch result in R program. The same experiment was simulated 1000 times with a catch probability from catch result of field experiment. For both of the passive trap type, same times, size catch and probability were used. The difference of catch result from the simulation experiment was compared with the difference in catch result of two passive trap types in the field experiment. As a result, the probability of having the difference found in field experiment can be calculated.
Results

Assumption check

To evaluate the assumption of dynamic equilibrium about the number of traps set in an atlas block, the number of traps set in the field is determined for three dates approximately 1 month apart (henceforth called ‘example days’). Furthermore, the number of newly set traps and the catch made by different trap types in each year were examined. As the number of Levend vangende kooi, Klemmenrekje and Slootafzetting met kooi in example days is considered too small, only 5 trap types are discussed.

Among the three example days, the number of Conibear traps, Duikerafzettingen and Lokaasklemmen show statistical significant difference in the same atlas block according to Friedman test (p-value: 0.92%, 0.15%, 8.0e-4%). Number of other types of traps are not significantly different. Figure 2 shows the number of Conibear in each atlas block in three example days. In most atlas blocks, number of Conibears remains unchanged or changes slightly. However, in some blocks the number changed a lot between these days.

![Figure 2 Number of Conibear traps in the field in three example days](image-url)
However, these example days are only taken from the year of 2017. Table 4 shows the number of traps first set in the study area among the years, where deleted trap, temporarily removed traps and traps in the field are all taken into account. The current trap number in the field (average of example days) is also listed for comparison. The number of newly set Conibear traps is approximately 2.5 times larger in 2017 than in 2016. The number of newly set Duikerafzetting is similar in the year 2014 to 2016, and goes up to 40 in the year of 2017. The number of newly set Lokaasklem traps is decreasing over the years. And the number of Lokaaskooi first set in these years is relatively similar. The current numbers of these four types of trap in the field are all smaller than the number of traps first set every year meaning frequent remove of these traps. It is obvious that once set in the field, Schijnduiker would be remained in the field and only few of them were once removed. As the number of Schijnduiker raised similar to current state before the end of the year 2014. The total number of Schijnduiker set in the field can be believed relatively unchanged within the study period.

<table>
<thead>
<tr>
<th>Trap Type</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conibear</td>
<td>292</td>
<td>878</td>
<td>570</td>
<td>947</td>
<td>2653</td>
<td>119</td>
</tr>
<tr>
<td>Duikerafzetting</td>
<td>1</td>
<td>12</td>
<td>11</td>
<td>15</td>
<td>40</td>
<td>9</td>
</tr>
<tr>
<td>Lokaasklem</td>
<td>28</td>
<td>159</td>
<td>89</td>
<td>73</td>
<td>48</td>
<td>19</td>
</tr>
<tr>
<td>Lokaaskooi</td>
<td>13</td>
<td>49</td>
<td>21</td>
<td>22</td>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>Schijnduiker</td>
<td>369</td>
<td>258</td>
<td>192</td>
<td>56</td>
<td>31</td>
<td>631</td>
</tr>
</tbody>
</table>

Table 5 shows the catch number made by different trap type each year in the study period. In the year 2017, Conibear caught 886 muskrats in total which is twice as much as the catch in the year 2016 and almost three times as the year of 2014 and 2015. The number of catch made by Duikerafzetting is relatively the same in first three years and increased largely in 2017. Catches made by Lokaasklem is decreasing over the years, which may indicate change of Lokaasklem use strategy. The catches made by Lokaaskooi and Schijnduiker are relatively similar each year.
Table 5 Number of catch made by different types of trap in the study area in past 4 years

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conibear</td>
<td>298</td>
<td>248</td>
<td>421</td>
<td>886</td>
</tr>
<tr>
<td>Duikerafzetting</td>
<td>23</td>
<td>26</td>
<td>26</td>
<td>64</td>
</tr>
<tr>
<td>Lokaasklem</td>
<td>96</td>
<td>69</td>
<td>37</td>
<td>16</td>
</tr>
<tr>
<td>Lokaaskooi</td>
<td>39</td>
<td>16</td>
<td>26</td>
<td>34</td>
</tr>
<tr>
<td>Schijnduiker</td>
<td>186</td>
<td>192</td>
<td>254</td>
<td>243</td>
</tr>
</tbody>
</table>

Catch efficiency

The field data starts from 03/06/2013. During the first year, 707 traps were set in the study area and no trapping was registered. The detailed muskrat trapping records in this area started from the following year 2014. All field data used in the analysis were updated until 25/12/2017. The catch data for the period 14/01/2014 till 21/12/2017 are included in this study. During this period, 3314 muskrats were caught. Most of the muskrats were captured by Conibear trap (1853 catches), followed by Schijnduiker (875 catches).

Several models were created to look into the relationship between the number of different traps, season, year and historical catch number. All models created were listed in Table 6 by the ranking of their AICc values. Among these models, the interaction between season and other variables is the best model supported by the data with lowest AICc value (9283.4), which shows catch efficiencies of traps vary between different seasons. None of the interactions of trap densities and atlas blocks is significant in Model A.4 suggesting no spatial preference of trap efficiency on scale of atlas blocks.

Table 6 Ranking of models created according to AICc values (K: number of free parameters in the model; AICc: corrected Akaike information criterion for small sample sizes; ΔAICc: difference between AICc of the model and the best model; AICc Wt: Akaike weight)

<table>
<thead>
<tr>
<th>Name</th>
<th>K</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>AICc Wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A.1</td>
<td>40</td>
<td>9283.4</td>
<td>0.0</td>
<td>0.999</td>
</tr>
<tr>
<td>Model B.1</td>
<td>32</td>
<td>9296.5</td>
<td>13.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Model A.4</td>
<td>31</td>
<td>9301.1</td>
<td>19.1</td>
<td>0.000</td>
</tr>
<tr>
<td>Model A.2</td>
<td>28</td>
<td>9367.6</td>
<td>84.2</td>
<td>0.000</td>
</tr>
<tr>
<td>Model C.1</td>
<td>28</td>
<td>9524.0</td>
<td>240.6</td>
<td>0.000</td>
</tr>
<tr>
<td>Model A.3</td>
<td>13</td>
<td>9594.6</td>
<td>311.2</td>
<td>0.000</td>
</tr>
<tr>
<td>Model N</td>
<td>8</td>
<td>11313.1</td>
<td>2029.7</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Figure 3 shows the relationship between observed relative catch and the predicted catch in each atlas block. The red dash line represents an ideal situation where observed values and predicted values perfectly match. The scatter points of catch and predict from the best model seem loosely distributed around the line with all atlas block having predicted values on both side of the line.

![Figure 3 scatter plot of observed and predicted catch number](image)

Cross validation was conducted to evaluate the stability of the best model. The best model was created 27 times in each of which data omitting an atlas block was used as training group and data from omitted atlas block as test group. The predicted catch numbers for Block 2131 are extremely higher than the observed catch numbers, having maximum predicted value of 1137140 catches. All predicted values larger than the maximum of observed catch in one unit are in this atlas block. Figure 4 shows the relationship between observed and predicted relative catch (catch number/km of waterway). 16 predicted values whose predicted relative catch are higher than 5 muskrats/km of waterway are removed for better comparison. The red dash line represents the ideal situation where predicted catch equals to observed catch number. Extreme predicted values are mostly present in test group.
block 2131, whereas in block 2054, large catch numbers can be hard to predict for the model. Figure 5 shows the mean squared error (MSE) among different test groups in which block 2131 has been removed as it is extremely higher than the others ($2.51e+10$). The MSE of block 2054, 2055 and 2046 are higher than the rest.

Figure 4 scatter plot of observed and predicted catch number

Figure 5 MSE of cross validation results of each test group of different atlas block
The coefficient of different variables varies among models created by different training group. The model can be considered more stable if the variation of these coefficient estimate is small. Figure 6 shows the coefficient differences between models from cross validation and the best model. The coefficient estimates for Duikerafzetting and its interaction with seasons vary dramatically between models using different training groups. The coefficient estimates for Lokaaskooi and Lokaasklem and their interactions with seasons also vary between models.

Fig 6 boxplots of the coefficient differences for each variable

To make clearer comparison of coefficient estimates, the data are discussed separately in different seasons. Three models are made to compare catch efficiency in three scales. The response variable is the capture number in an atlas block within four weeks. The length of waterway is used as offset in the model. The predictor variables are trap densities (number of traps in the field per trap type per length of waterway), year of catch and corresponding catch number per length of waterway in the last year. For data from 2014, the historical catch is set to be 0. The data are separated by different seasons. Each season has a model fit. Following is showed the formula of the regression model using five trap types:
\[
\log \left( \frac{\text{catch number}}{\text{length of waterway}} \right) = C_0 + C_1 \times \frac{\text{Conibear}}{\text{length of waterway}} + C_2 \times \frac{\text{Duikerafzetting}}{\text{length of waterway}} + C_3 \\
\quad \times \frac{\text{Lokaasklem}}{\text{length of waterway}} + C_4 \times \frac{\text{lokaaskooi}}{\text{length of waterway}} + C_5 \\
\quad \times \frac{\text{Schijnduiker}}{\text{length of waterway}} + C_6 \times \text{year} + C_7 \times \text{his.catch} \quad \text{eq. 4}
\]

Table 7 lists all coefficient estimates for different variables derived from models of four seasons. All the significant values are filled in grey. The positive values are listed in bold. These coefficient estimates represent the contribution of setting one more trap in the field to the total catch in that atlas block. Hence, a higher coefficient estimate for a trap type represents a higher catch efficiency.

Overall, most of the variables in the models are significant, for comparison reasons, the insignificant ones were retained in the model. Every trap-type variable has at least one significant interaction with a season. In different seasons, traps perform differently in contribution to muskrat catch, which is expressed by the different coefficient estimates per season in Table 3. Most of the estimated coefficients are positive, as the increase of trap number will in principle only positively influence the total number of catch. However, in some seasons, the coefficient estimates for Lokaasklem and Lokaaskooi are negative, which may lead to lower attentions.

Duikerafzetting, Conibear and Schijnduiker positively influence the overall catch result over four seasons. In general, Duikerafzetting highly contributes to the total catch number throughout the year with the highest coefficient estimates of four season among all traps. It performs the best in the autumn followed by summer and winter (coefficient estimates: 49.19, 22.93, 22.45). Conibear traps have relatively similar values for coefficients of different seasons, within which autumn has the highest value (3.21). The coefficient estimates of Schijnduiker are also similar among seasons with lowest value of 0.96 in.
winter. Trap density of Lokaasklem only significantly contribute to catch result in autumn with a coefficient estimates of 9.94. Lokaaskooi does the best in spring with a coefficient of 18.51 and has negative values in summer and autumn.

In spring, Lokaaskooi and Duikerafzetting work most efficiently, followed by Conibear and Schijnduiker. The catch results depend largely on Duikerafzetting in summer, having approximately 10 times of coefficient estimate than Conibear’s. In autumn, Duikerafzetting, Lokaasklem and Conibear are the most efficient. In winter, Duikerafzetting and Lokaasklem have higher ability of capturing muskrats.

Expect from variables of number of traps, season, year and the historical catch also affect the trapping results. The intercepts for different seasons vary slightly with highest value in winter and lowest in autumn. The catch results from the first three years are relatively similar. However, the catch results from the year 2017 are significantly higher from the other years. The historical catch only significantly contributes to catch result in winter. Although these variables do have significant influences on the final catch result, their contributions seem not that large compared to the contributions of trap numbers.

Table 7 Coefficient estimates from models of five specific trap types

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>All year</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-4.54</td>
<td>-4.89</td>
<td>-4.93</td>
<td>-4.48</td>
<td>-4.66</td>
</tr>
<tr>
<td>Conibear</td>
<td>2.50</td>
<td>2.53</td>
<td>3.21</td>
<td>2.56</td>
<td>2.97</td>
</tr>
<tr>
<td>Duikerafzetting</td>
<td>14.92</td>
<td>22.93</td>
<td>49.19</td>
<td>22.45</td>
<td>18.91</td>
</tr>
<tr>
<td>Lokaasklem</td>
<td>-5.45</td>
<td>1.53</td>
<td>9.94</td>
<td>-0.05</td>
<td>1.91</td>
</tr>
<tr>
<td>Lokaaskooi</td>
<td>18.51</td>
<td>-7.96</td>
<td>-10.93</td>
<td>15.46</td>
<td>11.20</td>
</tr>
<tr>
<td>Schijnduiker</td>
<td>1.43</td>
<td>1.64</td>
<td>1.18</td>
<td>0.96</td>
<td>1.18</td>
</tr>
<tr>
<td>year2015</td>
<td>-0.34</td>
<td>-0.69</td>
<td>-0.06</td>
<td>-0.03</td>
<td>-0.21</td>
</tr>
<tr>
<td>year2016</td>
<td>0.34</td>
<td>0.23</td>
<td>0.00</td>
<td>0.07</td>
<td>0.16</td>
</tr>
<tr>
<td>year2017</td>
<td>0.67</td>
<td>0.28</td>
<td>0.36</td>
<td>0.75</td>
<td>0.61</td>
</tr>
<tr>
<td>his.catch</td>
<td>0.63</td>
<td>0.22</td>
<td>-0.11</td>
<td>2.27</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Same model is made for all traps sorted by active or passive and by general types. Among trap types that ever caught a muskrat, Conibear and Grondklem are active traps and others are sorted into passive traps. As shown in Table 8, active trap is more catch-efficient in
general. However, in spring, passive traps work better than active traps. In winter, the catch ability between active and passive traps are similar. Active traps contribute most largely in autumn.

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>All year</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-4.94</td>
<td>-4.78</td>
<td>-4.75</td>
<td>-4.83</td>
<td>-4.88</td>
</tr>
<tr>
<td>Active</td>
<td>1.61</td>
<td>2.63</td>
<td>4.83</td>
<td>2.56</td>
<td>3.16</td>
</tr>
<tr>
<td>Passive</td>
<td>3.33</td>
<td>1.41</td>
<td>1.08</td>
<td>2.75</td>
<td>2.38</td>
</tr>
<tr>
<td>year2015</td>
<td>-0.34</td>
<td>-0.69</td>
<td>-0.06</td>
<td>-0.02</td>
<td>-0.21</td>
</tr>
<tr>
<td>year2016</td>
<td>0.34</td>
<td>0.23</td>
<td>0.01</td>
<td>0.08</td>
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<tr>
<td>year2017</td>
<td>0.67</td>
<td>0.28</td>
<td>0.37</td>
<td>0.76</td>
<td>0.61</td>
</tr>
<tr>
<td>his.catch</td>
<td>0.75</td>
<td>0.25</td>
<td>-0.15</td>
<td>2.00</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Conibear, Lokaasklem, Klemmenrekje and Grondklem are body-grip traps. Cages include Lokaaskooi, Slootafzetting met kooi and Levend vangende kooi. Schijnduiker and Duikerafzetting are Fykes. In general, body-grip traps work efficiently throughout the year, especially in autumn (Table 9). Fykes are more efficient in spring and summer. Cages contribute the most in spring and winter, having coefficient estimates of 17.21 and 17.88. However, cages contribute insignificantly to total catch result in summer and autumn.

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>All year</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-4.58</td>
<td>-4.87</td>
<td>-4.81</td>
<td>-4.46</td>
<td>-4.65</td>
</tr>
<tr>
<td>Body-grip trap</td>
<td>1.60</td>
<td>2.47</td>
<td>4.29</td>
<td>2.26</td>
<td>2.85</td>
</tr>
<tr>
<td>Cage</td>
<td>17.21</td>
<td>-2.77</td>
<td>-0.68</td>
<td>17.88</td>
<td>12.78</td>
</tr>
<tr>
<td>Fyke</td>
<td>1.77</td>
<td>1.81</td>
<td>1.34</td>
<td>1.14</td>
<td>1.36</td>
</tr>
<tr>
<td>year2015</td>
<td>-0.35</td>
<td>-0.69</td>
<td>-0.05</td>
<td>-0.02</td>
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</tr>
<tr>
<td>year2016</td>
<td>0.33</td>
<td>0.23</td>
<td>0.01</td>
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<tr>
<td>year2017</td>
<td>0.64</td>
<td>0.28</td>
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<tr>
<td>his.catch</td>
<td>1.06</td>
<td>0.24</td>
<td>-0.17</td>
<td>2.09</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**Cost efficiency**

Cost efficiency is considered as an evaluation of the estimate cost for each trap type and their relationship with catch ability. The cost is estimated by the results of a questionnaire, wage of professional trappers and the cost for traps.
The questionnaire is sent out to professional trappers by email with a Google form link in 2018/01/08. Until 2018/02/26, 35 valid responses are collected. An overview of the response sheet is given in Appendix E. Among all responses, average services time of a trapper is 15.8 year, 3 trappers only worked as a professional trapper for a year and most experienced trapper has worked for 43 years. Most of the trappers have been working in this catchment area for less than 5 years with an average of 6.8 years (Fig. 7). Only 4 out of 35 trappers make traps themselves. In average, it takes trappers approximately 2 hours to make a Schijnduiker. For Duikerafzetting, the making time relates largely to the size of the trap with an average of 2.27 hours. According to trappers, it usually takes around 3.19 hours to make a Slootafzetting met kooi (Fig. 8).

Trappers can choose the frequency of checking a set trap in the field between 4 to 5 times per week or more, 2 to 3 times per week, once a week, once every two weeks, once every three weeks or less and dose not apply. For estimation reasons, the frequency will be interpreted into times per week (see Fig. 9). Over 3/4 of trappers check Schijnduiker once per three weeks or less. Most of Postklem are checked once every two weeks or once a week (20/29). Most of trappers check Duikerafzetting and Slootafzetting met kooi once a week (16/24, 13/28). Klemmenrekje are usually checked between 1 to 3 times per week (13/21). Conibears, Lokaasklem, Grondklem are usually checked 2 to 3 times per week and 4 to 5 times per week (30/39, 11/14, 15/19). The checking frequencies for Lokaaskooi
varies between different trappers, which is relatively evenly distributed. All the trappers check levend vangende kooi 4 to 5 times a week or more following animal welfare rules. Overall, the checking frequency depends largely on situations such as population of the muskrats and weather condition for baits. Also the traps are usually checked more frequently in first several days of placement.

Figure 9 overall responses for checking frequency of different trap types

The time took to check a certain trap stays similar between trap types (Fig. 10). It usually takes less than 10 minutes for trappers to find a trap, remove the body, replace baits and reset the trap. For Levend vangende kooi, trappers need to kill muskrats first, which often takes a bit more time. In most of cases the checking time depends on the accessibility of the trap in the field.
In Question 6, the professional trappers were asked to estimate catch probability for different trap types. The result shows that Conibear is considered to have highest catch probability among all traps (an average of 70.3%) (Fig. 11). The catch probability of Grondklem is also believed quite high (60% in average). The probabilities of capture are considered relatively similar among rest of the traps, with Schijnduiker being the lowest. According to trappers, the catch result relates largely on population of muskrat near the spot. For passive traps, catch ability varies from different weather conditions and time periods. For Conibear, most of the trappers may consider the catch probability of catching muskrat by group.
Figure 11 overall responses for catch probability of different trap types

Table 10 lists the parameter values used to estimate the total cost for each trap type. Time for making a trap, check frequency and time used per check is the average value derived from responses of the questionnaire.

Table 10 Parameter values for total cost estimates mean and standard deviation

<table>
<thead>
<tr>
<th>Trap type</th>
<th>Time for making a trap (Tm) (hour)</th>
<th>Price for one trap (P) (Euro)</th>
<th>Check frequency (F) (per week)</th>
<th>Time per check (T) (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Schijnduiker</td>
<td>2.04 (1.50)</td>
<td></td>
<td>0.56 (0.62)</td>
<td>12.27 (4.82)</td>
</tr>
<tr>
<td>Duikerafzetting</td>
<td>2.27 (1.46)</td>
<td></td>
<td>1.26 (0.98)</td>
<td>11.98 (4.08)</td>
</tr>
<tr>
<td>Conibear</td>
<td>10</td>
<td>2.77 (1.34)</td>
<td>12.88 (5.23)</td>
<td></td>
</tr>
<tr>
<td>Lokaasklem</td>
<td>100</td>
<td>2.71 (1.38)</td>
<td>12.5 (4.52)</td>
<td></td>
</tr>
<tr>
<td>Klemmenrekje</td>
<td>NA</td>
<td>1.95 (1.41)</td>
<td>11.43 (4.13)</td>
<td></td>
</tr>
<tr>
<td>Grondklem</td>
<td>25</td>
<td>2.68 (1.41)</td>
<td>13.13 (5.43)</td>
<td></td>
</tr>
<tr>
<td>Postklem</td>
<td>NA</td>
<td>0.83 (0.65)</td>
<td>12.88 (4.45)</td>
<td></td>
</tr>
<tr>
<td>Lokaaskooi</td>
<td>144</td>
<td>1.72 (1.59)</td>
<td>11.7 (3.57)</td>
<td></td>
</tr>
</tbody>
</table>
Table:

<table>
<thead>
<tr>
<th>Trap Type</th>
<th>Checking Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slootafzetting met kooi</td>
<td>3.19</td>
<td>1.89</td>
</tr>
<tr>
<td>Levend vangende kooi</td>
<td>90</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 12 shows the estimated total cost for a single trap through time. Overall the influence of trap cost on the total cost estimate is relatively small. The total cost depends largely on the checking cost. The use of Levend vangende kooi cost the most among the 10 trap types used in the study area. The cost estimates for Conibear, Grondklem and Lokaasklem are similar with relatively high cost over time. Schinduiker cost the least among these trap types, whose cost estimate is around 8 times less than the cost of Levend vangende kooi after 200 weeks.

Figure 12 Total cost estimate for different trap type through time (for one trap)

Figure 13 shows the relationship between catch number a certain trap type made during the study period and corresponding cost estimate. The cost is estimated based on the checking cost for a single trap, number of trap per atlas block derived from three example days and the total trap weeks. As some trap types are seldom used, only 5 trap types that used most
often are discussed here. For each trap type, the catch number is considered a function of the cost. The points who have catches with no trap number are removed from the graph. Lines are estimated with intercept being zero, consequently the slopes represent the ratio of catch result and estimated cost. Trap with higher catch and cost ratio can be considered more cost-efficient. Different colors are used for different trap type in the graph and the grey area represent 95% confidence interval. As shown in graph, the Duikerafzetting has the highest catch and cost ratio. The rest of the trap types have similar ratios among which the ratios of Conibear and Lokaasklem are higher than the ratios of Schijnduiker and Lokaaskooi. The points for Conibear are widely spread in the graph resulting a wider confidence interval.

Figure 13 Relationship between catch number and cost estimate

Figure 14A shows the relationship between catch number and cost estimate by different general types. The catch numbers in different atlas block and corresponding cost estimate are aggregated into three general types. The body-grip trap has the highest slope among three, followed by Fyke and cage. However, the confidence interval for body-grip trap is
wide suggesting the result to be less certain. Looking into active or passive traps, the ratios of catch and cost are similar with active trap having wider confidence interval (Fig. 14B).

Figure 14 Relationship between catch and cost by general type(A) and active or passive trap(B)

Target specificity

In this section, the by-catch data used is downloaded in 2017/12/25, which contains all the by-catches made by the traps in the field at that day (referring to traps set in the field and temporarily removed from the field). And the catch records used to calculate by-catch rate are catches once made by these traps. Among 108 recorded by-catches, approximately 51% of the animals were European water voles (*Arvicola amphibius*), and 40% of them were brown rats (*Rattus norvegicus*). Others non-target animals include American mink (*Neovison vison*), common toad (*Bufo bufo*), Eurasian coot (*Fulica atra*), mole (*Talpa europaea*), northern pike (*Esox lucius*) and tench (*Tinca tinca*) (1%, 1%, 1%, 1%, 1.9%, 3.7%, respectively). However, as the by-catch data is deleted from time to time, the by-catch data downloaded from the dataset does not represent the whole picture of captures of non-target animals.

All the non-target animals are caught by Schijnduiker, Duikerafzetting, Conibear and Lokaasklem, among which Schijnduiker made the most by-catches (98 out of 108). Figure 15 shows the by-catch rate of different trap types. Although Schijnduiker caught the most
non-target animals, its by-catch rate (non-target species / muskrat catches) is lower than Lokaasklem and similar as the by-catch rate of Duikerafzetting. The by-catch rate of Conibear is the lowest among these four trap types. Considering the social acceptance of these animals, all the non-target animals caught by Duikerafzetting are below the average social acceptance from the survey of LCCM (Klop et al., 2011), indicating lower target specificity.

Figure 15 By-catch rate of different trap types.

Different trap types show selective trends on by-catch species according to their setting environment. Schijnduiker caught the most various of species, including small mammals, toad and waterfowl. All fish is caught by Duikerafzetting. And mink is only caught by Conibear.

Field experiment

The field experiment was held near Lepelaarsplassen between 08/11/2017 and 06/12/2017. In 08/11/2017, ten Lokaaskooi and ten Lokaasklem were set in pairs in the field. In 29/11/2017, passive traps were removed and 12 Conibears were set in the field. During this
period, in total 10 muskrats were captured, of which 5 were caught by Lokaaskooi, 4 were caught by conibear and 1 were caught by Lokaasklem. No non-target animal was caught during the field experiment.

It is assumed that the captured 10 muskrats were the whole population of muskrats living in this ditch. In the first phase of the experiment, Lokaaskooi caught 5 muskrats out of 10 and Lokaasklem caught 1 muskrat out of 10. Adding the catches and escaped muskrats separately, the average catch probability is 0.3. The same experiment of catching 10 muskrats with catch probability of 0.3 was simulated 1000 times separately for both trap types in R. In most of simulated experiments, both traps captured 2 to 4 muskrats (Fig. 16). 28 out of 1000 experiments had a difference of catch number from two trap types which is larger than 4 as happened in the field experiment. As a result, the probability of conducting same experiment with same catch probability with difference of catch result larger than 4 is 2.8%, which is statistically significant. Consequently, the catch probabilities of Lokaaskooi is significantly larger than Lokaasklem. Also, as it is assumed that Conibear traps eradicate muskrats in the end, the catch proportion of Conibear would be 100% while the catch proportion of passive traps being 60%. Therefore, the catch ability of Conibear is considered higher than passive traps.

![Figure 16 histogram of catch number from simulated experiments of two trap types](image_url)
Discussion

It is shown that the number of some trap types in the field does relatively change over time. For the trap types which are used fewer in the field, small changes of trap numbers may cause significantly difference of field numbers among example days. Also, as the numbers are only taken in 3 out of approximately 48 months, the result from Friedman test is not comprehensive enough for the assumption. The number of newly set Conibear traps and catches made by Conibears are much higher in the year 2017 than in other years. This may suggest that the usage of Conibear traps is more frequent and wider in this year than previous years. If so, the estimate for number of Conibear in the field using example days may lead to underestimate of catch efficiency in the first three years and inaccuracy of estimates in the year 2017.

For working efficiency, it is unavoidable to consider the input or cost of catching muskrats, which in most previous studies is expressed as total trap night or estimated cost (Garden, McAlpine, Jones, & Possingham, 2007; Gross, 2015; Warburton, 1982; Warburton & Gormley, 2015; Weihong et al., 1999). However, this information is not collected in the data system and can only be estimated. As a result, assumptions must be made to estimate the input. Although the assumption in this study may not solid enough, it can be seen sufficient for the study. The assumption may further be confirmed if the sample size could be larger and the example days could vary wider. Although for the data we used, it could be hard, as the number of trap in the field in the past would never be known.

The overall model fit of the best model for catch efficiency is poor according to the scatter plot of observed and predicted relative catches. This may because that the predictor variables used can only explain part of the catch results. There may be other factors influencing the catch number. On the other hand, the trap densities we used were estimated and not accurate enough to fully predict relative catches. The result from cross validation shows that the model coefficients, especially Duikeraffzetting, lokaaskooi and lokaasklem and their interaction with seasons, vary among models made by different training groups. The instability of the model with respect to these variables is partially due to the fact that
the number of these trap types is relatively small compared to the other trap types, as a result, small change of trap number may lead to large coefficient estimate change. The goodness of fit from cross validation also varies for different test groups. In particular, some of predicted values for the block 2131 are extremely larger than their real values causing extremely high MSE values. This can be explained by the fact that the density of Conibear in this block is approximately 4 times higher than the second largest one. As the data for this block is excluded in the training group, it is reasonable to predict higher values when there is higher input. The model does not manage to predict relatively high catches in block 2045 and 2055. Both blocks have extremely high total catches in the period 3 and 4 in the year 2017. In total 269 and 194 muskrats were caught in block 2045 and 2055 in these two periods in 2017, within which 238 and 177 were caught by Conibear. As the representative numbers of Conibear from example days for these blocks are both less than 10, the numbers were certainly underestimated. This may be because the trap densities were way larger in this short period in these two blocks and consequently caught 10 times muskrats more than usual numbers. As a result, it is understandable that the model is not able to predict these values. These findings suggest there are still potential instability in the current model.

The best model consists of 5 most used trap densities, season, year and historical relative catch. Overall, most of the coefficient estimates of trap densities in the model have reasonable values above zero. However, the coefficients for Lokaaskooi in summer and autumn are negative and are statistically significant. The potential reason for the negative values may due to unrepresentative values for variable Lokaaskooi, which lead to instability of the model. According to their coefficient estimates, Duikerafzetting makes the most contribution to the total catch number, followed by Conibear, and the Schijnduiker makes the least in general. However, from the questionnaire, the professional trappers believe that Conibear trap has the highest catch probability among all traps, and other traps have similar catch probabilities. This may because that several Conibear traps are usually placed in groups at one location of a burrow in the field. In the questionnaire, several trappers mentioned that the performance of Conibear traps is usually considered in such groups consequently leading to higher catch probability estimate. In data analysis, the
variable Conibear is the number of every single Conibear traps per block per length of waterway. As a group of Conibear are checked in the same time, it is more reasonable to consider these traps as one. The field experiment suggested that the catch ability of Lokaaskooi is significantly higher than Lokaasklem which is inconsistent with the result from data analysis. This may because that both variables of trap densities are not that representative. The coefficient estimates of both traps have some unreasonable negative values. And therefore the results of these traps may not be solid enough. On the other hand, the result from field experiment only came from a one-time experiment. Although, the result from field experiment is statically significant, it may be still not representative enough to claim the Lokaaskooi has higher catch ability in all seasons within four years.

The best model shows that catch efficiency varies among different seasons for different trap types. This is partly consistent with previous studies that suggest muskrat behavior, population and catch rate differ from seasons (Clark & Kroeker, 1993; Bos et al., 2016; Errington, 1954; MacArthur, 1980; van Hemert & Bos, 2016), and consequently the working efficiency of trap type changes as they are placed in different scenarios. Muskrat usually migrate and move more frequently in spring and autumn. The home range of muskrat is relatively small (Willner, Feldhamer, Zueker, & Chapman, 1980). Experiments conducted in the Netherlands showed that muskrats usually have a home range around 500 meters, sometimes up till approximately 1.5km (Haye et al., 2016), which is smaller than the scale of an atlas block. Therefore, it is assumed that catch efficiency fluctuation influenced by migration behavior occur within atlas blocks and the increase in catch efficiency caused by increasing movement in migration seasons have no spatial differences. Yet the result from best model does not show a clear pattern of variation of catch efficiency in these seasons. Some passive traps have higher catch efficiency than active trap in migration seasons. The catch efficiency between two migration season also changes a lot, trap show high catch efficiency in spring can have low efficiency in autumn. The increase of catch efficiency of passive traps can probably be explained by the fact that they are checked more frequently during migration seasons according to the questionnaire. The trap density especially for passive traps is expected to be higher in these busy seasons. As the trap number is mostly derived from winter, catch efficiency can be overestimated in
migration seasons. However, the reason for different efficiency pattern between spring and autumn has not been found yet.

Among all traps, the levend vangende kooi cost the most through time as it needs to be checked every day. The total cost estimate of different trap types mainly depends on the checking frequency. And the trap cost only influences the total cost estimate in the first 30 weeks. The evaluation of cost and catch relationships shows that the catch and cost ratios are relatively similar among different trap types. Duikerafzetting is the only trap whose catch and cost ratio is much higher than the rest trap types, as it catches muskrats with low checking frequency. The result that the cost efficiency between different traps have relatively similar cost efficiency is beyond our expectation. As in empirical knowledge, it is widely believed that active traps work more efficient than passive traps. Whereas according to the result, the cost for same muskrat catch would be similar when choosing between active and passive traps. However, the cost for Conibear was estimated based on the number of single Conibear traps rather than number of Conibear groups. Since most of active traps used are Conibear traps, the ratio of active traps may be underestimated.

The result from target specificity shows that Schijnduiker caught the most non-target animals. Yet Duikerafzetting might be most dangerous trap type for non-target animals as it catches one non-target animals every ten captures in average. And all the non-target animals it caught are less acceptable by social public. The trap types show selectivity between by-catch species. These findings are consistent with a report by LCCM in the year 2011 indicating Schijnduiker and Duikerafzetting catches the most non-target animals. According to the report, Duikerafzetting catches large amount of fish, whereas Lokaasklem catches most of the birds and mammals (Klop et al., 2011), which is reasonable as trap types have particular setting situation leading to the particular groups of by-catch species. As explained in the method part, the by-catch data used does not include all by-catch records. Therefore, the number of non-target animals can be underestimated in the area. For example, active traps such as Conibear are usually removed and deleted when catch probability declines. The by-catches made by these traps are consequently deleted. Also, as the selectivity of by-catch species varies between trap types, the percentage of catch
number of certain species are also inaccurate. The ratio of all non-target animals and muskrats can be compared between different trap types.

The study offers an evaluation of trap efficiency which can provide scientific support to empirical knowledge and also work as a reference when developing trapping strategy both in large scale and in a trapper’s perspective. Applications of the study are not limited to Friesland, but can also be informative for other areas with similar environment and use same trapping devices. The criteria to evaluate the trap efficiency in this study is mainly based on the aim of catching muskrats. However, some of the trap types have other functions. For example, the levend vangende kooi was used to catch muskrats alive allowing trappers to mark them to monitor the population size and their activities in previous research (Haye et al., 2016). The Duikerafzetting can help find out the movement direction of muskrats as it has entrances on both sides of trap and consequently help adjust trapping strategies. These functions are also indispensable when evaluating a trap.

The result this study provided is informative but limited. Similar research can be conducted using different dataset and the result can be compared with the findings we have. In future studies, the model of catch efficiency can be improved by exploring and adding more relevant predictor variables. If the data storage system were improved and the valuable information such as status change of a trap can be recorded, the whole trap arrangement in the area can be accurate to days. Using these data, more detailed analysis can be held to look into the performance of different traps in future studies. The working efficiency can be evaluated dynamically using trap placement information together with catch result. Further if a thorough way of evaluation was settled, an instant evaluation of efficiency of a trap in certain place can possibly be analyzed and provided as a reference information to trappers. In the study, the evaluation is based on every single trap. However, it would be more reasonable to consider a group of traps recorded at the same trap location as one when evaluate the performance of a trap type in the future, for example a group of Conibear traps set at several entrances of a burrow and sharing the same trap location record. These trap groups are placed, checked and removed at the same time. The only difference would be the trap cost, which is proved to have little influence in total cost estimate in the long term.
Therefore, taking every individual trap into account may overestimate the checking cost for traps set in groups. The flaw in the storage system which deletes by-catch records may lead to major problems, as it would be impossible to accurately summarize the exact amount of by-catch in the area. It would be more reasonable to look back and analyze the by-catch when this problem is fixed in future studies and the corresponding result may be different. If more data available, season of catch can also be included in this analysis. According to the simulated experiments, the difference between catch result made by two passive traps in the field experiment is statistically significant, which suggests that small scale field experiment is able to investigate the catch ability difference between two similar trap types. Similar field experiment can be held several times in similar environment in different seasons with longer period and larger study area for same two passive traps to further confirm the result or for other trap types with similar settings to compare their catch abilities.
Conclusion

The study aims to evaluate working efficiency among trap types used in Flevoland, Netherlands. Three aspects were used to evaluate the efficiency, namely catch efficiency, cost efficiency and target specificity. Historical working data from the year 2014 were used to analyze how different trap contributes to the total catch number in an atlas block. The total cost to use a trap type was estimated and compared with the catch result to look into the cost efficiency. The by-catch rate and species of by-catches from working data were analyzed to investigate target specificity.

The original idea was to compare the efficiency among all 10 trap types. However, some of the trap types are seldom used in the field or never catch any muskrats. Therefore, only 5 most frequently used trap types were discussed and compared in the study, namely Conibear, Duikerafzetting, Lokaasklem, Lokaaskooi and Schijnduiker. It can be concluded that Duikerafzetting works the most efficient among 5 most used trap types. It contributes the most to the total catch number and with lowest cost estimate. However, this trap was also found most dangerous to non-target species, especially for fish.

The catch efficiency varies between trap types, years, seasons, historical catches. Different trap types work differently among seasons. Active traps contribute the most in autumn and summer. Whereas passive traps are more catch-efficient in spring and winter. The body-grip trap works more catch-efficient in autumn and summer. Cages contribute the most to muskrat catch in spring and winter. Fykes work relatively the same in all seasons with low coefficient estimates. Duikerafzetting contribute the most in all seasons except spring. The catch efficiency of Conibear and Schijnduiker slightly varies through out the year with the former contributing larger than the latter. Lokaasklem only significantly contributes to the total catch results in autumn with second highest coefficient estimate of the season. Lokaaskooi works the most catch-efficient in spring and contribute the second in winter.

The Levend vangende kooi costs the most among all traps through time and Schijnduiker costs the least. Considering the relationship between catch and effort (cost estimate in the
study), Duikearzetting is the most catch-efficient trap with highest catch and cost ratio. The ratios of rest 4 trap types are similar with Lokaaskooi being the lowest. The body-grip trap is the most cost-efficient followed by fyke and cage. The difference between cost efficiency of active and passive trap is surprisingly small.

Only 4 trap types have caught non-target animals during study period, namely Schijnduiker, Duikerafzetting, Conibear and Lokaasklem. Lokaasklem has the highest by-catch rate among these four, every 1 out of 6 of whose catches is a non-target animal. Duikerafzetting catches the most portion of non-target animals that are less acceptable for social public. And the Schijnduiker caught the most non-target animals.

According to our findings, active traps catch muskrats more efficient than or similar as passive traps except for spring. It can be suggested that water organizations could consider the seasonal working efficiency change between trap types and the potential consequently by-catches when develop muskrat catching strategy.

Furthermore, the current data collection system is suggested to be updated. Any status change of a trap should be recorded. For example, the status change can be stored in a new file parallel to trap location, catch and by-catch datasets with date and destination status written in. The by-catch records should not be removed when corresponding trap location is deleted. With these improvements, detailed and precise analysis can be done using the working data in future studies to further look into the working ability of these trap and their relationship between external conditions.
Reference


muskusratten in Nederland: effectiviteit van bestrijding op grond van historie en een grootschalige veldproef Tussenrapportage, 118-136.


Appendix

A. Pictures of different trap types

Schijnduiker
Duikerafzetting
Conibear
Lokaasklem
Grondklem
Levend vangende kooi
### B. Overview of relevant variables in catch data (an example of muskrat catch data)

<table>
<thead>
<tr>
<th>ID (FID)</th>
<th>Date (datum)</th>
<th>User (gebruiker)</th>
<th>Number (aantal)</th>
<th>Location (the_geom)</th>
<th>Animal type (soort)</th>
<th>sex</th>
<th>Area (fk_vanggebied)</th>
<th>Region (rayoncode)</th>
<th>Trap type (naam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>rapport_vangsten.fid-67d58e92_15fe47ad90e_-65e2</td>
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<td>jacko</td>
<td>71</td>
<td>POINT (5.822080999189603 52.52361299475386)</td>
<td>Muskusrat</td>
<td>moer</td>
<td>ZZL-007</td>
<td>Flevoland-Oost</td>
<td>Conibear</td>
</tr>
<tr>
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<td>POINT (5.620968999217512 52.45979299475517)</td>
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<td></td>
<td>ZZL-007</td>
<td>Flevoland-Oost</td>
<td>Conibear</td>
</tr>
<tr>
<td>rapport_vangsten.fid-67d58e92_15fe47ad90e_-65e0</td>
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<td>Muskusrat</td>
<td>ram</td>
<td>ZZL-007</td>
<td>Flevoland-Oost</td>
<td>Conibear</td>
</tr>
</tbody>
</table>

### C. Overview of relevant variables in trap location data (an example of active traps in the field)

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<tr>
<th>ID (FID)</th>
<th>Catch number (aantal)</th>
<th>Active</th>
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<th>Deleted (verwijderd)</th>
<th>Area (fk_vanggebied)</th>
<th>User (gebruiker)</th>
<th>Date (datum)</th>
<th>Trap type (naam)</th>
<th>Region (rayoncode)</th>
<th>General type (vmttype)</th>
</tr>
</thead>
<tbody>
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<td>FALSE</td>
<td>ZZL-005</td>
<td>zitzter08</td>
<td>2013/11/12</td>
<td>Schijnduiker</td>
<td>Flevoland-Oost</td>
<td>fiuken</td>
</tr>
<tr>
<td>rapport_vangstlocaties.fid-67d58e92_15f33b4dbcd_-46b5</td>
<td>1</td>
<td>TRUE</td>
<td>POINT (5.6172715337295465 52.56036947767027)</td>
<td>FALSE</td>
<td>ZZL-005</td>
<td>zitzter08</td>
<td>2013/11/19</td>
<td>Schijnduiker</td>
<td>Flevoland-Oost</td>
<td>fiuken</td>
</tr>
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<td>rapport_vangstlocaties.fid-67d58e92_15f33b4dbcd_-46b4</td>
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<td>2015/06/18</td>
<td>Schijnduiker</td>
<td>Flevoland-Oost</td>
<td>fiuken</td>
</tr>
</tbody>
</table>
D. Questionnaire

(Original version is in English, the final version was translated to Dutch)

Time spent by muskrat catchers on different traps

This is an anonymous questionnaire about the field hours spent on different trap types in the field. This list is part of a master thesis project where the effectiveness and costs between different types of muskrat traps are compared. A trap that provides greater chance of capturing muskrats with fewer non-target animals caught and cost less is considered to be effective. The cost includes equipment cost and the time needed to make a trap and check in the field.

Based on the answers on time spend (question 1-5), the total costs for catching muskrats by different traps are estimated. Answers to the last question (6) are used to interpret the catch efficiency on the basis of the catch registration.

Base your answers on your own experience. Give multiple answers where applicable.

Filling in takes only a few minutes.

Thank you for your help!

Tilt your device when you enter the questionnaire on a smartphone.

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De tijdsbesteding door muskrattenbeheerders aan verschillende vangmiddelen

Dit is een anonieme vragenlijst die gaat over het aantal uur dat muskrattenbeheerders besteden aan verschillende vangmiddelen. De lijst is onderdeel van een Master-thesis project waarbij zowel de effectiviteit als kosten tussen verschillende typen vangmiddelen voor muskratten worden vergeleken. Een val die een grotere vangkans oplevert met minder bijvangsten wordt beschouwd als effectief; de kosten slaan zowel op materiaalkosten als op de tijd die nodig is om een vangmiddel te maken en in het veld te controleren.

Op basis van de antwoorden over tijdsbesteding (vragen 1 tot 5) worden de totale kosten voor het gebruik van verschillende vangmiddelen geschat. De antwoorden op de laatste vraag (6) worden gebruikt om de vangstefficiëntie op basis van de vangstregistratie te interpreteren.
Baseer je antwoorden op eigen ervaring. Wanneer nodig kun je meerdere vakjes aankruisen.

Het invullen kost maar enkele minuten.
Bedankt voor je hulp!

Kantel je toestel als je de vragenlijst op een smartphone invoert.
1. How long have you been working as a professional trapper?
   Hoeveel jaar ben je al muskrattenbeheerder? ____

2. How long have you been working in your current catchment area?
   Hoeveel jaar werk je al in je huidige vanggebied? ____

3. Do you make a trap? If yes, how long will it usually take to make a fyke or a cage trap (Choose the type you make and the estimated time needed for making this trap)? If no, skip this question.

   How many hours does it cost to make a schijnduiker? ____

   How many hours does it cost to make a duikerafzetting? ____

   How many hours does it cost to make a slootafzetting met kooi? ____
   Maak je vangmiddelen? Zo ja, hoe lang duurt om de volgende vallen te maken? Kies bij de vangmiddelen die je maakt de benodigde tijd om één vangmiddel te maken. Zo nee, sla deze vraag dan over.

   Hoeveel uur kost het ongeveer om een schijnduiker te maken? ____

   Hoeveel uur kost het ongeveer om een duikerafzetting te maken? ____

   Hoeveel uur kost het ongeveer om een slootafzetting met kooi te maken? ____

4. How often do you regularly check a certain type of trap? If a trap has already been set in the field for some time and will stay in the field at least until next visit. A week refers to a workweek.

5. How long does it usually take to check a single trap for one visit with capture? The time includes (but not limited to) finding the trap, removing the body, replacing baits and resetting the trap. Travel time by car is excluded.

If multiple answers are given, give a brief explanation of the different situations where they apply.

Als er meerdere antwoorden worden gegeven, geef dan een korte uitleg van de verschillende situaties waarop ze van toepassing zijn.
If multiple answers are given, give a brief explanation of the different situations where they apply.

Als er meerdere antwoorden worden gegeven, geef dan een korte uitleg van de verschillende situaties waarop ze van toepassing zijn.

6. In general, what do you think of the catch probability is of following traps used in the field? Try to describe the catch probability as the probability of catching a muskrat in a week after putting the trap ready to catch. (For those not checked every week, describe the probability per checking period.)
A week refers to five working days.

Wat denk je dat de vangkans over het algemeen van de volgende vangmiddelen is? Probeer de vangkans per week te beschrijven na het vangklaar zetten van een vangmiddel (voor de vangmiddelen die niet elke week worden gecheckt; beschrijf de vangkans per controleerronde).
Met een week worden vijf werkdagen bedoeld.

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If multiple answers are given, give a brief explanation of the different situations where they apply.

Als er meerdere antwoorden worden gegeven, geef dan een korte uitleg van de verschillende situaties waarop ze van toepassing zijn.
### E. Responses of questionnaire

(Q. 4: Eens per drie weken of minder – A; Eens per twee weken - B; Eens per week – C; 2 - 3 keer per week – D; 4 - 5 keer per week of meer – E; niet van toepassing- F; Q. 5: < 10 min – A; 10- 20 min – B; 20- 30 min – C; 30- 40 min – D; > 40 min – E; niet van toepassing- F; Q. 6: <30% - A; 30-50% - B; 50-70% - C; 70-90% - D; >90% - E; niet van toepassing - F)

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Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands
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</tr>
</thead>
<tbody>
<tr>
<td>1/26/2018</td>
<td>14:09:16</td>
<td>C</td>
<td>C</td>
<td>E</td>
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<tr>
<td>1/26/2018</td>
<td>17:55:38</td>
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<tr>
<td>1/29/2018</td>
<td>7:37:10</td>
<td>B</td>
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<tr>
<td>1/29/2018</td>
<td>9:22:05</td>
<td>A</td>
<td>D</td>
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<tr>
<td>1/29/2018</td>
<td>12:13:17</td>
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<tr>
<td>1/29/2018</td>
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<tr>
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<td>12:42:40</td>
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</tr>
<tr>
<td>1/29/2018</td>
<td>12:45:26</td>
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<td>A</td>
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</tr>
<tr>
<td>1/29/2018</td>
<td>14:02:13</td>
<td>A</td>
<td>C</td>
<td>E</td>
<td>F</td>
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<tr>
<td>1/29/2018</td>
<td>14:02:44</td>
<td>A</td>
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<tr>
<td>1/29/2018</td>
<td>14:37:01</td>
<td>B</td>
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<td>C</td>
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<td>15:59:12</td>
<td>A</td>
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<td>A</td>
</tr>
<tr>
<td>1/30/2018</td>
<td>8:50:40</td>
<td>B</td>
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<td>D</td>
<td>A</td>
<td>A</td>
<td>D</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>1/31/2018</td>
<td>9:53:31</td>
<td>A</td>
<td>B</td>
<td>C, D</td>
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<td>D</td>
<td>C</td>
<td>B</td>
<td>B</td>
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<tr>
<td>1/31/2018</td>
<td>10:19:09</td>
<td>A</td>
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<tr>
<td>1/31/2018</td>
<td>11:05:10</td>
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<tr>
<td>2/1/2018</td>
<td>10:30:11</td>
<td>A</td>
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</tr>
<tr>
<td>2/1/2018</td>
<td>12:44:13</td>
<td>A</td>
<td>B</td>
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<td>B</td>
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<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>2/2/2018</td>
<td>8:23:46</td>
<td>A</td>
<td>A</td>
<td>A</td>
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<td>A</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>2/3/2018</td>
<td>17:45:58</td>
<td>A</td>
<td>C</td>
<td>D</td>
<td>D</td>
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<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>2/3/2018</td>
<td>21:35:19</td>
<td>C</td>
<td>D</td>
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<td>C</td>
<td>B</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>2/4/2018</td>
<td>19:43:31</td>
<td>A</td>
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<td>A</td>
</tr>
<tr>
<td>2/5/2018</td>
<td>10:34:40</td>
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<td>F</td>
<td>A</td>
<td>F</td>
</tr>
<tr>
<td>2/8/2018</td>
<td>12:33:30</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>F</td>
<td>F</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>2/10/2018</td>
<td>11:50:13</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td>F</td>
</tr>
<tr>
<td>2/15/2018</td>
<td>9:03:53</td>
<td>A</td>
<td>A</td>
<td>D</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>2/20/2018</td>
<td>12:15:00</td>
<td>B</td>
<td>F</td>
<td>D</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>C</td>
<td>B</td>
<td>F</td>
<td>B</td>
</tr>
<tr>
<td>2/20/2018</td>
<td>13:00:23</td>
<td>A</td>
<td>B</td>
<td>D</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
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</tr>
</tbody>
</table>

Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands
Q4.11 Als er meerdere antwoorden worden gegeven, geef dan een korte uitleg van de verschillende situaties waarop ze van toepassing zijn.

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Uitleg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3/2018 13:53:22</td>
<td>Duikerafzetting tijdens trekperioden 2 a 3 x per week, buiten deze perioden eens per 2 weken. Conibear na de eerste vangdagen neemt de controlefrequentie af richting eens per week.</td>
</tr>
<tr>
<td>1/26/2018 14:09:16</td>
<td>Levend vangende kooi met zender, dus erheen wanneer signaal ligt aan de waterafvoer</td>
</tr>
<tr>
<td>1/29/2018 12:13:17</td>
<td>Bij meerdere antwoorden is het maar net hoeveel vangsten en of hoe druk het in het gebied is. Hoe drukker hoe vaker controle in de week bij deze vangmiddelen. Soms is het niet mogelijk om bepaalde vangmiddelen 1 x per week te controleren, dit in verband met de hoeveelheid vangmiddelen. Juist in de trekperiode.</td>
</tr>
<tr>
<td>2/1/2018 10:30:11</td>
<td>In de jonge tijd vaker de klem en kooi nakijken</td>
</tr>
<tr>
<td>2/1/2018 12:44:13</td>
<td>Conibear is afhankelijk van de vangsten.</td>
</tr>
<tr>
<td>2/2/2018 8:23:46</td>
<td>Is afhankelijk van de situatie</td>
</tr>
<tr>
<td>2/15/2018 9:03:53</td>
<td>Met pvc licht het er aan of er trek is. en met kooien of het een stroom bebied is.</td>
</tr>
<tr>
<td>2/20/2018 12:15:00</td>
<td>Soms moet een lokaas kooi meerdere malen per week gecontroleerd worden als erg drogend of vriezend weer is, om hetlokaas in optimale conditie te houden.</td>
</tr>
<tr>
<td>2/21/2018 18:08:05</td>
<td>Conibear wordt in eerste week na plaatsing vaker gecontroleerd. Daarna eens per week.</td>
</tr>
</tbody>
</table>

Q5.11 Als er meerdere antwoorden worden gegeven, geef dan een korte uitleg van de verschillende situaties waarop ze van toepassing zijn.
<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/30/2018 8:50:40</td>
<td>Ik heb dicht bij de weg fuik aan fuik staan, maar ook plekken waar ik toch een stuk voor moet lopen om 1 of 2 fuiken te controleren.</td>
</tr>
<tr>
<td>1/31/2018 9:53:31</td>
<td>Afhankelijk van plek waar ze staan</td>
</tr>
<tr>
<td>2/1/2018 10:30:11</td>
<td>Afhankelijk of het vangmiddel aan de weg staat of 2 km in het land</td>
</tr>
<tr>
<td>2/1/2018 12:44:13</td>
<td>Conibear is afhankelijk van de aantallen. Schijnduiker is afhankelijk van de bereikbaar heid in het veld.</td>
</tr>
<tr>
<td>2/2/2018 8:23:46</td>
<td>afhankelijk van de situatie</td>
</tr>
<tr>
<td>2/16/2018 9:47:37</td>
<td>Geen</td>
</tr>
<tr>
<td>2/20/2018 21:14:05</td>
<td>Verplaatsen</td>
</tr>
</tbody>
</table>

Q6.11 Als er meerdere antwoorden worden gegeven, geef dan een korte uitleg van de verschillende situaties waarop ze van toepassing zijn.

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3/2018 13:53:22</td>
<td>Voor de conibear geldt dat deze doorgaans in groepjes uitstaan, geschatte vangkans is per vanglocatie, niet per klem.</td>
</tr>
<tr>
<td>1/29/2018 9:22:05</td>
<td>In een gebied met lage aantallen zal de kans dat er wat in komt ook lager zijn, maar de aantallen die je vangt zijn wel heel doeltreffend. En daar gaat het om! Het gaat erom dat de aantallen onderuit gaan.</td>
</tr>
<tr>
<td>1/29/2018 12:36:10</td>
<td>Heb vanggebied al jaren onder controle alles wat ik vang is meestal op duikerafzetting schijnduiker of lokaaskooi. Als ik speur en vind muskusratten ruim ik ze met conibear klemmen op.Zeer effectief.</td>
</tr>
<tr>
<td>1/31/2018 10:19:09</td>
<td>Ligt grotendeels aan hoeveel ratten er ter plekke zitten!</td>
</tr>
<tr>
<td>1/31/2018 11:06:41</td>
<td>En hier kun je informatie uithalen? Ga dit maar overdoen.</td>
</tr>
<tr>
<td>2/1/2018 10:30:11</td>
<td>Afhankelijk van de bezettinggraad van de muskusrat</td>
</tr>
<tr>
<td>2/1/2018 12:44:13</td>
<td>ook dit is subjectief, is afhankelijk van de aantallen ratten in het vanggebied.</td>
</tr>
<tr>
<td>2/2/2018 8:23:46</td>
<td>Ga het veld in met een bestrijder want jou vragen hebben niets met de praktijk te maken.</td>
</tr>
<tr>
<td>2/20/2018 21:14:05</td>
<td>Afhankelijk van de periode waarin geplaatst (trek) of bij duidelijke aanwezigheid .</td>
</tr>
<tr>
<td>2/21/2018 18:08:05</td>
<td>Bedenk dat per aanwezige muskusrat gemiddeld zeker 10 conibear vallen geplaatst worden. De vangkans bij eerste controle is schat ik 50% de volgende controle 20% daarna minder dan 10% Dit is niet goed te vergelijken met passieve vangmiddelen waarbij de vangkans verband houd met de trekperioden ergo het weer en moment van plaatsing. Ik heb overigens op de meeste</td>
</tr>
</tbody>
</table>
passieve vangmiddelen nog nooit een rat gevangen terwijl ik er toch een paar honderd per jaar vang. Wat mij betreft zeer nuttig om eens naar efficiëntie te kijken!

F. Script for data analysis

The R script used to process and analyze data is given in blocks.

```r
## data analysis for master thesis
## jinrui yang 11387440
## 2017/12/04 - 2018/04/24

### load packages & set working directory
install.packages("raster")
install.packages("rgdal")
install.packages("sp")
install.packages("rgeos")

library(rgdal)
library(raster)
library(rgeos)
library(ggplot2)
library(forcats)

setwd(dirname(rstudioapi::getActiveDocumentContext()$path))
# set working directory where this file is stored

### import all data

# import study area
study_area = readOGR("vanggebieden", "vanggebiedenPolygon")

# import trap location data from different dates
trap_location1128 = readOGR("data20171128/rapport_vangstlocaties",
                          "rapport_vangstlocatiesPoint")
trap_location1017 = readOGR("data20171017/rapport_vangstlocaties",
                          "rapport_vangstlocatiesPoint")
trap_location1225 = readOGR("data20171225/rapport_vangstlocaties",
                          "rapport_vangstlocatiesPoint")

# import latest catch data
catch = readOGR("data20171225/rapport_vangsten",
               "rapport_vangstenPoint")

# import atlas block of entire netherlands
uurhok = readOGR("atlasblock_shapefile", "uurhok_waterschap_2014")

# reproject uurhok
uurhok_reproject = spTransform(uurhok, crs(study_area))

# import waterway shapefile
shap_waterway = readOGR("Waterways shape", "Watergangen")
# reproject waterway shapefile
shap_waterway = spTransform(shap_waterway, crs(study_area))

### catch efficiency
```

Trap efficiency in muskrat control, based on field data from Flevoland, the Netherland
### divide catch data by time period

# change the datum from factor to date
catch@data = transform(catch@data, datum = as.Date(datum, format = "%Y/%m/%d"))

# divide the dates into years, weeks, periods (every four week)
catch@data$week = format(catch@data$datum, format = "%W")
catch@data$year = format(catch@data$datum, format = "%Y")
period = seq(1, 53, 4)
catch@data$period = cut(as.numeric(catch@data$week), period, right = FALSE)
levels(catch@data$period) = 1:13

Catch = intersect(catch, uurhok_reproject)

### calculate length of waterway by atlasblok

# calculate length of waterway in each atlas block
waterway.in.studyarea = intersect(shap_waterway, intersect(uurhok_reproject, study_area))

# create a dataframe, containing the blokcode and the corresponding length of waterway
W.length = as.data.frame(cbind(unique(waterway.in.studyarea$BlokCode),
unique(waterway.in.studyarea$BlokCode)))
colnames(W.length) = c("BlokCode", "waterway")
length(unique(waterway.in.studyarea$BlokCode)) # there are 27 atlasblock within studyarea

# calculate the length of waterway each block
for(i in 1:27){
  # from 1st to last atlasblock
  Blok.i = waterway.in.studyarea[waterway.in.studyarea$BlokCode ==
unique(waterway.in.studyarea$BlokCode)[i], ]
  Blok.i  # pick the i.nd atlasblock
  W.length[i, 2] = sum(SpatialLinesLengths(Blok.i)) # or gLength()
  # add the length of each line in this block and store it in W.length$waterway
}

# check the results
sum(SpatialLinesLengths(waterway.in.studyarea))
sum(W.length$waterway)
# 2 numbers are the same, which means the total length of waterway within study area

### calculate number of traps in each atlasblok

# create a function to count trap number in each atlasblok

count_trap = function(trap_location){
  #-----function:count_trap-----
  #---input:row data of trap location
  #---output: dataframe with number of different type of traps in each atlas block
  Trap_location = intersect(trap_location, uurhok_reproject)
  # intersect row data with atlas block to give each point a block where it belongs
  b = unique(Catch$BlokCode)
n = unique(Catch$naam)
b.n = expand.grid(BlokCode = b, naam = n)
  # create a dataframe containing all the combination of different trap in different atlasblock
  Trap.agr = aggregate(aantal ~ BlokCode + naam, FUN = sum, data = Trap_location)
}
Trap = merge(b.n, Trap.agr,
  by.x = c("BlokCode", "naam"), by.y = c("BlokCode", "naam"),
  all.x=TRUE)
Trap[is.na(Trap)] = 0  # change NA to 0 indicating no traps in the field
# delete traps under others category
Trap = tapply(Trap$aantal, list(Trap$BlokCode, Trap$naam), sum)
Trap = data.frame(BlokCode = row.names(Trap), Trap)
Trap$Geweer = NULL
Trap$Slaan.en.delven = NULL
Trap$suiken = Trap$Schijnduiker + Trap$Duikerafzetting
Trap$klemmen = Trap$Conibear + Trap$Lokaasklem + Trap$Klemmenrekje + Trap$Grondklem
Trap$fooien = Trap$Lokaaskooi + Trap$Duikerafzetting.met.kooi + Trap$Levend.vangende.kooi
Trap$Active = Trap$Conibear + Trap$Grondklem
Trap$Passive = Trap$suiken + Trap$klemmen + Trap$fooien - Trap$Active
Trap

# count trap number for data from different date
Trap1017 = count_trap(trap_location1017)
Trap1128 = count_trap(trap_location1128)
Trap1225 = count_trap(trap_location1225)

# choose trap location arrangement on 17 Oct, 28 Nov and 25 Dec as examples
Trap = (Trap1017[, -1] + Trap1128[, -1] + Trap1225[, -1]) / 3
Trap = data.frame(BlokCode = row.names(Trap), Trap)

#------------------------calculate number of catch in each atlasblok------------------------

# exclude "the other" trap
Catch.rmothers = subset(Catch, naam != "Geweer" & naam != "Slaan en delven")

# count catch number in diffrent block and period
Catchnumber = tapply(Catch.rmothers$aantal,
  list(Catch.rmothers$BlokCode, Catch.rmothers$period, Catch.rmothers$year),
  sum)
Catchnumber = as.table(Catchnumber)
Catchnumber = as.data.frame(Catchnumber)
Catchnumber[is.na(Catchnumber)] = 0
colnames(Catchnumber) = c("BlokCode", "period", "year", "catch_number")

Catchnumber$period = as.numeric(Catchnumber$period)
season = c(1, 4, 7, 10, 13, 14)  # season = c(1, 2, 5, 8, 11, 14)
Catchnumber$season = cut(Catchnumber$period, season, right = FALSE)
levels(Catchnumber$season) = c("winter", "spring", "summer", "autumn", "winter")

#---------------------merge trap location, catch data and waterway---------------------------
Catch_loc = merge(Trap, Catchnumber, by.x = "BlokCode", by.y = "BlokCode")
CLW = merge(Catch_loc, W.length, by.x = "BlokCode", by.y = "BlokCode")

CLW$Total = CLW$Active + CLW$Passive

# divide each trap number by waterway

for(i in 2:15){
   CLW[, i] = CLW[, i] / CLW[,20]
}

###-------------------add historical catch-------------------------------------

str(CLW)  # year is a factor

CLW$Year = as.numeric(CLW$Year) + 2013

CLW$His.catch = 0

for(i in 1:1404){  # CLW has 1404 observations
   if(CLW$Year[i] == 2014){} else{
      CLW$His.catch[i] = CLW$Catch_number[CLW$BlokCode == CLW$BlokCode[i]
      & CLW$Year == (CLW$Year[i] - 1)
      & CLW$Period == CLW$Period[i]]
   }
}

CLW$His.catch = CLW$His.catch / CLW$Waterway  # divde historical catch by waterway

CLW$Year = as.factor(CLW$Year)

###------------------------creating models----------------------------------

fit1 = glm(catch_number ~ offset(log(waterway))
   + season + year + his.catch + 0 ,
   data = CLW, family = poisson)
summary(fit1)

fit1 = glm(catch_number ~ offset(log(waterway))
   + (Conibear + Duikerafzetting + Lokaasklem
   + lokaaskooi + Schijnduiker)*season + year + his.catch + 0,
   data = CLW, family = poisson)
summary(fit1)

fit1 = glm(catch_number ~ offset(log(waterway))
   + (Conibear + Duikerafzetting + Lokaasklem
   + lokaaskooi + Schijnduiker + year + his.catch + 0)*season,
   data = CLW, family = poisson)
summary(fit1)
#best model

fit1 = glm(catch_number ~ offset(log(waterway))

+ (Active + Passive)*season + year + his.catch + 0,
  data = CLW, family = poisson)

summary(fit1)

fit11 = glm(catch_number ~ offset(log(waterway))
  + (Conibear + Duikerafzetting + Lokaasklem
      + lokaaskooi + Schijnduiker):season + season + year + his.catch + 0,
  data = CLW, family = poisson)

summary(fit11)

fit111 = glm(catch_number ~ offset(log(waterway))
  + (Conibear + Duikerafzetting + Levend.vangende.kooi + Klemmenrekje +
     Lokaasklem
     + lokaaskooi + Schijnduiker + year + his.catch)*season,
  data = CLW, family = poisson)

summary(fit111)

fit3 = glm(catch_number ~ offset(log(waterway))
  + (Conibear + Duikerafzetting + Lokaasklem
      + lokaaskooi + Schijnduiker) + season + year + his.catch + 0,
  data = CLW, family = poisson)

summary(fit3)

--- graphs for best model ---

CLW$pred = fitted(fit1)

summary(lm(res ~ BlokCode, data = CLW))

anova(lm(res ~ BlokCode, data = CLW))

residuals(fit1, "pearson")

plot(fitted(fit1), residuals(fit1))

hist(residuals(fit1))

# obs vs catch

ggplot(CLW, aes(x = catch_number/waterway, y = pred/waterway, color = BlokCode)) +
  geom_point() +
  geom_abline(slope = 1, color = "red", linetype = "dashed") +
  theme(legend.position="right") +
  labs(x = "number of catches per waterway (n/km)", y = "predicted number of catches per waterway (n/km)")

--- cross validation ---

BlokCode = unique(CLW$BlokCode)

CLW.cl = CLW[,1:22]

# conduct cross validation

fit = NA

for(i in 1:27){
CLW.train = CLW.cl[CLW.cl$BlokCode != BlokCode[i],]
CLW.test = CLW.cl[CLW.cl$BlokCode == BlokCode[i],]
fit.i = glm(catch_number ~ offset(log(waterway))
 + (Conibear + Duikerafzetting + Lokaasklem
 + lokaaskooi + Schijnduiker + year + his.catch + 0)*season,
 data = CLW.train, family = poisson)
fit = rbind(c(BlokCode = BlokCode[i],fit.i$coefficients), fit)
CLW.cl$pred[CLW.cl$BlokCode == BlokCode[i]] = predict(fit.i, CLW.test ,type = "response")

} CLW.cl$error = CLW.clScatch_number-CLW.cl$pred
max(CLW$Conibear)

# the coefficient estimates of each model
fit = as.data.frame(fit[1:27,])
rownames(fit) = 1:27
fit$BlokCode = as.factor(fit$BlokCode)
levels(fit$BlokCode) = levels(BlokCode)
summary(fit)
boxplot(fit[,2:6])

fit
# the difference of coefficient between best model and model from cross validation
deltafit = cbind(BlokCode = fit$BlokCode, sweep(data.matrix(fit[,2:41]), 2, fit$coefficients))
deltafit = as.data.frame(deltafit)
deltafit$BlokCode = as.factor(deltafit$BlokCode)
levels(deltafit$BlokCode) = levels(BlokCode)
str(fit)
boxplot(deltafit[,2:41], xaxt = "n", ylab = "coefficient difference")
text(x =1:40, y = par("usr")[3] - 1, srt = 30, adj = 1,
    labels = colnames(deltafit)[2:41], xpd = TRUE, cex = 0.7)
deltafit

# calculate Mean Squared Error for each fit
MSE = NA
for(i in 1:27){
    MSE = rbind(c(BlokCode[i],sum(CLW.cl$error[CLW.cl$BlokCode == BlokCode[i]]^2)/
                 length(CLW.cl$error[CLW.cl$BlokCode == BlokCode[i]])), MSE)
}
MSE = as.data.frame(MSE[1:27,])
colnames(MSE) = c("BlokCode", "MSE")
MSE$BlokCode = as.factor(MSE$BlokCode)
levels(MSE$BlokCode) = levels(BlokCode)
rownames(MSE) = 1:27

plot(MSE$BlokCode, MSE$MSE)

plot(MSE$BlokCode[MSE$BlokCode != "2131"], MSE$MSE[MSE$BlokCode != "2131"],
     xlab = "BlokCode", ylab = "Mean Squared Error")
text(MSE$BlokCode[MSE$MSE > 100], MSE$MSE[MSE$MSE > 100],
     labels=MSE$BlokCode[MSE$MSE > 100], cex= 0.6, pos = 4)

sum(residuals(fit1)^2)/length(CLWS$res)
# obs vs. pred
CLW.ex = CLW.cl[CLW.cl$pred/CLW.cl$waterway < 5,]
sum(CLW.cl$pred/CLW.cl$waterway > 5)

ggplot(CLW.ex, aes(catch_number/waterway, pred/waterway, color = BlokCode))+
  geom_point() +
  geom_abline(intercept = 0, slope = 1, color = "red", linetype = "dashed") +
  geom_text(aes(label = ifelse(catch_number/waterway > 1.5, as.character(BlokCode),""),
             hjust = 0.5, vjust = 1.5, size = 3, show.legend = FALSE) +
  geom_text(aes(label = ifelse(pred/waterway > 1, as.character(BlokCode),""),
             hjust = -0.2, vjust = 0.6, size = 3, show.legend = FALSE) +
  labs(x = "number of catches per waterway (n/km)",
       y = "predicted number of catches per waterway (n/km)"

##-------------------------------- creating models from different seasons--------------------------------

CLWspring = subset(CLW, season == "spring")
CLWsummer = subset(CLW, season == "summer")
CLWautumn = subset(CLW, season == "autumn")
CLWwinter = subset(CLW, season == "winter")

create.seasonmodel = function(CLWspring){
  fitSpring = glm(catch_number ~ offset(log(waterway)) +
                  Conibear + Duikerafzetting + Lokaasklem +
                  lokaaskooi + Schijnduiker + year + his.catch,
                  data = CLWspring, family = poisson)

  fitSpring
}

fitSpring = create.seasonmodel(CLWspring)
summary(fitSpring, corr = T)

fitSummer = create.seasonmodel(CLWsummer)
summary(fitSummer, corr = T)

fitAutumn = create.seasonmodel(CLWautumn)
summary(fitAutumn, corr = T)

fitWinter = create.seasonmodel(CLWwinter)
summary(fitWinter)

fitallyr = create.seasonmodel(CLW)
summary(fitallyr, corr = T)

mod.ap = function(CLWspring){
  fitSpring = glm(catch_number ~ offset(log(waterway)) +
                  Active + Passive + year + his.catch,
                  data = CLWspring, family = poisson)

  fitSpring
}

apm.s = mod.ap(CLWspring)
Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands

```r
summary(apm.s)
apm.su = mod.ap(CLWsummer)
summary(apm.su)
apm.au = mod.ap(CLWautumn)
summary(apm.au)
apm.w = mod.ap(CLWwinter)
summary(apm.w)
apm.a = mod.ap(CLW)
summary(apm.a)

#-------------------------------compare number of different trap in the field in example days-------------------------------
tt1 = colSums(Trap1017[,1])
tt2 = colSums(Trap1128[,1])
tt3 = colSums(Trap1225[,1])

# total number of different traps set in the field in three example days
rbind(tt1, tt2, tt3)

TRap1017 = Trap1017
TRap1128 = Trap1128
TRap1225 = Trap1225

TRap1017$date = c("1017")
TRap1225$date = c("1225")
TRap1128$date = c("1128")

test = rbind(TRap1017, TRap1225, TRap1128)
test$total = test$Active + test$Passive
colnames(test)
anova(lm(Conibear ~ BlokCode + date, data = test))
friedman.test(Lokaasklem ~ date|BlokCode, data = test)

ggplot(data = test, aes(date, Conibear, color = BlokCode, group = BlokCode)) +
  geom_point(data = test, aes(date, Conibear, color = BlokCode, size = 2)) +
  geom_line()

#-------------------look into all traps once set in the field-------------------
traploc.del = readOGR("data20171225/rapport_vangstlocaties_verwijderd",
                      "rapport_vangstlocaties_verwijderdPoint")
traploc.pas = readOGR("data20171225/rapport_vangstlocaties_passief",
                      "rapport_vangstlocaties_passiefPoint")
alltrap1225 = rbind(traploc.del, traploc.pas, trap_location1225)
alltrap1225@data = transform(alltrap1225@data,
                              datum = as.Date(datum, format = "%Y/%m/%d"))
```

Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands 71
alltrap1225@data$year = format(alltrap1225@data$datum, format = "%Y")

# number of newly set traps in each year
tapply(alltrap1225$aantal, list(alltrap1225$naam, alltrap1225$year), sum)

trap_location1225@data = transform(trap_location1225@data, 
datum = as.Date(datum, format = "%Y/%m/%d"))

trap_location1225@data$year = format(trap_location1225@data$datum, format = "%Y")

# the year of first settlement of traps currently in the field (2017/12/25)
tapply(trap_location1225$aantal, list(trap_location1225$naam, trap_location1225$year), sum)

# number of different types of traps currently set in the field (2017/12/25)
tapply(trap_location1225$aantal, trap_location1225$naam, sum)

# number of capture made by different traps in each year
tapply(catch$aantal, list(catch$naam, catch$year), sum)

# number of catches by conibear is a lot higher in 2017 than previous years
# number of catches by Lokaasklem is decreasing every year from 96 in 2014 to 16 in 2017

alltrapagg = intersect(alltrap1225, uurhok_reproject)
alltrapagg = aggregate(aantal ~ BlokCode + year + naam, sum, data = alltrapagg)
tapply(alltrapagg$aantal, list(alltrapagg$BlokCode, alltrapagg$year, alltrapagg$naam), sum)

##~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~cost efficiency~~~~~~~~~~~~~~~~~~~~~~~~~~~

# graphs for questionnaire

syr = read.csv(file = "serviceyear.csv", header = T)
ques = read.csv(file = "ques.csv", header = F)
qq = read.csv(file = "questionnaire.csv", header = F)

#---Q12 service year
syr = as.data.frame(as.table(data.matrix(syr[,1:2])))[,-1]
colnames(syr) = c("group", "year")
ggplot(syr, aes(x=year, fill=group)) + 
  geom_histogram(binwidth=5, alpha=.5, position="dodge")

#---Q3 diy time
diytime = syr[,3:5]
diytime = as.data.frame(as.table(data.matrix(diytime)))[,-1]
colnames(diytime) = c("naam", "time")
ggplot(diytime, aes(x = naam, y = time)) + 
  geom_boxplot()+
  scale_y_continuous(name = "time (h)")

#---Q4 frequency
Trap efficiency in muskrat control, based on field data from Flevoland, the Netherland

```r
ques.fre = ques[,8:17]
colnames(ques.fre) =
  c("Schijnduiker","Duikerafzetting","Conibear","Lokaasklem","Klemmenrekje","Grondklem","Postklem" ,"Lokaaskooi","Slootafzetting.met.kooi","Levend.vangende.kooi")
ques.fre = as.data.frame(as.table(data.matrix(ques.fre)))[,-1]
colnames(ques.fre) = c("naam", "times")

ques.fre$groupA = as.factor(ques.fre$group)
levels(ques.fre) = c("A", "B", "C", "D", "E", "F")

ggplot(ques.fre[ques.fre$naam == "Schijnduiker"|ques.fre$naam == "Duikerafzetting"],
aes(x = times, fill = naam))+
  geom_histogram(binwidth = 0.5, position = "dodge", alpha = 0.5)+
  theme(legend.position="bottom")

ggplot(ques.fre[ques.fre$naam == "Conibear"|ques.fre$naam == "Lokaasklem"|ques.fre$naam == 
  "Klemmenrekje"|ques.fre$naam == "Grondklem"|ques.fre$naam == "Postklem"], aes(x = times ,
  fill = naam))+
  geom_histogram(binwidth = 1, position = "dodge", alpha = 0.5)+
  scale_fill_brewer(palette="Spectral")+
  theme(legend.position="bottom")

# scatter plot
q4 = qq[,8:17]
colnames(q4) =
  c("Schijnduiker","Duikerafzetting","Conibear","Lokaasklem","Klemmenrekje","Grondklem","Postklem" ,"Lokaaskooi","Slootafzetting.met.kooi","Levend.vangende.kooi")
q41 = as.data.frame(as.table(data.matrix(q4)))[,-1]
colnames(q41) = c("naam", "times")
times = as.factor(" ")
for(i in 1:10){
  times = fct_c(times, q4[,i])
}
times = times[-1]
q41$times = times

levels(q41$times)
levels(q41$times) = c(" ", "", "2 - 3 times per week","once per three weeks or less", 
  "once every two weeks", "does not apply", 
  "4 - 5 times per week or more", "once per week")
q41$times = ordered(q41$times, levels = c(" ","","once per three weeks or less", 
  "once every two weeks","once per week", 
  "2 - 3 times per week","4 - 5 times per week or more", 
  "does not apply"))
```
Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands

---

### Q5 checktime

```r
ggplot(q41[q41$times != "" & q41$times != "does not apply",],
    aes(x = naam,y = times, color = naam))+
geom_count()+
scale_size_area(max_size = 10)+
theme(axis.text.x = element_text(angle = 35, hjust = 1))+
scale_color_brewer(palette = "Spectral")
```

```r
#----Q5 checktime
ques.tim = ques[,19:28]
colnames(ques.tim) =
c("Schijnduiker","Duikerafzetting","Conibear","Lokaasklem","Klemmenrekje","Grondklem","Postklem", "Lokaaskooi","Slootafzetting.met.kooi","Levend.vangende.kooi")
ques.tim = as.data.frame(as.table(data.matrix(ques.tim)))[-1]
colnames(ques.tim) = c("naam", "minutes")
```

```r
ggplot(ques.tim[ques.tim$naam == "Schijnduiker"|ques.tim$naam == "Duikerafzetting",],
aes(x = minutes , fill = naam))+
geom_histogram(binwidth = 5, position = "dodge", alpha = 0.75)+
scale_fill_hue(c=55, l=80)+
theme(legend.position="bottom")
```

```r
ggplot(ques.tim[ques.tim$naam == "Conibear"|ques.tim$naam == "Lokaasklem"|ques.tim$naam == "Klemmenrekje" |
ques.tim$naam == "Grondklem"|ques.tim$naam == "Postklem".], aes(x = minutes , fill = naam))+
geom_histogram(binwidth = 5, position = "dodge", alpha = 0.7)+
scale_fill_brewer(palette="Spectral")+
theme(legend.position="bottom")
```

```r
ggplot(ques.tim[ques.tim$naam == "Lokaaskooi"|ques.tim$naam == "Slootafzetting.met.kooi" |
ques.tim$naam == "Levend.vangende.kooi",], aes(x = minutes , fill = naam))+
geom_histogram(binwidth = 5, position = "dodge", alpha = 0.6)+
theme(legend.position="bottom")
```

# scatter plot

```r
q5 = qq[,19:28]
colnames(q5) =
c("Schijnduiker","Duikerafzetting","Conibear","Lokaasklem","Klemmenrekje","Grondklem","Postklem", "Lokaaskooi","Slootafzetting.met.kooi","Levend.vangende.kooi")
q51 = as.data.frame(as.table(data.matrix(q5)))[-1]
colnames(q51) = c("naam", "minutes")
minutes = as.factor(""
for(i in 1:10){
    minutes = fct_c(minutes, q5[,i])
}
minutes = minutes[-1]
q51$minutes = minutes
```

```r
ggplot(q51[q51$minutes != "" & q51$minutes != "niet van toepassing".],
aes(x = naam,y = minutes, color = naam))+
geom_count()+
```

```r
```
Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands.

```r
#-----probability

# histogram
ques6 = ques[,30:39]
colnames(ques6) = c("Schijnduiker","Duikerafzetting","Conibear","Lokaasklem","Klemmenrekje","Grondklem","Postklem","Lokaaskooi","Slootafzetting.met.kooi","Levend.vangende.kooi")
ques6 = as.data.frame(as.table(data.matrix(ques6)))[-1]
colnames(ques6) = c("naam","probability")
ques[,30:39] = ques6

ggplot(ques6,aes(x = probability , fill = naam))+
  geom_histogram(binwidth = 0.2, position = "dodge", alpha = 0.75)+
  scale_fill_brewer(palette = "Spectral")+
  theme(legend.position="bottom")

# scatter plot
q6 = qq[,30:39]
colnames(q6) = c("Schijnduiker","Duikerafzetting","Conibear","Lokaasklem","Klemmenrekje","Grondklem","Postklem","Lokaaskooi","Slootafzetting.met.kooi","Levend.vangende.kooi")
q61 = as.data.frame(as.table(data.matrix(q6)))[-1]
colnames(q61) = c("naam", "probability")
probability = as.factor(" ")
for(i in 1:10){
  probability = fct_c(probability, q6[,i])
}
probability = probability[-1]
q61$probability = probability

q61$probability = ordered(q61$probability,
                            levels = c(" ", "", "<30%", "30-50%", "50-70%", "70-90%", ">90%","niet van toepassing"))

ggplot(q61[q61$probability !="" & q61$probability != "niet van toepassing",], aes(x = naam,y = probability, color = naam))+
  geom_count()+
  geom_count(na.rm = T)+
  scale_size_area(max_size = 10)+
  theme(axis.text.x = element_text(angle = 35, hjust = 1))+
  scale_color_brewer(palette = "Spectral")

##----total cost estimation----

Wage.h = 50 # hourly wage
```

Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands 75
Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands

```r
# Read parameter file
cost.par = read.csv(file = "parameterfromquestionnaire.csv", header = T)
cost.par$Checktime.h = cost.par$Checktime/60
cost.par

c.number = as.data.frame(tapply(Catch$aantal, list(Catch$BlokCode, Catch$naam), sum))
colnames(c.number)
colnames(c.number)[6] = c("Levend.vangende.kooi")
colnames(c.number)[10:11] = c("Slaan.en.delven", "Slootafzetting.met.kooi")

c.number$Geweer = NULL
c.number$Slaan.en.delven = NULL
c.number[is.na(c.number)] = 0
c.number = as.data.frame(as.table(data.matrix(c.number)))
colnames(c.number) = c("BlokCode", "naam", "catchnumber")
cost.par[10,1] = c("Levend.vangende.kooi")
t.number = as.data.frame(as.table(data.matrix(Trap[, -1])))
head(t.number)
colnames(t.number) = c("BlokCode", "naam", "trapnumber")

CC = merge(merge(c.number, t.number), cost.par)
CC[is.na(CC)] = 0
CC$Cf = CC$Checkfrequency* CC$Checktime.h* Wage.h  # check cost per week
CC$Cp = CC$Tm * Wage.h + CC$P
CC$Cost = CC$trapnumber * CC$Cf * 1437/7
# max(Catch$datum)-min(Catch$datum) = 1437
# only take checking cost into account

## plot total cost estimate
week = seq(1:200)
attach(cost.par)
for(i in 1:10 ) {
  Cost[((i-1)*200+1) :(200*i) ] = Checkfrequency[i]*Checktime.h[i]*Wage.h*week + Tm[i]*Wage.h + P[i]
}

COST = as.data.frame(cbind(week = rep(week, 10), cost = Cost, naam = rep(naam, each = 200)))
COST$naam = as.factor(COST$naam)
levels(COST$naam) = levels(naam)

ggplot(data = COST, aes(week, cost, color = naam)) +
  geom_line(data = COST, aes(week, cost, color = naam), size = 0.8) +
  scale_color_brewer(palette="Paired")

##----catch vs cost------

CCt = CC[CC$naam == "Conibear" | CC$naam == "Duikerafzetting" | CC$naam == "Lokaasklem"]
```
Trap efficiency in muskrat control, based on field data from Flevoland, the Netherlands.

```r
# general type
CC$type[CC$naam == "Duikerafzetting" | CC$naam == "Schijnduiker"] = "fuiken"
CC$type[CC$naam == "Conibear" | CC$naam == "Lokaasklem" | CC$naam == "Klemmenrekje"] = "klemmen"
CC$type[CC$naam == "lokaaskooi" | CC$naam == "Slootafzetting.met.kooi" | CC$naam == "Levend.vangende.kooi"] = "kooien"
CC$type = as.factor(CC$type)

ge.cost = as.data.frame(as.table(tapply(CC$Cost, list(CC$BlokCode, CC$type), sum)))
colnames(ge.cost) = c("BlokCode", "type", "Cost")
ge.catchnumber = as.data.frame(as.table(tapply(CC$catchnumber, list(CC$BlokCode, CC$type), sum)))
colnames(ge.catchnumber) = c("BlokCode", "type", "catchnumber")

ge.cc = merge(ge.cost, ge.catchnumber)
ge.cc = ge.cc[!(ge.cc$catchnumber != 0 & ge.cc$Cost == 0),]

ggplot(data = ge.cc , aes(Cost, catchnumber, color = type)) +
  geom_point() +
  geom_smooth(method = "lm", formula = y ~ x + 0, se = T, fullrange = F) +
  labs(y = "number of catches", x = "estimated cost (euro)")

summary(lm(catchnumber ~ Cost*type + 0, data = ge.cc))

# a/p
CC$ap = "passive"
CC$ap[CC$naam == "Grondklem" | CC$naam == "Conibear"] = "active"
CC$ap = as.factor(CC$ap)
ap.cost = as.data.frame(as.table(tapply(CC$Cost, list(CC$BlokCode, CC$ap), sum)))
colnames(ap.cost) = c("BlokCode", "ap", "Cost")
ap.catchnumber = as.data.frame(as.table(tapply(CC$catchnumber, list(CC$BlokCode, CC$ap), sum)))
colnames(ap.catchnumber) = c("BlokCode", "ap", "catchnumber")
ap.cc = merge(ap.cost, ap.catchnumber)
ap.cc = ap.cc[!(ap.cc$catchnumber != 0 & ap.cc$Cost == 0),]

ggplot(data = ap.cc , aes(Cost, catchnumber, color = ap)) +
  geom_point(data = ap.cc, aes(Cost, catchnumber, color = ap), size = 2) +
```
geom_smooth(method = "lm", formula = y ~ x + 0, se = T, fullrange = F) +
labs(y = "number of catches", x = "estimated cost (euro)", subtitle = "B") +
theme(legend.position = "bottom") +
  scale_colour_discrete(name = "type",
    breaks = c("active", "passive"),
    labels = c("Active trap", "Passive trap"))

summary(lm(catchnumber ~ Cost:ap + 0, data = ap.cc))

### ----------------------------- field experiment -----------------------------

f.catch = readOGR("fieldexperiment/rapport_vangsten", "rapport_vangstenPoint")

f.area = readOGR("fieldexperiment/fe_area", "fe_area")
f.area = spTransform(f.area, crs(f.catch))

f.bycatch = readOGR("fieldexperiment/rapport_bijvangsten", "rapport_bijvangstenPoint")

f.tloc = readOGR("fieldexperiment/rapport_vangstlocaties", "rapport_vangstlocatiesPoint")

f.tlocp = readOGR("fieldexperiment/rapport_vangstlocaties_passief", "rapport_vangstlocaties_passiefPoint")

f.tlocd = readOGR("fieldexperiment/rapport_vangstlocaties_verwijderd", "rapport_vangstlocaties_verwijderdPoint")

Sel_fd = function(f.catch){
  a = length(names(f.catch))
  f.catch = intersect(f.catch, f.area)
  f.catch = f.catch[,1:a]
  f.catch$datum = as.Date(f.catch$datum, format = "%Y/%m/%d")
  f.catch = f.catch[f.catch$datum > as.Date("2017-11-1", format = "%Y/%m/%d")
                   & f.catch$datum < as.Date("2017-12-25", format = "%Y/%m/%d")]
  f.catch
}

f.catch = Sel_fd(f.catch)

f.tloc = Sel_fd(f.tloc)

f.tlocp = Sel_fd(f.tlocp)

f.tlocd = Sel_fd(f.tlocd)

f.bycatch$datum = as.Date(f.bycatch$datum, format = "%Y/%m/%d")

f.bycatch = f.bycatch[f.bycatch$datum > as.Date("2017-11-1", format = "%Y/%m/%d")
                      & f.bycatch$datum < as.Date("2017-12-25", format = "%Y/%m/%d")]

cbind(f.catch[,4], f.catch[,10:11], f.catch[,18])@data

f.trap = rbind(f.tloc, f.tlocp, f.tlocd)

f.trap@data
f.catch@data

# the lokaaskooi set on 2017-12-06 seems not from the field experiment
# so does the conibear set on 2017-11-08
tapply(f.catch$s aantal, f.catch$s naam, sum)
### experiment simulation

Ak = rbinom(n = 1000, size = 10, p = 0.3)
Lk = rbinom(n = 1000, size = 10, p = 0.3)
hist(Ak)
hist(Lk)

es = as.data.frame(cbind(catch = c(Ak, Lk), naam = c(rep("Lokaaskooi", 1000), rep("Lokaasklem", 1000))))
es$catch = as.numeric(es$catch)

ggplot(es, aes(catch, fill = naam)) +
  geom_histogram(binwidth = 1, position = "dodge", alpha = 0.7, breaks = seq(0,10,by=1))

sum(abs(Ak - Lk)>4)/1000
deltap = Ak/10 - Lk/10
hist(deltap)

### target specificity

# import bycatch data (20171225)
bycatch = readOGR("data20171225/rapport_bijvangst", "rapport_bijvangstPoint")
bycatch$datum = as.Date(bycatch$datum, format = "%Y/%m/%d")
b1128 = readOGR("data20171128/rapport_bijvangst", "rapport_bijvangstPoint")

# import corresponding catch data (catch made by traps which were not deleted)
c.catch = readOGR("20171225_catch_intsect_tl_pas", "1225catchintersect")
c.catch$datum = as.Date(c.catch$datum, format = "%Y/%m/%d")
c.catch$aantal = as.numeric(c.catch$aantal)
tapply(bycatch$aantal, bycatch$soort, sum)
tapply(bycatch$aantal, list(bycatch$soort, bycatch$naam), sum)

bc = tapply(bycatch$aantal, bycatch$naam, sum)
cc = tapply(c.catch$aantal, c.catch$naam, sum)
cc = c(cc[1], cc[2], cc[6], cc[8])

bycatch.rate = bc/cc

bycatchtable = rbind(tapply(bycatch$aantal, list(bycatch$soort, bycatch$naam), sum), c(cc))
rownames(bycatchtable)[9] = c("muskrat")

bycatchtable = as.data.frame(as.table(data.matrix(bycatchtable)))
colnames(bycatchtable) = c("animal", "naam", 'number')

ggplot(bycatchtable, aes(x = naam, y = number, fill = animal)) +
  geom_bar(position = "fill", stat = "identity") +
  scale_fill_brewer(palette = "Spectral")

# by-catch data check

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Trap efficiency in muskrat control, based on field data from Flevoland, the Netherland
c1128 = readOGR("data20171128/rapport_bijvangsten", "rapport_bijvangstenPoint")
c1208 = readOGR("data20171208/rapport_bijvangsten", "rapport_bijvangstenPoint")
c1225 = readOGR("data20171225/rapport_bijvangsten", "rapport_bijvangstenPoint")
c0221 = readOGR("data20180221/rapport_bijvangsten", "rapport_bijvangstenPoint")
c1017 = readOGR("data20171017/rapport_bijvangsten", "rapport_bijvangstenPoint")

sum(c1017$aantal) # 111
sum(c1128$aantal) # 101
sum(c1208$aantal) # 100
sum(c1225$aantal) # 100
sum(c0221$aantal) # 108

c1128$datum = as.Date(c1128$datum)
c0221$datum = as.Date(c0221$datum)
str(c0221@data)

c1017@data[(c1017@coords[,1] %in% c1128@coords[,1]),]
# 16 bycatches is removed from the data in 1017

c1128@data[(c1128@coords[,1] %in% c1017@coords[,1]),]
c1128@data[c1128@data$datum > as.Date(c("2017-10-17")),]
#

c1128@coords[(c1128@coords[,1] %in% c1208@coords[,1]),]
# the bycatch from 2016/10/10 is missing in the bycatch storage in 1208

c1128@data[(c1128@coords[,1] %in% c1225@coords[,1]),]
# the bycatch from 2016/10/10 is missing in the bycatch storage in 1225

c1208@data[(c1208@coords[,1] %in% c1128@coords[,1]),]
# no more bycatch is made from 1128 till 1208

c1208@data[(c1208@coords[,1] %in% c1225@coords[,1]),]
c1225@data[(c1225@coords[,1] %in% c1208@coords[,1]),]
# no more bycatch is made from 1208 till 1225

ah = c0221@data[(c0221@coords[,1] %in% c1225@coords[,1]),]
sum(ah$aantal)

sum(c0221@data[c0221$datum > as.Date(c("2017/12/25")),]$aantal)
# 13 bycatches are made from 1225-0221
c0221@data[(c0221@coords[,1] %in% c1225@coords[,1]),]
# 11 of them are made in the new points
# there are 2 bycatches made in this period that has bycatches in the past (so they are in the same point)

c1225@data[(c1225@coords[,1] %in% c0221@coords[,1]),]
# 5 bycatches are removed from the data 0221

d1017 = readOGR("data20171017/rapport_vangstlocaties_verwijderd", "rapport_vangstlocaties_verwijderdPoint")
d1128 = readOGR("data20171128/rapport_vangstlocaties_verwijderd",
"rapport_vangstlocaties_verwijderdPoint")
d1208 = readOGR("data20171208/rapport_vangstlocaties_verwijderd",
"rapport_vangstlocaties_verwijderdPoint")
d1225 = readOGR("data20171225/rapport_vangstlocaties_verwijderd",
"rapport_vangstlocaties_verwijderdPoint")
d0221 = readOGR("data20180221/rapport_vangstlocaties_verwijderd",
"rapport_vangstlocaties_verwijderdPoint")

c1128@coords[!(c1128@coords[,1] %in% c1208@coords[,1]),] %in% d1128@coords
# False

c1128@coords[!(c1128@coords[,1] %in% c1208@coords[,1]),] %in% d1208@coords
# True

c1128@coords[!(c1128@coords[,1] %in% c1208@coords[,1]),] %in% d1225@coords
# True

c1225@coords[!(c1225@coords[,1] %in% c0221@coords[,1]),] %in% d1225@coords
# False

c1225@coords[!(c1225@coords[,1] %in% c0221@coords[,1]),] %in% d0221@coords
# True

c1017@coords[!(c1017@coords[,1] %in% c1128@coords[,1]),] %in% d1017@coords
# False

c1017@coords[!(c1017@coords[,1] %in% c1128@coords[,1]),] %in% d1128@coords
# True