Summary

Literature study into the effect of exotic crayfish, other grazers and bio-builders on the development of young terrestilization vegetation with a view to potential measures

The literature study in hand was conducted within the framework of the Knowledge Network OBN study *Stimulation of young terrestrialization vegetation to new floating mats: bio-builders and excessive foraging*. Much knowledge is available regarding the hindering role of abiotic factors in the development of young terrestrialization succession vegetations (acidification, groundwater depletion, eutrophication, nitrogen deposition, management), but less is known about the role of biotic factors. The main question in the OBN study is therefore: "Which concrete large-scale management measures can 1) solve the negative influence of excessive eating and trampling and 2) the lack of positive ecosystem builders, as a result of which young mesotrophic terrestrialization succession vegetation and the formation of floating mats is stimulated on the landscape level?" The study consists of field experiments, supplemented with a literature study. The literature study in hand focuses on the effects of the most important grazers, namely freshwater crayfish, water birds and muskrats and on measures to counteract the negative effects of damage caused by predators (excessive foraging).

Exotic freshwater crayfish in the Netherlands

The attention for freshwater crayfish in the Netherlands, as well as in Europe, has steadily increased since the end of the previous century. The available literature initially focuses on the European freshwater crayfish and the decline of the population of the species as a result of the crayfish plague, among other things. Europe began experimenting with the introduction of crayfish from America to compensate for the decline of the European crayfish *Astacus astacus.* The first American freshwater crayfish presumably reached the Netherlands through well-developed populations of *Orconectes limosus* in France and Germany. This American crayfish species can be found in the Netherlands since 1968 (more than 50 years already) and meanwhile inhabits all of the Dutch provinces. *Astacus leptodactylus* and *Pacifastacus leniusculus* followed in the footsteps of this first exotic species, later followed by other species, including *Orconectes virilis* and *Procambarus clarkii*.

Initial expectations were that the exotic species would not establish themselves permanently. A harsh winter season and the consumption of the crayfish by eels would most likely ensure that. However, these species had doubled in numbers by the beginning of the 21st century, causing concern. Studies show that practically the entire country is suitable for one or more exotic crayfish species, except in waters in Pleistocene sediments in the Netherlands and in raised bogs that are not a suitable habitat because of the low acidity in these systems. Because of their broad habitat preference, high reproduction and insensitivity to the crayfish plague, the crayfish steadily advanced (a few kilometers per year), in which they were assisted by being set free or escaping from aquaria and restaurants. It is not unlikely that our 'open' water management and dredging measures have helped the distribution somewhat.

In addition, species such as *Procambarus clarkii* and *Orconectes limosus* are capable of walking across land. Meanwhile, six exotic species of crayfish can be found in the Netherlands for a prolonged period. Expectations are that they have yet to reach their maximum limits of distribution, in which *Procambarus clarkii* in particular can still considerably expand. Six other species were observed at some point in time, but have yet to establish themselves permanently. There are approx. 638 species of freshwater crayfish known on a global scale, including species that can be potentially hazardous to the Netherlands. And so it is vital to continue to focus on other species in legislature and policy (pro-active ban on trading and possession).

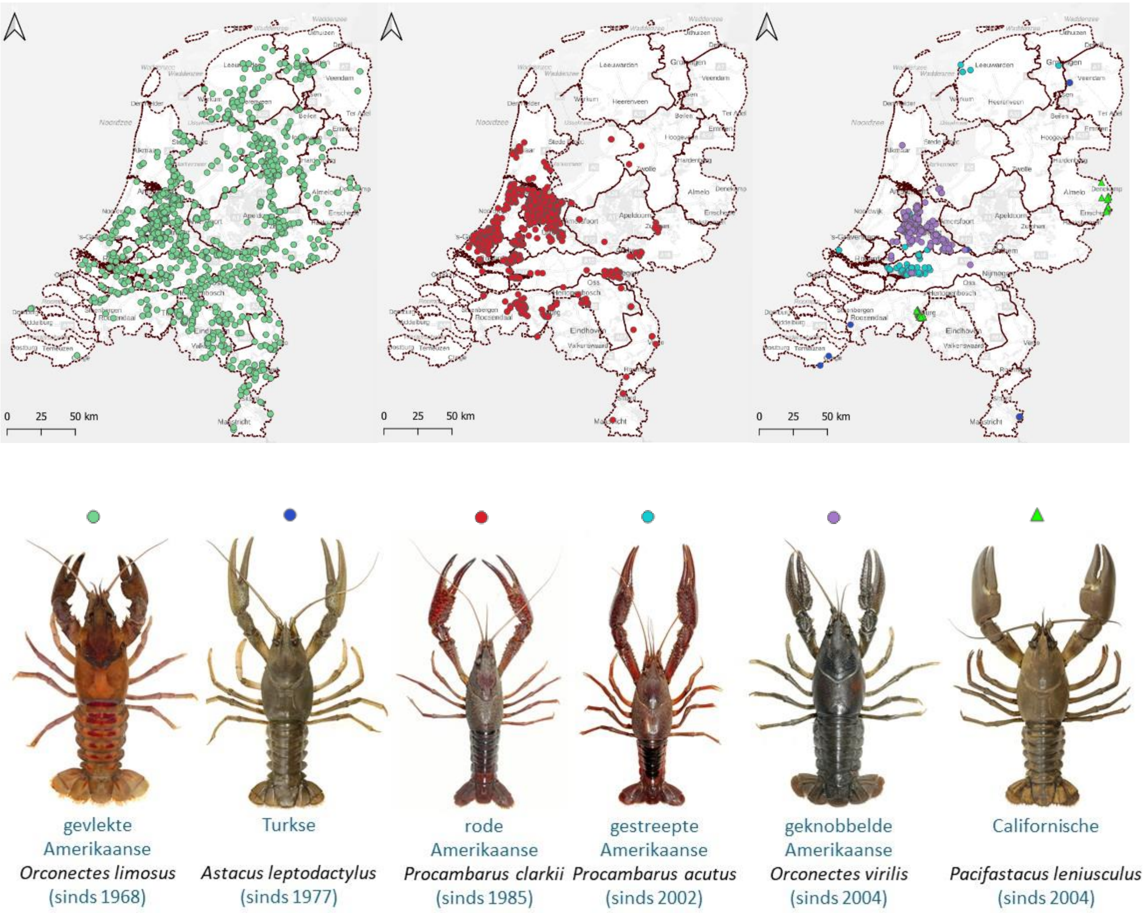

Figure 1: Distribution of six invasive crayfish in the Netherlands (source: NDFF with observations between 2008 and 2018; photos: drs. B. Koese).

Ecological damage

The ecological and economic damage that may be caused by the exotic freshwater crayfish is considerable. *Procambarus clarkii* is even in the top three of the list of '100 worst alien species in Europe' because of the negative economic and ecological impact that the species has. A species like *Orconectes virilis* seems to be less damaging. This species has been present in the Netherlands for the past 50 years and initially received but little attention. An overview of the ecological and economic damage that is caused by exotic freshwater crayfish and their behavior is given below.

Table 1: Summary of the behavior of invasive crayfish and corresponding ecological and/or economic effects.

behavior	**(possible) effects (ecological and/or economic)**	**literature**
grazing (foraging & non-consumptive cutting)	• Changes to composition & structure and loss of aquatic vegetation • Transition from clear and plant-rich situation to turbid water in which algae dominate • Loss of habitat fish, amphibians, beetles and birds, depending upon water plant vegetations and predation • Impediment formation of peat due to excessive eating of bio-builders, such as *Stratiotes aloides* • Expensive management measures are required for system restoration	Among others: Soes & Koese 2010 Heuts 2012 Souty-Grosset et al. 2016 Loeb et al. 2016
predation	• decrease diversity of macro-invertebrates • limiting of growth of fish population (damage due to consumption of fish eggs), with potential consequences for commercial fishing	Souty-Grosset et al. 2016 NVWA 2018
digging	• destabilization of the water bank (erosion) • damage to dykes/quays • increased turbidity system: induction of algae growth • accumulation of dredgings (additional costs of removal)	Rodriguez et al. 2003 Soes & Koese 2010 Koese & Soes 2011 Koese & Vos 2013 Gylstra et al. 2016 Souty-Grosset et al. 2016 Lemmers et al. 2018
Carrying of disease	• extermination of European freshwater crayfish due to crayfish plague • pathogens, parasites and diseases are fatal to various amphibians.	Souty-Grosset et al. 2016
Competition with domestic species	• suppression of fish populations, mainly demersal fish, as a result of competition in terms of shelter and choice of food, and the predation on eggs • possibly a positive effect on macrofauna due to suppression of population increase of predatory fish (excessive consumption of eggs) and because they are (an alternative)	Soes & Koese 2010 NVWA 2018

	source of food for predators that feed on soil fauna or for birds that eat fish. They also consume macrofauna.	

The ecological impact consists of various aspects, such as grazing pressure (consumption and the cutting of water vegetation), competition with domestic species, the spreading of the crayfish plague and amphibian chytrid fungus, increasing turbidity of the water system, hindering of terrestrialization succession vegetation in fens and predation on eggs and larvae of other species. Various interacting components of the ecosystem are influenced in this way. Although the overall effect is often difficult to predict, it is evident that high crayfish densities can have a negative influence on the presence of water plants. Damage to the water plants, combined with the whirling of sediment (and the higher level of nutrients that goes hand in hand), may presumably result in a shift from a clear to a turbid water system and therefore to a decline in the biodiversity.

There are various studies that examine at which critical crayfish density the influence of crayfish on the ecosystem becomes apparent. The effects appear to be significant at a density of 1 crayfish/m^2 bank, but this value will differ per water system. The afore-mentioned density of 1 crayfish/m^2 bank is exceeded in various Dutch waters: average crayfish densities of up to no less than 5 crayfish/m^2 have been observed. With a weight of around 25 grams per individual crayfish, this means that over 1000 kg/ha of crayfish can be present. For the sake of comparison, a fish biomass of 600 kg/ha is extremely high. This once again indicates that the species makes extremely efficient use of its habitat and that it can utilize virtually all sources of food.

The occurrence of the afore-mentioned ecological effects has been documented for areas abroad. Such effects have only been demonstrated to a limited degree in the Dutch situation. And practically nothing is known about the effects of the crayfish on the bio-builders of terrestrialization succession vegetations in particular, such as *Stratiotes aloides*. There have been sightings of crayfish on *Stratiotes aloides* plants. And so they may be present together. The question here is whether, and if so how, exotic crayfish species can subsequently encroach *Stratiotes aloides.* This aspect is not examined in the available literature. Specific research is needed to gain more insight into the situation.

A point of interest that has not yet been discussed in literature concerns the possible effect of freshwater crayfish on the distribution of invasive water plants. Their cutting behavior could possibly contribute to the distribution of parts of plants that can subsequently develop themselves elsewhere. Seeing that the district water boards pump a lot of money into suppressing these exotic species, this certainly merits further research.

Measures to counteract exotic freshwater crayfish species

In view of the negative effects of exotic freshwater crayfish, there has been much research into measures to counteract crayfish. To that end, the United Nations Convention on Biological Diversity (CBD) has developed a three-stage approach that is observed by the EU: 1) prevent the establishment of a new species; 2) timely detect new populations; 3) take quick action by eliminating the population.

The first measure (preventing invasive species from entering the country) is the best measure and can also be applied to species that are already present in the Netherlands, but are not yet present throughout the country (such as *Procambarus clarkii*).

The European Regulation on Invasive Alien Species, with a corresponding List of Invasive Alien Species of Union concern, was drawn up to that end. With respect to the freshwater crayfish on the Union list (*Pacifastacus leniusculus, Orconectes virilis, Orconectes limosus, Procambarus fallax forma virginalis* and *Procambarus clarkii*), there is a ban on the import and export, possession, trading, cultivation and transport of the species, as well as setting these free in the environment. The European regulation is yet to be implemented in the Netherlands and subsequently converted into work protocols/schemes and conduct codes for public bodies and nature organizations. The Ministry of Agriculture, Nature and Food Quality, the provinces and the district water boards are currently working on making this happen.

However, the implementation of this legislation comes too late for the locations where the established species can already be found. The legislation also does not cover new species or species that have already established themselves in neighboring countries and that can enter the Netherlands on their own. Control measures and management come into play once the species have established themselves. There are a number of management and control options to choose from, which can be implemented separately or simultaneously. These include doing nothing, mechanical measures, biological measures, system-level measures, chemical measures and physical measures.
Doing nothing is based on the assumption that there is a possibility that the problems caused by exotic freshwater crayfish will solve themselves with time. The species are suppressed in their country of origin in a natural manner by predators, disease and parasites. Competition between the various species of crayfish also plays an important role in stabilizing the crayfish populations. However, once freshwater crayfish are outside their natural habitat, these pressures disappear and the population can 'flourish'. It could be only a matter of time before domestic parasites and predators become better acquainted with the invasive species and the crayfish population is regulated naturally once again. It may however be decades before this natural regulation takes place. Mechanical measures involve catching and removing individuals, generally using (bait) traps. Biological measures include the introduction of disease, predators, sterilization etc. System-level measures include reclaiming land, making the eco-system more robust, filling up water areas, etc.. Chemical measures include the use of biocides, pesticides, pheromones, etc. Finally, physical measures involve the installation of barriers and electrocution.

Figure 2: An impression of traps used for freshwater crayfish; a baited trap (left photo) and an 'Artificial refuge' trap (right photo) (Green et al. 2018). The size of the openings of the traps must be such that otters, muskrats, large fish, etc. are not caught in the traps.

However, it seems to follow from a number of literature reviews that not one of the control methods is fully effective as a means to eliminating populations of invasive exotic crayfish species. The large-scale removal of freshwater crayfish fails in most of the studies that have been published due to the extremely high reproduction speed of the exotic freshwater crayfish (particularly *Procambarus clarkii*).
A recent experiment in the Distelvinkplas (part of the Molenpolder in the Natura 2000-region Oostelijke vechtplassen) - commissioned by district water board Amstel, Gooi en Vecht and the province of Utrecht - shows that the effects of the intensive removal of crayfish are initially positive. The biomass of adult crayfish decreased by about half after one year of intensive removal, the transparency increased from very turbid to ground visibility and the barren situation transformed into a cover with algae (*Nitella flexilis.*) of 60 - 80%. The question here is what this may mean for the long-term development and what will happen if the intensive removal is ceased. It is evident from the literature that the crayfish often become dominant again with time, in which it is unclear whether this will also be the case if the rest of the water system has also improved. There is also the question of whether catching and removing the crayfish intensively can be carried out in the Dutch fens and boglands regions on a large scale and in a cost-efficient manner.

There are opportunities for counteracting the crayfish on a smaller scale. Numerous authors recommend that a combination of methods be applied, for example a combination of removal, stimulating (fish) predation and strengthening the ecosystems. However, the effectiveness of a combination of methods of this kind is yet to be adequately studied. The hypothesis is that a more vigorous ecosystem (with clear water and many sight hunters) is better equipped to deal with the hazardous effects of the freshwater crayfish and/or that the crayfish themselves are at a disadvantage (because a strengthened water system accommodates more predators, for example). If a water system could be made stronger and healthier through system measures, then catching and removing freshwater crayfish from water systems of that kind could possibly be effective because these waters could offer more resistance to the high reproductive speed of the exotic crayfish species. However, it has not yet been demonstrated for the Dutch situation that strengthening the water systems can actually limit the damage caused by exotic freshwater crayfish. In addition, little is known about the predator-prey relationship and the mutual influences between populations. There have been no signs in the Netherlands so far that the size of the population of adult freshwater crayfish is significantly pushed back through predation, water quality improvement or catching and removing.

Table 2: summary of species characteristics

Species	**Characteristics**
Astacus astacus	• large species (an average of 8 cm). • conservation status applies. • present in streams and rivers with enough places to take refuge, shallow zones and hard soil. • sensitive to low temperatures. • sensitive to low oxygen levels. • sensitive to pollution (including thermal pollution). • sensitive to crayfish plague. • sharp decline of this species in the Netherlands. There is currently only one known population of this species in the country, namely in a pond near Arnhem.

Orconectes limosus	• small species. • not relevant as a commercial species because of limited size. Fishermen observe a minimum of 9 cm (economically profitable size). • Present in large eutrophic waters such as rivers, lakes and ponds, but may also surface in city ponds and canals. • associated with 'coarse soils' (sand, dumped rock, tree roots, water plants) for shelter. • not sensitive to low temperatures. • sensitive to competition with other freshwater crayfish. Is undercut at several locations by Orconectes virilis. There is also an obvious niche differentiation with Procambarus clarkii. Wherever Procambarus clarkii appears, Orconectes limosus disappears. Orconectes limosus will then maintain itself in relatively deep, large, faced waters that are not an appealing habitat for Procambarus clarkii. • established species. Widely distributed throughout the Netherlands. Mainly on its own.
Pacifastacus leniusculus	• small species. • present in slow-flowing waters that periodically fall dry. • only in light, oxygen-rich areas. • found in the Netherlands in the catchment basin of two lowland rivers: the Dinkel in Overijssel and the Oude Leij near Tilburg. Does not appear to be expanding.
Orconectes virilis	• large species. • present in its country of origin in deep waters with rubble (shelter). Present in the Netherlands mainly in ditches, canals and small rivers. Observed often in the Utrechts-Hollands peat soil pastures and clay areas along the Kromme Rijn. Less in ditches with a thick sludge layer. • low requirements water quality. • Has a niche that is comparable to that of Procambarus clarkii, but reproduces less quickly (2-year instead of 1-year cycle). It is pushed out by Procambarus clarkia in shallow zones. Procambarus clarkii has the competitive advantage that its eggs hatch sooner, so that the young can prey on the smaller young of Orconectes virilis. The distribution of this species will likely remain limited for that reason.
Procambarus acutus	• is very similar to Procambarus clarkii. Grows and reproduces just as quickly but remains somewhat smaller in the Netherlands. • not very particular in terms of biotope. Virtually all of the waters in the Netherlands are a potential habitat for this species. • preference for softer soils for the digging of holes for shelter. Can be found in the Alblasserwaard, where Procambarus clarkii is yet to be observed. • expectations are that the species will expand in the Netherlands from ditches and watercourses to swamps, ponds and river banks, among others. • is a competitor of Procambarus clarkii. If both species were to end up in the same waters, then the question is which of the two will win the competition.
Procambarus clarkii	• large and quickly growing species. • Interesting for commercial purposes (restaurants & aquaria). Dominant species in terms of both consumption and aquarium trading. • the species has few requirements in terms of habitat. • is associated in its country of origin with extreme biotopes, such as areas that fall dry (no fish) or in the effluent water of sewerage works. • sensitive to competition and fish pressure. • in its area of origin (Southeast United States) this species is suppressed by strong competition with other American freshwater crayfish. The species survives by being extremely flexible in terms of biotope and can even be found

	in sewerage (where other species are lacking and there are far fewer competitors). • the species is mainly found in the Randstad in the Netherlands (link to commercial function). It is quite striking that the species is yet to be found in Friesland. In view of the limited habitat requirements and the lack of strong competition in the Netherlands, the species can expand quickly and easily. • the habitat requirements do however highly resemble those of Procambarus acutus. Should both species end up in the same waters, then the question will be which species will win the competition. • the explosive growth of the species may possibly decrease in the years to come and a new balance may come about (provided there is enough competition and predation by fish, for example).

Because of the uncertainties, many studies emphasize the need for subsequent research and structural monitoring. A lot of the information that is available comes from abroad. However, the recommendations in these foreign research studies cannot be randomly applied to the Dutch situation, as the water systems, the climate and the soil conditions differ. As far as monitoring is concerned, with the exception of local field monitoring, there has been virtually no structural monitoring on the part of, for example the water boards or the Directorate-General for Public Works and Water Management, in the past ten years. It could become part of the monitoring of the Water Framework Directive as a means to give substance to the ecological system analysis that is needed to derive the goals of the directive and to formulate measures.

Other grazers

Although this study mainly focusses on the effect of exotic freshwater crayfish on the terrestrialization succession of fen vegetations, other grazers may also play a role in this process. For example, it is a known fact that excessive foraging on the part of geese, swans, common coots and muskrats can have an effect on the terrestrialization succession of fens. All of the afore-mentioned species can feed on the bio-builders of terrestrialization succussion vegetations, such as *Potamogetonaceae, Stratiotes aloides, Carex* and *Phragmites australis*. What's more, muskrats and geese also readily consume the sturdier waterside plants such as *Typhaceae*. And so the diet of these species partially overlaps that of the freshwater crayfish, in which the emphasis lies on the submerged vegetations for the crayfish and on the waterside vegetations for the birds and muskrats.

The effects of birds are the result of grazing, trampling and eutrophication. The focus is on geese in this respect, as they are large and their numbers are multiplying. The population sizes of all of the geese species that are present in the Netherlands have increased in the last 2 decades, and with that, so has the damage to waterside- and terrestrialization succession vegetations. In the past, eating and trampling by geese mainly occurred in the winter season. Nowadays, excessive foraging also occurs in the summer. Each season sees the consumption of different parts of the plants. Incidentally, not all of the species concerned graze on waterside and terrestrialization succession vegetations. *Anser albifrons,* for example, does not.

Geese are not the only animals that cause damage, other waterbirds also graze on waterside plants (aquatic plants), as well as on water plants (submerged, emerged and floating). The mute swan (*Cyggnus olor*), the common coot (*Fulica atra*) and diving ducks (*Aythyinae*) in particular can create grazing pressure on water vegetations all year round. In addition to stems, roots and leaves, seeds and fruits are also consumed. As is also the case for reed, the grazing pressure differs per season for water plants, depending upon the population densities and the availability and edibility of the desired plant parts.

Once a critical grazing pressure is reached, a transition from a clear and a plant-rich water system to a turbid and plant-poor system may occur, as may possibly also take place as a result of grazing by freshwater crayfish.

According to verbal comments from experts, *Stratiotes aloides* – an important bio-builder – also appears to suffer from excessive foraging by swans, common coots, geese, muskrats and exotic freshwater crayfish. The success of experiments in which *Stratiotes aloides* plants were put out was found to highly depend upon the degree of excessive foraging (presumably by water birds) and the extent of the protection to avoid this.

The muskrat has been present in the Netherlands since 1941 and quickly increased its habitat across the country. Fens and boglands are not avoided in this respect. The species can be found virtually everywhere along the banks of freshwater water bodies. The muskrat, together with the coypu, are mainly notorious for their digging. A single muskrat can move around thirteen wheelbarrows of soli per year. And with that, the species is a threat to water safety along quays and dykes. There is but little concrete information present in the literature concerning the effects of muskrats on specific terrestrialization succession vegetations. The literature does provide clear indications that muskrats can influence the species composition of waterside vegetations and water plant vegetations, as well as on the colonization speed of open water. Tests with exclosures clearly demonstrate an effect. Both waterside plants (*Phragmites Australia, Sparganium erectum*) as well as water plants (floating, mature pondweed (*Potamogeton lucens*), western waterweed (*Elodea nuttallii*) and *Stratiotes aloides*) maintained themselves better within the enclosures compared to outside.

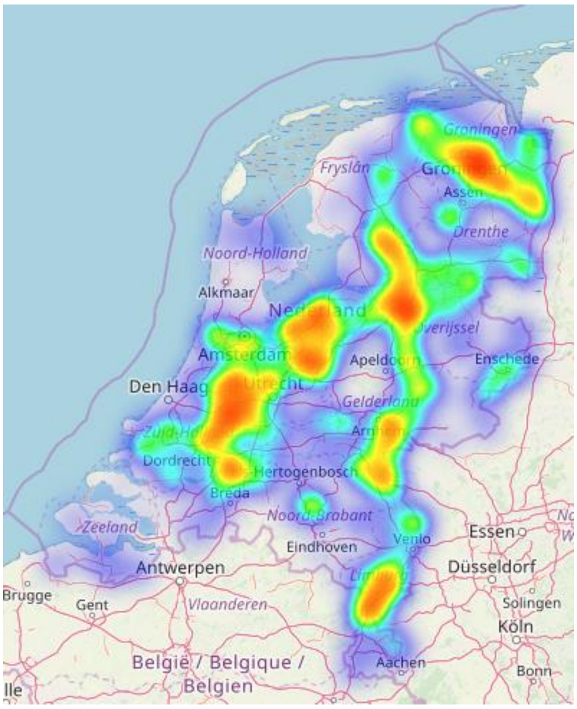

Figure ***Fout! Geen tekst met de opgegeven stijl in het document.****: Observation density (heat map) of observations of the muskrat in The Netherlands in the period from 2000 until 2018 (source: waarneming.nl; total of 3738 observations with 4218 individuals).*

Grazing pressure 'other grazers' versus grazing pressure freshwater crayfish

It is clear that freshwater crayfish and other grazers can have an effect on waterside plants and water plants (and therefore on terrestrialization succession vegetations). The effects in waterside areas that have been subjected to grazing or not are unmistakable in studies in which enclosures are used. However, the relative contribution of grazing by birds and muskrats compared to grazing by exotic freshwater crayfish is not clear; and the same applies to any specific effects of the species on the various bio-builders. One very basic reason for this is the fact that, in most cases, little or nothing is known about the sizes of the populations of the various grazers in the immediate vicinity of a field experiment. Whereas population size is certainly a decisive factor for the occurrence of excessive foraging or a lack thereof. There are several studies that point out that the populations of water birds and muskrats may be underestimated due to the nighttime activity of these species. It is clear however that water birds and muskrats cause problems even without freshwater crayfish. Besides excessive foraging, the development of vegetation is furthermore influenced by other aspects (such as the water depth, water transparency, water quality and alluvion); which are aspects that cannot always be distinguished from the effects of excessive foraging. A third reason is simply that research into grazing by the three species groups (and the effect of this on the terrestrialization succession vegetations) is rare. It is therefore difficult to quantify effects and to establish relationships between population sizes and the effect. Moreover, the effects of interaction must also be considered; the depletion of a fringe of reed by muskrats, as a result of which water birds have easier access to the bank, for example. Subsequent research is required.

Data concerning the muskrat is available. A muskrat eats approx. 82 - 140 grams of dry plant material per day, or approx. 820-1400 grams of wet plant material. However, muskrats mainly consume the lower stem parts, as a result of which the upper parts are lost. And so the biomass that is removed/lost can be two to three times higher than the amount of consumed biomass (and may reach up to no less than 6 kg per day). There is also data available on the daily dry matter consumption by the graylag goose (*Anser anser*) and the common coot (*Fulica atra)*. They consume 200 and 45-100 grams of dry vegetation per day respectively, which is less than the muskrat. The ultimate effect of grazing on the vegetation naturally depends upon the size of the population.

Where it concerns restoration measures – whether these concern the construction of nature-friendly watersides or dredging – it is in any event important to take into account the effect of excessive foraging.

Measures to counteract other grazers

The effect of other grazers (birds and muskrats) can be decreased by:

- Diminishing the population;
- Installing physical barriers;
- Making the vegetation more robust by creating large surfaces with vital terrestrialization succession communities (the ration between border length and area must be kept small);
- Habitat management, that is to say, making the habitat unsuitable for nesting and development by interfering in the vegetation and/or water system.

Measures to counteract geese have been in place for some time now, due to the increasing numbers and the damage to farm crops. Of course, the Nature Conservation Act is to be observed in this respect and the provincial fauna management units also have an important role. However, not all of the measures to counteract geese are sustainable in the long term.

Habitat management currently appears to be the most promising route to follow. Habitat management involves implementing measures that change certain factors such that an area is made to be more or less appealing to the species, so that they find the area no longer appealing or they find an adjacent area more appealing.

The water boards are obligated by law to take all reasonable measures to prevent damage to public waterworks by the muskrat or coypu. This is achieved by keeping the population of muskrats as small as possible. A smaller population also means that fewer animals need to be captured and killed, which limits suffering on the part of the animals as much as possible. The objective for the coypu is extermination.

There have been studies into alternative ways to counteract muskrats and to make their habitat less appealing, but mainly with a view to preventing damage resulting from digging and to reduce the risks for water safety. As far as is known, this has not been examined for the prevention of damage due to excessive foraging and certainly not for counteracting negative effects on terrestrialization succession vegetations. Making watersides and waterways unappealing as a habitat is virtually impossible. Muskrats are very opportunistic.

Rapport nr. 2019/OBN228-LZ:
Bureauonderzoek naar het effect van uitheemse rivierkreeften, andere grazers en biobouwers op de ontwikkeling van jonge verlanding met een doorkijk naar potentiële maatregelen