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Review Article

Current knowledge of the Neozoa, Nutria and Muskrat in Europe and their environmental impacts

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Abstract
In this study we focus on literature dealing with differences in habitat use, environmental impact, reproductive output and management strategies concerning nutria and muskrat in Europe in general and in Germany in particular. What is the current knowledge about these species in European countries, and what management strategies exist so far? We summarised more than 200 references on these topics using common scientific databases. In their original distribution area, habitats suitable for muskrats are characterised by low water level fluctuations and sufficient low water resources, broad river banks and adequate water depths. In newly inhabited areas, different habitat structures are exploited, although an aquatic environment is required. In Europe, the presence of muskrats can lead to habitat changes and consequently to biodiversity loss. Overall, muskrats are regarded as generally being able to cope well with changing habitat conditions. Feeding on crops merely seems to be a behaviour restricted to new settlements in both nutrias and muskrats. Nutrias, too, often achieve a reduction in plant diversity in the habitat through their choice of food in the newly populated areas. Additionally, an urban occurrence along with sightings of the animals during the day are almost exclusively observed in new habitats. Concerning the modelling of nutria population development, low winter temperatures and aquatic habitats are substantial factors. Research on reproductive outcome of both species in Europe is rare, and mostly reaches back to before the millennium. However, both species do have larger litter sizes and might reproduce all year round, which is not yet confirmed for all habitats. The environmental impact of invasive alien species (IAS) ranges from a mere nuisance in private gardens up to severe damage on protective dykes and a reduction in biodiversity in several countries. The management of IAS is cost intensive and differs widely among countries.

Keywords: coypu,

Environmental impact, habitat, management,

muskrat, *Myocastor coypus*, nutria, *Ondatra zibethicus*, reproduction, review.

Introduction
Since the beginning of globalisation a few centuries ago, alien species have been accidentally or deliberately taken to other continents. Some of these species have established themselves in their new habitat over time, which means that due to human activity (e. g., targeted release, escape from breeding facilities), these species have settled outside their natural range and formed autonomous populations of so-called alien species. When populations of these species cause economic damage or pose a significant threat to native biodiversity as they spread, they are called invasive alien species (IAS) (Vitousek *et al*. 1997, Nehring *et al*. 2015).
There are many reasons for the invasiveness of species. It is often noticeable that an invasive species behaves differently in its area of origin than in its new distribution area. Climate change

can also contribute to the proliferation of a species, for example, through mild winters (Nentwig 2010). It was only in 1958 that Charles Elton followed the assessment of science in the direction of critical invasion biology (Elton 2000). However, even today, there are different approaches in the field of biological invasion management. The tendency to accept alien species as a "symptom and witness of anthropogenic environmental changes" is quite pragmatic (Kowarik 2010), in some cases one can even speak of new ecosystems that have come into being as a result (Hobbs *et al*. 2006). Nonetheless, important protected goods can be endangered, and enormous ecological consequences and economic losses arise (Pimentel *et al*. 2005, Vilà *et al*. 2010). Alien species are known to be an important driver of recent extinctions (Bellard *et al*. 2016). The majority of alien species in Germany are plants and insects, which represent two thirds of the approximately 2000 non-native species here (Nentwig 2010), not all of which are invasive. In the category of terrestrial vertebrates, the European database DAISIE (Delivering Alien Invasive Species Inventories for Europe, www.europe-aliens.org) lists the nutria and muskrat in the top 100 of the worst invasive species, thus representing two of the IAS that cause significant ecological and economic harm. Originating from North (muskrat) and South (nutria) America, nutrias inhabit all continents except Australia, Antarctica and New Zealand (Carter and Leonard 2002), while muskrats were introduced into most of the Palearctic, including Great Britain, Northern and Central Europe, Ukraine, Russia, parts of China and Mongolia, and Honshu Island in Japan as well as in South America (Genovesi 2006). Due to their semiaquatic way of life and intensive burrowing in river banks and dykes, the invasive nutria and muskrat species have gained immense importance in Germany, where risk assessment already should have been completed (Ikeda 2006), and biodiversity loss and the threat to protected goods (Nehring *et al*. 2015) certainly pose an immense risk.

Within the framework of the EU biodiversity strategy, Regulation 1143/2014 was adopted, in which measures to combat IAS are presented. The nutria and muskrat species are currently listed on the Union List of this Regulation (Implementing Regulation (EU) 2016/1141 and Implementing Regulation (EU) 2017/1263), and both are considered established in Germany. Species listed were identified as invasive by an evidence-based risk assessment, in accordance with prescribed criteria. Listing of a species means it is banned from import, trade, possession, breeding, transport, use and release into the environment (Genovesi *et al*. 2015). In Germany, the nutria is subject to hunting laws of some of the Federal States (NJagdG 2018). In Lower Saxony, hunting of muskrats is currently the responsibility of specially trained muskrat hunters who, as employees of the Lower Saxony Chamber of Agriculture, carry out the contractually agreed monitoring and control of the populations (Fritz and Röver 2016).

This review reveals intensive examination of both species either by science, administration or inhabitants, concerning completely different foci depending on area and species. Throughout the review, it is the main aim to summarise differences in habitat use, find information on reproduction figures and compile the impacts on the environment of both species. Additionally, papers on current management strategies are compared since it is our hypothesis that no common strategy exists for Europe so far.

Material and methods

Between October 2017 and April 2018, we searched for articles on *Myocastor coypus* and *Ondatra zibethicus* using electronic databases including Web of Science, Medline, Google Scholar and electronic union catalogues of the University of Veterinary Medicine Hannover, Germany. Search terms included “Myocastor coypus”, “coypu”, “Nutria”, “Ondatra zibethicus”, “muskrat”, “Bisam”, “Bisamratte”. After compiling a bibliography of more than 200 articles traced through the database search, we acquired additional information using reference tracing, focusing on articles that discussed *Myocastor coypus* and *Ondatra zibethicus* distribution, reproduction, control, management or eradication. In addition, as far as possible, contact was made with experts responsible for the respective animal species in Germany in particular or Europe in general in order to integrate any relevant grey literature into the study, which consisted of very few institutional reports and final theses. Throughout the study, the main questions concerning both species comprised:

Are there differences in habitat use in original habitats compared to newly adapted habitats?

What is the reproductive output of both species?

What is the impact on the environment in newly adapted habitats, and which kind of management strategies are considered?

Results

Nutria habitat use

In the wet grasslands of the Argentine pampas, nutrias mostly stay close to the water and favour foraging on grazing areas, despite neighbouring agricultural landscapes, which was confirmed by faecal analyses. Since these results are partly contrary to observations in Europe, it is discussed whether possible causes are based on the utilisation possibilities of resources or ecological interactions in the newly populated areas (D'Adamo *et al*. 2000). Aquatic and semiaquatic food sources may be preferred over terrestrial plants, which might be due to a cost-benefit principle and reduce the risk of predation. A further explanation for the conflicting experiences, especially in Europe, where nutrias are sometimes regarded as a threat to crops, could be the different structure of habitats, since many European agricultural areas are close to the waterways populated by nutrias and therefore easier to reach (Borgnia *et al*. 2000, Guichon *et al*. 2003a). In addition, a reduced suitability of the new habitats is assumed (Scheide 2012).

The sparse occurrence of indigenous nutrias in urban and semi-urban areas may be due to increased hunting pressure on animals there (Leggieri *et al*. 2011). The effect on vegetation diversity and herbivore density in the swamps of Louisiana, USA, differs between nutrias and muskrats. While nutria occurrence negatively affected biodiversity and species richness of the vegetation in swamp areas, the opposite was the case with increased muskrat occurrence (Nyman *et al*. 1993, Shaffer *et al*. 2015). In prediction models, temperature was considered as a significant factor for the spread and settlement of nutrias. The occurrence of frost days (<0°C minimum, <5°C maximum (Gosling 1981)) was assumed to impede the survival of the animals. Several scientists combined models to make reliable predictions of nutria distribution (Doncaster and Micol 1989, Guichon *et al*. 2003b, Sheffels 2013, Jarnevich 2017). Based on current weather trends and hydrological processes, new settlements of nutrias could be detected early and invasions could be prevented (Sheffels 2013, Jarnevich 2017). For example, the northwest of Iran proved to be a suitable distribution area for nutrias, representing approximately 35% of the country's area (Farashi and Shariati Najafabadi 2015).

Nutrias are predominantly nocturnal in their native range (Palomares *et al*. 1994), which was also documented for invasive nutrias by English and American studies (Chabreck 1962, Gosling 1979, Gosling *et al*. 1980), and explained mainly with predator avoidance behaviour, whereby deviations from the nocturnal activity are known at food shortage and high population density (Chabreck 1962). In Germany, however, it has been shown that nutrias tend to have diurnal activity in urban areas, especially when fed by humans (Meyer *et al*. 2005). High activity during daytime has also been observed in various suburban areas of Oregon, USA (Sheffels 2013).

Muskrat habitat use

Studies on habitat use usually refer to current landscape changes or adaptation abilities of the animals. For example, authors from Illinois, USA, report that muskrat populations have to switch to habitats where unstable water levels can occur due to the running dry of wetlands and stream control. Radio-telemetric studies on these animals showed that they mainly fed on riparian vegetation and stayed close to the riverbanks instead of visiting higher-lying agricultural areas (Ahlers *et al.* 2010a). Subsequently, the authors investigated the effects of unstable water levels on the risk of local muskrats being predated during higher water levels. Ultimately, the animals were more exposed to predators, especially along the upper reaches of the rivers. However, this did not result in a higher mortality rate, as the main predator, the American mink, only hunted at lower water levels. A positive correlation between the survival rate of muskrats and bank width, especially in small rivers and agricultural ditches, was discovered (Ahlers 2010, Ahlers *et al.* 2010b). Additionally, a positive correlation between muskrat occurrence, precipitation and water depth was observed. Muskrats were increasingly encountered on wide rivers with higher banks and in urban regions, where trap hunting and higher levels of low tide were presumably predominant (Cotner and Schooley 2011).

In Canadian swamps, locations with 10 cm water depth minimum and deposits of reed (*Typha spp., Scirpus spp.*) are regarded as a preferred habitat and food source depending on muskrat density (Clark 1994). In these habitats, too, flooding has an indirect negative influence on muskrat density, as it has reduced emerging vegetation (Clark and Kroeker 1993).

In Germany and the Netherlands, it is assumed that muskrats leave their areas seasonally, for instance, during the main migration seasons in spring and autumn (Böhmer *et al.* 2001). Research on the biodiversity of swamp ponds in the Netherlands has shown that, in addition to many habitat characteristics (such as turbidity, water depth, nutrients and sulphate concentration), the presence of muskrats also plays a role: Higher muskrat density seems to reduce plant diversity (Sarneel *et al.* 2011). Foraging on shellfish can lead to a strong threat of rare species in small areas (Stemmer 2017). A reduction in plant diversity and a change in abiotic conditions and existence of native invertebrates in muskrat habitats also is reported from North America and Argentina (De Szalay and Cassidy 2001, Silva and Saavedra 2008, Skinner and Skinner 2008). The resulting effects on fish and other predators of invertebrates are also considered problematic (Nummi *et al.* 2006). In Sweden, muskrats seem to be the main food for foxes, so that a predator-prey relationship is assumed (Danell 1978, Danell 1985).

In Poland, the long downward trend of the muskrat hunting bag is in contrast to the increase in the hunting bag of the likewise occurring mink and also points to a predator-prey cycle (Brzezinski *et al.* 2010).

In the Russian biosphere reserve, *Prioksko-Terrasnyi*, the influence of muskrats on the ecosystem is assumed to be insignificant due to their limited occurrence (Bobrov *et al.* 2008).

- Reproduction

Indigenous nutria populations reproduce all year round, with the main reproduction period being in the summer. In males and females, sexual maturity is reached at a body weight of 3 kg. The survival rates do not differ significantly between the seasons here. In comparison, indigenous nutria populations seem to mature more slowly and have a lower body weight than established populations in the USA and Northern Europe, which the authors attribute mainly to the cold winters in Europe (Guichon *et al.* 2003b).

In the 1970s, a study in England confirmed a relationship between the amount of body fat of females in winter and the number of reproducing females in the following spring. There is a significant, inverse correlation of both body fat and reproduction in spring that provides the hypothesis that cold winters cause a critical nutritional situation of the animals which results in a reduced number of litters in the population T (Gosling 1981, Gosling *et al.* 1983). Brown (1975) calculated an average litter size of 5.75 with a range of 3 to 12 foetuses for nutria populations living in Florida, USA. Female and male animals reproduced all year round according to histological ovarian and sperm examinations. With a gestation period of approximately 134 days, female animals could produce up to 2.7 litters per year (Brown 1975). In a French study, no juveniles could be observed during the winter time. However, a parturition peak was reached during early summer (Doncaster and Micol 1989). A decrease in population density after severe winters is confirmed in Mediterranean areas (Reggiani *et al*. 1995). Food restriction could have a direct influence on the ovarian secretory activity of nutrias, so that fertility could also be directly influenced in case of food shortages (Sirotkin *et al*. 2000).

Puberty of muskrats generally starts at four to six months of age, and gestation usually takes 25-30 days (Beer 1950, Reeves and Williams 1956, Donohoe 1966). Studies in East Germany in the 1950s assume a gestation period of 28 days, and the age of reaching sexual maturity to be five months. Average litter size of free-living populations in East Germany was 6.8, reaching a maximum of ten. The author postulates that up to five litters per year may be accomplished and that young animals of the first litter can already participate in reproduction up to twice a year (Hoffmann 1958). Muskrats in Northern Europe seem to have smaller litters and might have adapted a shorter reproduction time to weather conditions, resulting in lower overall reproduction rates (Danell 1978, Hjältén 1991).

Environmental impact and management strategies

In Germany, damage to agricultural land near watercourses is observed due to nutrias foraging on roots or tubers, digging and partial collapse of dams and dykes, damage to softwood and foraging in allotments. Increased feeding of nutrias can lead to water pollution in urban areas (Biela 2008, Scheide 2012, Nehring *et al*. 2015). Reed beds (*Typha spp.*), which serve as breeding habitats for black terns (*Chlidonias niger*), can be severely damaged by nutrias (Vossmeyer *et al*. 2016), as well as freshwater mussel populations (*Anodonta cygnea*, Stemmer 2017). The digging of both nutrias and muskrats poses a serious risk to the stability of dams and dykes (Burghause 1996, Böhmer *et al*. 2001, Reinhardt *et al*. 2003, Nehring *et al*. 2015).

In the Netherlands, the purpose of management is to significantly minimise the number of muskrats and simultaneously eradicate invading nutrias. A high percentage of the country is located below sea level, which makes the preservation of dykes even more important. A professional hunting system is implemented with the help of 400 full-time professional trappers on behalf of the state, which includes both a dense trapping network and active hunting. Nutrias are caught mainly with wire box traps that can also be installed on rafts (Waterschappen 2017).

Since muskrats have been caught all year round for years, an evaluation of alternative strategies should clarify whether for example a temporal or a spatial adaptation of the hunting actions can be helpful. Using a population model, Bos and Ydenberg (2011) showed that there are differences in the efficacy of strategies. However, more information is needed on the costs of harvesting for each method.

Great Britain eliminated the muskrat species as early as 1939 in the course of the first muskrat and nutria eradication campaign using snap traps. However, the trapping method included high by-catch rates (Gosling and Baker 1989). In accordance with the FACE (Federation of Associations for Hunting and Conservation of the EU) guidelines for catching muskrat, the spring and autumn migration of animals must be used for intensified catching (FACE 2013).

The successfully implemented eradication programme in the UK may serve as a model for European management plans. After an initially failed experiment in the 1960s (Norris 1967), a population of about 3000 adult female nutrias was reduced to 20 animals between 1981 and 1986. The extinction was facilitated by coincidental severe winters. The operation, originally planned over a ten-year period, cost at least £ 2.5 million (Gosling and Baker 1987). A cost evaluation of the harmful effects of nutrias in Italy distinguishes between agricultural damage, damage to river banks, prevention and management measures, with nutria occurring in 75% of Italy's regions. While the cost of damage amounts to tens of millions of dollars, the national campaign cost several millions of euros without the actions having taken place in a concerted manner. The authors propose researchers and managers to approach management strategies via cost-benefit analyses within the context of different ecological and economic settings (Panzacchi *et al*. 2007). In addition, better coordination between neighbouring countries and import bans for areas not yet populated are recommended (Bertolino and Genovesi 2007).

The coastal wetlands of Louisiana, southern US state on the Gulf of Mexico, serve as an essential habitat for nutrias in North America. Since 2001, damage caused by this species has led to a continuous loss of marshland. The Coastwide Nutria Control Program (CNCP) was developed as a result of this. Implemented methods include trapping and shooting animals with shotguns or rifles (Normand and Manuel 2016).

Maryland, a US state on the Atlantic coast, also hosts important nutria populations near Chesapeake Bay. The Chesapeake Bay Nutria Eradication Project, which was launched in 2002, pursues a systematic hunting concept, developing novel methods for collecting and eliminating nutrias. Conibear traps, leghold traps and snares are used alongside box traps and positioned on paths frequented by the animals. By-catches were minimised by specific manipulation of the traps (Kendrot 2011). In the northwest of the USA, damage to agriculture, dykes, banks and dams dominates, depending on different habitat types in the south of the United States (Meyer 2005, Sheffels and Sytsma 2007, Sheffels 2013).

In some studies, habitat adaptation is proposed to prevent nutria colonisation. In addition to well drained field areas, a bank slope of less than 45° is regarded as an obstacle; in areas with adjustable water levels, a lowering of the level in summer (supporting emigration) and an increase in winter (deterrence by exposure to cold water) are helpful (Peloquin 1968, LeBlanc 1994). Wire mesh fences and electric fences prevent the settlement and entry of garden areas. Metal wrapping of the trunk is suitable for protecting individual trees. Seedlings in woody vegetation may be protected by plastic tubes (LeBlanc 1994, Sheffels 2013).

As a general conclusion of many studies, the lack of concerted management in experiments on nutria reduction is obvious (Kuhn and Peloquin 1974, Sheffels and Sytsma 2007, Hong *et al*. 2015).

Discussion

Research on nutrias and muskrats reveals fundamental differences in the use of habitat in native and newly adapted ranges, respectively. This is in line with the behaviour and ecology of alien species, forming one of the main problems when the species is considered invasive (Wright *et al*. 2010, Kumschick *et al*. 2015, Bellard *et al*. 2016). Knowledge on reproductive ecology is an important part of scientific evaluation of population growth and essential for developing management plans. Especially for IAS, reproductive ecology might differ from what is established or known about native species (Koen *et al*. 2018, Ramírez-García *et al*. 2018). The impact of IAS on the environment ranges from economic to ecological threats of different degrees. Whereas in Germany, the risk assessment was carried out by the Federal Agency for Nature Conservation (Nentwig 2010) without the concern of management implications, international approaches of scientists include data-based risk analyses to include and improve further management tools (Early *et al*. 2016, Booy *et al*. 2017, Carboneras *et al*. 2018, Roy *et al*. 2018).

According to several studies, different prerequisites are necessary for the complete eradication of an already widespread species. Thus, a very early stage of invasion or a spatial limitation (insularity) can favour eradication (Robertson *et al*. 2017). Particularly successful were the eradication of domestic and migratory rats (*Rattus rattus, Rattus norvegicus*) on

Mediterranean and US islands, as a result of which the vulnerability of some breeding birds has declined significantly (Genovesi 2005, Witmer *et al*. 2011). To successfully eliminate established species, sufficient financial resources, clear responsibility of authorities with sufficient support of the general public, as well as successful trapping or hunting techniques must be made available. In addition, reinvasion must be ruled out and, if necessary, the ecosystem must be restored (Myers *et al*. 2000). A feasibility study on the eradication of the Australian "pest animals" stipulates clear conditions: 1) the rate of removed animals must exceed the reproduction rate, 2) the immigration rate must be zero, 3) all reproducing animals must be targeted. Furthermore, eradication is only considered a preferred option if 1) the animals can be found at low densities, 2) a cost-benefit analysis has shown that eradication is indeed preferred over a control measure and 3) an appropriate, supportive socio-political environment prevails. Since these criteria are rarely met in existing widespread species, regional eradication would rarely be considered (Bomford and O'Brien 1995a;b), and complete extinction of IAS in new habitats is hardly possible (Koike *et al*. 2006). A thorough evaluation of cost-benefit-ratios for the different management options in each country is essential to evolve a professional, scientifically supported management for the further handling of IAS in Germany and the rest of Europe.

Conclusion

When dealing with management implications, knowledge on current IAS reproduction rates is essential. Information on sexual maturity and litter sizes relies on studies of the 20th century, so that especially in newly inhabited areas, current research would be appropriate. The management strategies of countries are closely connected with the damage caused by nutrias and muskrats and therefore range from local prevention measures, e.g., in private gardens, up to habitat adaption, e.g., by water level adjustment and intensive hunting. Since eradication can only be achieved in countries without re-immigration (Robertson *et al*. 2017), appropriate management plans have to prioritise actions including a cost-benefit analysis (Booy *et al*. 2017, Roy *et al*. 2018).

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