COST-BENEFIT ANALYSIS OF INVASIVE MUSKRAT CONTROL IN THE NETHERLANDS

COMPLETE REMOVAL AS FINANCIALLY RATIONAL STRATEGY

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Muskrats threaten public safety in The Netherlands by burrowing into water-retention structures, and a control programme has been in effect since 1941. Recent European legislation on Invasive Alien Species requires Member States to take appropriate action in muskrat control, based on the cost-effectiveness and socio-economic aspects of control. The costs of inaction must also be considered. Possible control strategies include (i) year-round trapping to maintain numbers at a given level; (ii) no control; and (iii) complete removal. We estimate the costs of labour, the costs of repairing damage inflicted by muskrats, and investment in preventive measures of each strategy, and conclude that the Net Present Value (assuming 3% inflation and 5% interest rate) is lowest for the 'complete removal' option. Importantly, complete removal is achievable, but its success is dependent upon competent staff that work in a motivated and coordinated manner.

In Europe, 1200-1800 invasive alien species (IAS) are associated with an annual damage and control costs estimated at €12 billion (Kettunen *et al*. 2008, Scalera *et al*. 2010, Williams *et al*. 2010). Besides financial costs associated with damage (e.g. to agricultural crops) and population control, IAS are considered a significant threat to biodiversity, and are associated with impacts on human health, as recognized by several international agreements (Roy *et al*. 2016). European legislation (EU regulation No. 1143/2014) is now in place that requires Member States to take appropriate action against IAS listed as high-profile through, for instance, management obligations and trade restrictions (Genovesi *et al*. 2014). In such European policy, cost-benefit analyses are recognized as an important decision support framework in IAS management (Reyns *et al*. 2017). According to the EU regulation, muskrats are deemed to pose a high-risk, requiring EU Member States to take appropriate action when muskrats are found on their territory (Genovesi *et al*. 2015, Booij *et al*. 2017, Roy *et al*. 2018). The control actions should be based on sound information on the cost-effectiveness and socio-economic aspects of control.

The muskrat (*Ondatra zibethicus*) is a semi-aquatic rodent native to North America and invasive in Europe. Muskrats are considered a threat to public safety in several low-lying European countries due to their habit of burrowing into water-retention structures such as dykes, dams and levees (Ydenberg *et al*. 2019). The Netherlands is a country vulnerable to flooding with a vast network (~280.000 km) of waterways and carefully regulated water levels. However, along with rich waterway vegetation, few predators and a mild maritime climate, these features offer high-quality habitat to muskrats, and their numbers grew quickly after initial settlement. Dutch authorities recognized the risks associated with muskrat's burrowing habits, and responded by setting up a control programme immediately after invasion of the species in 1941 (van de Peppel 1949, Barends 2002, van Loon *et al*. 2017*a*). The Dutch muskrat control programme is carried out by professional trappers, who spend their time looking for signs of muskrat presence, setting and checking lethal traps along hundreds of thousands kilometres of waterway (Barends 2002). Regular revisits are required to check for remnant animals. In recent years, around 400.000 person-hours were spent and in 2018 ~54.000 muskrats were trapped (Unie van Waterschappen 2018). There has been a declining trend in the catch since 2004 (van Loon *et al*. 2017*a*), which population modelling (van Loon *et al*. 2017*b*) indicates is related to a declining population.

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Associated with this decline, the control organisations have been able to slowly diminish trapping effort over the past decade.

The primary objective of the Dutch muskrat control programme is to safeguard the integrity of the water infrastructure, and to maintain public safety. Until June 2019, the strategy aimed to maintain the muskrat numbers at or below an average trap-rate of 0.15 muskrats per kilometre of waterway per year, a level barely attained after several decades of effort. Because control measures are expensive, large numbers of animals are killed annually, and other species are (directly and indirectly) killed as well (Zandberg *et al*. 2011, Bos and Gronouwe 2018), there is ongoing debate about the rationality, desirability and effectiveness of muskrat trapping as a control method.

Other possible control strategies exist. Other than lowering or raising the desired capture rate, alternative strategies for Dutch muskrat control would be *no control* or *complete removal.* Under the latter, once all muskrats have been removed, limited control measures are required (Gren 2008, Bos and Gronouwe 2018). Complete removal differs from eradication in the sense that a (minor) ongoing trapping effort will be required along the borders to prevent recolonisation (Robertson *et al*. 2017). Practical field examples at regional scale from the Netherlands, Flanders (Belgium) and the UK (Gosling and Baker 1989) illustrate that complete removal of muskrat is feasible (Bos and Gronouwe 2018). Good evidence shows that the Dutch control programme reduces muskrat population size provided that the levels of the effort are in adequate proportion to the population present (van Loon *et al*. 2017*a*, Bos *et al*. 2019). Under the strategy of no control, preventive measures are required to discourage or prevent muskrat burrowing (Spoorenberg 2007), for example by applying mesh wire, concrete or steel along all dykes and levees (BCM 2007, Zandberg *et al*. 2011).

In general, the political assessment of alternative strategies should be based on careful risk assessment and evaluation by multiple and diverse criteria, including ethics, biodiversity, effectiveness with regard to public safety, practicality, negative impacts, acceptability and costs (Booy *et al*. 2017, Roy *et al*. 2018). Risk assessments are given by Kumschick *et al*. (2015) and Carboneras *et al*. (2018). Biodiversity criteria are debated in Bos & Gronouwe (2018) and Bakker & Bos (2019). In this paper we aim to analyse muskrat control from a financial point of view.

Methods

Three main types of financial cost can be identified in relation to muskrat control: (i) ongoing costs for repair of damage caused by muskrats; (ii) ongoing costs associated with control activities; (iii) one-time costs for the installation of measures to prevent damage. Some of these costs incur to the Regional Water Authorities, and others to third parties, but these are not distinguished here. We distinguish two relevant time periods: short-term (≤12 years; intended to allow time for implementation); and long-term (13-30 years). We estimated the annual cost (2018 prices) of the components of each strategy based on: (i) data from the Regional Water Authorities and their member control organisations; (ii) questionnaires. The long-term required effort in each scenario has been calculated from the available length of waterways in the country and in a zone along the border, in combination with best professional judgement on required effort in relation to muskrat presence (Bos and Gronouwe 2018). With this information, we calculated the Net Present Value for each strategy over 30 years, assuming 3% inflation and 5% interest rate (see table 1). We examine the robustness of the findings with a sensitivity analysis changing relevant assumptions and parameter values. Further details may be found in a technical report (in Dutch) by Bos & Gronouwe (2018).

The strategy *complete removal* refers to a nationally-coordinated effort to remove muskrats from The Netherlands completely. We assumed that control effort would have to be maintained for twelve years at a level of 400.000 hours per year, after which it could be reduced to 200.000 hours per year, concentrated along the national borders to prevent recolonisation from neighbouring countries. This scenario is derived from a population modelling exercise by van Loon *et al*. (2017*b*). No preventive measures are required. We assume that muskrats will be eliminated in The Netherlands, and that costs associated with damage control and damage recovery will fall to zero.

The second strategy, *maintaining numbers at a given level*, works towards low muskrat population size (as indicated by an annual catch below 0.15 muskrat per km waterway) by ongoing control. Based on 2018 levels, the effort can be reduced to about 280.000 hours per year over the long-term, and no preventive measures are required. Given that the required low numbers are achieved, the ongoing costs for inspection, repair, dredging and damage to third parties (being parties other than Regional Water Authorities) are limited.

The third strategy, *no control*, is implemented by investing in preventive measures along 17.800 km of essential water infrastructure. For practical reasons, it would not be possible to implement these everywhere at once, and these costs are therefore assumed to increase linearly over a period of twelve years until all investments have been realised. The costs for preventive measures refer to installation of mesh wire at a unit value of €45/m (Unie van Waterschappen 2014). Preventive measures are assumed to have a limited lifetime and will be written off over a period of 30 years. Capital costs have been

Category	Cost item	Complete removal		Maintaining numbers at a given level		No control	
		Short-term costs in K€	Long-term costs in K€	Short-term costs in K€	Long-term costs in K€	Short-term costs in K€	Long-term costs in K€
Control	Labour	30.660	15.190	30.660	23.280	30.660	0
	Transport and trapping equipment	5.800	2.870	5.800	4.400	5.800	0
	Innovation and research	300	150	150	150	150	150
	Other	4.630	2.290	4.630	3.520	12.300	0
Water safety	Physical preventive measures	0	0	0	0	3.890	46.690
	Inspection (labour)	1.350	960	1.350	1.155	1.350	2.660
	Damage recovery water retaining structures	1.630	0	1.630	160	1.630	0
Water systems (maintenance)	Dredging for restoration water system	230	0	230	20	230	460
	Restoration of banks	800	0	800	80	800	7.080
Other costs	Communication	120	0	120	60	240	120
	Zoönotic diseases	0	0	5	0	10	10
	Damage to third parties	100	0	100	10	100	2.460
Total		**45.620**	**21.460**	**45.475**	**32.835**	**57.160**	**59.630**

Table1: Annual estimated short-term and long-term costs (in K€; price levels of 2018) of muskrat control under the three strategies. Short-term costs refer to costs made in year 1.

activated in order to spread them over the years. Due to the lack of any control programme, we assume that the muskrat numbers will rise to be higher than in 2018 (Bos *et al*. 2019). Thus, costs for inspection, damage repair, dredging, zoönotic diseases and damage to third parties along the remaining lengths of waterway, are expected to increase. Under the strategy of no control, costs associated with professional trapping are zero, because no trapping would be required. There are, however, friction costs during the transition period, for retraining the current team of professional trappers.

Other strategies, varying in control intensity in space or time (Bos and Ydenberg 2011), have not been included in the analysis, because they had previously been dismissed as unsuitable or suboptimal (Bos and Gronouwe 2018). They are considered to lead to higher muskrat population sizes than publicly can be accepted without large investments in preventive measures. In addition, they are intermediate to the three strategies studied and therefore less informative.

Results

Table 1 summarizes the estimated annual cost (2018 prices) of each component of each strategy, over both the short- and long-terms. Note that the estimate is given for year 1 of the short-term period. The cost declines over the remaining 11 years of the short-term period under two out of three strategies. Figure 1 displays the trajectory of annual costs (2018 prices) over the full 30-year period. The most important contrast lies in the ongoing cost for labour (muskrat control) and the up-front implementation of preventive measures. To a lesser extent there are differences in costs for maintenance of the water system, especially the restoration of earthen banks, and inspection related to water safety. Figure 2 compares the distribution of costs across the main categories in years 1 and 30 of each strategy.

Under the strategy of *maintaining numbers at a given level,* the costs follow the current declining trend to stabilise at ca. €33 million annually in the long-term (figure 1). This is in contrast to the strategy of *complete removal* in which control effort is maintained at the current level, until complete removal is accomplished. Under *complete removal* long term annual costs are estimated at ca. €21 million. Thus, after 10-15 years of investment, the annual difference in costs between these two scenario's amounts to approximately €10 million. The long-term costs of the strategy *no control* are highest at ca. €60 million, which is mainly due to the high investment in preventive measures. To a lesser extent, there are expected costs of damage to the extensive network of earthen banks of waterways that are not essential for water safety and thus not protected by preventive measures.

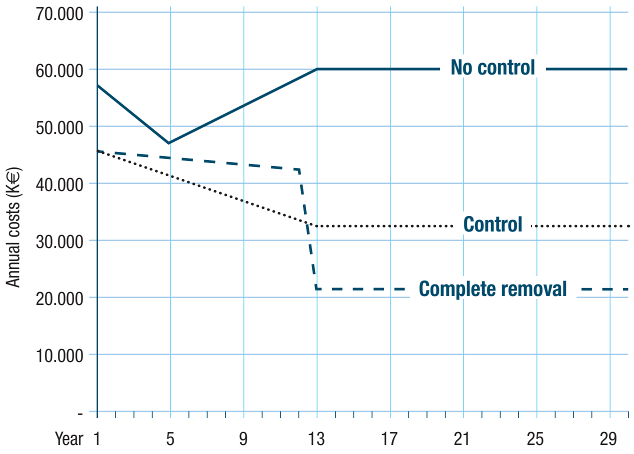

Figure 1: Development of annual costs in K€ over a 30-year period. The striped line represents the strategy of complete removal, the dotted line the strategy of continued control at low equilibrium and the solid line refers to no control.

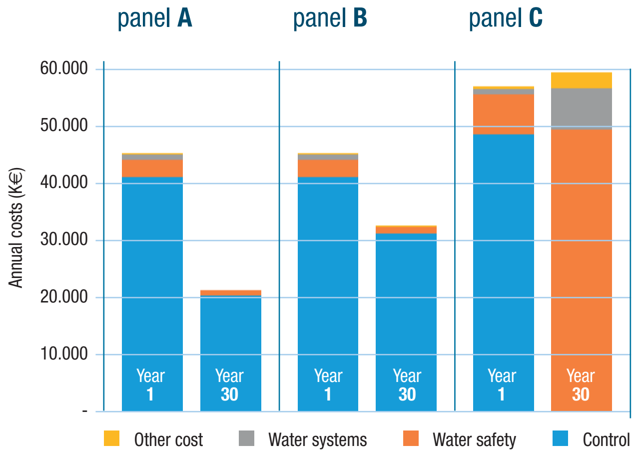

Figure 2: Distribution of costs under the three scenario's in year 1 and year 30. Panel A represents a strategy of complete removal, B refers to a strategy of continued control at low equilibrium and C refers to no control.

Table 2 shows the 'Total Cost' (i.e. the sum over the 30 year trajectory of each strategy, in 2018 €) and the 'Net Present Value' (the total cost, with costs after year 1 discounted by 3% inflation, and raised by 5% borrowing costs for capital investments). Both measures indicate that *complete removal* has the lowest expected cost. The Net Present Value of *complete removal*, is €740 million, €832 million under *maintaining numbers at a given level,* and €1.3 billion under the scenario of *no control* (table 2). The sensitivity analysis, in which we tested for the effect of changing parameter values (± 20%) on model outputs, showed that these estimates are robust, and change little in response to alterations of parameter values (table 3).

Discussion

The important finding of this study is that complete removal of muskrats from the Netherlands is financially rational. We are confident that this outcome of the analysis is robust, though agree that the exact levels of costs identified are open to debate. Here we devote attention to the costs of labour, and the implementation of preventive measures, because these are pivotal in the analysis at large. The costs of labour in future scenarios are based on best professional judgment of staff responsible for coordination of control at national level. It directly relates to historical data from The Netherlands (van Loon *et al*. 2017*a*). The historical data indicate that control costs are higher with a higher population density. This important finding is substantiated by population modelling (van Loon *et al*. 2017*b*) and corroborated by practical experience in Flanders (Stuyck 2008; pers. comm. M. vanderWeeën) and in The Netherlands. Because each trap requires time to set out, and must be checked regularly, the rate at which waterways can be patrolled (km per hour) is low when the capture rate is high, in turn presumably due

Table 2: Total costs and Net Present Value in K€ of the three relevant scenarios

Scenario	Total costs (K€)	Net Present Value (K€)
Complete removal	915.735	739.763
Maintaining numbers at a given level	1.067.210	832.393
No control	1.707.832	1.298.674

Table 3: Effects of ±20% variation in parameter values on total costs and Net Present Value

Parameter	Effect
Short-term costs for labour under no control	3%
Speed at which physical preventive measures are installed under no control	3%
Interest rate in calculation of capital charges under no control	6%
Costs for inspections under complete removal	1%
Length of water retaining structures requiring preventive measures under no control	13%
Costs per meter of preventive measures under no control	12%
Costs of third parties under no control	1%
Costs for bank recoveries under no control	2%

to a high population level. As a consequence, control organisations need to invest less in labour as the catch rate declines

The costs for preventive measures strongly depend on the timeframe and the extent (length of dikes and levees, km) over which they are implemented. We have opted for gradual implementation (over a period of 12 years), using mesh wire, along the entire length of essential dikes and levees (17.800 km). The use of mesh wire as a preventive measure is among the cheapest options and we assume that it is technically feasible everywhere. The use of other materials, such as concrete or steel, would result in higher costs. Lowering the annual costs for preventive measures by protecting less of the essential water-retaining infrastructure will lower public safety (Bayoumi and Meguid 2011, Ydenberg *et al*. 2019). Given the fact that the investments in safety from flooding in The Netherlands exceed billions of euro's, we believe that such a compromise cannot be acceptable for the Dutch Water Authorities, the Dutch government or the general public.

The results of the analysis presented here are generally consistent with Bomford & O'Brien (1995) and Clark (2010), who show that control can be an economically rational activity, depending on the rate of inflation, the damage caused by muskrats and the cost of trapping them. Reducing the population is an investment that can be regained in the longer term. Reinhardt *et al*. (2003) conclude that eradication of muskrats on a national scale in Germany is likely to be economically sound, taking into account the maintenance costs for waterways and water infrastructure, as well as costs for public health, agriculture and fisheries. Panzacchi *et al*. (2007) show that eradication of the coypu (*Myocastor coypu*) in Italy presumably has a very favourable cost-benefit ratio. The successful eradication campaigns for muskrats and coypu in England (Gosling and Baker 1989, Baker 2010) were carried out because it was clear at the time that this investment would prove effective in the long run. In retrospect, that is also the case.

In addition to the financial arguments presented above, the difference between each of the strategies has also been weighed for other criteria, as has been mentioned in the introduction (Bos and Gronouwe 2018). Each Regional Water Authority has been informed and has debated the pro's and con's of the different strategies. Finally, the information has supported a policy decision by the Dutch Water Authorities in June 2019 to change the previous management objective from *maintaining numbers at a given level* to *complete removal*.

Now there may be a strong economic incentive for complete removal, as indicated by the large difference in Net Present Value between the strategies (table 2), but this has little relevance for the individual trapper, unless their job perspectives are taken into account properly. Thus, given that the success of any muskrat control programme is to a large extent dependent upon competent staff that works in a coordinated and motivated way, the personal interests of the trappers need to be taken serious by the control organisations. If not, the analysis presented has limited relevance.

Conclusion

We have shown, based on a cost-benefit analysis, that complete removal would be a financially rational strategy for Dutch muskrat management. Under compete removal the investments required are lower than future costs to maintain a strategy of control at low equilibrium population size, or to apply a strategy of no control coupled with preventive measures to protect against flooding and maintain public safety.

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ABSTRACT

Door graverij in waterkeringen bedreigen muskusratten de Nederlandse waterveiligheid en daarom wordt de soort al sinds de vestiging in 1941 bestreden. Recente Europese wetgeving met betrekking tot invasieve exoten verplicht de lidstaten van de EU om passende maatregelen te treffen ten aanzien van het beheer van muskusratten, afhankelijk van kostenefficiëntie en socio-economische factoren. Ook dient het alternatief van een beheerstrategie waarin geen muskusratten worden bestreden te worden overwogen. Mogelijke strategieën in het muskusrattenbeheer zijn (i) bestrijding waarbij de dichtheden op een bepaald laag niveau worden gehouden; (ii) geen bestrijding; (iii) volledige verwijdering. In dit artikel schatten we de kosten voor arbeid, de kosten voor het repareren van schade aangebracht door muskusratten en investeringen in preventieve maatregelen voor elk van deze strategieën op korte en lange termijn in. We concluderen dat de Netto Contante Waarde (uitgaande van 3% inflatie en 5% rente) het laagst is voor 'volledige verwijdering'. Volledige verwijdering van de muskusrat is realistisch en haalbaar, maar het succes van deze strategie is afhankelijk van competente bestrijders die gemotiveerd en gecoördineerd kunnen werken.

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