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REVIEW ARTICLE

History and Current Status of Invasive Nutria and Common Muskrat in Korea

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Abstract Nutria, or coypu (*Myocastor coypus*), were introduced to South Korea in 1985 and became an invasive species in the late 1990s. Despite being limited to the Nacdong River system, the nutria population is well established there. The common muskrat (*Ondatra zibethicus*) invaded North Korea via the Russian and Chinese borders during the 1960s, but the species is still confined to the extreme northeastern portion. In South Korea, muskrats were introduced in 2005. Although muskrat farms are not commercially viable, they have increased. Since 2009, local and federal governments have tried to remove nutria using trappers and bounty hunting. From 2011 to 2015, 11,258 nutrias were removed but a sustainable population still exists. Although complete nutria removal has been achieved in other countries, the eradication campaign in South Korea has not been strictly modeled on these successes. Despite the concern about muskrats, prevention against their possible release has never been implemented. We present the history of nutria and muskrat in Korea and examine the current eradication projects. We propose that unified science-based eradication strategies would be the most likely to succeed, and urge the South Korean government to initiate management designed to avert potentially harmful ecosystem effects of invasive muskrats.

Keywords Eradication · Invasive species · Korea · Muskrat · Nutria

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Introduction

Since the Korean War, several invasive species have affected Korean ecosystems such as bluegill (*Lepomis macrochirus*) since 1969, largemouth bass (*Micropterus salmoides*) since 1973, and American bullfrog (*Rana catesbeiana*) since 1971 (NIER 2011). Various non-native furbearers have been imported, with 222 fox (*Vulpes vulpes*) farms with 14,313 foxes, and 229 mink (*Neovison vison*) farms with 23,388 mink registered in 1990. These labor-intensive fur industries declined to 65 fox farms with 978 foxes and 115 mink farms with 6,577 minks by 1995 (KOSIS 2015). Since the 2000s, there have been no fox or mink farms officially registered in South Korea, and known escapees have failed to establish populations in the Korean Peninsula. Unlike other furbearers, however, two riparian rodent species, muskrat (*Ondatra zibethicus*) and nutria, or coypu (*Myocastor coypus*), have established populations in extreme northeastern North Korea and southeastern South Korea, respectively. Therefore, nutria was designated as the only invasive mammal species in South Korea (NIER 2011). Despite concerns about invasive organisms, South Korea has not implemented appropriate animal trade regulations.

Although international cooperation and reporting is necessary for management and control of invasive species, little has been published on the history and status of invasive alien species in Korea. Since the Convention on Biological Diversity (CBD) adopted invasive species as one of the Aichi targets at the plenary session of CBD in 2010 and South Korea hosted the 12th conference of parties in 2014, the South Korean government has been interested in

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management of invasive species (Mun et al. 2013). However, there is little systematic management of invasive or alien species in South Korea.

The South Korean government began designating invasive species in 1999 and currently, one mammal, one amphibian, one reptile, two fishes, one insect, and twelve plant species are recognized as invasive species in South Korea (Table 1). In addition to invasive species, import permission-required species have been listed since 2013. In 2015, 24 species (17 plants, one insect, one invertebrate, two fishes, one bird and two mammals) needed permission for import to South Korea (Table 2). Although 13 species of alien mammals were listed by the government (Table 3), apart from designating nutria as an invasive species, other practical management efforts were rare. In 2015, nutria were the main target of invasive animal control in South Korea.

Before introduction of nutria, the American bullfrog was the important nonindigenous invasive species in South Korea. Bullfrogs were introduced for food and farming them was encouraged by the South Korean government (Kang and Yoon 1994). However, the bullfrog market failed and farming collapsed due to lack of public interest in the exotic meat; subsequently, a number of bullfrogs were released into the Korean ecosystem (Jeong and Park 1996). By the 1990s, bullfrogs were distributed throughout South Korea and the invasive species became a national issue.

Despite public awareness of invasive species, nutrias were released at the height of the bullfrog issue in the 1990s. Nutria introduction in South Korea is the most recent known release globally; invasive nutria in other countries had been introduced before the 1960s (Carter and Leonard 2002). Although the governments of neighboring Japan have demonstrated success in managing multiple alien mammal invasions (e.g., raccoon *Procyon lotor*, small Indian mongoose *Herpestes javanicus*, and masked palm civet *Paguma larvata*), South Korea has not instituted a system for management of invasive mammals.

Nutria and muskrat have enlarged their distributions from the northern and southern tips of the Korean Peninsula, but the history and current status of these alien rodents have not been reported (Carter and Leonard 2002). Here, we provide their current status and introduction history in the Korean Peninsula, and discuss potential control solutions.

Common Muskrat

This North American species was introduced into northeastern Asia for fur production in 1927 (Won and Smith 1999). Colonization of the Korean peninsula by muskrats, presumably across the northeastern border from Russia and China, began sometime after 1965 (Won 1968). Since then, the muskrat has become invasive, expanding southward into North Korea. The source population presumably was established in eastern Russia from releases during the 1920s; 38,000 muskrats were reported in the Soviet Union by 1940 (Ognev 1948).

The muskrat population is currently confined to extreme northeastern Korea (Kim 1988). Instead of eradication, North Korea has conducted research on husbandry and extraction of musk (Park and Ju 2000; Ko and An 2003; Ju 2007). The river system in the extreme northeastern Korean peninsula is isolated from the rest of Korea by high mountain ranges; unless deliberate muskrat introductions occur, southward range expansion is unlikely.

Muskrats were imported to South Korea in 2005 before the legislative regulation of importing foreign species in 2010. There are 2 large farms in central South Korea, and 60–80 muskrat farms are distributed throughout South Korea (NIER 2011). The price of one live individual was $600-1000 USD.

An invasive population has not been confirmed in South Korea, but a single feral muskrat was killed in central South Korea during nutria control in 2014 (NIE 2015). Despite public and government concerns, no plan is in place to prevent or respond to future muskrat invasions in South Korea.

Nutria (Coypu)

South Korea imported 100 nutrias from France in 1985 but none survived due to poor husbandry techniques. Two years later, 60 individuals were imported from Bulgaria and breeding was successful (NIE 2015). A single escapee in Seoul in 1989 caused some public attention, but invasiveness was not considered to be a risk at that time. The government listed nutria as livestock for 13 years (2001–2013).

In the early 1990s, nutrias were at the center of a doomed commercial enterprise that may have contributed to the present invasive species problem. A group of companies convinced investors of likely profits from purchasing nutrias at $1200–1600 each (0.9–1.2 million Korean Won). By 1995, a substantial breeding program was underway at farms throughout Korea, but there was no obvious market. Koreans do not traditionally consume rodents, and attempts to market nutria meat as ‘healthy food’ and ‘good for stamina’ failed to change public perception.

Since then, several escapees have been recorded. In 1995, an “albino otter” reported in Seo-myeon, Yeongwol-gun (county) was later identified as a nutria. Also, a frequently reported “otter” on Dalcheon River near a rest area in Goesan-gun was a nutria. These individuals did not likely contribute to the subsequent invasion. There were 470 nutria farms with 150,000 nutrias in South Korea in 2001 (Lee et al. 2012). In 1999, the same year nutria were officially recognized as an invasive species, the Upo wetland was designated as an Ecosystem Conservation Area and feral nutria were

Table 1 List of invasive species in South Korea

	Scientific name	Common name	Designation year
Insect	*Lycorma delicatula*	Spot clothing wax cicada	2012
Fish	*Lepomis macrochirus*	Blue gill	1998
	Micropterus salmoides	Largemouth bass	1998
Amphibian	*Lithobates catesbeianus*	American bullfrog	1998
Reptile	*Trachemys spp.*	Slider	2001
Mammal	*Myocastor coypus*	Nutria	2009
Plant	*Amrosia trifida*	Great ragweed	1999
	Ambrosia artemisiifolia	Ragweed	1999
	Eupatorium rugosum	White snakeroot	2002
	Paspalum distichum	Knotgrass	2002
	Paspalum distichum var. *indutum*	Knotgrass	2002
	Solanum carolinense	Horse nettle	2002
	Sicyos angulatus	Bur-cucumber	2009
	Aster pilosus	White heath aster	2009
	Hypochaeris radicata	Cat's ear	2009
	Rumex acetocella	Sheep sorrel	2009
	Solidago altissima	Tall golden rod	2009
	Lactuca scariola	Prickly lettuce	2012

known to occur there (Jung and Jo 2012). In 2006, the South Korean government began a national survey of 11 alien species, and confirmed the existence of a nutria population in the Nacdong River system (NIER 2006).

Table 2 Import permission required for unintroduced species in South Korea

	Scientific name	Common name	Native range
Insect	*Anoplolepis gracilipes*	Yellow graze ant	West Africa
Mollusk	*Perna viridis*	Green mussel	Indo-pacific
Fish	*Micropterus dolomieu*	Smallmouth bass	North America
	Siniperca chuatsi	Mandarin fish	Northeatern China
Bird	*Acridotheres tristis*	Common myna	South Asia
Mammal	*Rattus exulans*	Polynesian rat	South Asia
	Peromyscus maniculatus	N. American deermouse	North America
Plant	*Vincetoxicum rossicum*	Dog-strangling vine	Russia; Ucraine
	Carduus acanthoides	Spiny plumeless thistle	N. Africa; Europe; W. Aisa
	Carduus tenuiflorus	Slenderflower thistle	N. Africa; Europe
	Centaurea maculosa	Spotted knapweed	Eastern Europe
	Chromolaena odorata	Bitter bush	North & central America
	Mikania micrantha	Mile-a-minute	Central & South America
	Senecio madagascariensis	Madagascar ragwort	South Africa
	Sphagneticola trilobata	Creeping ox-eye	Central America
	Cenchrus echinatus	Southern sandbur	Tropical America
	Neyraudia reynaudiana	Burmareed	Southeast Asia
	Spartina alterniflora	Smooth cordgrass	Western Atlantic coast
	Spartina anglica	Common cordgrass	Soutern England
	Urochloa mutica	Para grass	Africa
	Vulpia bromoides	Squirreltail fescue	Africa; Europe; W. Asia
	Fallopia baldschuanica	Mile-a-minute vine	W. China
	Heracleum sosnowskyi	Sosnowski's hogweed	Caucasus; Turkey
	Hydrocotyle ranunculoides	Floating marshpennywort	Africa

Table 3 Alien mammals in South Korea as listed by NIER (2011)

Family	Scientific name	Common name	Native range	Note
Felidae	*Felis catus*	Feral cat	Domestic	
Mustelidae	*Neovision vison*	American mink	North America	
	Mustela furo	Ferret	Domestic	No report in wild
Procyonidae	*Procyon lotor*	Raccoon	N. America	No report in wild
Equidae	*Equus asinus*	Donkey	Domestic	No report in wild
Suidae	*Sus scrofa*	Miniature pig	Domestic	Pet breed, no report in wild
Cervidae	*Cervus elaphus*	Red deer	N. Eurasia & N. America	No report in wild
	Cervus nippon	Sika deer	Northeast Asia	Native, different subspecies
Bovidae	*Capra hircus*	Goat	Domestic	
Cricetidae	*Ondatra zibethicus*	Muskrat	N. America	One report in wild
Muridae	*Rattus norvegicus*	Brown rat	Central Asia	
	Rattus rattus	Black rat	Southeast Asia	
Myocastoridae	*Myocastor coypus*	Nutria	S. America	Designated invasive species

In 2009, Haman county government started bounty hunting for nutria eradication at 30,000 per individual ($30 USD). Bounty hunting has since expanded to other local governments and the Nacdong River Environmental Management office, part of the Ministry of Environment (MOE). By July 2015, bounty hunting accounted for 11,418 nutrias and the Nacdong River Environmental Management office established a nutria eradication team in 2014. The team killed 4,883 nutrias in 19 months (Table 4). Although nutria occurred throughout the Nacdong River System, control efforts have been concentrated on Busan Metropolitan City, in southeastern South Korea (Fig. 1). The National Institute of Ecology (NIE) under the MOE, implemented the first national nutria survey in 2014 (NIE 2015). Despite increasing nationwide concern about invasive nutria, no systematic eradication strategy was implemented.

Table 4 Eradication results of number of nutria from the Nacdong River from 2011 to 2015 (data from Nacdong River Environmental Management Office, MOE)

Year	Bounty hunting		Eradication team	Total
	Local governments	MOE		
2011	581	–	–	581
2012	1116	–	–	1116
2013	3343	–	–	3343
2014	1859	2802	3053	7711
2015[a]	729[b]	988	1830	3547
total	7628	3790	4883	11,258

[a] 2015 data is until July

[b] Data from one local government (Busan Metropolitan City) and other cities and counties data are not included

Discussion

As with the well-documented introduction of invasive bullfrog (Shim 2005), exotic nutrias are also causing ecological problems. The common muskrat may become the next invasive species. Currently, the invasive range of nutria in South Korea is limited to the Nacdong River system and federal and local governments are trying to eradicate the animals. Although the muskrat has established in extreme northeastern Korean peninsula, only one individual was reported in South Korea. Without precise diagnosis of status, strategic prevention and efficient management, however, population expansion by nutria and the establishment of muskrat appear likely.

After reviewing worldwide nutria control, Carter and Leonard (2002) suggested 3 conditions for a successful eradication of nutria; 1) isolated population, 2) cold weather and 3) continued trapping until no nutria remain. South Korea already fulfills the first two conditions. The nutria population is confined to the Nacdong River which freezes in winter. However, the current range limit may be a function of a population lag time preceding significant range expansion to other river systems (NIE 2015). Recent climate warming in the Korean peninsula may also facilitate northward expansion (Hong et al. 2015).

The confinement of invasive nutria to the Nacdong River system, and its relatively slow northward range expansion may be partly explained by colder temperatures in uncolonized areas and the central part of the country is considered a nutria-free zone (Hong et al. 2015). However, population dynamics of invasive nutria in Korea seem to include a 'lag phase', and population increases followed by range expansion could still occur (Crooks and Soule 1999; Holt et al.

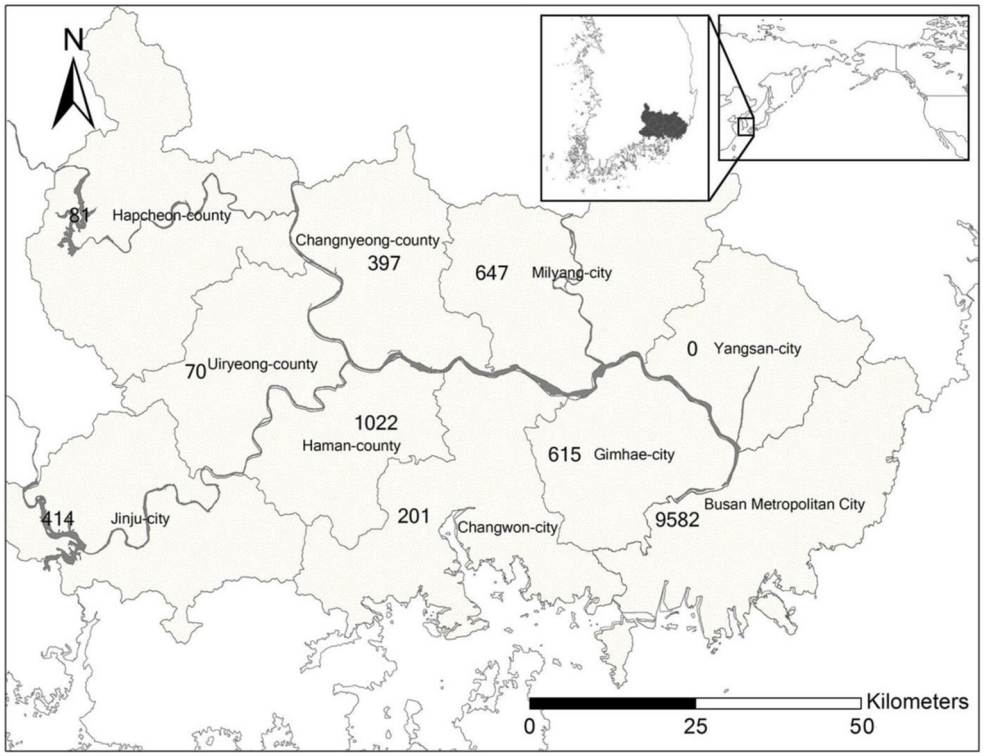

Fig. 1 Nutria range in South Korea. Each number is nutria caught (2011–2014). *Bold gray line* is Nacdong River system

2005). There is high potential for nutria to adapt to cold Korean winters after the lag phase. A historic cold winter combined with active trapping in UK removed 90% of nutria in the 1960s. However, the population recovered for a decade (Gosling and Baker 1989). The feral nutria population in Korea possesses considerable genetic variation from at least two sources (Jung and Jo 2012). Korean nutria may have already overcome the genetic effects of a prolonged lag and may be poised to expand their range despite harsh environmental factors.

Although the US state of Louisiana recently suggested several control methods (Mach and Poche 2002), eradication of nutria is not the objective in Louisiana (Jojola et al. 2009). The situation of nutria in Korea more closely resembles the historical British example. The countries are similar size with similar climates. The Korean and British nutria populations were concentrated in one region. Unlike in UK where nutria farms were closed in 1939, nutria farms in Korea were started in the 1980s just after eradication in the UK had been achieved. Gosling and Baker (1989) identified several factors related to success or failure of nutria and muskrat removal (Table 5). The roles of three of these factors help explain why nutria control in Korea failed to replicate these successful eradication case studies.

First, Korea hired too few nutria trappers and instead depended on bounty hunters. Simulation by Gosling and Baker (1989) showed that, regardless of mean winter temperatures, the number of trappers (adult mortality) was the most important factor for nutria eradication (Gosling et al. 1983). In the Norfolk Broads, UK, 14 trappers failed to achieve eradication, but 24 trappers removed all nutria (Gosling and Baker 1989). Each month, 12–13 trappers were hired by the MOE and covered 23,800 km^2 of Nacdong River basin. For removing nutria from 2.1 km^2, 2 trappers spent 3 years (Bertolino et al. 2005). Compared to more than 200,000 annual trap-nights in the UK (Baker and Clarke 1988), the trap-nights of the Korean campaign in 2014 were 66,480. Without more intensive trapping, eradication of nutria in Korea may not be feasible.

Second, trapping strategies were not systematic in Korea. In UK, trapping deployment was supported by wildlife biologists and it started in core habitat, later expanding to peripheral areas (Gosling and Baker 1989). In the Blackwater National Wildlife Refuge, Maryland, USDA Wildlife Services divided the removal site into 162,000 m^2 trapping units and 15 trappers removed nutria in each unit until complete removal was confirmed (Jojola et al. 2005). Although counties and cities around the Nacdong River basin are connected, there are no unified guidelines or strategies for nutria removal, and each local government independently spends financial resources on bounties. Understanding the current demography and population status of nutria is necessary and the control efforts should be informed by ecological information.

Third, ecological research has not been used to inform South Korea's nutria eradication campaign. While ecological research of nutria was conducted by the National Institute of Environmental Research (NIER) until 2013 and NIE since 2014, the control campaign was implemented by local

Table 5 Comparison of Nutria and Muskrat control between UK and Korea

Examples from UK (Gosling and Baker 1989)	Diagnosis on control nutria project in Korea
Successful factors for Muskrat eradication	
Large number of trapper (39 trappers)	The number of trapper is 12.5/month
Trapping was concentrated in core area and then gradually enlarge to peripheral habitats	Trapping is sporadically implemented and most trapping is concentrated in metropolitan city
Specialized searchers followed by trappers	No support by wildlife biologists
Trapping efforts was continued after muskrats were critically declined.	Nutria population isn't declining yet
Failure factors for Nutria eradication in 1960s	
Small number of trapper (14 trappers)	The number of hired trapper is smaller (12.5)
Main trapping force was wasted in low density area	Density of nutria isn't properly calculated; trapping is concentrated on high human density places
Capture was not intensive enough	Capture intensity isn't estimated yet
Absence of demographic knowledge	Absence of knowledge on demographic and population trends
Not enough following efforts of trapping after nutria decline	There's no critical decline yet
Successful factors for Nutria eradication in 1980s	
Estimating population size and demography	Research and control isn't compatible
Intensive trapping (Simulation shows that at least 24 trappers are necessary)	Trapping is not intensive (monthly 12.5 trappers are hired)
Knowledge supported by wildlife biologists (deploying trappers and monitoring)	No support by wildlife experts Research and control are separated
Incentive to trappers	No incentive for trappers
Cage trapping not leg hold trap[a]	Leg hold trap

[a] Jojola et al. (2009) recommend leg hold trap based on high capture rate. Unlike Louisiana, however, Nacdong river basin has healthy population of Eurasian otter (*Lutra lutra*) and two species ranges are mostly overlapped. Eurasian otter is endangered species and natural monument species in Korea

governments and local environment management offices without scientific support. Unfortunately, local governments in South Korea do not hire wildlife biologists. Baker (2006) pointed out the key feature in success of the nutria eradication in UK is the linkage between research and control. Although the MOE is the headquarters of terrestrial invasive species in Korea, its affiliated agencies are not equipped or trained for nutria control. While the NIE is in charge of nutria research, local environmental management offices implement pest control without being informed by research. Since the South Korean government has composed a taskforce against bird flu, it may be possible to team up with a nutria control taskforce like the Coypu Research Laboratory used for nutria eradication in the UK (Gosling and Baker 1989).

The control of invasive muskrats in the UK has prevented further import of alien animals (Sheail 1988). However, South Korea did not learn the lesson from bullfrog and nutria invasions. Including 2 large farms in central South Korea, 60–80 muskrat farms were scattered throughout the country (NIER 2011) but detailed information about muskrat farms has not been reported. Since parceling-out happened in 2005 and still there is no market for muskrat in Korea, it is expected that failed farms will release muskrats without any preventive measures by the government. Still muskrat sellers are advertising musk from muskrat as a traditional medicine. However, 'American musk' of muskrat is a different chemical compound from 'musk' of musk deer which has been used for perfume and expensive oriental medicine (Philip and Erickson 1942; Ward and van Dorp 1981). Although 'American musk' from muskrat has been regarded as commercially worthless (Groom 1997), muskrat sellers have advertised the pseudo-musk since North Korea developed a technique to extract 'American musk' from muskrat (Ko and An 2003; Ju 2007). Once the facts of 'American musk' are more widely known, muskrat value may plummet, increasing the risk of deliberate release from farms.

Muskrats are ecologically similar to nutria but more cold-hardy (Carter and Leonard 2002) and as they are already established in northeastern Korea, the species may be more problematic to control compared to nutria. Despite 40 years of intensive trapping, the Netherlands is still struggling with muskrat removal (Bos and Ydenberg 2011). Before initiating a control program, the South Korean government would benefit from conducting a thorough review of commercial muskrat operations in order to understand the source population and the potential for accidental or deliberate releases. Occurrences

of feral muskrats should be documented, and clear legal restrictions could prevent further releases. The government may need to acknowledge that ecological safety throughout Korea has priority over private property. Without comprehensive knowledge of the current scale of muskrat invasions or strong legal prohibition, South Korea may have to deal with a much greater challenge from invasive muskrats in future.

Although comprehensive nutria control has not been attempted and muskrat introductions have exacerbated the country's invasive rodent problem, eradication and prevention is still possible in South Korea. However, protracted delays in implementing effective eradication strategies may result in the nutria and the common muskrat becoming permanent members of the country's biota. Eradication will require governmental agencies and local governments to cooperate through unified science-based strategies. Following public agreement on the potential threats from introduced muskrats, Korea's ecological integrity would likely benefit from a prompt government decision on its invasive species status.

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