The survival of captive-born animals in restoration programmes – Case study of the endangered European mink *Mustela lutreola*

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ABSTRACT

As part of a conservation initiative, captive-bred individuals of the endangered European mink *Mustela lutreola* were released to a Baltic island 'sanctuary', Hiiumaa Island (Estonia), and their survival was monitored over eight years. Altogether, 54 released mink were equipped with radio-collars between 2000 and 2003 and their survival and causes of death were studied as a function of sex, age, housing conditions before release and number of generations in captivity. Mortality was greatest ($\sim$ 50%) during 1–1.5 months following release. The survival of males was significantly higher than that of females (25% decline in 21 days, and 10 days, for males and females, respectively). Releasing pregnant females appeared to be an unsuccessful strategy. There was no evidence that the number of generations for which the lineage of the released individuals had been bred in captivity had any effect on survival. The main cause of death was other carnivores and raptors, although this broad categorization may conceal a diversity of fatal scenarios.

We recommend for the future that the European mink being prepared for release should be maintained in large naturalistic enclosures beforehand, that a preponderance of females should be released, and that the indications that younger animals make better candidates for release should be investigated.

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1. Introduction

Restoration is a major element of practical conservation, and the release of captive-born individuals into the wild can be an important component of it. Indeed, re-introduction biology is an important emergent field (Seddon, 1999; Seddon et al., 2007) and there is a growing number of reviews of release methodologies and their effectiveness (e.g. Breitenmoser et al., 2001; Griffith et al., 1989; Reading and Clark, 1996; Seddon et al., 2005).

In a classic review by Griffith et al. (1989), 700 release operations conducted in 1973–1986 were considered with respect to such variables as the number of founders, availability of shelters, origin of founders (captive versus wild animals), taxonomic origin of the animals, repeated releases versus a single operation. Jule et al. (2008) recently showed that the use of wild animals in carnivore restoration is, in general, significantly more successful than

the use of captive-bred animals. Further, analysing the releases of carnivores, Reading and Clark (1996) concluded that too often the focus is on biological variables, while sociological and organizational variables are unwisely neglected (see also Macdonald et al. 2002a,b).

However, Breitenmoser et al. (2001) express doubts as to the validity of such generalisations as they are often based on incomplete information, and Seddon (1999) emphasises difficulties and inconsistencies in defining re-introduction success. Despite these caveats, the survival of the released animals is surely a fundamental benchmark of success, and evidence as to the factors associated with their fates will contribute usefully to the adaptive management of future releases.

The factors potentially influencing the survival of released animals can be divided into four classes: (a) biological variables, e.g. age and sex; (b) pre-release factors, e.g. maintenance conditions, pre-conditioning, experience with humans; (c) release methodology, e.g. along a continuum between hard and soft releases; (d) release site characteristics, e.g. availability of suitable shelter and habitat, abundance of predators, availability of food resources and level of disturbance. These categories may interact with one another in their influence on survival.

Systematic studies of the post-release survival of captive-born mammals, and especially Carnivores, are few. The effect of

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pre-release training and housing has been studied on Black-footed ferret *Mustela nigripes* (Biggins et al., 1998a, 1999; Vargas et al., 1998). Swedish studies have shown that translocated wild-born otters *Lutra lutra* have higher survival than do re-introduced captive-born otters (Sjoasen 1996, 1997). Hellstedt and Kallio (2005) demonstrated experimentally that the survival of released weasels *Mustela nivalis* improved when young animals were released during the periods of high food abundance, while Bremner-Harrison et al. (2004) report that important predictors of the survival of released swift foxes *Vulpes velox* are the extent of their habituation to captivity and measures of their 'boldness'.

European mink is a slender, small, dark-colored, semi-aquatic mustelid that once inhabited streams and rivers throughout Europe. It inhabits riparian zones along small rivers and streams in forested landscapes and seldom moves further than 100 m from riverbank (Danilov and Tumanov, 1976). Today the European mink is globally endangered, and critically endangered within the European Union (Temple and Terry, 2007). Principal threats to its survival are habitat loss, over-exploitation and the impact of the alien American mink *Neovison vison* (Maran and Henttonen, 1995; Maran et al., 1998; Sidorovich, 2001; Sidorovich and MacDonald, 2001). There are no data on the survival of captive-bred European mink in the wild. In 2000, as part of a programme to conserve the European mink, we initiated an experimental release of captive-bred individuals into an island sanctuary, Hiiumaa in the Baltic Sea (Macdonald et al., 2002c; Maran, 2006). This experiment allowed us to test the impact of biological and pre-release factors on the survival of released individuals.

Our wider approach to European mink conservation, and the background to the Hiiumaa experiment, is given in Macdonald et al. (2002c) and in Maran(2003, 2006). In summary, since 2000, European mink bred at a special conservation breeding facility at Tallinn Zoological Gardens (Estonia) have been released to the island of Hiiumaa. The research aim of these releases has been to study the factors relevant to establishing island populations of the European mink as a means of safeguarding them from the neg-

ative impacts of the invasive American mink (Sidorovich et al., 1999).

The experiment contrasted the survival outcomes of alternative release processes, in terms of animal selection, their pre-conditioning, while the release methodology and release site selection followed identical protocols. The release procedure is detailed in Maran (2006). For each released individual we noted the age, sex, number of generations in captivity, housing conditions before release and pregnancy of released females. Radio-tracking data revealed the causes of mortality and facilitated the retrospective analysis of survival, the effect of the dependent variables on survival and the dependence of survival on these variables.

Our study aims to answer the following questions:

1. What is the survival rate of released mink and how does it change with time since release?
2. Do age, sex of an individual, and the conditions in which it is kept prior to release, affect its subsequent survival in the wild?
3. What are causes of mortality?

2. Methods

2.1. Study area

Hiiumaa Island, with an area of 1019 km^2 and a coastline of 326 km, is located in the Baltic Sea in the Atlantic continental region of the Temperate Zone (Fig. 1). The climate is characterized by mild winters (average temperature −3.5−−4.5 °C) and warm summers (+16.5–+17 °C). The annual precipitation ranged in 1961–2002 between 400 and 825 (average 625) mm (Põdra and Maran, 2003).

The shortest distance to the mainland is 22 km and to other larger islands (Vormsi and Saaremaa) – 9 km and 5 km, respectively.

As of 2001, the island had a human population of 11 335 (11.1 inhabitants/km^2), dispersed between three small towns and 182 villages (www.hiiumaa.ee; as of 15.02.2009).
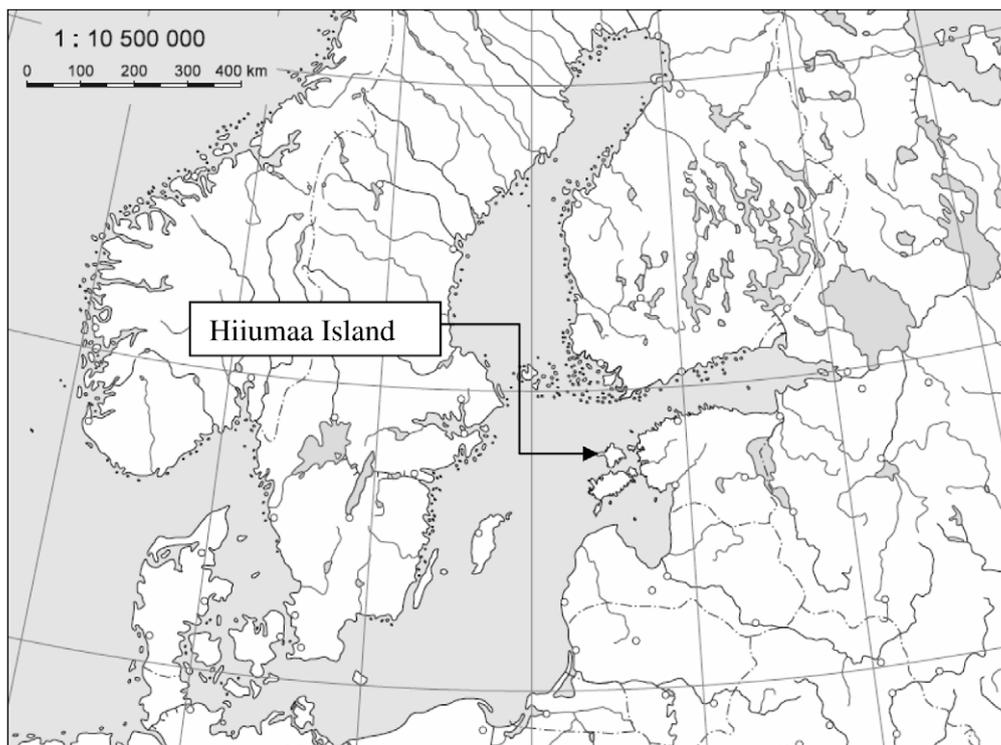

Fig. 1. Location of Hiiumaa Island.

Forest covers around 70% of the island, and more than 22 nature reserves encompass over 20% of the land area (www.eelis.ee; as of 15.02.2009).

2.1.1. Fauna

In addition to the European mink, the mammal fauna of the island includes eight carnivore species – weasel *M. nivalis*, stoat *Mustela erminea*, pine marten *Martes martes*, otter *L. lutra*, raccoon dog *Nyctereutes procyonoides*, red fox *Vulpes vulpes*, lynx *Felis lynx* and wolf *Canis lupus*. There are records of earlier occurrence of polecat *Mustela putorius* and American mink *Neovison vison* in the island but the American mink was eradicated in 1998–2000 (Macdonald et al., 2002c). Other semi-aquatic mammals include beaver *Castor fiber*, northern water vole *Arvicola terrestris* and water shrew *Neomys fodiens*. At least eight species of small rodents have been recorded in Hiiumaa (Põdra and Maran, 2003).

The possible competitors and predators of the European mink among the local raptors are white-tailed eagle *Haliaetus albicilla*, golden eagle *Aquila chrysaetos*, eagle owl *Bubo bubo*, Ural owl *Strix uralensis*, common buzzard *Buteo buteo*, northern goshawk *Accipiter gentilis*, northern harrier *Circus cyaneus*, Montagu's harrier *Circus pygargus* and marsh harrier *Circus aeruginosus* (Põdra and Maran, 2003).

Amphibians are represented by five species. Common frog *Rana temporaria*, moor frog *Rana arvalis* and common toad *Bufo bufo* are common. Natterjack toad *Bufo calamita* and common newt *Triturus vulgaris* are rare. Reptiles are represented by common viper *Vipera berus*, grass snake *Natrix natrix*, slow worm *Anguis fragilis* and common lizard *Lacerta vivipara* (Põdra and Maran, 2003).

The following fish species have been recorded in the inland water bodies of Hiiumaa: *Esox lucius, Perca fluviatilis, Gymnocephalus cernus, Salmo trutta, Lota lota, Anguilla anguilla, Gasterosteus aculeatus, Pungitius pungitius, Rutilus rutilus, Leuciscus leuciscus, Leuciscus idus, Leucaspius delineatus, Carassius carassius, Tinca tinca, Lamperta fluviatilis*. Populations of crayfish *Astacus astacus* exist in four water courses (Põdra and Maran, 2003).

2.1.2. Inland water bodies

There are 40 bigger streams or rivers (with the total length of 326 km) in the island and ∼ 100 km of bigger drainage ditches and 13 lakes with the total length of shoreline of ∼ 25 km (Põdra and Maran, 2003).

2.2. Origin of released animals

The released animals were born in captivity at the conservation breeding facility of Tallinn Zoological Gardens, which is coordinated by the European mink EEP programme (European Endangered Species Program under the European Association of Zoos and Aquaria, www.eaza.net). The captive management follows the European mink EEP captive breeding and husbandry guidelines (unpublished document: accepted by, and lodged with, European mink EEP animal committee in 2005). The founders of the EEP captive population originate from Tver, Vologda, Pskov, Novgorod and

Leningrad Regions of Russia. These regions are considered to be inhabited by one subspecies – *M. lutreola novikovi* (Heptner et al., 1967) though the validity of subspecies for *M. lutreola* has been questioned (Michaux et al., 2005; Youngman, 1982).

2.3. Methodology of release

Before release, the animals were provided an opportunity to catch the prey they were likely to encounter on the island, and their contact with humans (keepers) was reduced to a minimum (human presence was restricted to unavoidable husbandry). Further, the animals were checked for their ability to swim and, as necessary, 'coached' through encouraging the use of artificial ponds (see Macdonald et al., 2002c for details). Releases followed a hard release protocol – transportation from the breeding facility to the release area, where individuals were set free in the most suitable habitats – that is riverbanks of small rivers or canals with lush riparian vegetation and abundant prey. Transport was over a distance of *c*. 150 km and lasted some four to five hours, including a 1.5-h ferry trip. The majority of the radio-tracked released individuals travelled widely, the survivors settling in established home ranges after 1–2 months (Macdonald et al., 2002c).

2.4. Radio-tracking

Fifty-four out of the 172 released mink were equipped with radio-collars (Biotrack, UK; Table 1). In open terrain the signals were detectable at ∼1 km, and in woodland at ∼600 m. The life-span of transmitters was around six month and their weight (14 g) constituted ∼2% of male and ∼3% of female weight. The sample size was reduced due to some transmitter failures and, as is commonplace in radio-tracking studies of mustelines, because the thick neck and narrow head of the mink resulted in occasional loss of radio-collars (Table 2).

The receivers used were TR-4 (Telonics; USA) and R-1000 (Communication Specialist; USA).

After the release, the animals' locations were recorded 1–3 times a day during the first week, every day during the next 20 days, every two days during the second and third month, and once a week thereafter. The status of the free-living mink was regularly monitored by spring and autumn live-trapping (Table 2).

2.5. Survival analyses

Live-trapping records revealed that a proportion of the released animals survived for up to 39 months. However, for the sake of consistency, we included only radio-tracked individuals in these analyses, but excluded eight juveniles released exceptionally in autumn (Table 2).

Failure time analyses were used to study the survival of animals after release and the effect of co-variables on their survival. The animals were divided into groups by variable values (age class, sex, enclosure of origin, number of generations in captivity, year

Table 1
Number of released European mink in 2000–2003.

Year	Number of releases						With radio-collars
	Males	Females		Total released	In summer	In autumn	
		Non-pregnant	Pregnant				
2000	8	9	0	**17**	9	8	17
2001	19	22	0	**41**	41	0	23
2002	23	19	12	**54**	39	15	12
2003	32	14	14	**60**	42	18	2
Total	82	64	26	172	131	41	54

Table 2
Mink radio-tracked in 2000–2003. Maximum survival time – known from yearly live-trapping census following the release operation. These data are not included in the analysis for the sake of consistency in measuring methods. Average *T* - Number of generations in captivity. Status – Mink with the following status were censored: Lost – signal lost; Alive – alive at the end of radio-tracking; Collar – radio-collar lost.

ID	Sex	Pregnant	Birth date	Release date	Last recorded signal	Survival time (radio-tracking)	Maximum survival time	Enclosure type	Age	Average *T*	Status
686	Female	No	09.06.1999	28.06.2000	7.07.2000	9	9	Small	1	1.500	Lost
695	Male	No	18/06/1999	28.06.2000	29.11.2000	154	196	Small	1	3.125	Alive
679	Female	No	04/06/1999	28.06.2000	6.08.2000	38	38	Large	1	1.000	Signal failure
680	Female	No	04.06.1999	29.06.2000	16.07.2000	17	17	Large	1	1.500	Dead
682	Male	No	27.05.1999	29.06.2000	23.11.2000	147	630	Small	1	1.500	Alive
697	Male	No	18.06.1999	29.06.2000	3.08.2000	35	35	Large	1	1.500	Lost
681	Female	No	04.06.1999	30.06.2000	3.12.2000	156	156	Large	1	1.500	Alive
685	Female	No	09.06.1999	30.06.2000	16.07.2000	16	16	Small	1	2.250	Dead
696	Male	No	18.06.1999	30.06.2000	14.07.2000	14	14	Small	1	2.125	Collar
844	Male	No	2.06.2000	12.06.2001	23.06.2001	11	11	Small	1	6.866	Dead
876	Female	No	8.06.2000	12.06.2001	27.06.2001	15	15	Small	1	7.092	Collar
866	Female	No	6.06.2000	13.06.2001	23.06.2001	10	10	Small	1	7.092	Dead
886	Male	No	10.06.2000	13.06.2001	20.06.2001	7	7	Small	1	7.092	Collar
867	Female	No	6.06.2000	16.06.2001	3.07.2001	17	17	Small	1	7.092	Dead
894	Male	No	13.06.2000	16.06.2001	4.07.2001	18	650	Small	1	6.866	Lost
694	Female	No	18.06.1999	17.06.2001	2.07.2001	15	15	Small	2	7.479	Collar
842	Male	No	29.05.2000	17.06.2001	18.08.2001	62	62	Large	1	6.205	Collar
891	Male	No	11.06.2000	17.06.2001	25.08.2001	69	69	Large	1	1.875	Lost
872	Female	No	8.06.2000	18.06.2001	26.06.2001	8	8	Small	1	1.875	Lost
897	Female	No	13.06.2000	18.06.2001	26.06.2001	8	8	Small	1	2.250	Dead
898	Male	No	15.06.2000	18.06.2001	20.08.2001	63	1020	Large	1	2.375	Lost
677	Female	No	7.06.1999	19.06.2001	15.07.2001	26	26	Small	2	2.375	Lost
678	Male	No	4.06.1999	19.06.2001	4.07.2001	15	15	Large	2	1.500	Lost
689	Female	No	13.06.1999	19.06.2001	25.06.2001	6	6	Small	2	1.875	Lost
887	Female	No	10.06.2000	19.06.2001	5.07.2001	16	16	Small	1	1.750	Collar
683	Male	No	9.06.1999	20.06.2001	25.08.2001	66	146	Small	2	1.750	Alive
856	Female	No	5.06.2000	20.06.2001	27.06.2001	7	7	Large	1	1.500	Collar
772	Male	No	7.06.2000	28.06.2001	1.07.2001	3	3	Small	1	3.250	Collar
830	Male	No	19.05.2000	28.06.2001	19.07.2001	21	21	Small	1	3.250	Collar
862	Female	No	5.06.2000	28.06.2001	2.07.2001	4	4	Small	1	2.563	Dead
868	Male	No	7.06.2000	28.06.2001	19.07.2001	21	21	Small	1	2.563	Dead
880	Male	No	10.06.2000	28.06.2001	25.08.2001	58	198	Small	1	1.500	Alive
832	Female	Yes	19.05.2000	4.05.2002	5.05.2002	1	1	Small	2	2.250	Dead
852	Female	Yes	2.06.2000	4.05.2002	9.05.2002	5	5	Small	2	2.250	Collar
881	Female	Yes	10.06.2000	4.05.2002	9.05.2002	5	5	Small	2	2.500	Dead
904	Female	Yes	17.05.2001	4.05.2002	11.07.2002	45	45	Small	1	2.250	Collar
853	Female	Yes	2.06.2000	15.05.2002	22.05.2002	7	7	Small	2	2.125	Dead
906	Female	Yes	17.05.2001	15.05.2002	27.05.2002	12	12	Small	1	2.250	Lost
560	Female	No	25.05.1998	27.05.2002	5.06.2002	9	9	Small	2	1.750	Dead
592	Female	No	9.06.1998	27.05.2002	15.06.2002	19	19	Small	2	1.750	Dead
927	Female	Yes	2.06.2001	27.05.2002	21.08.2002	86	305	Large	1	1.938	Alive
935	Female	No	4.06.2001	27.05.2002	4.07.2002	38	38	Small	1	1.500	Dead
952	Female	No	14.06.2001	27.05.2002	11.06.2002	15	15	Small	1	2.625	Dead
1014	Female	No	31.05.2001	27.05.2002	2.06.2002	6	6	Small	2	1.750	Dead
911	Female	Yes	30.05.2001	27.04.2003	5.05.2003	8	8	Large	2	6.376	Dead
980	Male	No	7.05.2001	27.04.2003	30.04.2003	3	3	Large	2	7.979	Lost

of release). The priority of this project was the successful release of valuable specimens of the rare European mink, and of their welfare. This led to some constraints on the experimental design, and we are alert to the resulting partial lack of orthogonality between variables. Although this reduces the power of our final conclusions, we make this explicit and believe that our findings nonetheless add significantly to the scientific basis for future releases of this, and similar, species.

Kaplan–Meier survival analysis was used (Muenchow, 1986; Pollock et al., 1989a, 1989b; Scheiner and Gurevitch, 2001) to analyse the overall survival curve and the effect of sex and housing on survival.

The multivariate Cox proportional hazard regression (Muenchow, 1986; Scheiner and Gurevitch, 2001; StatSoft, 2007) was applied to identify the model best fitting our data. The general model was reduced stepwise, following the Akaike's Information Criterion (AIC) and Schwarz's Bayesian Information Criterion (Schwarz's BIC; Burnham and Anderson, 2002). To reduce the effect of correlation between variables the data subsets with eliminated correlating variable were used.

Two data subsets were used for modelling:

1. Yearlings within 2000–2001 ($N = 27$). The main purpose of the model was to test the impact of yearly variation on survival.
2. Yearlings and adults in 2000–2003 excluding pregnant females ($N = 38$).
   Kaplan–Meier survival analysis was applied to three datasets:

3. Yearlings and adults of both sexes released in 2000–2003 from standard enclosures ($N = 28$). This dataset eliminated any effect of different housing conditions, and provided an opportunity to distinguish the survival of different sexes. Pregnant females were excluded.
4. Datasets of males ($N = 17$) and females ($N = 21$) released in 2000–2003. These datasets were used to test the effect of housing conditions while controlling for any effect of sex. Pregnant females were excluded.
5. Females, both pregnant and non-pregnant, released from standard enclosures in 2002 ($N = 11$). This dataset was used to test for any effect of pregnancy.

The Systat v 12 for Windows (Systat, 2007) was used to analyse the survival distribution and to model our data with Cox proportional hazard regression.

2.6. Co-variables measured (Table 2)

2.6.1. Average number of generations in captivity

The number of generations in captivity depends upon the length of pedigree lineages of all the ancestors of a given individual. The number of generations in captivity is therefore best characterized by the average length of all these ancestral lineages. These values were calculated with SPARKS v1.55 software (ISIS, 2007). The animals were divided into two groups: an average of <3 ($n = 26$) and >3 generations in captivity ($n = 12$). Data for pregnant females were omitted.

2.6.2. Housing conditions before release

The animals were kept in enclosures of two types (data for pregnant females omitted):

1. Small enclosures: twenty 2×4 m enclosures located in two rows separated by a service corridor. The enclosures were furnished with a few stumps and pipes for environmental enrichment. Each enclosure included one pool 30×50 cm in area and 25 cm in depth. Adjacent enclosures were separated with double welded wire above a 50 cm tall plywood partition at the ground level. The animals were fed and the enclosures cleaned daily. A total of 28 individuals was released from these enclosures.
2. Large enclosures: four $25–50$ m^2 pre-conditioning enclosures constructed of welded wire net encompassing natural areas with trees, bushes and stumps. Each enclosure includes a naturalistic pond (approximate area $1.5 \times 1.5–2.5 \times 2.5$ m and depth $\sim$1 m). Contact with keepers was minimal. A total of 10 individuals was released from these enclosures.

2.6.3. Age classes

The released animals were divided into two age classes (pregnant females excluded):

1. Yearlings: animals released during the second warm season after birth ($n = 29$).
2. Adults: animals released later than the second warm season after birth ($n = 9$).

2.6.4. Sex

Twenty-one females and 17 males were included in the Cox Proportional Hazard Regression (having excluded pregnant females).

2.6.5. Pregnant females

Only females released from standard enclosures in 2002 were included in testing the effect of pregnancy ($N = 11$). Six of these were pregnant and released during their third week of pregnancy.

2.6.6. Year of release

The impact of years to survival was tested in two datasets: (a) release of yearlings in 2000–2001 ($N = 27$) and an expanded dataset from 2000–2003 ($N = 38$).

2.7. Causes of mortality

Field signs were used to ascertain, as far as possible, the causes of death of radio-tracked mink.

3. Results

3.1. Overall survival

Most mortality was recorded during the first 30 days following release (Fig. 2). The mean survival time was 54 days and 25% of the mortality occurred during the first 16 days (95% Conf. Lower – 10 days; 95% Conf. Upper – 22 days).

3.2. Cox proportional hazard analysis

3.2.1. Dataset 1. Yearlings within 2000–2001 (N = 27)

According to the Cox proportional hazard regression analysis (Statistic = 11.391; df = 4; $P = 0.023$), at least one of the candidate dependent variables was significantly related to survival (general model in Table 3). There is no evidence of an effect of history in captivity or of a year of release. According to this general model, sex has a strong and significant effect. The reduced model confirm the effect of sex on survival (Statistic = 9.755; df = 2; $P = 0.008$; Table 4). The omission of the year and the generations from this model improved its fit to our data.

3.2.2. Dataset 2. Yearlings and adults in 2000–2003. (N = 38)

Considering that fitting the model to dataset 1 had shown that inter-annual differences did not explain significant variation, we expanded the dataset with results from 2002/2003 and repeated the model fitting exercise. The results were similar. The general model showed that at least one of the variables had significant
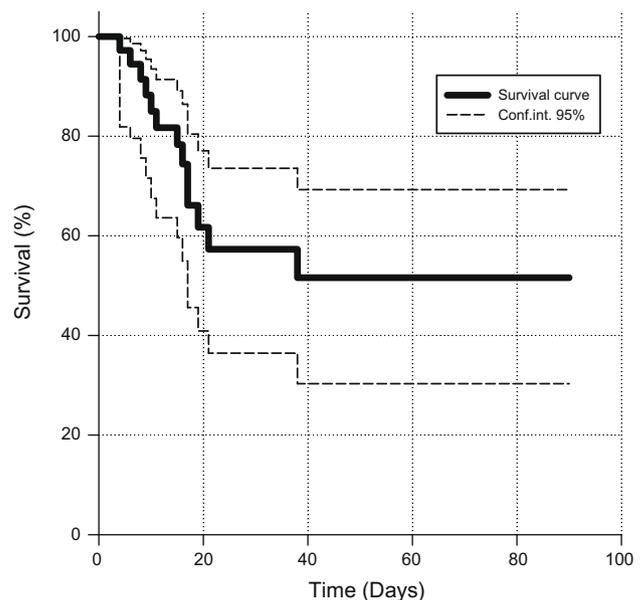

Fig. 2. Overall cumulative survival curve of released European mink ($N = 38$).

Table 3
General model for Dataset 1 of yearlings in 2000–2001 ($N = 27$). Cox proportional hazard regression analysis (the value of estimate means the covariate increases the hazard, that is – decreases the survival; AIC = 42.218; Schwarz's BIC = 42.536).

	Estimate	Standard error	Z	P-value
Sex	−2.406	1.023	−2.351	0.019
Year	0.628	1.040	0.604	0.546
Housing	−1.983	1.331	−1.490	0.136
No of generations	−0.299	0.931	−0.321	0.748

Table 4
Reduced model for Dataset 1 of yearlings in 2000–2001 ($N = 27$). Cox proportional hazard regression analysis (the value of estimate means the covariate increases the hazard, that is - decreases the survival; AIC = 38.605; Schwarz's BIC = 38.764).

	Estimate	Standard Error	Z	P-value
Sex	−2.323	0.954	−2,434	0.015
Housing	−2.262	1.163	−1,945	0.052

Table 5
General model for Dataset 2 of yearlings and adults in 2000–2003 ($N = 38$). Cox proportional hazard regression analysis (the value of estimate means the covariate increases the hazard, that is – decreases the survival; AIC = 74.813; Schwarz's BIC = 77.638).

	Estimate	Standard error	Z	P-value
Sex	−1.874	0.837	−2.239	0.025
Year	0.367	0.515	0.713	0.476
Housing	−1.505	1.229	−1.225	0.221
Age	−0.475	0.689	−0.690	0.490
No of generations	0.065	0.137	0.478	0.633

Table 6
Reduced model for Dataset 2 of yearlings and adults in 2000–2003 ($N = 38$). Cox proportional hazard regression analysis (the value of estimate means the covariate increases the hazard, that is – decreases the survival; AIC = 56.911; Schwarz's BIC = 58.041).

	Estimate	Standard error	Z	P-value
Sex	−2.050	0.800	−2.563	0.010
Housing	−2.029	1.071	−1.894	0.058

effect to survival (Statistic = 15.642; df = 5; $P = 0.008$; Table 5), but there was no significant impact of history in captivity, age, housing or the year of release. These variables were omitted from the model in a stepwise manner. The reduced model incorporates only two variables, sex and housing, and is stratified by age (Statistic = 11.724; df = 2; $P = 0.003$; Table 6). The impact of sex is clearly significant and that of housing nearly so. There was no significant difference between two age strata (yearlings and adults; Mantel test, Statistic = 0.212; df = 1; $P = 0.644$).

3.3. Survival of females and males (Dataset 3)

The survival of males was significantly higher than that of females (Statistic = 6.973; df = 1; $P = 0.008$; Fig. 3). Male survival rate fell by 25% over 21 days, while the female survival rate reached this point over 10 days. The median survival time for females was 17 days and declined to a plateau of 25% in 38 days. The fall in male survival was slower and then declined to a plateau of 74%.

3.4. Survival of animals depending upon pre-release housing conditions (Dataset 4)

Our data were insufficient to detect difference in survival of males released from different enclosures ($N = 16$; Statistic = 1.221; df = 1; $P = 0.269$). Although, there are indication that females released from large enclosures survived better, the data are insufficient to confirm this ($N = 21$; Statistic = 3.021; df = 1; $P = 0.082$).

3.5. Survival of pregnant and non-pregnant females (Dataset 5)

There were no significant differences in survival of pregnant and non-pregnant females (Statistic = 0.038; df = 1; $P = 0.864$).
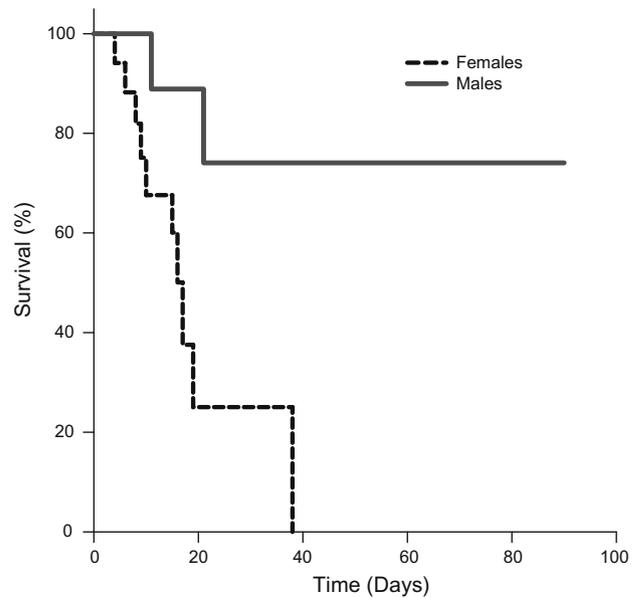
Fig. 3. Survival curves for males ($N = 11$) and females ($N = 17$) released from standard enclosures in 2000–2003.

In three cases, the litters produced by females released when pregnant could be monitored. In each case the litter disappeared at about 1.5–2 months of age, and the mothers were recorded alive more than a year later.

3.6. Causes of death

The majority of attributable causes of death were due to other carnivores (59%; Fig. 4), most of them due to red fox *V. vulpes* and domestic dog.

Four deaths, all females, were attributed to raptors, probably goshawks, *A. gentilis*, or Ural owl, *S. uralensis*. We observed three Goshawk attacks on mink held in enclosures in Hiiumaa Island (Maran & Põdra, unpublished).

Three deaths were caused by humans: one was shot, the second was hit by a car and the third was beaten to death when venturing into a farmyard.

4. Discussion

A quarter of the released European mink died within the first ten days. Survival decreased by half in 38 days and then stabilised. This is in line with Macdonald et al. (2002c) who analysed an earlier sub-sample of the first five released mink (released in 2000) and reported that they established stable home ranges in 25–72 days (median = 31, mean = 41.2). Overall, we conclude that mink adapt to the wild c. 1–1.5 months after release.

4.1. Challenges in retrospect analysis of re-introduction data

Our retrospective analyses were constrained by the priorities of the re-introduction programme. Nonetheless, they provide the most substantial scientific basis yet for planning the restoration of this highly imperilled mustelid, and also provide a basis for planning further experimental releases in the quest for definitive analyses.

4.2. The effect of recorded co-variables on the survival curve

Survival varied between males and females, but we could detect no effect of age. Although no effect of year could be detected, its
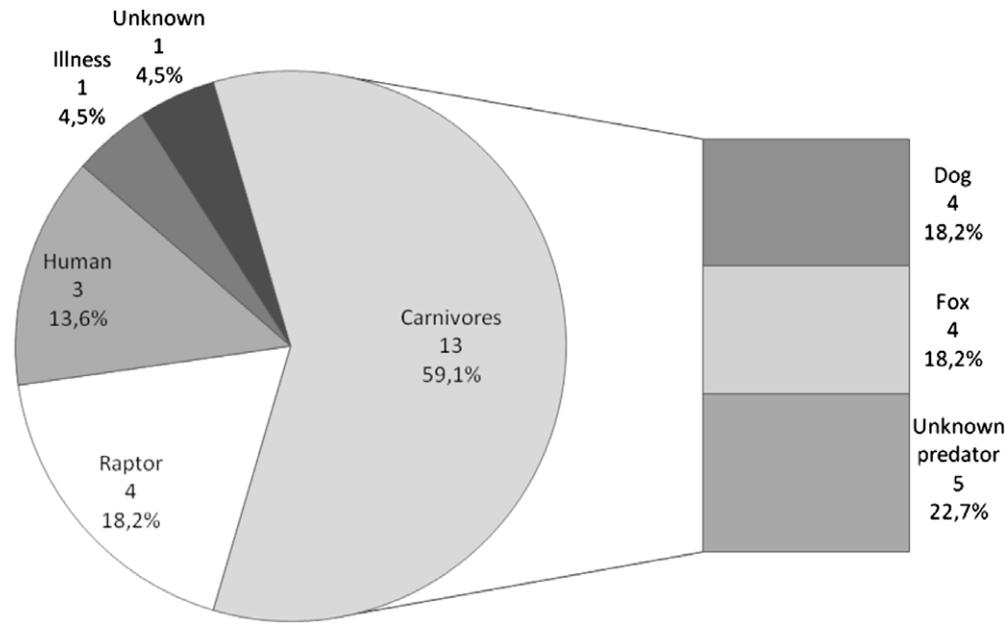
Fig. 4. Causes of death (*N* = 22).

interaction with other factors means that it cannot be fully disregarded.

Although our study represents the largest attempt to reintroduce European mink, the data were nonetheless too few to demonstrate more than indicative effects of housing conditions. However, these indications clearly deserve further investigation. The importance of pre-release housing conditions has been demonstrated by the black-footed ferret *M. nigripes* release operation (Biggins et al., 1998a; Vargas and Anderson, 1999; Vargas et al., 1998).

The survival of mink did not seem to be affected by the number of generations their ancestors had spent in captivity. Pre-release factors, which shape the behavioural capability of mink after release, matter more.

The results show that genetically managed, long-term breeding programs within the zoo community can be a source of individuals for re-introductions (WAZA, 2005).

The sex difference in survival might be a consequence of sexual dimorphism. Female European mink are about 60% the weight of males (Danilov and Tumanov, 1976). This might provide males with an advantage in finding food and avoiding predators, but similar differences between male and female survival have been reported for species without sexual dimorphism, such as swift fox *V. velox* in Canada (Moehrenschlager and Macdonald, 2003). Interestingly, of all the fatalities recorded in our study, the victims of raptors were always females.

The release of pregnant females is controversial. If successful it could lead to rapid bolstering of the population. On the other hand, if survival of pregnant females was low, it could diminish the efficiency of release operations and raise ethical concerns. Our data fail to show a significant difference between the survival of pregnant and non-pregnant females after one year, or within a single year.

The disappearance of litters approximately two months post partum suggests failure to reach independence (during a period when the energetic demand on lactating mammals is known to increase). As lactation progresses the energetic drain on female mammals increases to 4–7 times above the basal metabolic rate (Allen and Ullrey, 2004).

Although our data were too few to reveal any impact of age on survival, the short reproductive lifespan of females – only 3–4 sea-

sons (T. Maran, unpublished) – underlines the likelihood that using mostly younger females for release is prudent.

4.3. Causes of death

Predators caused a large proportion (75%) of all the recorded deaths. During the adaptation period the released European mink undertook extensive movements, often through unsuitable habitats (Macdonald et al. 2002c). The associated strains may be debilitating, increasing susceptibility to predation. Consequently, although predators are the proximate cause of death, the ultimate causes may be a syndrome of mal-adaptations.

5. Conclusions and recommendations

Re-introduction of mammalian predators is an important and challenging component of re-introduction biology, where limited sample sizes and practicalities often thwart systematic analyses. Although our analyses were to some extent constrained by these problems, our data nonetheless provide the fullest opportunity to study the re-introduction of European mink to date. Furthermore, they reveal several statistically significant affects on survival. These are the basis for the following conclusions and recommendations for future releases of European mink (and may plausibly be relevant to other species too):

1. The first 1–1.5 months after release – the months with the highest mortality – are critical for a release operation. Any actions planned to support the survival of released individuals should focus on this period.
2. The higher mortality of females should be compensated by releasing a greater proportion of them.
3. The release of pregnant females is not a successful strategy.
4. Housing of animals in enclosures with a natural interior is sufficiently likely to contribute to post-release survival that prudence favours this approach.
5. The number of generation in captivity contributes less to survival than the preparation of animals for release and biological parameters of the individuals.

Finally, although this analysis considers critically important impacts of biological factors, and aspects of pre-release management on survival, it is noteworthy that no single prescription for release is likely to suit all circumstances – a wide array of consideration will always affect project planning.

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