Arch. Hydrobiol. 155 1 163-176 Stuttgart, August2002

An endangered species as indicator of freshwater quality: fractal diagnosis of fragmentation within a European mink, *Mustela lutreola,* population

T. Lodé[1]

With 2 figures and 4 tables

Abstract: Decline of endangered species may be regarded as an indication of a deteriorating environment. European mink *Mustela lutreola* are freshwater predator populations which suffered a severe decline and are currently restricted to only two areas in Europe. A survey on distribution revealed that mink western population was highly fragmented. Watercourses occupied by mink significantly differed by their quality from watercourses where no mink were evidenced, with regard to most physico-chemical parameters studied, organic and oxidizable matters, nitrogenous matters, phosphorus concentration, heavy metals, pesticides and other micropollutants, and hydrobiological quality. A Gaussian representation of mink breeding dispersal was performed and, based on a ln-ln regression analysis, the fractal dimension *D* provided an accurate quantitative evaluation of the subdivision level. As revealed by low fractal dimension (*D* =1.40), subdivision within the mink population may be reaching a critical threshold for European mink conservation. Fractal investigation constitutes a resourceful method for relating environmental deterioration and breeding dispersal in endangered species. Moreover, mink were found to avoid some watercourses which still provide domestic water supplies for human people and the level of fragmentation should be seen as a warning of the deterioration of freshwater ecosystems.

Key words: Pollution, water quality, indicator species, *Mustela lutreola*, fractal.

Introduction

One of the more direct effects of environmental degradation is the decline of sensitive species and habitat alteration may be regarded as the chief threat for most of the world's endangered species (SOULÉ 1986, KERR & CURRIE 1995). Habitat degradation refers to both habitat loss and habitat fragmentation (FAH-

[1] **Author's address:** Laboratoire d'Écologie Animale, Université d'Angers, Belle-Beille, 2, bd Lavoisier, F49045 Angers, France
E-mail: thierry.lode@univ-angers.fr

0003-9136/02/0155-0163 $ 3.50

RIG 1997). For wildlife species, habitat patches may be interspersed in damaged environments, which gives rise to a heterogeneous fragmentation within the population. How the spatial pattern of the landscape affects wildlife populations at various scales is of considerable evolutionary interest (WIENS 1989, HASTINGS 1990). Habitat fragmentation is expected to produce a pronounced decline of populations because decreasing connectivity results in a lessening of population exchanges (LANDE 1987, 1988, FAHRIG & MERRIAM 1994, COLLINGHAM & HUNTLEY 1999). The effect of population spatial subdivision varies according to the size of the discrete subpopulations, but could cause a severe decline leading to extinction, if no immigration can occur from a main population (SLATKIN 1987, LANDE 1987, BENDER et al. 1998).

Because they are at the top of the food chain, freshwater predators such as otters or mink may be especially vulnerable to habitat loss and deteriorating water quality (MASON & MAC DONALD 1986, LODÉ 1993, KRUUK 1995). Most European mink *Mustela lutreola* populations have dramatically declined all over Europe and the range of the species is now divided into an eastern area (from the Baltic to the Black Sea) and a western population restricted to Western France and Northwestern Spain (YOUNGMAN 1982). The species may be regarded as one of the most endangered mammals in the world (SCHREIBER et al. 1989). Numerous causes have been evoked to explain such a decline, including trapping, unfavourable competition with introduced American mink and habitat loss (MARAN & HENTTONEN 1995, LODÉ et al. 2001). It has been also suspected that mink as subaquatic predators might be sensitive to watercourse quality and affected by bioaccumulation of contaminants.

In freshwater ecosystems, water contamination by toxicants may be considered as a major constraint for wildlife species. Because of the degradation of freshwater habitats, mink could be unable to settle in and to colonise the vicinity of areas occupied by other congeners. It could be predicted that mink avoidance from polluted watercourses might result in a greater subdivision of populations.

Conversely, it may be suspected that the level of fragmentation of such an endangered species could be regarded as a chief alarm for deteriorating water quality. A population is fundamentally a group of interacting individuals and population exchanges are both distance-dependent and more frequent in contiguous zones (GADGIL 1971). Even if landscape connectivity is not apparent, subpopulations should be functionally connected by breeding dispersal to persist (FAHRIG & MERRIAM 1994; FRANKHAM 1995). Therefore, landscape characteristics do not only result in a structural, but in a functional connectivity and breeding dispersal occurs in what MANDELBROT (1975, 1983) called a fractal dimension smaller than an Euclidean surface such as a square. The fractal dimension takes into account the different scales of a distribution and results from the trend to increase boundaries and surfaces of exchange in nature (MANDELBROT 1975, 1983). Emphasising that distance and disruption in connectivity affect exchanges, the fractal dimension measures the level of fragmentation within the population.

This study aims at relating the patchy distribution of the *Mustela lutreola* western population in France to watercourse quality. I propose a Gaussian representation the fractal measurement of which allows to quantitatively investigate fragmentation level within the population. The aim is to estimate whether the deterioration of water courses may have affected breeding dispersal, resulting in fragmentation. Dealing with an endangered species, this study is an original approach combining a mathematical model of dispersal with an evaluation of environmental deterioration.

Methods

European mink distribution

The distribution pattern of European mink *Mustela lutreola* was based on a cumulative approach to distribution-mapping. Firstly, 168 hydrographical zones corresponding to sub-basins were surveyed for the presence or the absence of *M. lutreola* using trap-lines of 10 box traps set during 10 days along 1-2 km of bank side from 1992 to 1998. These provided 47 evidences of mink (see MAIZERET et al. 1998). Secondly, 72 other data (accidental captures, road-killed animals etc…) showing the presence of *M. lutreola* from 1992 to 1998 were accurately mapped. Thirdly, the distribution map was updated for 1998-2001 and extended to 34 other hydrographical zones including all new records based on trapping (n = 44). Thus, the distribution was studied in a total of 202 hydrographical zones (between two river confluences) and mink was presumed absent if no mink was evidenced during the study period. Mink are known to use the banks of a 2.4-6 km river stretch (DANILOV & TUMANOV 1976; PALAZON & RUIZ-OLMO 1993), therefore, I estimated that for each capture a maximum length of 6 km was occupied by a mink. For the 202 hydrographical zones studied, the quality of most water-courses was based on measurements obtained in 436 to 875 stations depending on the parameter (from 2 to 6 stations per zone, except pesticides for which data on only 194 stations were available). Most of the watercourses were partitioned into five classes of quality (class 1: excellent, 2: good, 3: medium, 4: poor and 5: heavily polluted) regarding seven physico-chemical and biological parameters: *1)* organic and oxidizible matters, *2)* nitrates, *3)* other nitrogenous matters, *4)* phosphorus concentration, *5)* heavy metals, *6)* pesticides and micropollutants and *7)* hydrobiological quality (Table 1). The hydrobiological quality was assessed by a global normalised biological index (IBGN Indice biologique global normalisé, AFNOR 1992) partly based on benthic invertebrate biodiversity regarded as a bio-indicator with five classes. Measurements were performed ten times per year by Agence de l'Eau Adour-Garonne in 1998. Nonetheless, data on quality were not available for the total length of every water-course.

Table 1. Physico-chemical and biological factors taken into account for defining classes of watercourse quality according to seven parameters of contamination

Organic and oxidizible matters	Class 1	Class 2	Class 3	Class 4	Class 5
O_2 (mg/l)	>7	5-7	3-5	3-1	<1
O_2 saturation (%)	>90	90-70	70-50	49-30	<30
BOD (mg/l O_2)	<3	3-5	5-10	10-25	>25
COD (mg/l O_2)	<20	20-25	25-40	40-80	>80
Oxydation by KMnO4 (mg/l O_2)	<3	4-5	6-8	9-10	>10
DOC (mg/l C)	<5	6-7	8-10	11-15	>15
Nitrates					
NO_3^- (mg/l-NO_3)	<5.0	5-25	25-50	50-100	>100
Other nitrogenous matters					
NH_4^+ (mg/l-NH_4)	<0.1	0.1-0.5	0.5-2.0	2.0-8.0	>8.0
Kjeldahl nitrogen (mg/l-N)	<1	1-2	2-3	3-5	>5
Phosphorus concentration					
Total Phosphorus (mg/l-P)	<0.1	0.2-05	0.5-1.0	1-5	>5
PO_4^{3-} (mg/l-PO_4)	<0.1	0.1-0.25	0.25-0.50	0.5-2.5	>2.5
Heavy metals (mg/kg dry matter)					
Arsenic	<0.7	0.7-1	1-7	7-10	>10
Cadmium	<0.7	0.7-1	1-4.2	4.2-6.3	>6.3
Chromium	<5.2	5.2-7.8	7.8-52	52-78	>78
Copper	<1.9	1.9-2.8	2.8-19	19-28	>28
Mercury	<1.3	1.3-2	2-7	7-11	>11
Nickel	<1.6	1.6-2.4	2.4-16	16-24	>24
Lead	<4.1	4.1-6.1	6.1-41	41-61	>61
Zinc	<124	124-186	186-271	271-407	>407
Pesticides and micropollutants					
alachlore (ìg/l)	<3	3-30	30-1400	1400-1425	>1425
aldicarbe (ìg/l)	<0.05	0.05-0.5	0.5-50	50-60	>60
aminotriazole (ìg/l)	<38	38-380	380-3800	3800-27200	>27200
atrazine (ìg/l)	<0.2	0.2-2.0	2-20	20-440	>440
carbofuran (ìg/l)	<0.015	0.015-0.15	0.15-1.5	1.5-300	>300
deltamethrine (ìg/l)	<0.0002	0.0002-0.002	0.002-0.02	0.02-4	>4
dinoterbe (ìg/l)	<0.003	0.003-0.03	0.03-3.0	3-407	>407
diuron (ìg/l)	<0.2	0.2-2.0	2-20	20-550	>550
flusilazole (ìg/l)	<1	1-10	10-1200	1200-2000	>2000
lindane (ìg/l)	<0.01	0.01-0.1	0.1-1.1	1.1-22	>22
mancozebe (ìg/l)	<1	1-10	10-110	110-2000	>2000
simazine (ìg/l)	<0.02	0.02-0.2	0.2-2.2	2.2-200	>200
tebuconazole (ìg/l)	<1	1-10	10-110	110-2000	>2000
trifluraline (ìg/l)	<0.2	0.2-2	2-10	10-43	>43
trichloroethane 1-1-1 (mg/l)	<0.13	0.13-1.3	1.3-11	11-26	>26
carbon tetrachlorure (mg/l)	<0.35	0.35-3.5	3.5-35	35-38	>38
dichloroethane 1-2 (mg/l)	<1.1	1.1-11	11-120	120-160	>160
tetrachlorethylene (mg/l)	<0.05	0.05-0.5	0.5-5	5-33	>33
trichlorethylene (mg/l)	<0.18	0.18-1.8	1.8-18	18-23	>23
pentachlorophenol (ìg/l)	<0.1	0.1-1	1-54	54-80	>80

Table 1. Continued**.**

	Class 1	Class 2	Class 3	Class 4	Class 5
chloroforme (mg/l)	<0.12	0.12-1.2	1.2-18	18-79	>79
H.A.P. (µg/kg)	<113	113-226	226-1500	1500-3000	3000
hexachlorobenzene (µg/kg)	<4.5	4.5-9	9-45	45-90	>90
D.D.E. (µg/kg)	<0.2	0.2-0.4	0.4-2	2-4	>4
D.D.T. (µg/kg)	<1.6	1.6-3.2	3.2-16	16-32	>32
PolyChloroBiphenyls (µg/kg)	<2	2-4	4-22	22-44	>44
Hydrobiological quality					
IBGN index (indicator organisms)	17-20	13-16	9-12	5-8	<5

Fishing quality	Class 1	Class 2	Class 3
CSP index	*conformed to the expected community*	*Absence or proliferation of some species*	*discordance regarding the expected community*
Salmonid watercourses	Trout associated with bullhead, minnow, loach, grayling and running water cyprinids		
Cyprinid watercourses	Roach, rudd, carp, bleak associated with pike, pikeperch and river perch,		

Furthermore, regarding the different ecological characteristics and the type of fish (cyprinids or salmonids) stocked, the fishing quality of watercourses was appreciated through three classes among cyprinid watercourses and three among salmonid watercourses. The estimation was carried out from data obtained in 1995 by electrical fishing (Conseil Supérieur de la Pêche). The assemblage composition (number of individuals per species) was used because this evaluation reflected the quality of the fish community better than a biomass estimation which could vary locally. Three levels of quality were possible: first the sample conformed to the expected community (class 1), second some species were not found or some species proliferated (class 2), third the sample revealed a clear discordance regarding the expected community (class 3). The χ^2 tests (eventually with Yates' correction) were performed on the number of sampling sites.

The fractal model of dispersion

Mink distribution was treated in two steps: a Gaussian representation and a fractal analysis. In order to model potential breeding dispersal, the mapping was smoothed out through a Gaussian blur of the conventional form

$$f(j,k)=\left(\frac{1}{\sqrt{2p s}}\right)^{\left(\frac{-(j^2+k^2)}{2s^2}\right)}$$

with (j,k) representing the intensity at the position (j,k) (PRESS et al. 1992). Six areas of 128 km x 128 km were arbitrarily defined (see Fig. 1). Because breeding dispersal occurred over about twelve kilometres in male mustelids (LODÉ 2001,GARIN et al. 2002), the Gaussian blur illustrates the potential dispersal within a radius of 12 km around every occupied site (24 km diameter). The representation does not illustrate the density in subpopulations but their connectivity and when numerous population exchanges are possible the Gaussian blur representation is represented with a darker shade. The patchy distribution i.e. its fractal dimension *D*, is estimated through the slope of a ln-transformed regression between grid cell L and the scale of resolution (G) as L (G) G ($^{1-D}$) (MANDELBROT 1983). Using the box counting method (MORSE et al. 1985), the fractal analysis was performed for every 128 km x 128 km area, repeatedly divided into 4 squares in 5 iterations, each one increasing the scale of resolution by 0.5 (4 squares, 62 km), 0.25 (16 squares, 31 km), 0.0625 (64 squares, 15.5 km), 0.0156 (256 squares, 7.75 km), and 0.0039 (1024 squares, 3.875 km), the finest resolution reaching 3.875 km. Within each scale of resolution, the number of squares occupied was counted and a ln-ln regression analysis was performed between the scale and the number of inhabited squares (N). Fractal dimension was calculated as $D = k \ln N / k \ln G$ (MANDELBROT 1983) (where *k* is the prefactor and G the scale of resolution) from the slope of the equation following VIRKKALA (1993) reviewed by GAUTESTAD and MYRESTUD (1994). The number of empty cells in the distribution pattern reduces the value of the fractal dimension *D* which is lower when the fragmentation is great.

Results

In France, the European mink *Mustela lutreola* western population was restricted to the southwest occupying 978 km of watercourses (Fig. 1).

Mink were not uniformly distributed but the population was subdivided into several demes, few of them connected in the south of the range. Regarding potential breeding dispersal, the Gaussian representation showed a clear fragmentation within the population and mink distribution greatly differed among areas. Some subpopulations appeared to have a significant role for exchanges, constituting "bridges" between "island" subpopulations. All regression slopes of the ln-ln analysis were significant and obviously negative (Fig. 2). The fractal dimension *D* reached 1.684 in area 1 but the value was only 1.032 in area 6 (Table 2). The fractal dimensions of the three eastern areas 2, 4 and 6 were smaller than the average *D* = 1.40, indicating a greater subdivision.

The hydrobiological quality could be regarded as altered since 63.4% of the watercourses were in classes 3 (medium), 4 (poor) and 5 (heavily polluted). Regarding the same quality classes, pesticides and other micropollutants affected 54.6% of the watercourses while phosphorus and nitrate concentrations exceeded detection threshold of class 3 in 41.5% and 34.3% of the watercourses, respectively. Similarly, heavy metals were found in 26.4% of the watercourses. By contrast, only 4.4% of the salmonid streams and 3.2% of the cyprinid watercourses showed a poor fishing quality.

Mink significantly avoided watercourses with a bad quality for all parameters except nitrate contamination (Table 3). Unsurprisingly, mink signifi-

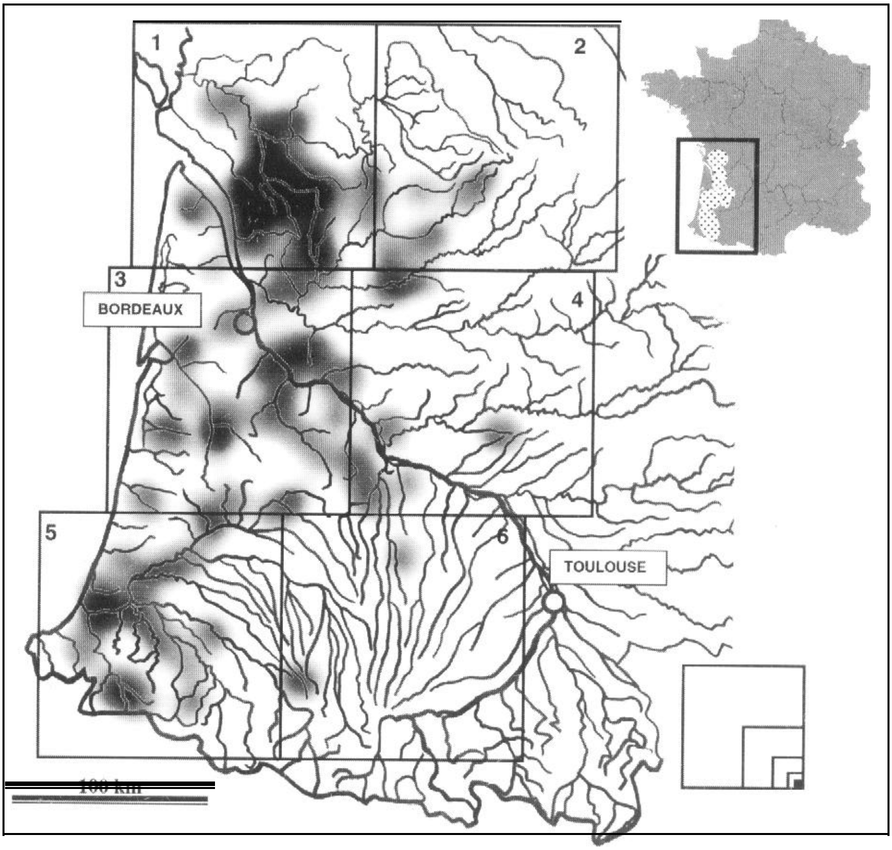

Fig. 1. **Gaussian** representation **of** European **mink,** *Mustela lutreola*, **population in** Southwestern France. (Lower right: squares show the 5 reiterated divisions **of the 6 main areas for** fractal **analysis).**

cantly occupied watercourses showing the better fishing quality either in salmonid or in cyprinid water courses (Table 4).

Finally, the fractal values D of mink distribution in the 6 areas were significantly related to watercourses (occupied by mink) showing the best quality (classes 1 et 2) either for organic and oxidizible matters ($r_{Spearman} = 0.886$, $p < 0.033$), other nitrogenous matters ($r_{Spearman} = 0.928$. $p < 0.017$), phosphorus concentration ($r_{Spearman} = 0.986$, $p < 0.003$), or heavy metals ($r_{Spearman} = 0.928$, $p < 0.017$). Only a marginal significance was obtained for pesticides and other micropollutants ($r_{Spearman} = 0.812$, $p < 0.06$). No con-elation war found for the level of nitrates ($r_{Spearman} = -0.029$ $p > 0.05$), hydrobiological ($r_{Spearman} = 0.638$, $p > 0.05$) and fishing qualities ($r_{Spearman} = 0.314$, $p > 0.05$).

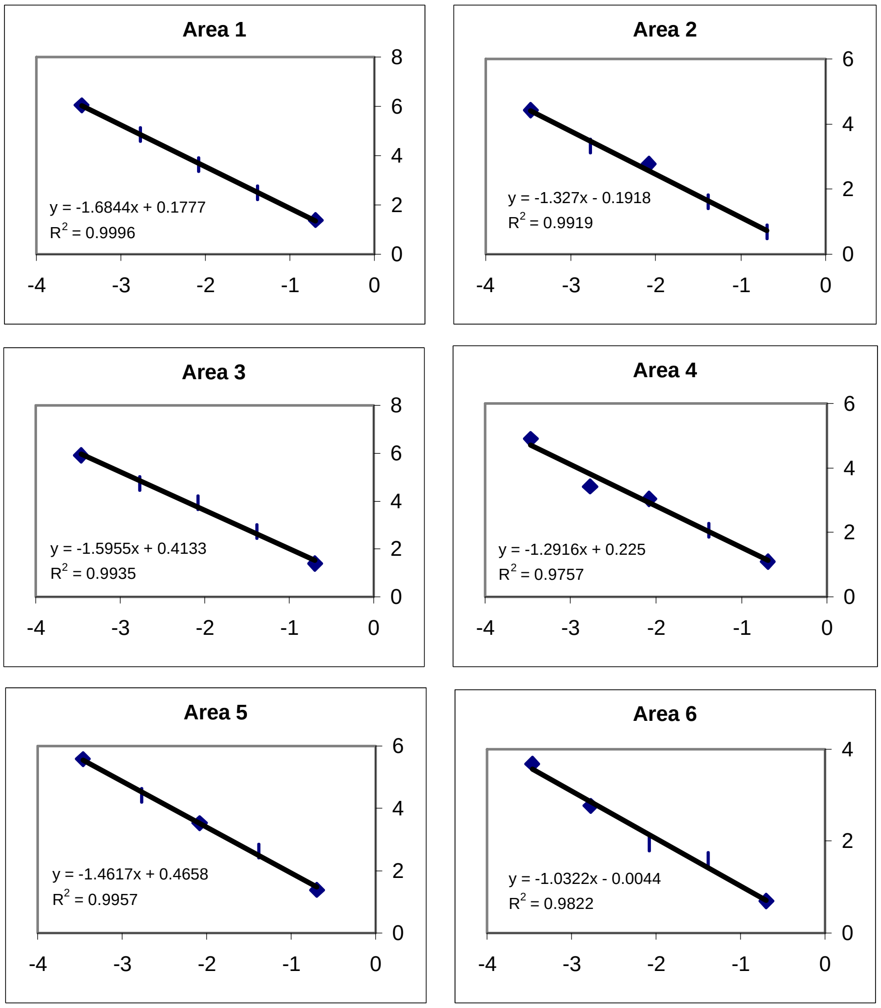

Fig. 2. Ln-ln regression analysis considering number of squares where mink were evidenced (y = ln number of squares for each iteration) and scale of resolution (x = ln resolution for each iteration, as ln0.5, ln0.25, ln0.125, ln0.0625, ln0.03125) for the 6 areas inhabited by the *Mustela lutreola* western population (France).

Discussion

Gene flow in subdivided populations results either from the permanent transfer of migrants settling in other subpopulations or from short-term mating excursions (KOENIG et al. 1996, AARS & IMS 1999). In fact, spatial patterns of animals are strongly influenced by environmental constraints (BURROUGH

Table 2. Fractal dimensions of *Mustela lutreola* distribution regarding potential breeding dispersal in the six areas in Western France (Fig. 1)

	Fractal dimension D	Explained variance	p
Area 1	**1.684**	99.9%	<0.0001
Area 2	**1.327**	99.2%	<0.0003
Area 3	**1.596**	99.4%	<0.0002
Area 4	**1.292**	97.6%	<0.0016
Area 5	**1.462**	99.6%	<0.0001
Area 6	**1.032**	98.2%	<0.001
Mean study area	**1.398**		

Table 3. Proportions of stations where mink were evidenced and where no mink were evidenced related to different classes of watercourse quality (from the best to the worse class) for seven contamination parameters. (Classes 3 and 4 were pooled for calculating χ^2, except for phosphorus concentration, hence the dfs, N = number of stations)

Watercourse quality		Class 1	Class 2	Class 3	Class 4	Class 5	*N*	χ^2	*P*
Organic and oxidizible matters	Mink present	6.9	77.0	13.8	2.3	0.0	*87*	13.3 df3	<0.004
	No mink	15.0	57.2	25.6	0.7	1.5	*788*		
Nitrates	Mink present	10.9	58.9	30.2	0.0	0.0	*73*	2.6 df3	= 0.452
	No mink	11.9	53.4	31.8	2.9	0.0	*754*		
Other nitrogenous matters	Mink present	25.6	69.8	4.6	0.0	0.0	*86*	10.4 df3	<0.015
	No mink	26.9	56.1	12.6	3.2	1.2	*665*		
Phosphorus concentration	Mink present	40.0	47.6	8.7	3.7	0.0	*80*	31.1 df4	<0.0001
	No mink	25.8	29.5	28.9	11.2	4.5	*748*		
Heavy metals	Mink present	79.0	16.1	0.0	4.9	0.0	*62*	32.5 df3	<0.0001
	No mink	43.0	27.0	25.4	4.6	0.0	*374*		
Pesticides and micropollutants	Mink present	13.3	44.4	42.2	0.0	0.0	*45*	8.9 df3	<0.03
	No mink	4.7	36.9	49.0	9.4	0.0	*149*		
Hydrobiological quality	Mink present	16.8	62.5	18.7	2.0	0.0	*48*	45.7df3	<0.0001
	No mink	4.0	28.5	45.1	19.8	2.6	*501*		

Table 4. Proportions of stations of watercourses where mink were evidenced and not evidenced related to different classes of fishing quality (from the best to the worse class). *N* = number of stations.

Fishing category		Class 1	Class 2	Class 3	*N*	c^2	P
Salmonid streams	Mink present	70.6	29.4	0.0	*17*	4.83 *df1*	<0.028
	No mink	32.1	60.7	7.2	*28*		
Cyprinid watercourses	Mink present	39.3	60.7	0.0	*28*	4.93 *df1*	<0.026
	No mink	11.8	82.3	6.9	*34*		
Total distribution	Mink present	51.1	48.9	0.0	*45*	9.31 *df1*	<0.0023
	No mink	21.0	72.6	6.4	*62*		

1981, MILNE 1992, FERGUSON et al. 1998). In Western France, the European mink distribution is spatially divided into discrete subpopulations and the results of this study suggest that the level of fragmentation within the mink population mainly results from degradation of watercourse quality.

Mink are not exclusive fish predators (MARAN et al. 1998) and the fish availability of watercourses may be suspected to have only a low impact on fragmentation as found here. By contrast, contamination of the aquatic ecosystems by bioaccumulating heavy metal and chemical residues has been often evoked as a decisive factor for the decline of endangered species (MASON & MAC DONALD 1986, MASON 1989, LODÉ 1993, MARAN & HENTTONEN 1995). Analysing levels of PCBs in mink tissues, LOPEZ-MARTIN et al. (1994) found on average 122.5µg/g in four mink from Spain. Ammonium, heavy metals and PCBs have a long-term toxic effect on organisms, notably disturbing reproduction and lactation. In American mink, breeding failed when levels of PCBs exceeded 50 µg per g of lipid (JENSEN et al. 1977). The deterioration of watercourses affects distribution emphasizing that population fragmentation should be seen as both a serious alarm for alteration of water quality and an alert for mink conservation.

Although the European mink mainly inhabited forest brooks, bank configuration did not seem to have a determinant influence on mink distribution (MAIZERET et al. 1998). Trapping should not be a current cause of decline because the species has been protected by law since 1976. Therefore, it may be suspected that river quality constitutes a decisive factor for mink distribution.

Studies on fragmentation are often difficult to perform in large scale analysis (BENDER et al. 1998). But here the fractal diagnosis clearly emphasises the fragmentation within the mink population. It has already been observed that animal movements were influenced by the fractal dimension of landscapes (JOHNSON et al 1992, FERGUSON et al. 1998). Habitat loss abruptly disrupts connectivity leading to fractal landscapes which drastically affect animal movements (WITH et al. 1999). Analysing various fractal properties, SAPOVAL (1997) emphasized that potential exchanges dwindled with the decreasing fractal dimension and *D* 1.33 is regarded as a limit threshold. Here, the fractal dimension of mink distribution only averaged 1.40 revealing a high fragmentation within the mink population. Such a subdivision may alter the long-term survival of this endangered species.

In polygynous mustelids, spacing patterns are mainly governed by the breeding system and the general pattern of dispersal revealed a chief dispersal by subadult males while philopatry predominated in females (DOBSON 1982, STENSETH & LIDICKER 1992, KOENIG et al. 1996, LODÉ 2001). Nevertheless, patterns of dispersal in breeding mustelids are expected to proceed according to the stepping-stone model in which sub-population exchanges are favoured in contiguous zones (GADGIL 1971, ERLINGE 1977, LODÉ 2001). The quality of contiguous habitats is decisive for populations. Thus subdivision may directly affect breeding and viability of small isolated populations because of the low number of breeding adults. Allee effect hypothesis (ALLEE et al. 1950) predicts that poor habitats through habitat deterioration may result in such extensively scattered home-ranges that low densities prevent most females from finding mates. Because of watercourse quality, mink may have widely spaced territories disturbing the social system, and many adults may fail to breed supporting the Allee effect hypothesis. Such a phenomenon was suspected in marten populations (KATNIK et al 1994).

Genetic drift is predicted to lead to depression by inbreeding in fragmented populations (NEI 1973, SLATKIN 1987, FRANKHAM 1995, KAWATA 1997). Investigating genetic diversity in mink western population, a heterozygote deficit and a strong inbreeding index were found, disclosing such a perturbation of breeding exchanges (LODÉ 1999). Thus, the genetic study also supported the disruption of connectivity revealed by fractal analysis. Furthermore, genetic depletion can weaken the immune response to pathogens, such a deficiency worsening the vulnerability of mink to disease, notably to the Aleutian disease (BERGSTROM et al.1999).

Conservation of rare species requires the development of a global system of large protected habitats (SOULÉ & SANJAYAN 1998). Thus fractal investigation possesses a real heuristic value and constitutes a resourceful method for relating environmental deterioration and breeding dispersal in endangered species. Moreover, mink avoided many streams, which still provide domestic water supplies for man, and the level of fragmentation within the population should be seen as a chief warning on the deterioration of freshwater ecosystems.

Acknowledgements:

I thank all the people who really worked for the conservation of European mink population in France. Thanks are due to numerous field naturalists and especially A. BERGEON, F.NOEL, J. S. DEVISSE, J. P. DURAND, F. DUSSENTY, A. FLEURY, G. GUIRAL, F. IBANEZ, D. DANUSSE, Agence de l'eau Adour-Garonne, and Conseil Supérieur de la Pêche. Gratitude is expressed to Prof. E. PATTEE for his helpful comments in improving the manuscript.

References

AARS, J. & IMS, R. A. (1999):The effect of habitat corridors on rates of transfer and interbreeding between vole demes. - Ecology **80:** 1648-1655.

AFNOR. (1992): Essais des eaux - Détermination de l' indice biologique global norma-lisé (IBGN). - Association Française de Normalisation, norme homologuée T90.350. - 8p.

ALLEE, W. C., PARK, O., EMERSON, A., PARK, T. & SCHMIDT, K. P.(1950): Principles of animal ecology. - Saunders Company, Philadelphia, 837p.

BENDER, D. J., CONTREAS, T. A. & FAHRIG, L.(1998): Habitat loss and population decline: a meta-analysis of the patch size effect. - Ecology **79:** 517-533.

BERGSTROM, C. T., MACELHAMY, P. & REAL, L. A. (1999) Transmission bottlenecks as determinants of virulence in rapidly evolved pathogens. - Proc. Natl Acad. Sci. USA **96:** 5096-5100.

BURROUGH, P. A. (1981): Fractal dimensions of landscapes and other environmental data. - Nature **294:** 240-242.

COLLINGHAM, Y. C. & HUNTLEY, B. (1999): Impacts of habitat fragmentation and patch size upon migration rates. - Ecol. Appl. **10:** 131-144.

DANILOV, I. & TUMANOV, I. L. (1976) Mustelids of Northwestern U.S.S.R.- Nauka, Leningrad, 245p.

DOBSON, F. S. (1982): Competition for mates and predominant juvenile male dispersal in mammals. - Anim. Behav. **30:** 1183-1192.

ERLINGE, S. (1977): Spacing strategy in stoats *Mustela erminea* L. - Oikos **28:** 32-42.

FAHRIG, L.(1997): Relative effects of habitat loss and fragmentation on population extinction. - J. Wild. Manag. **61:** 603-610.

FAHRIG, L. & MERRIAM, G. (1994): Conservation of fragmented populations. – Conserv. Biol. **8:** 50-59.

FERGUSON, S. H., TAYLOR, M. K., BORN, E. W. & MESSIER, F.(1998): Fractals, sea-ice landscape and spatial patterns of polar bears. - J. Biog. **25:** 1081-1092.

FRANKHAM, R. (1995): Conservation genetics. - Ann. Rev. Gen. **29:** 305-327.

GADGIL, M. (1971): Dispersal: population consequences and evolution. - Ecology **52:** 253-260.

GARIN, I., ZUBEROGOITIA, I., ZABALA, J., AIHARTZA, J., CLEVENGER, A. P. & RALLO, A. (2002): Home range of European mink (*Mustela lutreola*) in Southwestern Europe. - Acta theriol. **47:** 55-62.

GAUSTESTAD, A. O. & MYSTERUD, I. (1994): Fractal analysis of population ranges: methodological problems and challenges. - Oikos **69:** 154-157.

HASTINGS, A. (1990): Spatial heterogeneity and ecological models. - Ecology **71:** 426-428.

JENSEN, S., KIHLSTRÖM, J. E., OLSSON, M., LUNDBERG, C. & ÖRBERG, J. (1977): Effects of PCB and DDT on mink (*Mustela vison*) during the reproductive season. - Ambio **6:** 239.

JONHSON, A. R., MILNE, J. A. & CRIST, T. O. (1992): Diffusion in fractal landscapes: simulations and experimental studies of Tenebrionid beetle movements. - Ecology **73:** 1968-1983.

KATNIK, D. D., HARRISSON, D. J. & HODGMAN, T. P.(1994): Spatial relations in a harvested population of marten in Maine. - J. Wild. Manage. **58**: 600-607.

KAWATA, M. (1997): Loss of genetic variability in a fragmented continuously distributed population. Research on population. - Ecology **39:** 227-237.

KERR, J. T. & CURRIE, D. J. (1995): Effect of human activity on global extinction. - Conserv. Biol. **9:** 1528-1538.

KOENIG, W. D., VUREN, D. V. & HOOGE, P. N. (1996): Defectability, philopatry, and the distribution of dispersal distances in vertebrates. - TREE **11:** 514-517.

KRUUK, H. (1995): Wild otter. - Oxford University Press, Oxford. 290p.

LANDE, R. (1987): Extinction thresholds in demographic models of territorial populations. - Amer. Nat. **130:** 624-635.

- (1988): Genetics and demography in biological conservation. - Science **241:** 1455-1460.

LODÉ, T. (1993): The decline of otter *Lutra lutra* populations in the region of Pays de Loire (western France). - Biol. Conserv. **65:** 9-13.

- (1999): Genetic bottleneck in the threatened western population of European mink *Mustela lutreola*. - Ital. J. Zool. **66:** 351-353.

- (2001): Mating system and genetic variance in a polygynous mustelid, the European polecat. - Genes Gen. Syst. **76:** 221-227.

LODÉ, T., CORMIER, J. P. & LE JACQUES, D. (2001): Decline in endangered species as an indication of anthropic pressures: the case of European mink *Mustela lutreola* western population. - Env. Manage. **28:** 727-735.

LOPEZ-MARTIN, J. M., RUIZ-OLMO, J. & PALAZON, S. (1994): Organochlorine residue levels in the European mink (*Mustela lutreola*) in Northern Spain. - Ambio **23:** 294-295.

MAIZERET, C., MIGOT, P., GALINEAU, H., GRISSER, P. & LODÉ, T. (1998): Répartition et habitats du Vison d'Europe (*Mustela lutreola*) en France. - Arvicola "Actes Amiens": 67-72.

MANDELBRODT, B. (1975): Les objets fractals. - Flammarion, Paris. 191p.

MANDELBRODT, B. (1983): The fractal geometry of nature. - Freeman, New-York. 468p.

MARAN, T. & HENTTONEN, H. (1995): Why is the European mink (*Mustela lutreola)* disappearing ? A review of the process and hypotheses.- Ann. Zool. Fen. **32:** 47-54.

MARAN, T., KRUUK, H., MAC DONALD, D. W. & POLMA, M. (1998): Diet of two species of mink in Estonia: displacement of *Mustela lutreola* by *M. vison*. - J. Zool. Lond. **245:** 218-222.

MASON, C. F. (1989): Water pollution and otter distribution: a review. - Lutra **32:** 97-131.

MASON, C. F. & MAC DONALD, S.(1986): Otters: ecology and conservation. – University Press, Cambridge. 236p.

MILNE, B. T. (1992): Spatial aggregation and neutral models in fractal landscapes. - Amer. Nat. **139:** 32-52.

MORSE, D. R., LAWTON, J. H., DODSON, M. M. & WILLIAMSON, M. H. (1985): Fractal dimension of vegetation and the distribution of arthropod body lengths. - Nature **314:** 731-733.

NEI, M. (1973): Analysis of gene diversity in subdivided populations. - Proc. Natl Acad. Sci. USA **70:** 3321-3323.

PALAZON, S. & RUIZ-OLMO, J. (1993) Preliminary data on the use of space and activity of the European mink (*Mustela lutreola*) as revealed by radio-tracking. Small Carn. Conserv. **8**: 6-8.

PRESS, W. H., FLANNERY, B. P., TEUKOLSKY, S. A. & VETTERLING, W. T. (1992): Numerical recipes in C: the art of scientific computing. - Cambridge Univ Press, Cambridge. 1020p.

SAPOVAL, B. (1997): Universalités et fractales. - Flammarion, Paris. 275p.

SCHREIBER, A., WIRTH, R., RIFFEL, M.& ROMPAEY, H. (1989): Weasels, civets, mongooses and their relatives.An Action plan for the conservation of mustelids and viverrids. - IUCN & NR, Gland. 99p.

SLATKIN, M. (1987): Gene flow and the geographic structure of natural populations. - Science **236:** 787-792.

SOULÉ, M. E.(1986): Conservation Biology: the science of scarcity and diversity. – Sinauer Associate, Sunderland, Mass, U.S.A. 584p.

SOULÉ, M. E., & SANJAYAN, M. A. (1998): Conservation targets : do they help? – Science **279:** 2060-2061.

STENSETH, N. C. & LIDICKER jr., W. Z. (1992): Animal dispersal: small mammals as a model. - Chapman et al., London. 365p.

VIRKKALA, R. (1993): Ranges of northern forest passerines: a fractal analysis. - Oikos **67:** 218-226.

WIENS, J. A. (1989): Spatial scaling in ecology. - Funct. Ecol. **3:** 385-397.

WITH, K. A., CADARET, S. J. & DAVIS, C.(1999): Movement responses to patch structure in experimental fractal landscapes. - Ecology **80:** 1340-1353.

YOUNGMAN, P. M.(1982): Distribution and the systematics of the European mink *Mustela lutreola* Linnaeus 1761. - Acta Zool. Fenn. **166:** 1-48.