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Potential impact of an exotic mammal on rocky intertidal communities of northwestern Spain

Miguel Delibes[1,*], Miguel Clavero[1,2], José Prenda[2], María del Carmen Blázquez[3] & Pablo Ferreras[4]

[1]*Department of Applied Biology, Estación Biológica de Doñana, CSIC, Avda. María Luisa, s/n, 41013 Sevilla, Spain;* [2]*Department of Biología Ambiental y Salud Pública, Universidad de Huelva, C.U. El Carmen, Avda Andalucía, 21071, Huelva, Spain;* [3]*Centro de Investigaciones Biológicas del Noroeste (CIBNOR), P.O. Box 128, La Paz, Baja California Sur, 23000 Mexico;* [4]*Instituto de Investigación en Recursos Cinegéticos, UCLM-CSIC-JCCM, P.O. Box 535, 13080 Ciudad Real, Spain;* [*]*Address for correspondence (e-mail: mdelibes@ebd.csic.es; fax: +34-95-4621125)*

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Abstract

Being the interface of sea and land, the coast can be invaded by introduced species coming from either of these two worlds. Recent reviews of coastal invasions emphasize the human-mediated transport of non-indigenous marine plants and invertebrates, forgetting the potential role of invaders of terrestrial origin. By studying the diet of the introduced American mink (*Mustela vison*) on a rocky shore of southwestern Europe, we draw attention to the potential impact on intertidal communities of exotic species coming from inland. We analysed 199 mink faeces collected in August 1997 and August 1999 in Baiona, a coastal and urban area of northern Spain recently invaded by minks. The diet of the species was based almost exclusively on crabs (45.4% of individual prey) and fish (53.3%). Most crabs were marbled crabs (*Pachygrapsus marmoratus*) and most fish were adult blennies (*Coryphoblennius galerita* and *Lipophrys pholis*). Given its energy requirements (about 1250 kJ/day), a single mink will consume during the month of August approximately 945 blennies and 496 crabs. Although we lack accurate data on mink abundance, a cautious estimation (4 mink/km before dispersal), supported by field observations, suggests that predation in August may reach 3780 blennies and 1984 crabs per km of shoreline. This predation pressure could affect the numbers of blennies and (less probably) crabs, indirectly benefiting the populations of their prey, that is, sessile invertebrates and snails. More field research is needed, but our results suggest that an exotic non-marine top predator such as the American mink could affect intertidal communities in Eurasia.

Introduction

Biological invasions are a significant component of human caused global change (Vitousek et al. 1997) and a main cause of the current loss of biodiversity (Diamond 1989). Exotic, introduced species are considered the second most important cause of extinctions, immediately behind habitat destruction (Macdonald and Thom 2001). For example, more than 18% of 941 endangered vertebrate taxa are threatened in some way by exotic species (Macdonald et al. 1989), both in terrestrial and in aquatic ecosystems. Moreover, extinction is only the most dramatic potential result of predation or competition by introduced species, which more often modify the distribution, abundance, behaviour and evolutionary trajectories of native flora and fauna (Simberloff 1981) and consequently the species composition and dynamics of native communities.

Historically, the study of coastal invasions has received less attention than similar studies of terrestrial and freshwater ecosystems. However, coastal marine habitats are among the most heavily invaded systems on Earth, with many ecological and evolutionary consequences (Grosholz 2002). Usually, reviews of coastal invasions (e.g. Ruiz et al. 2000; Grosholz 2002) take into account almost exclusively plants and invertebrates as invaders and consider the human-mediated transport of non-indigenous species by shipping (resulting from ballast water or hull fouling) and the intentional or unintentional result of aquaculture and fisheries as the dominant mechanisms producing invasions. However, the coast represents the interface of land and sea and coastal invaders could be also semi-aquatic species coming from inland. The prime purpose of this paper is to contribute to the understanding of coastal invasions by drawing attention to the potential ecological impact on intertidal communities of some exotic species from mainly inland origin. We will use as an example the case of the alien American mink (*Mustela vison*) in the rocky shore of northwestern Spain.

The American mink is a mustelid of about 1 kg body weight whose native range includes Canada and the United States except the extreme north and the arid southwest. Since the late 19th century the species has been bred at fur farms in its native countries and in the 1920s the first American minks were brought to Europe for commercial farming. Due to either deliberate releases or escapes from fur farms, the American mink is now widespread in most European and some Asian and South American countries (Dunstone 1993). In its native range and wherever introduced, the species occupies many mesic and wet habitats, from rivers to marshes, lakes and coasts. At present, it is reported in most European Atlantic coasts north of 48° N latitude and in some Mediterranean coasts (Mitchell-Jones et al. 1999). Its presence is increasing in coastal areas of northern Spain (Palomo and Gisbert 2002).

The introduced American mink is an opportunistic predator (Dunstone 1993). Wherever it became established in Eurasia and South America it has been recognised as a serious threat to the conservation of native species, both to its competitors (e.g. European mink, *Mustela lutreola*, Patagonian huillín, an endemic otter, *Lutra provocax*) and to its prey (e.g. water voles, *Arvicola terrestris*, riverine and sea birds, white-clawed crayfish, *Austropotamobius pallipes*) (Ferreras and Macdonald 1999; Macdonald and Strachan 1999; Macdonald and Thom 2001; Nordström et al. 2003). We suspect that predation by shore-living American minks could influence the distribution and abundance of its intertidal prey and henceforth the composition of intertidal communities in Europe. By describing the summer diet of the mink in a recently invaded rocky coastal area of northern Spain, we will try to estimate the absolute number of fish and crabs that minks remove daily. This could suggest a potential impact of mink predation on the invaded intertidal communities.

Study area and methods

The diet of the mink was estimated through the analysis of its faeces. We collected mink faeces in August 1997 and 1999 along a 2 km stretch of exposed Atlantic rocky shore in the town of Baiona (NW Spain; 42°10′ N, 8°50′ E), a relatively small city which receives thousands of visitors during the summer. The intertidal fringe is an almost continuous (there are two sandy beaches about 100 m long) rocky platform between 20 m and more than 100 m wide, including large natural boulders and frequent pools during low water on the tidal range. The upper rocky border provides numerous den sites for the mink. The shore is separated from the hinterland by roads and urban walls. The climate is temperate with Mediterranean influence; annual average temperature and rainfall (1931–1980) are 15 °C and 1337 mm, and in August average temperature is 21.6 °C and rainfall 20.3 mm.

Minks were common in the area. At least two different family groups with three and four individuals (presumably one female with almost fully grown young) and some solitary individual were repeatedly observed in August 1999. Otters (*Lutra lutra*) are lacking in this portion of the coast.

We collected 199 mink faeces (102 in 1997 and 97 in 1999), probably corresponding to 6–10 different individuals each summer. Diet analyses followed standard methodology (Beja 1997). Prey remains were identified using published keys (Webb 1980; Roselló 1986) and our own collection for comparison. Each identified prey class in a scat was considered as an ‘occurrence’, being the relative frequency of occurrence (RFO) the percentage of the total number of occurrences corresponding to a certain prey class. Diet diversity was quantified using the Shannon–Weaver index (H') with RFO data of the general prey items (fish, crabs, birds, insects and amphibians) to allow appropriate comparisons with other studies.

The minimum number of different individuals of each prey class was estimated from the number and position (left–right) of diagnostic hard parts (mainly mouth bones for fish and third maxillipeds for crabs) (Beja 1996), which were measured with a calliper to the nearest 0.1 mm. In those cases when diagnostic pieces did not appear, remains of a certain prey item were considered to belong to a single individual (i.e. a minimum estimate).

We applied regression equations to estimate the original weight of the prey consumed by the mink. In the case of fish, regressions between the size of key bones and original length (PR Beja, unpubl. data), and between length and weight (own unpubl. data) were computed. The weights of ingested crabs (at least four different species) were estimated by direct regression between the third maxilliped's meros size and crab weight without claws (they were rarely found in scats) computed from a sample of shore crabs (*Carcinus maenas*) (own unpub. data). The lengths and weights of crab and fish individuals without measured key hard parts were assumed to follow the frequency distribution in the estimated samples of each prey class. Constant weights were assigned to the remaining prey groups: insects, 1 g; amphibians (*Rana* sp.), 15 g; birds, 30 g.

The ingested biomass of each prey class has been estimated through two methods. First, we summed the estimated biomass of consumed individuals of each size class for fish and crabs, as explained before. Because this method can overestimate the contribution of some prey groups producing more remains (e.g. crabs or birds), we have also weighed the dry remains of each prey class in the faeces, assuming that the relative defecated biomass is proportional to the ingested fresh biomass. This estimation was carried out only for the larger prey categories (i.e. fish, crabs, etc.).

The estimated ingested biomass belonging to each prey type was transformed to their energetic contribution according to the calorific values (kJ/g wet weight) given by Dunstone (1993). The diet analysis results were expressed as RFO, percentage of individuals, percentage of biomass ingested and percentage of energetic contribution of the different prey classes. The last two results were expressed as a range, because they include the estimations obtained by two methods.

To calculate the prey requirements of an individual mink we assumed a daily energy requirement of 1250 kJ, the mean of the values given by Dunstone (1993) for an adult female (1000 kJ) and an adult male (1500 kJ). The percentage of energy obtained from each prey class was used to calculate the ingested biomass of the different classes. This value was divided proportionally among the different weight categories to estimate the number of individuals of a prey class predated daily by a single mink.

Results

Frequencies of occurrence of main prey types in the mink faeces did not show significant variations between the two years ($\chi^2 = 4.99$; df $= 2$; $P > 0.08$), therefore we pooled the results. Mink diet was based almost exclusively on crabs (RFO 51.6%) and fish (RFO 46.3%) (Table 1). Birds appeared in four faeces, insects in two, and only one contained amphibian remains. We have not considered any other kind of prey, although during the analyses remains of small mussels, snails and limpets were found in more than 40% of the samples. These occurrences corresponded to animals predated by blenny fish, which were in turn taken by mink. The association of remains of blennies and molluscs in the faeces was highly significant ($\chi^2 = 58.33$; df $= 1$; $P < 0.001$). In addition, we found mollusc remains of the same taxa and sizes in the stomachs of some blennies captured in the study area.

The marbled crab (*Pachygrapsus marmoratus*) was the most frequently consumed species in terms of RFO (34.9%), because the class 'blennies' (38.1%) included more than one species (at least two were identified: the Montagu's blenny, *Coryphoblennius galerita*, and the shanny, *Lipophrys pholis*, which according to our field observations and the literature are, with a great difference, the most frequent blennies in the upper intertidal zone of the Atlantic coast on the Iberian Peninsula: Arruda 1979; Ibáñez et al. 1989; Faria and Almada 1999). Other identified crab species were velvet swimming crab (*Necora puber*), shore crab, and warty crab (*Eriphia verrucosa).* Regarding other fish species, rocklings were probably *Gaidropsarus* sp. and gobies were *Gobius cobitis*. Diet diversity was lower ($H' = 0.80$) than reported in other studies of American mink diet in Europe (Jedrzejewska et al. 2001), due to the low proportion of occurrence of prey classes other than fish or crab.

In the study area mink fed mainly on small prey (Figure 1). Median length of consumed fish was 7.8 cm (mean $\pm$ SD $= 7.9 \pm 1.87$ cm; $n = 131$); the largest recorded fish was a 14 cm long goby. Usually, Montagu's blennies and shannies are considered juveniles when they are less than 3 cm total length (Faria

Table 1. Relative frequency of occurrence and percentage of individuals, ingested biomass and obtained energy from the different prey classes found in mink faeces collected in the study area in summer of 1997 and 1999.

	RFO	% Individuals	% Biomass	% Energy
Blennies	38.1	47.7	34.2	52.7
Rocklings	2.9	2.3	2.6	4.0
Gobies	2.1	1.3	1.8	2.7
Unidentified fish	3.2	2.1	1.6	2.4
Total fish	**46.3**	**53.3**	**42.8–68.1**	**61.8–82.4**
Marbled crabs	34.9	33.0	36.9	24.0
Swimming crabs	5.6	3.9	4.6	3.0
Shore crabs	4.4	4.1	4.2	2.8
Warty crabs	0.6	0.4	0.4	0.3
Unidentified crab	6.2	3.9	4.4	2.9
Total crab	**51.6**	**45.4**	**30.0–53.9**	**15.6–33.3**
Birds	1.2	0.8	1.5–2.9	1.9–4.3
Insects	0.6	0.4	0.0	0.0
Amphibians	0.3	0.2	0.1–0.4	0.1–0.5
Total other prey	**2.1**	**1.4**	**1.6–2.3**	**2.0–4.8**
Total numbers	**341 occurrences**	**533 individuals**		

and Almada 1999); hence, the blennies captured by the mink should be adults (Figure 1A). The median weight of prey was 5.2 g for fish (mean $\pm$ SD $= 6.4 \pm 4.5$ g; $n = 131$) and 5.1 g for crabs (mean $\pm$ SD $= 8.0 \pm 8.46$ g; $n = 139$). Mean weight values were larger than median values since the distribution of weights, both for fish and crabs, was heavily skewed toward larger individuals (Figures 1B and C).

Fish represented between 43% and 68% of the biomass ingested by mink and crabs represented between 30% and 54%. According to our estimates, fish represented between 62% and 82% and crabs between 16% and 33% of the energy intake (Table 1).

Due to the small size of consumed prey, minks must capture many individuals (between 30 and 50) of the different prey classes to satisfy their daily energetic requirements (1250 kJ for an average weight individual). On average, a single mink must consume 110–147 g of fish (26–35 individuals) and 65–139 g of crabs (10–22 individuals) daily, depending on the method used to estimate the proportions of ingested biomass. Assuming these results can be extrapolated to the whole month of August (31 days), a single mink would consume about 945 fish and 496 crabs.

Discussion

It is well known that the American mink is an opportunistic and adaptable predator, which can feed on mammals, birds, amphibians, fish and invertebrates (Dunstone 1993). Our results corroborate this opportunistic foraging behaviour, showing that the species is able to rely exclusively on a low diversity diet of marine prey captured in a narrow shore strip of an urban area. Rather similar results were provided by Skirnisson (1979) from a coastal population in Iceland, where mink fed mainly on fishes and birds. Also, Dunstone and Birks (1987) found rocky pool fish in 41% of mink faeces collected on the coast of southwest Scotland, where rabbits (*Oryctolagus cuniculus*) comprised the bulk of mink food. Overall, fish seems to be the most important prey of coastal minks wherever their diet has been studied in Eurasia (Macdonald and Strachan 1999; Jedrzejewska et al. 2001). Hence, the phenomenon on which we pay attention could be rather common in rocky shore areas of Eurasia invaded by mink. By comparing stable isotope ratios of mink tissues with those of the potential prey, Ben-David et al. (1997) also concluded that, in southeast Alaska, diets of native coastal minks in spring and summer consisted largely of intertidal fishes. The RFO of crabs in Baiona is the highest reported in mink diet studies from coastal habitats, but shore crabs are an important prey also in Scotland (Dunstone and Birks 1987).

In our study, mink seems to forage almost exclusively on intertidal pools, where, according to our unsystematic observations, both blennies and marbled crabs were by far the most abundant available prey. We observed that some shrimp (e.g. *Palaemon* spp.)

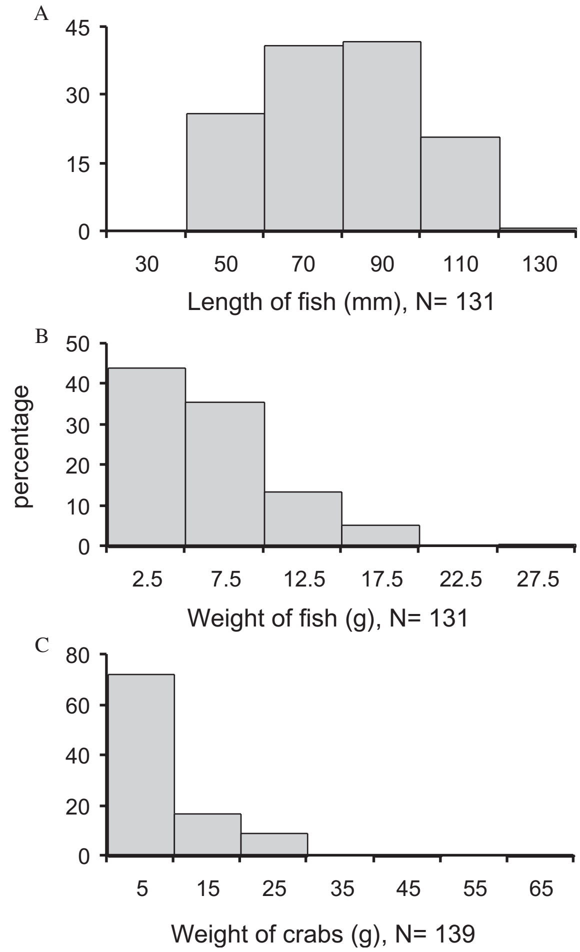

Figure 1. Distribution of estimated lengths (*A*) and weights (*B*) of fish and weights of crabs (*C*) consumed by the American mink in the study area. Numbers in horizontal axes indicate the central value of the intervals.

were common but not predated. Dunstone and Birks (1987) also found that shrimp were rather abundant in pools, but rarely eaten in Scotland. Maybe this is because shrimp are too small or because they are more abundant in the middle and low tidal areas, whereas mink forage mostly in the high tidal zone because of its reduced ability to hunt underwater (Poole and Dunstone 1976). In fact, some blennies could be captured out of water, as they show nocturnal emergence behaviour (Louisy 1987) and coastal mink forage mainly during darkness and when the tide is low (Dunstone 1993). Otters feeding in similar Iberian rocky shore areas select bigger and more profitable subtidal fishes, such as wrasses (*Symphodus* sp.) (Beja 1997). The mink diet we report could be rather similar to the diet of coastal young otters, which have a lower diving success rate than adults and predate more often on crabs and small fish (Watt 1993).

It is usually recognized that most predation upon rocky intertidal fish assemblages is exerted by 'external' predators, that is, larger subtidal fish and diving birds in high tide, and terrestrial predators, such as birds, reptiles and mammals, when the tide is out (Gibson and Yoshiyama 1999). However, the influence of predation on local abundance and distribution of intertidal fish is essentially unknown (Gibson and Yoshiyama 1999; Pfister 1999). We cannot estimate the impact of mink predation on intertidal fish or crabs in our study area because we lack accurate information about the abundance of mink and the abundance and renewal rates of their prey. However, we can propose an approach.

Mink female home ranges of about 1 km long and winter adult abundance of about 2 mink/km of coastline have been reported in Scotland (Dunstone and Birks 1983). As we repeatedly saw 2 family groups with 3 and 4 individuals in our study area in August 1999, it was possible to estimate conservatively that 8 different individuals (adults and young) were living in our 2 km of coastline (i.e. a predispersal abundance of 4 mink/km). Based on our results, these minks could consume about 3780 blennies (3240–4340) and 1984 crabs (1240–2728) per km of coastline during August.

We are aware these numbers cannot be extrapolated to the whole year, for at least two reasons. First, blennies along the Iberian Atlantic coast seem to be more available to predators in summer (Beja 1997) and mink diet could be different in other seasons. Second, energy requirements (i.e. prey consumption) of the breeding mink population are highest in August, when the young are almost fully grown but still living in their mother's home range (Dunstone 1993). Besides, feral mink invaded the study area only some years ago and a high predation pressure seems to be characteristic of recently introduced predators, which meet naïve prey (e.g. Breitenmoser and Haller 1993). Regardless, even if absolute predation is lower in other periods, our results seem to suggest a potential impact of the American mink on intertidal fish and crab populations.

This population effect of predation depends heavily on the numbers of blennies and crabs existing in the area. Intertidal fishes are usually scarce, densities rarely exceeding on average a few individuals per square meter, even when they are concentrated in low-tide refuges such as rocky pools (Gibson 1982). Besides, tide pools experimentally depopulated of fishes show relatively slow recolonization rates, the effects of depopulation being appreciated for weeks (Gibson 1982). However, Faria and Almada (1999) strongly suggested that density-dependent mechanisms control the numbers of adult blennies found in Portuguese tide pools. In this case, mortality by mink predation could be at least partially compensatory. Clearly, more field studies are needed to accurately determine the impact of predation by non-indigenous coastal mink, but removal of several thousand individual blennies per month and kilometre of shoreline could have a serious effect on their populations. Maybe mink predation on crabs has a lesser impact, although not negligible, in our area, because at least marbled crabs seem to be extraordinarily abundant.

By reducing numbers of shore crabs and fish, mink predation could influence intertidal communities as a whole. Predation has long been considered a main factor in structuring intertidal assemblages (e.g. Paine 1974). For instance, crabs are known to be able to alter the surrounding habitats through predation on snails and mussels (e.g. Leonard et al. 1998; Gerard et al. 1999). Similarly, an increasing body of knowledge indicates that predation by intertidal fish can have dramatic effects on their prey (Anderson and Connell 1999; Norton and Cook 1999). The invasion by a top predator such as the American mink can produce cascading effects in different trophic levels of the complex structure of the marine intertidal food webs, by releasing the predation pressure of crabs and fish upon snails and sessile invertebrates (Polis and Strong 1996). Additionally, the presence of exotic mink could influence intertidal communities by altering the behaviour of its prey, resulting in cascading indirect effects on competitive interactions and food chains (Trussell et al. 2003).

In summary, the importance for coastal invasions of exotic species arriving through the sea is well known (Grosholz 2002), but those arriving through inland can be also significant. This is because at low tide shore birds and mammals (including non-indigenous rats, feral cats, dogs and pigs, minks, mongooses, etc.) can consume intertidal organisms at high rates, probably exceeding those from fully aquatic predators (Edwards et al. 1982).

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