LETTER

Consumers' taste for rarity drives sturgeons to extinction

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Abstract

The international market for luxury goods puts pressure on many wildlife species, with potentially irreversible consequences for many of them. Although classical economic theory suggests that trade alone would not drive a rare species to extinction, in practice numerous species are being threatened by overexploitation. This is for example the case for sturgeons, exploited for their caviar, of which all 27 species are threatened with extinction. We performed a caviar-tasting experiment, combined with a modeling approach merging ecological theory and psychosociology. This allowed us to demonstrate that the human predisposition to place exaggerated value on rarity drives sturgeons' overexploitation, despite caviar's ever-increasing price and the imminent loss of these species. These findings suggest that this mechanism probably drives the entire market for wildlife based luxury goods.

Introduction

The international market for luxury goods, including certain food items, has almost doubled since 1990, with a worldwide increase of 10% annually (Nueno & Quelch 1998). This trade is fuelled by a great deal of legally and illegally exploited wildlife species, putting pressure on many of them, with potentially irreversible consequences. The large decline of sturgeon populations (Pala 2005; Pikitch *et al.* 2005) is a good example. Sturgeons are exploited for their caviar, the most coveted delicacy in the market of luxury goods. Their trade is restricted, with all 27 species listed since 1997 under Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix I (two species) or II (25 species). However, despite their well-publicized imperiled status and application of quotas, commercial pressure on 15 species persists (Pikitch *et al.* 2005), fuelled by a rising demand and thriving illegal trade (Speer *et al.* 2000; Stone 2002). In the Caspian Sea, from where 90% of caviar comes (Stone 2005), the sturgeon population has declined by 90% over the past two decades (Stone 2002; Pikitch *et al.* 2005).

Standard economic theory predicts that exploitation alone is unlikely to result in extinction of a species because of the escalating cost of finding the last individuals of a declining species (the functional response, Choquenot *et al.* 1999). According to this theory, economic extinction (the cessation of exploitation) should precede ecological extinction (population or species disappearance), giving it a chance to recover to exploitable levels (Clark 1990). But in the case of sturgeon, exploitation remains highly profitable (the global legal trade in caviar is currently worth several hundred million US dollars annually (Pikitch *et al.* 2005) and prices (which reflect the demand) increase as sturgeon stocks deplete and become rarer (Figure 1). At this rate, specialists estimate that there will be virtually no more sturgeon left in the Caspian Sea by 2012 (Pala 2007).

In this study, our aim was to identify the mechanism responsible for the overexploitation that is quickly driving the 200-million-year-old sturgeon fish to extinction. Caviar-tasting experiments showed that the perceived rarity of caviar influences positively the gustative appreciation of the consumers. Using a modeling approach, we showed that this predisposition to place exaggerated

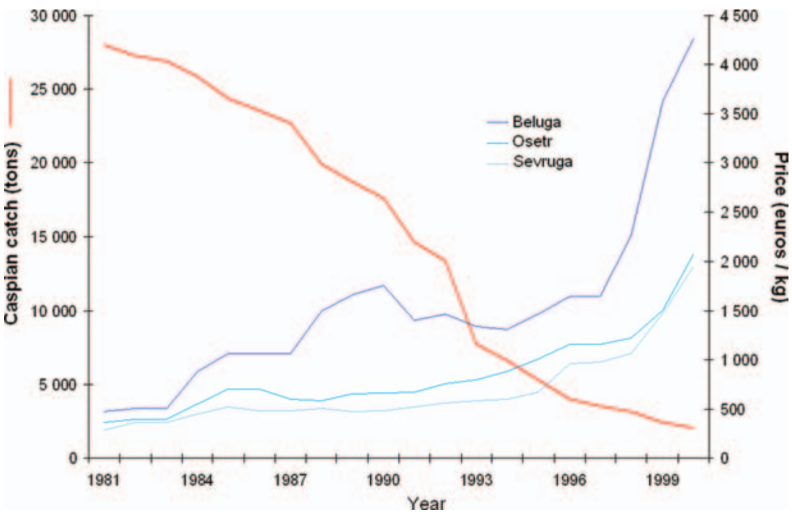

Figure 1 Increase in the price of three caviars as sturgeon stock in the Caspian Sea were depleted over the period 1981–2000. The Beluga (*Huso huso*), the Osetr (*Acipenser gueldenstaedtii*), and the Sevruga (*Acipenser stellatus*) caviars are the most coveted in the world. All three species are listed as endangered on the CITES red list since 1996. For each caviar, the price is inversely correlated (inverse cubic relationship) to the size of the stock (for Beluga, Osetr, and Sevruga caviars, respectively, $R^2 = 0.3913$, $P = 0.0032$; $R^2 = 0.554$, $P = 0.0002$; $R^2 = 0.5542$, $P = 0.0002$). Catch data obtained from Catarci (2004).

value on rarity can push the exploited species into an extinction vortex. We suggest that this human predisposition to place exaggerated value on rarity probably drives the entire luxury market for luxury goods from reptile skins to exotic woods, and thereby constitutes a threat to biodiversity.

Methods

Tasting sessions

We organized caviar-tasting sessions during private Parisian luxury receptions hosting guests belonging to the upper socio-professional classes (the French are among the largest caviar consumers in the world; TRAFFIC 2007). The caviar offered during those tasting sessions (*Acipenser baeri* caviar) came from a French sturgeon-breeding farm (Sturgeon Company, Saint Sulpice et Cameyrac, France). It was a high-quality caviar that had previously been evaluated as excellent by a jury of French experts (Leygnier & Victoria 1999). Each can of caviar used for the experiments was divided vertically in two halves, which were subsequently presented in two strictly identical display bowls. One half was labeled as coming from a "rare species" of sturgeon, and the other as coming from a "common species" of sturgeon. Thus, the only (apparent) difference between the two caviars was the label ("rare species" or "common species"), and any other difference in flavor, aspect, smell, or presentation was avoided. We regularly switched the position of the two labels to avoid an effect of the initial position of the samples (which was subsequently tested and not found to influence choice). We proposed simultaneously two samples of "rare" and "common" caviar to 316 volunteer consumers. Consumers were asked to taste both caviars, but chose the sample they wanted to taste first. Tasting was followed by a short questionnaire in which the consumer was asked to (1) give and justify his/her preference, if any, (2) give a mark out of 20 to each of the caviars, (3) justify the choice of the first caviar tasted, and (4) indicate the frequency at which he/she usually ate caviar. Justification of the choice of the first caviar tasted provided an index of the consumers' intellectual/mental approach when facing a choice between a product coming from a "rare" or a "common" species.

As a control, we also conducted three sessions in three large supermarkets located in the suburbs of Paris, where customers were more representative of the average French consumer, that is, a noncaviar-consuming public. In total, 308 customers were interviewed there. The experimental design was similar to that for the luxury receptions.

Analyses

Selection of variables affecting consumers' preference

We first tested for potential effects of different aspects of the methods on the choice made by consumers in each of the two tasting session categories (i.e., luxury reception or supermarket). We used generalized linear models (GLM) with binomial distribution and logit link function to test the effects of the following variables: gender of the consumer, position of the label "rare" (i.e., to the right or to the left of the consumer), session (i.e., session 1, 2, or 3), and the sample tasted first (this variable is noted "first" in Table 1). Identity of observer ($n = 8$) was not tested because of a correlation with the session variable. Candidate models were constructed a priori and

Table 1 Selection of variables affecting consumers' preference. Models are sorted from largest to smallest by AIC weight. Model selection shows a strong effect of a positive a priori for the "rare" caviar on the preference expressed by consumers after the tasting session.

Models	AIC	AIC weights	Nb par	% of explained deviance
Tests of method effects on consumer preference				
1. preference ∼ first	318.77	0.3760	1	4.37%
2. preference ∼ gender + first + session[a]	319.26	0.2943	4	6.04%
3. preference ∼ gender + first[b]	319.90	0.2137	2	4.63%
4. preference ∼ gender + position + first + session	321.16	0.1138	5	6.07%
5. preference ∼ gender × position × first × session	330.63	0.0010	23	14.13%
6. preference ∼ gender	332.90	0.0003	1	0.08%
Tests of effects determining the choice of the first sample tasted				
7. first ∼ a priori	281.12	0.5292	1	10.62%
8. first ∼ a priori + profile	281.51	0.4354	4	12.42%
9. first ∼ a priori × profile	286.53	0.0354	7	12.74%
10. first ∼ profile	317.72	<0.0001	3	0.10%

[a] As "position" was randomized during the protocol, we made the hypothesis that the respective positions of the samples "rare" and "common" had no effect on the preference.

[b] As volunteers of the three sessions belonged to the same socio-professional class, we made the hypothesis that the session variable had to effect on the preference.

contrasted using Akaike's information criterion (AIC). The relative support of the models was obtained by comparing AIC weights and percent of explained deviance (Table 1).

Model selection process indicated that only the order in which consumers tasted the two samples had an effect on the preference (cf. Figure 2B and Table 1; for clarity, only the results obtained with the luxury receptions dataset are presented, results obtained with the supermarkets dataset being similar). Using the same method, a second GLM allowed us to explore whether the choice of the first sample tasted might have been influenced by a positive a priori in favor of the rare species sample and by the consumers' profile (i.e., their consumption frequency). The potential effect of the consumers' profile was only tested in luxury receptions. Overall, only the effect of a positive a priori for the rare species sample was selected by the models as a factor influencing the choice of the first sample tasted (Table 1).

Quality appreciation of the two caviar samples

Marks did not follow a normal distribution (Shapiro-Wilk test for normality; $W = 0.95$; probability of making a Type I error < 0.0001; $n = 1030$), but fitted a gamma distribution (Adequacy LR test; $\chi^2 = 0.279$; probability of making a Type I error $= 0.87$; $n = 1030$). To compare the marks given to the two samples by each consumer, we defined a generalized linear mixed-effects model (GLMM) with gamma distribution and log link function, with the sample label "rare" or "common" as the fixed effect and the individual as a random effect.

Statistical analyses of the data obtained were performed using JMP 5.0.1 (SAS Institute Inc., Cary, NC, USA, 2002) and R 2.1.1 software (The R Foundation for statistical computing, Vienna, Austria). Continuous data are described through their mean and standard deviation (mean ± SD).

Optimal strategy for consumers informed of the rarity of a resource

We next established a game theoretic model to identify the most rational behavior (i.e., consume now or postpone consumption) of consumers attracted by a rare but fragile resource, such as caviar, to optimize their payoff (i.e., satisfaction) over time. Immediate consumption is satisfying, while postponing consumption allows the population to recover to safer levels. We first built a two-player payoff matrix to identify the optimal strategy for a consumer attracted by a resource that can be depleted by consumption. This game, based on the same hypotheses as a prisoner's dilemma game (both players have the same strategy space and they can not see what the other do before they act), is dominant solvable (i.e., there is an evolutionary stable strategy). We then modified it into a second matrix, with n players and a possibility for the consumers to modify their own strategy when they observe the others (see Figure 3 for details). The matrix (Figure 3B) displays expected payoffs for focal consumer A, depending on his own strategy and the

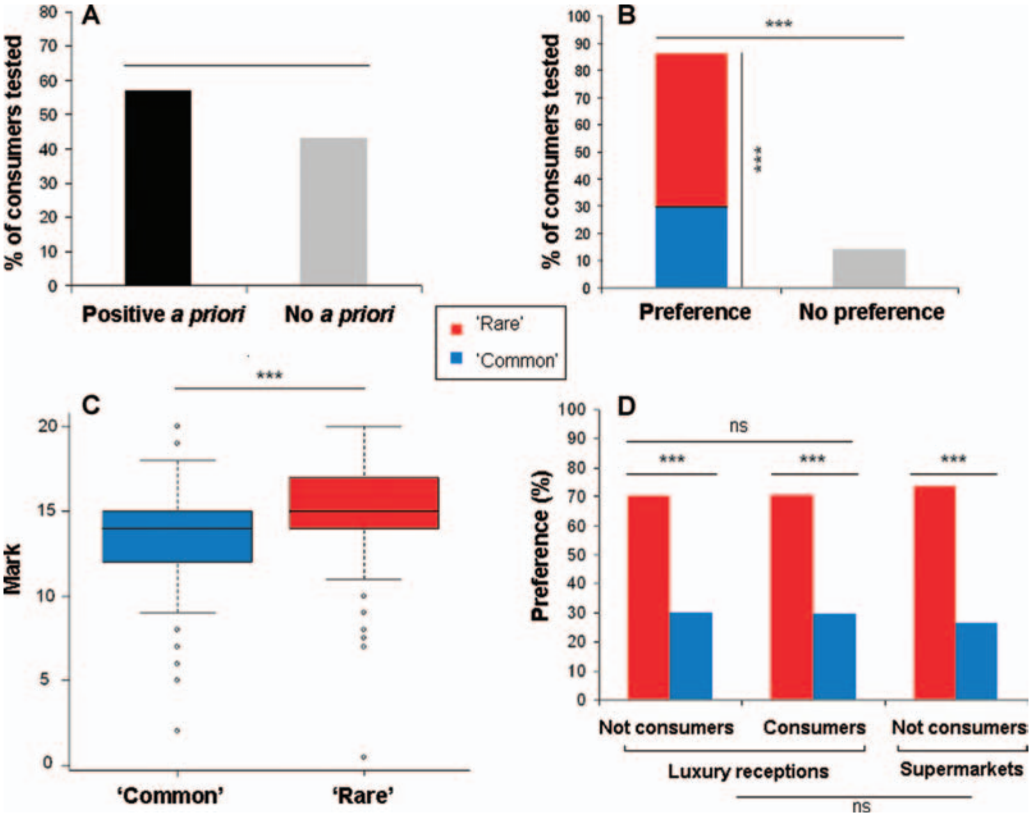

Figure 2 Preference of consumers for rare caviar. (A), Proportion of consumers who had a positive a priori for the rare species caviar even before tasting the samples. (B), Posttasting preferences. (C), Marks they attributed to the two samples. (D), Effect of consumer profile on expressed preference for rare or common species caviar. The existence of a positive a priori preference for the rare species caviar determined which sample the consumers chose to start with. This in turn determined the final preference expressed by the consumer. These results were similar whether the experiments were conducted in luxury receptions or in supermarkets (see the Methods section for details of the statistical analysis). The symbol "***" indicates a probability of making a Type I error < 0.0001; "ns" indicates a probability of making a Type I error > 0.05.

strategies adopted by the n other potential consumers, which A is assumed to observe. A is assumed to decide at time t whether he shall consume immediately or postpone his consumption until $t + \tau$. Consuming lasts until the end of the game. If A observes i consumers ($0 \leq i \leq n - 1$) at t, expected payoff of postponing consumption is $X \cdot P_\tau^i - Q_\tau^i$, unless the exploited resource is depleted before $t + \tau$, in which case payoff is 0, where P_τ^i is the probability (estimated by A) that the resource will not be depleted at $t + \tau$. Assuming consumers take account of this probability in the computation of their expected payoff is not tantamount to saying that they explicitly focus on the possibility that the resource go depleted; it simply means that they rationally integrate this element to their strategy choice. Here, $Q_\tau^i = \sum_{k=i,n-1} R_{\tau i}^k \cdot c^k$, and $R_{\tau i}^k$ is the probability (estimated by A) that there will be k consumers at $t + \tau$, given that there are i consumers at t (for a definition of the other parameters, see Figure 3).

c^i is an increasing function of i, as competition intensifies with the number of consumers. Hence, $X - c^i$ is a decreasing function of i. Similarly, $X \cdot P_\tau^i - Q_\tau^i$ is a decreasing function of i. Moreover, for ($0 \leq i \leq n - 1$), $X \cdot P_\tau^i - Q_\tau^i < X - c^i$ (this is because for $i \leq j \leq n - 1$, $R_{\tau i}^j \leq 1$, as there are at least as many consumers at $t + \tau$ than there were at t). This leads to the matrix structure showed on Figure 3B, which determines the dominant strategy for A.

Demographic consequences for rare species

We devised a macroscopic model, adapted from the classical logistic model, to study the consequences of the behavior of potential consumers (players) on the dynamics of an exploited population of size N. In this model, each player could choose at each time step to start consuming an individual from the exploited population or wait

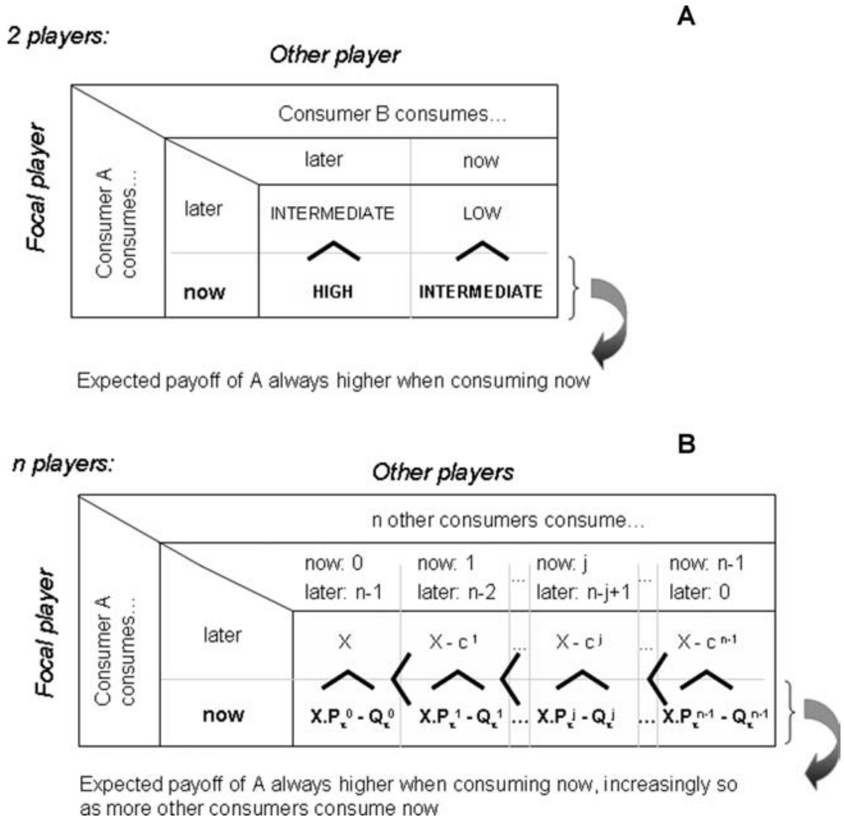

Figure 3 Game theory models demonstrate the benefit of consuming now rather than postponing consumption of rare commodities. (A) Matrix of expected payoff of a simple two-player game theory model in which both players can either consume now or postpone consumption to the next time step. (B) Equivalent matrix with n players, where A chooses to consume either now (t) or later ($t + \tau$) while knowing how many consumers will consume the resource now. This model accounts for the decrease of the elementary gain X through the competition with i other consumers, (c^i), the probability (estimated by A) for the resource not to be depleted at $t + \tau$ when i players consume at t, (P^i_τ), and the corresponding expected value of c^i, (Q^i_τ). In both matrices, the rational strategy is to consume now, until extinction.

until the next time step. We supposed that consumers were aware of others' decisions and that they could thereby influence each other. The behavior of the players was given by the game theory model and each player removed one individual from the exploited population at each time step. Population dynamics were given by the per capita growth rate (Θ), i.e., dN/Ndt, with $dN/dt = rN\,(1 - N/K) - i$. The change in consumer numbers was given by $di/dt = [\varphi + i\psi] \times [n - i]$. We obtained Θ by solving these two equations. r is the intrinsic growth rate of the exploited population and K its carrying capacity. Among the n players (potential consumers), there are i consumers at time t, φ is the number of players who consume the exploited species irrespective of what others do, and ψ is the increment in the number of players who consume due to the other's choice to consume.

Results

Caviar consumers' attraction to rarity

Even before they tasted either sample, 57% of the consumers interviewed during luxury receptions explicitly expressed an a priori preference for the rare species caviar, (Pearson Chi-square homogeneity test: $\chi^2 = 6.02$, $df = 1$, probability of making a Type I error < 0.0001, $n = 307$). No one expressed an a priori preference for the common caviar (Figure 2A).

Having tasted the two samples, a majority (86.1%; Pearson Chi-square homogeneity test: $\chi^2 = 111.01$, $df = 2$, probability of making a Type I error < 0.0001, $n = 316$) preferred one of the two samples, despite the samples being strictly identical. Among this majority, 70.2% preferred the rare species caviar (Figure 2B; Pearson Chi-square homogeneity test: $\chi^2 = 44.49$, $df = 1$, probability of making a Type I error < 0.0001, $n = 272$).

When asked to give a mark to each sample to judge its gustative quality, consumers scored the caviar of the rare species higher than the common one (14.96 ± 2.6 vs. 13.42 ± 2.94; $n = 272$; GLMM; $F = 49.017$, $df = 1$, probability of making a Type I error < 0.0001; Figure 2C). The preference for the rare caviar did not vary with the frequency of consumption of caviar by the interviewees in the luxury receptions (GLM; $\chi^2 = 3.943$, $df = 3$, probability of making a Type I error $= 0.27$, $n = 271$; Figure 2D).

Similar results were obtained with consumers interviewed in supermarkets: 52.3% expressed a positive a priori and 74.2% a confirmed preference for the rare caviar (Figure 2D). The rare species caviar also obtained higher grades than the common species caviar (GLMM; $F = 0.164$, $df = 1$, probability of making a Type I error $= 0.69$, $n = 515$; see the Methods section for details of the analysis).

Optimal strategy for consumers informed of the rarity of a resource and demographic consequences for rare species

Our game theory model showed that the expected payoff of consuming later, for the sake of sustainable resource management, is always lower than the expected payoff of consuming now, whatever the choice of other consumers (Figures 3A and 3B). This model also shows that when a species is rare, the rationality of rushing to consume instead of waiting increases as more consumers decide to consume (Figure 3B). This principle of diachronic rationality (or rationality over time) explains, at least in part, why people exhibit such seemingly irrational behavior towards sturgeon exploitation. It should be emphasized that this result would be reinforced if the hypothesis were made, as it is usually made in economic modeling (Olson & Bailey 1981), that consumers apply a positive temporal discount rate to their payoff. Our model shows this debatable hypothesis to be unnecessary, and it may hence appear more robust than standard economic models in this regard. Finally, the demographic model shows that the human attraction for rarity fuels a disproportionate exploitation of the resource, rendering it increasingly rare and thus ever more desirable, until total depletion (Figure 4).

Discussion

Our findings with both novice and regular caviar consumers demonstrate an irrational preference for the caviar they believed came from a rare species, although both the rare and common samples came from the same can. However, when interviewees were asked to grade the two samples, and thus to quantify how much better the "rare" caviar tasted, the grades they gave were close, the "common caviar" being graded only about 1.5 points less than the "rare caviar" (out of 20). Although there was statistical evidence for a difference, it was not large. Our interpretation is that the information people were given on rarity introduced confusion on their actual gustative preference. This means that preference for rarity does exist and influences behavior. In our study, only French consumers, renowned, ironically, for their taste for luxury products and their sophisticated palates, were

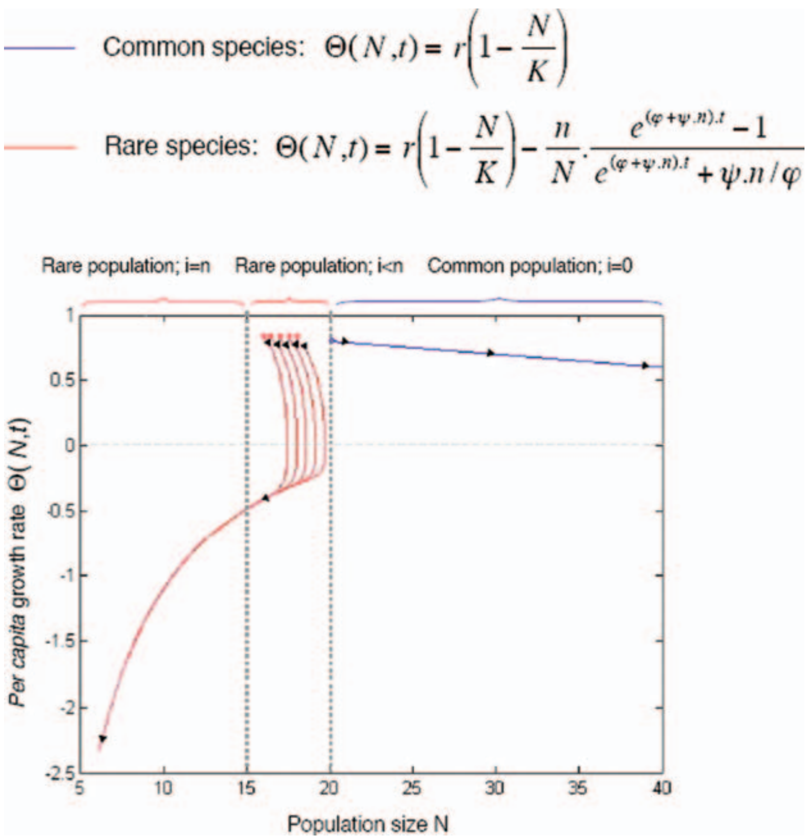

Figure 4 Trend of exploited populations of size N and per capita growth rate Θ. This graph shows the relationship between the population growth rate and its size with time, when the population is rare (red lines) and when it is not (blue line). The initial conditions are symbolized by the colored circles, and the trend, towards $N = 0$ (red lines) or $\Theta = 0$ (blue line), is shown by black arrowheads; when $i = n$ or $i = 0$, all possible initial conditions are along the line (see text for parameter explanations). While under this model populations that are not rare are not exploited and keep a positive growth rate until K, exploitation of a rare population decreases its growth rate. Below a given population threshold (here arbitrarily set at $N = 20$), there are increasingly more players deciding to consume without waiting, until all do so ($i = n$; here at $N = 15$). Exploitation amplification drives the population to extinction.

tested. However there is no reason to think that this preference does not hold for consumers outside France.

The artificial value placed on rare products probably drives the entire luxury goods market, in which interpersonal motives (Vigneron & Johnson 1999), reflecting the consumers' self-consciousness (Brinberg & Plimpton 1986) and social influence, play a major role for prestige-seeking consumers. We show here that, in a simple setting where consumers directly extract a rare resource, this human attraction for rarity can lead to its depletion. On real world markets, however, the whole story is likely to be more complicated. Indeed, the phenomenon we pinpoint is entirely based on demand-side considerations. One could argue that, in the face of such a demand, basic supply-side management practices would consist in refraining from depleting the resource in order to secure future gains from trade. The impeccable part of this rejoinder is that economic institutions and local property rights regimes are indeed undoubtedly likely to influence the fate of resources (as is analyzed in numerous case studies, drawing on Coase's 1960 insight: for example, Ostrom *et al.* 1994, Grafton 2000, Grafton *et al.* 2000). But our aim here was not to provide for a grant all-encompassing theory, it was to stress on a basic mechanism whose multifarious consequences we urge should be investigated. Indeed, the very notion that rarity itself could exaggerate demand is apt to throw a new light on the debates on how to alleviate the "Tragedy of the Commons" (Hardin 1968) and how to secure "optimal extraction" of renewable resources. This process we identified is characteristic of an anthropogenic Allee effect: a human-generated mechanism that leads the exploited species into an extinction vortex (Courchamp *et al.* 2006). This process was named by analogy with the Allee effect (Courchamp *et al.* 1999, Berec *et al.* 2007), a mechanism by which plants or animals have a lower fitness in small populations than in larger populations. This translates into lower population growth rates (and even negative growth rates) at low densities, ultimately driving these populations to extinction.

The phenomenon we describe here presents a risk for biodiversity in general: it seems that any species, exploited for whatever reason, can turn into a rare and coveted species exposed to high extinction risks. It is the case for sturgeon caviar, which used to be inexpensive when common, was consumed in large quantities by Russian nobility and served in the 1900s in American bars for a penny a pound to make consumers thirsty. It may also be the case for many other delicacies, such as the abalone Haliotis spp., the bluefin tuna, *Thunnus thynnus*, and the Napoleon wrasse *Cheilinus undulates* (a single pair of lips costs US$250; Lee & Sadovy 1998). Other wildlife products are also concerned: exotic woods (mahogany, ebony), reptile skins (snakes, crocodiles, lizards), furs and leather hides (wild cats, antelopes) are used for luxury clothes and accessories. For example, the demand for shahtoosh shawls made from the wool of the Tibetan antelope (*Pantholops hodgsonii*, also called chiru), caused the global population of chirus to decline over the last 50 years (Harris *et al.* 1999; Mallon 2003). As they become rarer, these animals may be increasingly exploited.

The tendencies of both confirmed and novice caviar consumers to prefer rare species suggests that this predilection is not restricted to current consumers, but that anyone reaching a sufficient level of wealth to afford luxury items would probably respond in this way. This finding is especially worrying as the general level of world wealth grows. The luxury market has expanded continually over the past 25 years due to people's growing materialism (Powderly & MacNulty 1990; Vigneron & Johnson 1999), their increased buying power (The World Bank Group 2008), and the recent tendency towards "democratisation" of luxury (Dubois & Laurent 1998). The emerging economies of Brazil, Russia, India, and China are also swelling the number of consumers able to enter this market (Wong & Ahuvia 1998). For example, by 2011 a quarter-billion consumers will make China the world's largest consumer of luxury goods (Ernst & Young 2005). The pressure on wildlife species that are already rare or likely to become rare is thus likely to increase in the short run.

The fact that rarity seems to play a role in fueling caviar trade makes it particularly difficult to control sturgeon exploitation. In addition to this psychological aspect stands a nonnegligible cultural aspect for countries that have been historically producing and consuming caviar, such as the Caspian Littoral States, and especially Russia.

Given the threatened status of sturgeons today, it might seem the straightforward policy recommendation should be to ban all caviar imports. However, evidence suggest that trade bans can also stimulate illegal trade (Rivalan *et al.* 2007). Applying quotas would generate a situation with a tradeoff difficult to manage: low quotas (small trade volumes) would not reduce the caviar value enough (it would still be "rare") while high quotas (large trade volumes) would not protect the species. Whatever the quota policy selected, it should be applied in conjunction with producer and especially consumer education, as well as valorization of a farmed substitute for wild caviar (e.g., through employment of local fish workers, payment of incentives and revenues for good management). Switching to farmed caviar will not be easy for caviar consumers, as they might prefer wild caviar, just as they prefer a "rare" caviar compared to a "common" one. Such a preference for wildlife products rather than their farmed equivalents has been demonstrated in the market of traditional Asian medicine (Anderson *et al.* 2002, Nowell & Ling 2007). A change in the consumers' behavior towards an ethical and sustainable consumerism (Cooney & Jepson 2006) seems the key to sturgeon survival, as well as other wildlife species concerned with luxury trade.

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