

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

The future of caviar production on the light of social changes: a new dawn for caviar?

This is a pre print version of the following article:

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1664469> since 2018-03-29T11:17:32Z

Published version:

DOI:10.1111/raq.12235

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

This is the author's final version of the contribution published as:

Sicuro B. The future of caviar production on the light of social changes: a new dawn for caviar? *Reviews in Aquaculture* (2018) 0, 1–16 doi: 10.1111/raq.12235

The publisher's version is available at:

<https://onlinelibrary.wiley.com/doi/abs/10.1111/raq.12235>

When citing, please refer to the published version.

Link to this full text:

<https://onlinelibrary.wiley.com/doi/abs/10.1111/raq.12235>

This full text was downloaded from iris-AperTO: <https://iris.unito.it/>



The future of caviar production on the light of social changes: a new dawn for caviar ?

Journal:	<i>Reviews in Aquaculture</i>
Manuscript ID	Draft
Manuscript Type:	Review
Date Submitted by the Author:	n/a
Complete List of Authors:	Sicuro, Benedetto; University of Torino, Veterinary Sciences
Keywords:	caviar, caviar production, caviar consumption, farmed caviar, sturgeon farming, luxury consumers

SCHOLARONE™
Manuscripts

View Only

1 **The future of caviar production on the light of social changes: a new dawn for caviar**

2 ?

3

4 Benedetto Sicuro

5 Department of Veterinary Sciences, L. go Braccini, 2, 10095 Grugliasco, (TO), Italy

6 E-mail: benedetto.sicuro@unito.it, tel +39 011 6709260, fax + 39 011 6709240

7

8 Running title: Sicuro. The future of caviar soc. chang.

For Review Only

1 **The future of caviar production on the light of social changes: a new dawn for caviar**

2 ?

3

4 **Abstract**

5 Caviar consumption is increasing and main projections indicate that the presumable
6 maximum production will be of 3000 t/year. From the productive point of view, the
7 principal difference from the past caviar production is the definitive shift from wild to
8 farmed caviar. Due to the recent advances in sturgeon aquaculture and the expansion of
9 luxury consumers, there remains vast potential to reshape caviar consumption. Luxury
10 market is extremely lucrative, it accounted for €217 - €253 billion in 2016 and this is about
11 1,5 times of world aquaculture production. However these perspectives are not only
12 positive as this market segment is also affected by the diffusion of imitation (*i.e.* caviar
13 substitutes, in this case). The proliferation of caviar substitutes can be interpreted as a kind
14 of commercial Müllerian mimicry while the adoption of new marketing strategy defined
15 “Masstige”, that describes a downward luxury extensions directed toward middle class
16 consumers, introduce new perspectives to this sector in its totality. What suggestions can be
17 made by observing luxury consumers attitudes ? This review takes in consideration the
18 relation between sturgeon farming and quality of caviar on the light of modern societal
19 changes. . The main challenge for sturgeon aquaculture will be to spread a positive image
20 of farmed caviar, thus introducing the aspects of excellence related to extensive aquaculture
21 in controlled conditions by the adoption of shared rules on caviar quality. The most
22 interesting aspects emerged are related to potential social expansion of caviar consumption,
23 particularly in the middle class of consumers.

24

25 **Keywords:** caviar, caviar consumption, sturgeon farming, caviar production , luxury
26 consumers, farmed caviar
27

For Review Only

28

29 **1. Introduction**

30

31 Caviar is the most expensive aquaculture product and the retail prices in sturgeon caviar
32 can range from 1000 up to 5000 US\$/kg. Caviar production is historically originated in
33 Russia and by the early 20th century Russia was a major caviar trading country (Bronzi &
34 Rosenthal 2014; Bronzi *et al.* 2011; Pourkazemi 2006; Pikitch *et al.* 2005; Williot *et al.*
35 2001). Nowadays, in order to contrast the decline of natural populations of sturgeon, caviar
36 production is completely originated by aquaculture (Bronzi & Rosenthal 2014), this fact
37 open extremely positive perspectives for sturgeon aquaculture. The annual caviar
38 production is about 262 t and estimates for future range from 500 to 2000 t (Bronzi &
39 Rosenthal 2014; Wei *et al.* 2011). Considering the extraordinary economic interest,
40 traditional producer countries increased the production as the example of Kazakhstan that
41 in 2010 launched a state caviar monopoly (Orange 2010). Currently, the Swiss and French
42 are the biggest caviar consumers followed by Americans, British and Japanese.

43 In order to promote caviar market, it is important to consider the potential caviar consumers
44 that belong to the category of luxury product consumers and useful suggestions can be
45 taken observing these consumers attitudes. Caviar is a luxury product, but not more as
46 exclusive as was in the past, it can be purchased by modern wealthy consumers and these
47 consumers will be the future target for caviar producers.

48 Traditional and modern luxury consumers have specific features as high expending power
49 and reasons for acquiring luxury products brand can act as a social marker, especially for
50 middle-class wealthy consumers (Shukla *et al.* 2016; Godey *et al.* 2013). Emotional aspects
51 of luxury products as the prestigious appeal and the rarity of products, made the difference

52 of successful products. These aspects will also affect the success of modern caviar
53 producers.

54 From the productive point of view, the principal difference from the past caviar production
55 is the definitive shift from wild to farmed caviar. Due to the recent advances in sturgeon
56 aquaculture and the awareness of social changes with an expansion of luxury consumers,
57 there remains vast potential to reshape caviar consumption. The point is: is this sector of
58 aquaculture ready to answer to the modern market demand of caviar ? what are the aspects
59 in sturgeon farming that can ameliorate the production of modern caviar ? what suggestions
60 can be made by observing luxury consumers attitudes ? what can be the perspective of a
61 food luxury sector that is inevitably affected by the emergence of imitations (*i.e.* caviar
62 substitutes ?)

63 This article encompasses two main aspects of caviar production: supply (*i.e.* aquaculture)
64 and demand (*i.e.* consumers). These aspects are rarely considered together in an
65 aquaculture context, but caviar is not a mass production products and customer needs,
66 attitudes and expectancies are of primary importance for the future development of caviar
67 production. Progresses in aquaculture techniques are tangible and quantitative, while
68 consumer attitudes are more related to human psychology and emotional, thus, more
69 elusive and unfamiliar to aquaculture producers, but it is the time to include these aspects in
70 order to have a profitable and realistic perspective of this sector.

71 This review takes in consideration in the first part the relation between sturgeon farming
72 and quality of caviar, thus considering the current definition of caviar quality. Caviar
73 substitutes are also shortly described in order to give a comprehensive perspective of the
74 complete category. In the second part, the current and potential caviar consumers are
75 considered. Considering the combination of these two main aspects, the present paper aims
76 to consider caviar production and perspectives on the light of modern societal changes.

78 **1 Caviar and aquaculture: the bright side of the moon**

79 Caviar history follows the trend of typical luxury stereotype, in fact, in the beginning of
80 1900 it was sold for one penny per pound in the US, successively, passing through an
81 intermediate phase, it reached the current extraordinary price. Its rarity and the need to
82 preserve natural populations of sturgeon pushed to definitive shift to aquaculture (Bronzi &
83 Rosenthal 2014). The effects of progress of sturgeon aquaculture combined with increased
84 demand, have caused some main effects, that are typical of any kind of farming industry
85 evolution: delocalization of production (sturgeon farms out of original geographic area),
86 fragmentation of productive process (separation between production and processing) and
87 diversification of products.

88 The recent advances in sturgeon aquaculture make this production much more exportable
89 than in the past, in fact 41% of sturgeon farms are localized out of traditional area of caviar
90 production and 31 out of 41 countries where the sturgeon farms are localized, are out of
91 traditional consumers area (Bronzi & Rosenthal 2014). New countries have progressively
92 entered in this production, with new sturgeon species as China and US and exotic
93 geographical regions, as United Arab Emirates, Uruguay and Vietnam (Fig. 1). From the
94 point of view of volumes, since 2006 the exports of Chinese farmed caviar have been
95 constantly increasing (Wei *et al.* 2011). It is very well known that China is the first country
96 for aquaculture in the world and represents 75 - 80 % of world production of sturgeon meat
97 (YJC.IR 2013). Currently the estimated Chinese caviar production range between 128 and
98 144 t (Bronzi & Rosenthal 2014, Wei *et al.* 2011) (Fig. 1) in particular for medium priced
99 product (Godfrey 2013).

100

101 **1.1 Functional plasticity: the effects of sturgeon farming on caviar composition**

102

103 In order to promote diversification of products, it is necessary to synthetically clarify the
104 current concept of quality and parameters affecting quality. In the past it was not possible to
105 precisely define the quality of caviar, as the fishermen caught several species of sturgeons
106 from the wild with different age and stage of maturation. Grading caviar methods were
107 developed at the beginning of caviar history in Iran and Russia, were essentially based on
108 size uniformity. Currently, the reference point is considered the definition of Codex
109 Alimentarius (CAC 2013) .

110 At present days, the complete shift to caviar production from aquaculture has introduced
111 some disadvantages as the loss of unicity and rarity related with the wild caviar and these
112 aspects are central in the definition of luxury foods (Hartmann *et al.* 2016), but there are
113 also advantages as modern aquaculture techniques can introduce plasticity in these
114 products, that means diversification. In aquaculture (and any modern zootechnic activity) a
115 new category of novel products has been recently introduced, so-called “functional foods”,
116 targeted on specific consumer needs. Therefore, the adoption of these consolidate
117 aquaculture techniques in sturgeon farming will presumably improve caviar quality during
118 the long farming cycle (Zhang 2011).

119 On the light of recent progress in aquaculture, it is clear that caviar from aquaculture can
120 reach high quality as a consequence of control of rearing conditions, particularly for the
121 importance of farm water quality and sturgeon artificial feeds that can influence caviar
122 sensory profile and fatty acid composition (Czesny *et al.* 2000; Cardinal *et al.* 2002;
123 Gessner *et al.* 2002b; Gessner *et al.* 2008; Lu & Rasco 2013; Zhang 2011). Caviar
124 characteristics can be synthetically clustered into two main categories: “*pre-mortem*”
125 related with farming; “*post-mortem*” related with caviar processing and conservation.

126

127 **1.1.2 “*Pre mortem*” caviar quality**

128 Caviar off flavor are originated by lipophilic compounds that are stored in the fish eggs
129 during vitellogenesis. Several researches have been carried out on seafood flavor and more
130 than 300 volatiles have been identified in freshly harvested and processed fish (Schrader &
131 Rimando 2003). Aldehydes, geosmine and isoborneol represent the largest group of
132 substances isolated that can confer several kind of off flavors (Caprino *et al.* 2008). These
133 compounds are known in aquaculture products and they are both originated from the
134 presence of actinomycetes (*Streptomyces* and *Nocardia* spp.) and cyanobacteria (*Anabaena*,
135 *Aphanizomenon*, *Lyngbya*, *Oscillatoria*, *Microcystis* e *Pseudanabaena*) naturally occurring
136 in water bodies (Souza *et al.* 2012; Percival *et al.* 2008). For these reasons the farming
137 conditions are carefully controlled in the sturgeon farms and several attempts have been
138 made in order to contrast the formations of of-flavours, both chemical treatments (Schrader
139 2005) or biological (Schrader & Rimando 2003), but these researches demonstrated that the
140 rearing water treatment is not practically suitable and the use of rearing water geosmine and
141 isoborneol naturally-free is the optimal solution, at least in the final part of farming period.

142

143 **1.1.3 Caviar: proximate and fatty acids composition**

144 It is very well known that fish roe and particularly caviar contains high amounts of proteins
145 (Al-Holy & Rasco 2006) and lipids. The average protein content of caviar is about 30% and
146 fat ranges from 11 to 27 % (wet weight) (Billard *et al.* 2002; Gessner *et al.* 2006; Mol &
147 Turan 2008; Wirth *et al.* 2002), among fatty acids oleic acid is the dominant and
148 eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are particularly abundant
149 (Caprino *et al.* 2008; Gussoni *et al.* 2006; Intarasirisawat *et al.* 2011; Wang *et al.* 2012).
150 While proteins play a minor role in the definition of caviar quality, lipids, in particular fatty
151 acids, noticeably influence caviar taste, being off flavors mainly originated by lipophilic
152 compounds. During vitellogenesis, fatty acids are mobilized from the lipid reserves

153 localized in the adipose tissue and are included into the oocytes. Therefore, the fatty acid
154 composition of the oocytes it is influenced by the fish diet (Gessner *et al.* 2002a; Webb *et*
155 *al.* 2001; Wirth *et al.* 2000; Zhang *et al.* 2011). Similarly to sturgeon flesh, the majority of
156 researches found a relation between diet and caviar composition (Badiani *et al.* 1997; Zhang
157 *et al.* 2011). Caviar fatty acid composition varies among different sturgeons species, farmed
158 or wild, freshwater or marine origin (Czesny *et al.* 2000; Shin *et al.* 2010). Farmed caviar
159 from intensive aquaculture significantly differs from that of wild origin, while composition
160 of extensively farmed caviar does not largely differ from wild caviar (Gessner *et al.* 2002b;
161 Gessner *et al.* 2002a). Few recent researches indicated that in some cases sturgeon diet did
162 not affect the amount of egg yield and egg texture in white sturgeon (*A. transmontanus*)
163 (Zhang *et al.* 2011) or fatty acid composition in white sturgeon that was only minimally
164 influenced by dietary fatty acid composition (Caprino *et al.* 2008). These authors explained
165 this fact considering that the optimal threshold levels of fatty acids of caviar were reached
166 independently from dietary fatty acids. As regard as possible change in fatty acids
167 composition during conservation, Gussoni *et al.* (2007) investigated *A. transmontanus*
168 caviar thus showing that during caviar storage at 4 °C for a period of 4 months the fat
169 content and fatty acid composition remained unchanged.

170 Fatty acid profile can be a viable tool in discrimination of different sturgeon populations
171 with respect to caviar source (Czesny *et al.* 2000; Gessner *et al.* 2008). Capric acid has
172 been proposed as cheap and easy-to-assess fatty acid useful for discriminating caviar from
173 aquaculture (Wuertz *et al.* 2009). A patent application was submitted in US in 1998
174 (Birnstein *et al.* 1998). Considering the compositional plasticity of caviar, Gessner *et al.*
175 2008 proposed an international commercial agreement between feed producers and
176 sturgeon farmers that would ensure the utilization of specific feed compositions that include
177 peculiar fatty acids that will mark farmed sturgeon from wild ones.

178

179 **1.1.4 Contaminants**

180 Sturgeons reach maturity at 5 – 30 years of age (Billard & Lecointre 2001), consequently
181 caviar is prone to bioaccumulation of toxic substances eventually contained in feeds.
182 Considering the exiguous consumption of caviar, the risks for human health is really low
183 and the diffusion of caviar from aquaculture will probably reduce these risks. Even if the
184 situation of contaminant in caviar is highly variable, in different researches (Gessner *et al.*
185 2002b; Kruger & Pudenz 2002; Wang *et al.* 2008), the amount of contaminants in caviar
186 seems to be primarily influenced by geographical area of production and secondarily, for
187 wild caviar, by trophic level occupied by sturgeon species. Beluga caviar is most exposed
188 to accumulation of chlorinated hydrocarbons (Gessner *et al.* 2002b). The highest
189 concentration of toxic compounds in caviar was found by Billard *et al.* 2002 that reported
190 concentration of polychlorinated biphenyl (PCBs) ranging from 10 to 100 times higher than
191 the limit for sturgeon flesh, particularly in Beluga from Romania. Kruger & Pudenz (2002)
192 stated that the quantity of organochlorines, as DDT, in caviar coming for Black and
193 Caspian Sea was largely influenced by trophic level occupied by species. Caviar coming
194 from Azerbaijan, Bulgaria, Iran, and Russia was found with high organochlorine and
195 polychlorinated biphenyls (PCBs) contents (Wang *et al.* 2008), while caviar
196 commercialized in Pakistan resulted in a very low concentration of various toxic elements
197 and heavy metals (Rehana 2008).

198

199 **1.2“*Post mortem*” caviar quality**

200 The techniques utilized for caviar processing have a significant impact on product quality
201 (Gessner *et al.* 2002a; Rasco *et al.* 2006), off flavors originated during conservation, total
202 volatile nitrogen, histamine and other biogenic amines are related with microbial

203 contamination caused principally by *Pseudomonas* and coliforms (Jelodar & Safari 2006).
204 Microbial contamination can take place in processed fish products and caviar (Bagge-Ravn
205 *et al.* 2003), in particular caviar can be contaminated with various species of opportunistic
206 bacteria, as *Aeromonas* sp., *Proteus* sp. and *Vibrio* sp. (Bledsoe *et al.* 2003) or coliforms
207 and *Escherichia coli* (Altug & Bayrak 2003). The principal factors favoring the caviar
208 bacterial contamination are pH level, the storage temperature and presence of free amino
209 acids. Bacterial contamination during the processing increases the content of total volatile
210 nitrogen, peroxide value, free fatty acid, ammonia and biogenic amines as methylamine and
211 trimethylamin (Křízek *et al.* 2011; Lapa-Guimaraes *et al.* 2011; Safari & Yosefian 2006).
212 Although processing techniques for canned caviar are generally safe from this problem
213 (Altug & Bayrak 2003), one of the most efficient method tested for control the
214 contamination and spoilage of caviar is considered the Hazard Analytical Critical Control
215 Point (HACCP) system (Jelodar & Safari 2006).

216

217 **1.2.1 Additives and conservation methods**

218 Caviar refrigeration at 4 °C is the main conservation method for caviar (Gussoni *et al.*
219 2006) while sodium chloride (NaCl) is the only preservative universally accepted by
220 consumers. Caviar is added with salt for preservation, that normally ranges between 3%
221 and 5%. The best quality caviar is only slightly salted and is called “Malossol”. Packaging
222 in anaerobic condition is also used for the control of contamination and spoilage of caviar
223 (Salmani *et al.* 2009). In other fish roe the addition of preservatives (as sodium benzoate or
224 citric acid) or colorant is permitted (Kirschbaum *et al.* 2006; Lapa-Guimaraes *et al.* 2011),
225 in Europe, the only permitted caviar preservatives are boric acid and sodium borate at
226 maximum concentration of 4g/kg, Commission Regulation (EU) 1129/2011. Borax use is
227 prohibited in the U.S (Shin *et al.* 2010). Currently only few preservatives can be used,

228 while physical treatments are not suitable for caviar conservation (Tab.1). Natural
229 antioxidants can be eventually used during processing or directly in the fish feed, in order
230 to decrease dietary artificial antioxidants commonly used, as happens in other sectors of
231 aquaculture (O'Sullivan *et al.* 2005).

232

233 **1.3 Analytical methods: war between man and machine**

234 Promotion of quality needs quantification, but in several luxury foods as wine or cheese,
235 human taste still plays a central role in the definition of quality. The scientific literature
236 basically shows analytical methods from one side and panel test on the other.

237 Historically, the assessment of quality of caviar was principally based on sensory
238 evaluation by specialized panelists and their job represented a great cost for enterprises,
239 consequently several analytical methods have been developed in these last years (Ludvig *et*
240 *al.* 2002; Moradi 2003; Rodushkin *et al.* 2007). Caviar quality is evaluated by four main
241 methodologies: sensorial, chemical, physical and microbial tests. Eggs size, color and
242 intensity of darkness and bronze color are crucial from the point of view of consumer. Pale
243 caviar and bigger size eggs are worldwide considered better quality, secondary parameters
244 are texture and flavor (Guinard & Mazzucchelli 1996; Wilkinson *et al.* 2000; Szczesniak
245 2002; Sorensen *et al.* 2003). Flavor profile can be defined by panel test, chemical
246 evaluation with chromatography and mass spectrometry or by gas – chromatography and
247 olphactometry (Golovnya 1976; Triqui & Zouine 1999; Jonsdottir *et al.* 2004; Caprino *et*
248 *al.* 2008). Considering the effect of sturgeon feeding, panel test analysis has been also
249 applied on caviar for the evaluation the effects of dietary flavonoids on sturgeon (Wang *et*
250 *al.* 2012). Between the methodologies used, the olfactometric approach seems to be more
251 suitable (Caprino *et al.* 2008). Texture analysis can be carried out with sensorial or
252 instrumental analysis, but texture is heavily influenced by packaging methods. Instrumental

253 detection of texture has been also studied in several fish product and it is considered more
254 suitable (Hyldig & Nielsen 2001). Previous study demonstrated the efficacy of instrumental
255 detection of texture even comparing result obtained with sensorial analysis (Borderias *et al.*
256 1983; Hyldig & Nielsen 2001).

257 Compared with others food products, the caviar sensory analysis still needs a shared
258 lexicon with specific and univocal descriptors and standardized methods. Some attempts
259 have been carried out by Cardinal *et al* (2002) that defined a list of descriptors for caviar
260 sensory analysis in order to discriminate between farmed and wild caviar and Rasco *et al.*
261 (2006) that listed 16 attributes useful to discriminate between 22 commercial caviars.
262 Successively, a lexicon for standardized sensory evaluation based on 16 sensory attributes
263 for evaluation was proposed (Baker *et al.* 2014). Sensory analysis was initially used in
264 caviar production for detection of difference between farmed and wild caviar (Cardinal *et*
265 *al.* 2002), successively other parameters were investigated as sturgeon feeding, farming
266 techniques, geographical origin, conservation and processing (Schrader & Rimando 2003;
267 Lu & Rasco 2013).

268

269 **1.4 Caviar substitutes in an evolutionary perspective: the raise of modern market** 270 **parasitism or mimicry?**

271 There is a proliferation of alternative products of caviar that deliberately or unconsciously
272 refers to appeal of true caviar (Bronzi & Rosenthal 2014). From an evolutionary point of
273 view, the relationship between caviar and its substitutes can be interpreted following two
274 main ecological paradigms: parasitism or mimicry, that in turn reflect two sides of this
275 phenomenon: vertical relation between original and substitutes or horizontal relation
276 between substitutes and original (Fig. 4).

277 If the relation caviar - caviar substitutes can be considered a parasitic relation, the most
278 similar case of parasitism can be considered the cuckoo example that lays eggs in other bird
279 nest (host species), that in the case of caviar is the consumer. Exactly as happens for bird
280 eggs, in this case fish eggs (caviar substitutes) are produced in the marketplace (bird nest)
281 in order to confuse host bird (or consumer). This can be the case of substitutes that try to
282 passively refer to caviar (some products that have only assonant names, for instance Deluga
283 caviar).

284 Otherwise, if the similitude between caviar and caviar substitutes is emphasized, it is clear
285 that the presence of exclusive products immediately stimulates the surrounding elements to
286 imitate the original one. Observing with more attention the production of caviar and caviar
287 substitutes, it is likely that the diffusion of caviar substitutes has benefitted also caviar,
288 therefore this phenomenon can be compared with Müllerian mimicry, that is a form of
289 mimicry where all the species take benefit from mutual resemblance (Benson 1972). A
290 lexical Müllerian convergence sequence is immediately visible already in the abuse of
291 “caviar” definition (Fig. 5), that induces a confusion in the consumers exactly in the same
292 way as a predator bird can confuse bees with an innocuous insect, but at the same time
293 stimulates general consumption of caviar and its substitutes.

294 Considering these analogies, the point is: what is the advantage to consider caviar and
295 caviar substitutes market in an evolutionary approach, does it makes really sense?

296 Shortly considering the occurrence of these phenomena in the natural ecosystems, (*i.e.*
297 cuckoo parasitism and Müllerian convergence), two simple considerations can be made and
298 transposed to the caviar production market: those caviar substitutes that try to passively
299 imitate caviar, similarly to cuckoo are condemned for their evolutionary lifespan to
300 incessantly follow their host, following the Red queen hypothesis, as the consumers will be
301 progressively able to discern original caviar from this substitute. In practical terms, this

302 indicate that few companies can imitate passively original caviar in the future and from
303 aquaculture point of view these two categories of company will both survive, but these
304 substitutes of caviar will not proliferate. In fact, few species of cuckoos are currently
305 diffused that are extremely specialized on few species of host birds.

306 Otherwise, if we take in consideration the horizontal imitation process that by the proposed
307 analogy can be considered the origin of a Müllerian convergence sequence, the number of
308 mimics is markedly more elevated, thus indicating that those companies that produce caviar
309 substitutes with distinctive features are likely to be more numerous in the future. This
310 Müllerian sequence looks more convenient for substitute caviar producing companies and
311 for true caviar itself. Therefore, this paradigm fits better to the description of current
312 situation of caviar and it has been already observed in the packaging of other food products
313 (Sherratt 2008).

314

315 **1.5 Caviar substitutes: the downshifting of caviar**

316 If the caviar substitutes are considered in the context of luxury market dynamic, some
317 interesting considerations can be made. From this point of view, caviar substitutes can be
318 considered as an effect of adoption of marketing strategy of imitation. The presence of
319 imitations in luxury market is very well known, that has stimulated competition and has
320 forced the traditional companies to develop new strategies to increase customers loyalty
321 and fidelity (Anselmsson *et al.* 2014).

322 Caviar substitutes and imitations are represented by an highly heterogeneous category of
323 products which were estimated about 50000 t/year in 2011 (Bronzi & Rosenthal 2014; FAO
324 2012) (Fig.2 and 3). This impressive production can be interpreted in a negative sense in
325 terms of competition with true caviar or in positive sense in terms of market demand of low
326 price caviar for new consumers. This demand may be an opportunity for aquaculture.

327 Market demand for products made from the roe of salmon, herring, cod, Alaskan pollock,
328 lumpfish, rainbow trout, capelin and other species is increasing (Airado-Rodriguez *et al.*
329 2010; Johannesson 2006; Machado *et al.* 2016). Bronzi & Rosenthal (2014) excellently
330 described these products and their potentialities, thus showing that caviar definition by
331 itself represent an appeal and the abuse of this term can induce confusion in modern
332 consumers by one hand and loss of competitiveness for caviar producers by another hand.
333 Within caviar substitutes, traditional products, as lumpfish (*Cyclopterus lumpus*) caviar,
334 encounter a constant market demand (Johannesson 2006), they gained a specific market
335 segment that apparently will not represent a competition with true caviar, while modern
336 substitutes can interfere with caviar production. A modern entry in this category is “caviar
337 from ovulated eggs”, i.e. obtained without animal sacrifice, that sounds more ethically
338 sustainable and improves the acceptance of consumers concerned on sturgeon over
339 exploitation. The main disadvantage is that the ovulated eggs lose some organoleptic
340 characteristics, mainly the typical consistence of traditional caviar. First attempts to get
341 caviar from ovulated eggs were carried out in France, where in 1997 a EU COST project
342 titled “Production of caviar from roe and ovulated oocytes from some farmed sturgeon
343 species” was funded, successively in Romania and Moldova (Billard *et al.* 2002) and more
344 recently a method have been patented in Germany (Köhler-Günther 2007) based on caviar
345 production from ovulated stripped sturgeon eggs. Roe can be eventually harvested again
346 from these fish during later spawning cycles (AWI 2011). A case of seven harvests from
347 same fish over a period of 15 years has been reported (Bledsoe *et al.* 2003).

348 In southern Spain the first organic sturgeon farm in the world has been founded in 2009
349 (Wrathall 2009), while the first organic caviar farm in North America has been launched in
350 February 2013 (Global Trust 2013). However organic caviar is not obtained by

351 standardized procedure and this definition is still self-referential and based on local farm
352 definition.

353

354 **1.6 Labels**

355 In order to protect and promote future caviar trade, the correct caviar labeling is a primary
356 question of international relevance, unfortunately, at the moment there is not yet a clear
357 agreement on this question. International organizations as FAO, Convention on
358 International Trade of Endangered Species (CITES) and International Union for
359 Conservation of Nature (IUCN) primarily emphasized the importance of species indication
360 in caviar labels (Carocci *et al.* 2004; Wuertz *et al.* 2009). FAO and Convention on
361 International Trade in Endangered Species of Wild Fauna and Flora (CITES) documents
362 stated that roe from any fish not belonging to the Acipenseriformes species are considered
363 "substitutes of caviar" (Carocci *et al.* 2004; CITES 2002).

364 Despite these suggestions, caviar labels change in different countries and fraudulent
365 mislabeling is a serious problem, with low value caviar substituted for highly prized caviar
366 (Birnstein *et al.* 1998; Pikitch *et al.* 2005; Wuertz *et al.* 2007). Currently only in the U.S.
367 sturgeon caviar can be labeled as "caviar", roe from other fish species must be identified
368 with a specific term that should include the common name of the fish. China, that is
369 emerging country in caviar production, is strongly oriented toward the adoption of CITES
370 requirements for labeling, in order to open up to international markets (Wei *et al.* 2011).

371 Labeling must be supported by analytical methods necessary to detect certified quality.
372 Several methods as DNA-based techniques, scanning calorimetry (DSC), N and C stable
373 isotopes, and reverse transcription PCR have been applied for identification of caviar
374 authenticity species and source (wild vs farmed) (Arvanitoyannis *et al.* 2005; Debus *et al.*
375 2002; Rehbein *et al.* 2008). The indication of geographical origin and modern labeling are

376 already adopted in other fish roe. In Sweden a quality scheme called Protected Designation
377 of Origin (PDO), based on EU rules, has been recently proposed for a vendace
378 (*Coregonus albula*) roe (Bonow & Rytönen 2013), in Mauritania an artisanal fish product
379 obtained from mullet roe, the “Imraguen Women's Mullet Botargo”, has obtained an
380 international label, sponsored by an Italian Association that protect local products, “Slow
381 Food”,

382 (http://www.slowfood.com/donate/pagine/eng/donate/dettaglio_progetti.lasso?-idp=038).

383 same foundation sponsored mullet roe product in Italy, “Bottarga”

384 <http://www.slowfoodfoundation.com/italian-presidia/details/3306/orbetello-botargo>.

385

386 **2. Caviar and consumers: the dark side of the moon ?**

387 Historically, caviar was a food product exclusively consumed by aristocracy. In fact in the
388 United Kingdom there is a special link between royal family and caviar from Middle Age.
389 Today the market is changed, much more consumers can afford caviar as other luxury
390 products. There is an extended scientific literature that investigated the luxury product
391 consumers market (Anselmsson *et al.* 2014; Chandon *et al.* 2016; Hartmann *et al.* 2016)
392 and the consideration that caviar belong to this category (i.e. luxury products) may add
393 interesting aspects to the discussion on caviar itself.

394 First of all, it should be remembered that luxury market is extremely lucrative. The global
395 luxury market includes several modern brands and products, it has constantly grown from
396 €77 billion in 1995 to €217 - €253 billion in 2016 and it is traditionally not affected by
397 economic crisis (Parguel *et al.* 2016; Hartmann *et al.* 2016). This amount is about 1,5 times
398 of last estimate of entire world aquaculture production that is of €147,6 billion (FAO 2016).
399 Nowadays, the customer demand of luxury products is increasing due to a combination of

400 demographic and cultural shifts, in combination with an increase of incomes that increased
401 the general availability to spend more money on premium products.

402 Looking a little bit inside this market segment, it results clear that there is a lot of internal
403 competition and it is a really challenging market as new products original or imitations,
404 constantly are introduced in this sector. New perspectives for caviar market are not
405 exclusively positive and although this market segment is promising, it is also intrinsically
406 unstable. Technical advantages in luxury products quickly become ordinary as new
407 competitors standardize innovations. Nearly 80% of all cars contain standard features that
408 were considered luxury features only a few years ago (Silverstein & Fiske 2003).Luxury
409 food market is also of cyclic nature “In short, our eating habits today largely are the result
410 of, and reflect, the luxury food of the past” (Hartmann *et al.* 2016). For 25 centuries, luxury
411 has been the privilege of few persons, starting with modern society, luxury spread to other
412 social groups. Luxury goods entered in a new era, providing a kind of democratic right to
413 happiness and the inaccessible become accessible to almost everyone, and the average
414 European citizens buys two luxury items every year (Chandon *et al.* 2016; Godey *et al.*
415 2013). Luxury consumers represent a small portion of our society, but they are the core
416 target of caviar production. If we take in consideration the most successful brand of luxury
417 products, some new suggestion can be adopted for the promotion of caviar consumption in
418 the future. Caviar is a symbol and new consumers are probably more attracted by its
419 prestige and rarity than by its flavor. In fact Gault *et al.* (2008) demonstrated that caviar
420 consumers show an irrational attraction for more rare caviar has happens in several luxury
421 product originated by rare animals.

422 New luxury consumers are emerging and Silverstein & Fiske (2003) in an Harvard
423 Business Review article entitled “Luxury for Masses”, defined “Masstige” term indicating
424 “luxury but attainable” products. These products occupy a position between mass and class.

425 Masstige describes downward luxury extensions and this marketing strategy has been used
426 by several industries producing premium level products, with success. It is considered as an
427 innovative strategy to position a prestige company without changing the appeal (Truong *et*
428 *al.* 2009). Masstige has grown in that segment of consumers that switch some of their
429 purchases from normal products to something more exclusive (Silverstein & Fiske 2003).
430 Caviar can be perfectly included in the category of old-luxury brand extension products.
431 Successful producers of food luxury products may be useful examples for modern caviar
432 entrepreneurs. Considering wine for instance, it is clear that France spent centuries to make
433 one of the most prestigious wine industry in the world and U.S. in few decades adopted the
434 French model. Today American wine producers contend in quality with the best French
435 wines. One of the most successful premium wine producers in California said “I realized
436 there was a hole in the market I could drive a truck through, really good wines that the
437 average person could afford.” (Silverstein & Fiske 2003).
438 Caviar producers can take great advantage looking to this marketing strategies. Many new-
439 luxury brands move down-market to make their products more accessible and competitive
440 (Kapferer & Lauren 2016; Silverstein & Fiske 2003), this could the case of future caviar
441 production. A kind of mentality shift is requested to modern caviar producers that will
442 include caviar production in the modern society, it is clear that it is not more only a
443 question of aquaculture, but also a question of positioning caviar in the modern society.
444 Even if it appears a promising perspective, it is not exempt of risks, principally the brand
445 dilution. This can happens when purchases from middle class consumers becomes frequent.
446 The more affordable a product is, less prestigious is its perception (Parguel *et al.* 2016).
447 While middle class consumers may be gained adopting downshifting market strategies,
448 higher class consumers may be gained thus transferring best aquaculture practices
449 (principally related to rearing water conditions and artificial feeds) into a sturgeon

450 aquaculture, in order to contrast the erroneous belief that reared caviar has lost the
451 characteristics of rarity and authenticity of wild caviar. Authenticity is an important aspect
452 of traditional luxury foods (Arvanitoyannis *et al* 2005; Hartmann *et al* 2016) and it
453 represents the relation between a food product and its distance from industrial product and
454 mass production. Considering that the concept of luxury products is strongly related with
455 local traditions, it is likely that high class consumers will mainly increase in the area of
456 traditional caviar consumption, specifically in Russia.

457

458

459 **Conclusion and perspectives**

460 The perspectives of caviar consumption are based on two main pillars: one is the caviar
461 supply, i.e. sturgeon aquaculture, another is the caviar demand. The future of caviar will
462 essentially regard geographical and social expansion of consumption, the most interesting
463 aspects emerged from this paper are related to potential social expansion of caviar
464 consumption. Similarly to other luxury products, it is clear that caviar is not more an
465 exclusive product as in the past and sturgeon aquaculture will play the major role in the
466 future diffusion of caviar.

467 Scientific literature clearly shows that caviar quality is affected by sturgeon farming
468 practices in several ways, by sturgeon artificial feeds, by conditions of rearing not only
469 inside the farm but also in the processing phases and farmed caviar can be better respect
470 wild one, as the controlled farming conditions can guarantee consumers health,
471 organoleptic characteristics and conservation of endangered wild populations of sturgeons.

472 Moreover, a shared international definition of caviar and clear caviar labeling is an urgent
473 need in order to promote effective quality in the future. Considering the questions posed in
474 the beginning of the article, it can be stated that the sturgeon aquaculture is ready to answer

475 to modern consumers demand, thus keeping in mind the rapid changes of modern society
476 and the concept of luxury products.

477 In the 80s the world caviar production reached 3000 t/year and main projections indicate
478 that it is the presumable maximum production for the future, however these estimates don't
479 take into account the social changes of our society. Looking at luxury market trend, it is
480 likely that caviar consumption will go over these previsions, considering the expansion of
481 middle class consumers and diversification of caviar productions, promoted in turn by
482 modern aquaculture techniques and food processing techniques. Making a comparison with
483 other food luxury products, as French wines, their market evolution showed that from
484 original area, new geographical areas have gained success as California or South Africa or
485 Australia. This expansion (similarly to other successful products) has been characterized by
486 a combination of geographical vocation, sharing of technical advances and increased local
487 market demand. A well-established aquaculture industry (as the case of China and
488 Vietnam) combined with favorable geographical conditions, favors the creation of new
489 sturgeon farms out of the traditional regions. China is the country where the highest
490 number of caviar consumers and producers are expected. Moreover, new opportunities will
491 emerge looking the successful market strategies in particular for the middle class of
492 consumers. Many luxury brands have engaged in "masstige" positioning strategies , if
493 applied to caviar productions, these strategies can promote a tremendous success for future
494 of caviar.

495 The challenge for sturgeon aquaculture will be to spread a positive image of caviar from
496 aquaculture that has substituted wild caviar, thus introducing the aspects of excellence
497 related to extensive aquaculture in controlled conditions by the adoption of shared rules on
498 caviar quality. Scientific literature showed that sturgeon extensive farming doesn't
499 negatively affect quality of caviar and can even ameliorate the safety of caviar, thus

500 reducing the risks of contamination with toxic compounds naturally spread in polluted
501 regions. Moreover, looking at the experience of other sectors of aquaculture, it is clear that
502 modern consumers are concerned about sustainability of products and these aspects will
503 improve the future acceptance and diffusion of caviar, considering that this product is
504 traditionally linked with negative image of over exploiting wild stocks of sturgeon. The
505 attention for environmental impact of fish farms and fish welfare confers an extra value to
506 those products that respect natural exploitation of resource and sustainability of production.

507 The impressive amount and proliferation of caviar substitutes represents the potentiality to
508 gain large segment of low class consumers or an opportunity to increase their consumption,
509 as happened in several aquaculture products that have become common food products
510 following success of aquaculture. Considering that this proliferation can be considered a
511 social Müllerian convergence sequence, other research efforts can be addressed to
512 understand what is the maximum number of caviar imitators (i.e. substitutes) that can be
513 expected in the market, or in more formal terms, where is the limit of this sequence. In this
514 context, it is likely that Game Theory (Meyerson 1991) could be a really useful approach to
515 investigate the relation between consumers, caviar companies and substitute caviar
516 companies, as this relation can be probably explained by a non-cooperative game with
517 relevant implications for future sturgeon farming.

518 Finally, being an exclusive and evocative luxury product, the future expansion will be
519 influenced by emotional forces that are rather evanescent and intangible. These aspects are
520 only indirectly related to aquaculture and are largely influenced by media, for this reason,
521 appropriate marketing plans will be necessarily aimed at communicating these new
522 products to the consumers. Research is needed on the overlapping area between caviar
523 production and consumer needs, consumer choices analysis and purchase attitudes for
524 caviar. Future aquaculture should not finish on the store threshold, as the rest of the path,

525 from the store to the consumer home, has a particular relevance in these sectors where
526 human psychology plays a crucial role. The knowledge of social attitudes and behavior of
527 caviar consumers may probably drive successful caviar producing companies as strongly as
528 the diffusion of modern aquaculture techniques.

529

530

531 References

532

533 Airado-Rodriguez D, Skaret J, Petter Wold J (2010) Assessment of the Quality Attributes
534 of Cod Caviar Paste by Means of Front-Face Fluorescence Spectroscopy. *Journal of*
535 *Agricultural and Food Chemistry* **58**, 5276–5285

536 Al-Holy M, Wang Y, Tang J, Rasco B (2005) Dielectric properties of salmon
537 (*Oncorhynchus keta*) and sturgeon (*Acipenser transmontanus*) caviar at radio frequency
538 (RF) and microwave (MW) pasteurization frequencies. *Journal of Food Engineering* **70**:
539 564–570

540 Al-Holy M, Rasco B (2006) Characterization of salmon (*Oncorhynchus keta*) and sturgeon
541 (*Acipenser transmontanus*) caviar proteins. *Journal of Food Biochemistry* **30**: 422–428

542 Altug G, Bayrak Y (2003) Microbiological analysis of caviar from Russia and Iran Food
543 *Microbiology* **20**: 83–86

544 Anselmsson J , Bondesson NV, Johansson U (2014) Brand image and customers'
545 willingness to pay a price premium for food brands. *Journal of Product & Brand*
546 *Management* **23**(2): 90-102

547 Arvanitoyannis I S, Tsitsika E V, Panagiotaki P (2005) Implementation of quality control
548 methods (physicochemical, microbiological and sensory) in conjunction with multivariate

- 549 analysis towards fish authenticity. *International Journal of Food Science and Technology*
550 **40**: 237–263
- 551 AWI (2011) New sustainable caviar production – without the necessity to kill sturgeon.
552 Available from URL:
553 http://www.awi.de/en/institute/general_services/technology_transfer/technology_offers_awi_innovations/biotechnology/sustainable_production_of_caviar.pfd
- 554
- 555 Badiani A, Stipa S, Nanni N, Gatta P, Manfredini M (1997) Physical indices, processing
556 yields, compositional parameters and fatty acid profile of three species of cultured sturgeon
557 (Genus *Acipenser*). *Journal of the Science of Food and Agriculture* **74**:257–64.
- 558 Bagge-Ravn D, Ng Y, Hjelm M, Christiansen J N, Johansen C, Gram L (2003) The
559 microbial ecology of processing equipment in different fish industries—analysis of the
560 microflora during processing and following cleaning and disinfection. *International*
561 *Journal of Food Microbiology* **87**: 239– 250
- 562 Baker AK, Vixie B, Rasco BA, Ovissipour M, Ross CF (2014) Development of a Lexicon
563 for Caviar and Its Usefulness for Determining Consumer Preference. *Journal of Food*
564 *Science* **79**(12): 2533-2541
- 565 Benson WW. 1972 Natural Selection for Müllerian Mimicry in *Heliconius erato* in Costa
566 Rica. *Science*. **176** (4037):936-9.
- 567 Billard R, Leicontre G (2001) Biology and conservation of sturgeon and paddlefish.
568 *Reviews in Fish Biology and Fisheries* **10**: 355-392.
- 569 Billard R, Cardinal M, Kirschbaum F (2002) Caviar. In Billard R (eds) *Esturgeon et caviar*.
570 pp 187-213. Tec et Doc. Paris, Collection Aquaculture-Pisciculture,
- 571 Birnstein V J, Doukakis P, Sorkin B, Desalle R (1998) Population aggregation analysis of
572 three caviar-producing species of sturgeon and implications for the species identification of
573 Black Caviar. *Conservation Biology* **12**: 766-775

- 574 Bledsoe G E, Bledsoe C D, Rasco B (2003) Caviars and Fish Roe Products. *Critical*
575 *Reviews in Food Science and Nutrition* **43**: 317–356
- 576 Bonow M, Rytönen P (2013) Kalixlövrom caviar– an institutional analysis of the
577 application and implementation of Sweden's first PDO. *Spanish Journal of Rural*
578 *Development*, **43**: 12 -24
- 579 Borderias A J, Lamua M, Tejada M (1983) Texture analysis of fish fillets and minced fish
580 by both sensory and instrumental methods. *Journal of Food Science & Technology* **18**: 85–
581 95.
- 582 Bronzi P, Rosenthal H, Gessner J (2011) Global sturgeon aquaculture production: an
583 overview. *Journal of Applied Ichthyology* **27**: 169–175
- 584 Bronzi P, Rosenthal H (2014) Present and future sturgeon and caviar production and
585 marketing: A global market overview. *Journal of Applied Ichthyology* **30**: 1536–1546
- 586 Caprino F, Moretti VM, Bellagamba F, Turchini GM, Busetto ML, Giani I, Paleari MA,
587 Pazzaglia M (2008) Fatty acid composition and volatile compounds of caviar from farmed
588 white sturgeon (*Acipenser transmontanus*). *Analytica Chimica Acta* **617**:139–147
- 589 Cardinal M, Cornet J, Vallet J L (2002) Sensory Characteristics of Caviar from Wild and
590 Farmed Sturgeon. *International Review of Hydrobiology* **87**: 651– 659
- 591 CAC (Codex Alimentarius Commission) (2013) CODEX STAN 291-2010. Standard for
592 sturgeon caviar. pp 4 (available at
593 http://www.codexalimentarius.org/download/standards/11516/CXS_291e.pdf.)
- 594 Carocci F, Lagrange C, Levavasseur V, Yakimushkin A (2004) Sturgeons
595 (*Acipenseriformes*) in *World markets and industry of selected commercially-exploited*
596 *aquatic species*, FAO Fisheries Circulars - C990, FAO Corporate Document Repository,
597 Fisheries and Aquaculture Department. Available from URL:
598 <http://www.fao.org/docrep/006/y5261e/y5261e06.htm>

- 599 CITES (2002) CITES guidelines for a universal labelling system for the trade in and
600 identification of caviar. Available from URL: [http://www.cites.org/eng/res/12/12-](http://www.cites.org/eng/res/12/12-07R13.php)
601 [07R13.php](http://www.cites.org/eng/res/12/12-07R13.php)
- 602 Chandon J, Laurent G, Valette-Florence P (2016) Pursuing the concept of luxury:
603 Introduction to the JBR Special Issue on “Luxury Marketing from Tradition to Innovation”
604 *Journal of Business Research* **69**: 299–303
- 605 Czesny S, Dabrowski K, Christensen J E, Van Eenennaam J, Doroshov S (2000)
606 Discrimination of wild and domestic origin of sturgeon ova based on lipids and fatty acid
607 analysis. *Aquaculture* **189**: 145 – 153
- 608 Debus L, Winkler M, Billard R (2002) Structure of Micropyle Surface on Oocytes and
609 Caviar Grains in Sturgeons. *International Review of Hydrobiology* **87**: 585–603
- 610 European Parliament and the Commission of the European Communities. (1995) European
611 Parliament and Commission Directive 95/2/EC. Off. J. Eur. Comm. **61**: 1-40.
- 612 FAO (2012). FISHSTAT. Caviar and caviar substitutes (Dimension Member). Rome, Italy,
613 FAO. (Latest update: 27 Nov 2013) Accessed (13 June 2017). URI:
614 <http://data.fao.org/ref/77851ba5-ec8c-4f74-b7a9-954e8915b228.html?version=1.0>
- 615 FAO (2016) The State of World Fisheries and Aquaculture 2016. Contributing to food
616 security and nutrition for all. Rome. 200 p
- 617 Fioretto F, Cruz C, Largeteau A, Sarli T A, Demazeau G, El Moueffak A. (2005)
618 Inactivation of *Staphylococcus aureus* and *Salmonella enteritidis* in tryptic soy broth and
619 caviar samples by high pressure processing. *Brazilian Journal of Medical and Biological*
620 *Research* **38**: 1259-1265
- 621 Gault A, Meinard Y, Courchamp F (2008) Consumers' taste for rarity drives sturgeons to
622 extinction. *Conservation Letters* **5**: 199-207

- 623 Gessner J, Wirth M, Kirschbaum F, Patriche N (2002a) Processing Techniques for Caviar
624 and Their Effect on Product Composition. *International Reviews of Hydrobiology* **87**: 645–
625 650
- 626 Gessner C, Wirth M, Kirschbaum F, Kruger A, Patriche N (2002b) Caviar composition in
627 wild and cultured sturgeons – impact of food sources on fatty acid composition and
628 contaminant load. *Journal of Applied Ichthyology* **18**: 665–672
- 629 Gessner J, Wirth M, Kirschbaum F, Patriche N (2002c) Processing Techniques for Caviar
630 and Their Effect on Product Composition. *International Reviews of Hydrobiology* **87**: 645–
631 650
- 632 Gessner J, Wurtz S, Kirschbaum F, Wirth M (2008) Biochemical composition of caviar as a
633 tool to discriminate between aquaculture and wild origin. *Journal of Applied Ichthyology*
634 **24**: 52–56
- 635 Global Trust (2013) British Columbia-based Target Marine Hatcheries' Northern Divine
636 caviar has become the first certified organic caviar produced in North America. Available
637 from URL: http://www.gtcert.com/layout/content_details.cfm/ck/31/ctk/35/k/182
- 638 Godey B, Pederzoli D, Aiello G, Donvito R, Wiedmann K, Hennigs N (2013) A cross-
639 cultural exploratory content analysis of the perception of luxury from six countries, *Journal*
640 *of Product & Brand Management* **22**(3): 229-237
- 641 Godfrey M (2013) Caviar producers eye China for sales Caspian sea caviar. Available from
642 URL:
643 http://www.seafoodsource.com/newsarticledetail.aspx?id=22468&utm_source=Informz&utm_medium=Email&utm_campaign=Insert+Campaign+Name+here
644
- 645 Golovnya R V (1976) Problems in investigation of the aroma of foodstuffs and the
646 production of imitations. *Russian Chemical Reviews* **45**: 971- 981.

- 647 Guinard J, Mazzucchelli R (1996) The sensory perception of texture and mouth feel.
648 *Trends in Food Science & Technology* **71**: 213-219.
- 649 Gussoni M, Greco F, Vezzoli A, Paleari MA, Moretti VM, Beretta G, Caprino F, Lanza B,
650 Zetta L (2006) Monitoring the Effects of Storage in Caviar from Farmed *Acipenser*
651 *transmontanus* Using Chemical, SEM, and NMR Methods *Journal of Agricultural Food*
652 *Chemistry* **54**: 6725-6732
- 653 Gussoni M, Greco F, Vezzoli A, Paleari M A, Moretti V M, Lanza B, Zetta L (2007)
654 Osmotic and aging effects in caviar oocytes throughout water and lipid changes assessed by
655 ¹H NMR T1 and T2 relaxation and MRI. *Magnetic Resonance Imaging* **25**: 117– 128
- 656 Hartmann LH, Nitzko S, Spiller A (2016) The significance of definitional dimensions of
657 luxury food, *British Food Journal* **118**(8): 1976-1998
- 658 Hyldig G, Nielsen D (2001) A review of sensory and instrumental methods used to evaluate
659 the texture of fish muscle. *Journal of Texture Studies* **32**: 219-242.
- 660 Intarasirisawat R, Benjakul S, Visessanguan W (2011) Chemical compositions of the roes
661 from skipjack, tongol and bonito *Food Chemistry* **124**: 1328–1334
- 662 Jelodar AS, Safari R (2006) Microbial and chemical quality evaluation of caviar in Iranian
663 processing plants in line with the European Community code. *Journal of Applied*
664 *Ichthyology* **22**: 411-415
- 665 Johannesson J. (2006) Lumpfish caviar – from vessel to consumer. *FAO Fisheries*
666 *Technical Paper*. No. 485. Rome, FAO. 60p.
- 667 Jonsdottir R, Olafsdottir G, Martinsdottir E, Stefansson G (2004) Flavor Characterization
668 of Ripened Cod Roe by Gas Chromatography, Sensory Analysis, and Electronic Nose.
669 *Journal of Agricultural and Food Chemistry* **52**: 6250-6256

- 670 Kapferer J, Lauren G (2016) Where do consumers think luxury begins? A study of
671 perceived minimum price for 21 luxury goods in 7 countries. *Journal of Business Research*
672 **69**: 332–340
- 673 Kirschbaum J, Krause C, Bruckner H (2006) Liquid chromatographic quantification of
674 synthetic colorants in fish roe and caviar. *European Food Research Technology* **222**: 572–
675 579
- 676 Krížek M, Vácha F, Pelikánová T (2011) Biogenic amines in carp roe (*Cyprinus carpio*)
677 preserved by four different methods. *Food Chemistry* **126**: 1493–1497
- 678 Kruger A, Pudenz S (2002) Chlorinated Hydrocarbon Pollution in Caviar Samples
679 *International Review of Hydrobiology* **87**: 637–644
- 680 Lapa-Guimarães J, Trattner S, Pickova J (2011) Effect of processing on amine formation
681 and the lipid profile of cod (*Gadus morhua*) roe. *Food Chemistry* **129**: 716–723
- 682 Lu X, Rasco BA (2013) Sturgeon (*Acipenser transmontanus*) sexual maturation and caviar
683 quality. *Reviews in Aquaculture* **5**: 1–11
- 684 Ludwig A, Debus L, Jenneckens I (2002) A Molecular Approach to Control the
685 International Trade in Black Caviar. *International Reviews of Hydrobiology* **87**: 661–674
- 686 Machado TM, Tabata YA, Takahashi NS, Casarini LM, Pinheiro Neiva CR, Barbosa
687 Henriques M (2016) Caviar substitute produced from roes of rainbow trout (*Oncorhynchus*
688 *mykiss*). *Acta Scientiarum* **38**(2): 233-240
- 689 Myerson RB (1991) Game theory. Analysis of Conflict., Harvard University Press. 600 pp
- 690 Mol S, Turan S (2008) Comparison of proximate, fatty acid and amino acid compositions
691 of various types of fish roes. *International Journal of Food Properties* **11**: 669–677.
- 692 Moradi Y (2003) HACCP in Iranian Caviar. *Emirate Journal of Agriculture Science* **15** (2):
693 72-79

- 694 Orange R (2010) Kazakhstan launches state caviar monopoly. *The Telegraph*. Available
695 from URL:
696 <http://www.telegraph.co.uk/news/worldnews/asia/kazakhstan/8042351/Kazakhstan->
697 [launches-state-caviar-monopoly.html](http://www.telegraph.co.uk/news/worldnews/asia/kazakhstan/8042351/Kazakhstan-launches-state-caviar-monopoly.html)
- 698 O'Sullivan A, Mayr A, Shaw NB, Murphy SC , Kerry JP (2005) Use of Natural
699 Antioxidants to Stabilize Fish Oil Systems. *Journal of Aquatic Food Product Technology*
700 **14**, (3): 75-94
- 701 Parguel B, Delécolle T, Valette-Florence P (2016) How price display influences consumer
702 luxury perceptions. *Journal of Business Research* **69**: 341–348
- 703 Percival S, Drabsch P, Glencross B (2008) Determining factors affecting muddy-flavour
704 taint in farmed barramundi, *Lates calcarifer*. *Aquaculture* **284**: 136–143
- 705 Pikitch EK, Doukakis P, Lauck L, Chakrabarty P, Erickson D L (2005) Status, trends and
706 management of sturgeon and paddlefish fisheries. *Fish and Fisheries* **6**: 233–265
- 707 Pourkazemi M (2006) Caspian Sea sturgeon Conservation and Fisheries: Past present and
708 Future. *Journal of Applied Ichthyology* **22**: 12-16
- 709 Rasco B, Guinard J, Reid D, Barrows F, Su Y, Morrissey M (2006). Optimizing Quality
710 and Shelf-Life of Sturgeon Caviar. Western Regional Aquaculture Consortium, Final
711 report. Seattle, WA.
- 712 Rehbein H, Molkentin J, Schubring R, Lieckfeldt D, Ludwig A (2008) Development of
713 advanced analytical tools to determine the origin of caviar. *Journal of Applied Ichthyology*
714 **24**: 65–70
- 715 Rehana I (2008) Determination of Selected and Potentially Hazardous Elements in Caviar.
716 *World Applied Sciences Journal* **5** (2): 189-192,
- 717 Reza S, Zabihollah Y. (2010) Study of *Clostridium botulinum* by Various Formulations of
718 Salt and Preservatives in Persian Caviar. *Environmental Justice* **3**(1): 27-32

- 719 Rizzi G (2007) On the Effect of Tetraborate Ions in the Generation of Colored Products in
720 Thermally Processed Glycine-Carbohydrate Solutions. *Journal of Agricultural and Food*
721 *Chemistry* **55**: 2016-2019
- 722 Rodushkin I, Bergman T, Douglas G, Engstrom E, Sorlin D, Baxter D C (2007)
723 Authentication of Kalix (N.E. Sweden) vendace caviar using inductively coupled plasma-
724 based analytical techniques: Evaluation of different approaches. *Analytica Chimica Acta*
725 **83**: 310–318
- 726 Safari R, Yosefian M (2006) Changes in TVN (Total Volatile Nitrogen) and psychrotrophic
727 bacteria in Persian sturgeon Caviar (*Acipenser persicus*) during processing and cold
728 storage. *Journal of Applied Ichthyology* **22**:416-418
- 729 Salmani A, Safari R, Soltani M, Tavakoli H R (2009) Growth and toxigenesis behavior of
730 *Clostridium botulinum* type E in Persian sturgeon (*Acipenser persicus*) Caviar prepared
731 with various preservatives. *International Journal of Veterinary Research* **3**: 17-23
- 732 Schrader KK, Rimando AM (2003) Off-flavor in aquaculture: an overview. In Off-flavors
733 in aquaculture. ACS - Symposium Series, American Chemical Society **848** (1): 1-12.
- 734 Sherratt TN (2008) The Evolution of Müllerian Mimicry.” *Die Naturwissenschaften* **95.8**:
735 681–695.
- 736 Shin J, Oliveira A C M, Rasco B A (2010) Quality attributes and microbial storage stability
737 of caviar from cultivated white sturgeon (*Acipenser transmontanus*) *Journal of Food*
738 *Science* **75**: 43-48
- 739 Shukla P, Banerjee M, Singh J (2016) Customer commitment to luxury brands: antecedents
740 and consequences. *Journal of Business Research* **69**: 323–331
- 741 Silverstein MJ, Fiske N (2003) Luxury for the masses. *Harvard Business Reviews* **81**(4):
742 48-57

- 743 Sorensen LB, Moller P, Flint A, Martens M, Raben A (2003) Effect of sensory perception
744 of foods on appetite and food intake: a review of studies on humans. *International Journal*
745 *of Obesity* **27**: 1152–1166.
- 746 Souza SM, Dias MV, Fioravanzo RF (2012) Off-flavor by geosmine and 2-
747 methylisoborneol in aquaculture. *Semina-Ciencias Agrarias* **33** (2): 835-846
- 748 Szczesniak AS (2002) Texture is a sensory property. *Food Quality and Preference* **13**: 215–
749 225.
- 750 Triqui R, Zouine K (1999) Sensory and instrumental assessments of the ripening process of
751 anchovy (*Engraulis encrasicolus*). *Lebensmittel-Wissenschaft and Technologie* **32**: 203-
752 207.
- 753 Truong Y, McColl R, Kitchen P (2009) 'New Luxury Brand Positioning', *Brand*
754 *Management* **16** (5/6): 375-382.
- 755 Wang W, Batterman S, Chernyak S, Nriagu J (2008) Concentrations and risks of organic
756 and metal contaminants in Eurasian caviar. *Ecotoxicology and Environmental Safety* **71**:
757 138–148
- 758 Wang Y, Yu J, Zhang C, Li P, Zhao Y, Zhang M, Zhou P (2012) Influence of flavonoids
759 from *Phellinus igniarius* on sturgeon caviar: Antioxidant effects and sensory
760 characteristics. *Food Chemistry* **131**: 206–210
- 761 Webb MAH, Van Eenennaam JP, Feist GW, Linares-Casenave J, Fitzpatrick MS, Schreck
762 CB, Doroshov SI (2001) Effects of thermal regime on ovarian maturation and plasma sex
763 steroids in farmed white sturgeon, *Acipenser transmontanus*. *Aquaculture* **201**: 137–151
- 764 Wei QW, Zou Y, Li P, Li L (2011) Sturgeon aquaculture in China: progress, strategies and
765 prospects assessed on the basis of nation-wide surveys (2007–2009). *Journal of Applied*
766 *Ichthyology* **27**: 162–168

- 767 Williot P, Sabeau L, Gessner J, Arlati G, Bronzi P, Gulyas T, Berni P (2001) Sturgeon
768 farming in Western Europe: recent developments and perspectives. *Aquatic Living*
769 *Resources* **14**: 367–374
- 770 Wilkinson C, Dijksterhuis GB, Minekus M (2000) From food structure to texture. *Trends in*
771 *Food Science & Technology* **11**: 442–450.
- 772 Wirth M, Kirschbaum F, Gessner J, Kruger A, Patriche N, Billard R (2000) Chemical and
773 biochemical composition of caviar from different sturgeon species and origins. *Nahrung*
774 **44(4)**: 233–237
- 775 Wirth M, Kirschbaum F, Gessner J, Williot P, Patriche N, Billard R (2002) Fatty acid
776 composition in sturgeon caviar from different species: comparing wild and farmed origins.
777 *International Review of Hydrobiology* **87**:629–36.
- 778 Wrathall C (2009) An organic fish farm that produces caviar. *Financial Time*, available at:
779 www.ft.com/cms/s/0/27d92b26-ca62-11de-a3a3-00144feabdc0.html#axzz2f9oghuLQ
- 780 Wuertz S, Gröper B, Gessner J, Krüger T, Luckas B, Krüger A (2009) Identification of
781 caviar from increasing global aquaculture production — Dietary capric acid as a labelling
782 tool for CITES implementation in caviar trade. *Aquaculture* **298**: 51–56
- 783 Wuertz S, Belay M, Kirschbaum F. (2007) On the risk of criminal manipulation in caviar
784 trade by intended contamination of caviar with PCR products. *Aquaculture* **269**: 130–134
- 785 YJC.IR (2013) China employs Iranian expertise to farm caviar. Available from URL:
786 <http://www.yjc.ir/en/news/2157/china-employs-iranian-expertise-to-farm-caviar>
- 787 Zhang Y, Doroshov S, Famula T, Conte F, Kueltz D, Linares-Casenave J, Van Eenennaam
788 J, Struffenegger P, Beer K, Murata K (2011) Egg quality and plasma testosterone (T) and
789 estradiol-17b (E2) in white sturgeon (*Acipenser transmontanus*) farmed for caviar. *Journal*
790 *of Applied Ichthyology* **27**: 558–564

- 791 Zhang Y (2011) Husbandry and Dietary Effects on Sturgeon (*Acipenser transmontanus*)
792 Farmed for Caviar . *Dissertation of Master Thesis* University of California, Davis 41 pp
793

For Review Only

1 Figure captions

2

3

4 Fig.1 Main caviar producer and importer countries in 2011 (Bronzi and Rosenthal, 2014 ;

5 FAO 2012, modified. Geographical elaboration obtained with R, version 3.3.2, Copyright

6 © 2016 – The R Foundation for Statistical Computing, library(rworldmap))

7

8

9 Fig.2 Main caviar substitutes producer countries in 2011 (FAO 2011)

10

11 Fig.3 Production of caviar substitutes in main producers countries, between 2001 and

12 2011 (FAO 2011, modified)

13

14

15 Figure 4. The relation between caviar and caviar substitutes is a parasitism or a Müllerian
16 mimicry ?

17

18

19 Fig. 5 Canine caviar: an example of social Müllerian mimicry

20

21

Table 1. Caviar preservatives

Additive	species	Reference
Borax	<i>A. persicus</i>	Salmani <i>et al.</i> 2009;
Methylparaben	<i>A. persicus</i>	Reza & Zabihollah 2010
5% NaCl plus 0,3% boric acid plus 0,4 borax	<i>A. persicus</i>	Salmani <i>et al.</i> 2009
5%NaCl plus 0.15% methyl paraben	<i>A. persicus</i>	Salmani <i>et al.</i> 2009
Flavonoids extracts from the fungus <i>Phellinus igniarius</i>	n.r.	Wang <i>et al.</i> 2012
Radio frequency and microwave heating	<i>A. transmontanus</i>	Al-Holy <i>et al.</i> 2005
High pressure Pasteurization	<i>A. baeri</i>	Fioretto <i>et al.</i> 2005 Bledsoe <i>et al.</i> 2003; Shin <i>et al.</i> 2010)
Pasteurization in airtight or vacuum packaged containers (50 – 70 °C)	<i>A. transmontanus</i>	Al-Holy <i>et al.</i> 2005 Shin <i>et al.</i> 2010
NaCl between 3.2% to 11.8%	<i>H. huso</i> , <i>A. gueldenstaedti</i> , <i>A. stellatus</i> , <i>A. baeri</i> , <i>Polyodonspathula</i>	<i>A.</i> Gessner <i>et al.</i> 2002
Borates (4g/kg)	French caviar	Rizzi 2007

n.r. not reported



Fig.1

Review Only

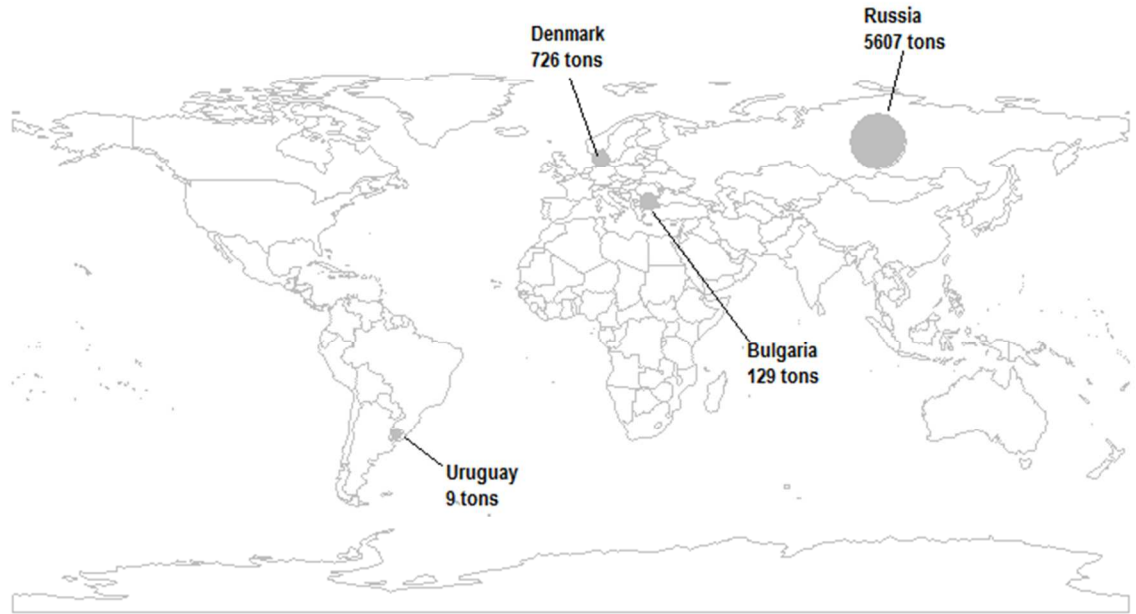


Fig.2

view Only

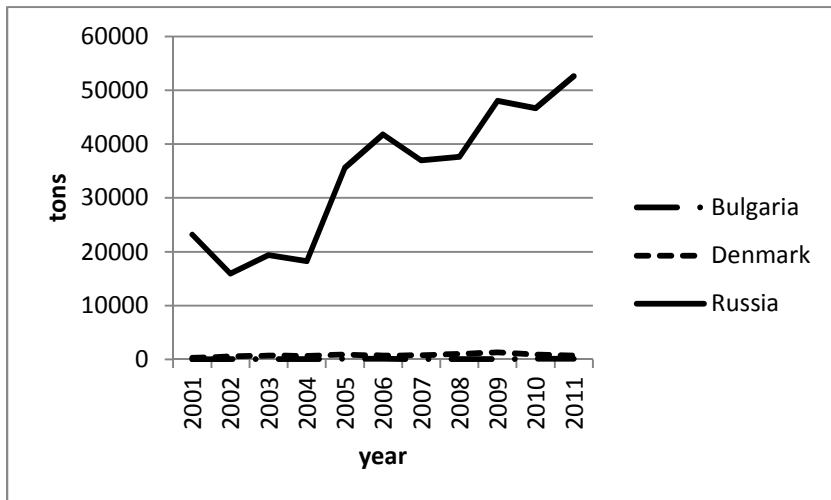


Fig.3

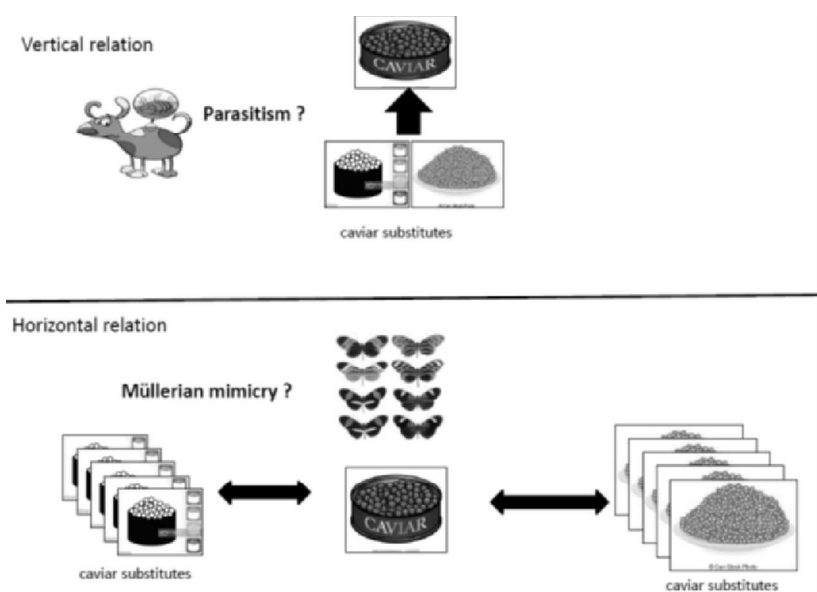


Figure 4.

Review Only



Fig. 5

For Review Only