

1 Integrating science and citizen science: the dusky grouper (*Epinephelus*
2 *marginatus*) sustainable fishery of Copacabana, Rio de Janeiro, Brazil

3

4 **Short title: The dusky grouper sustainable fishery of Copacabana**

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18

20 **Abstract**

21 We followed landings of dusky grouper, *Epinephelus marginatus*, from 2013 to 2019.
22 We observed 1,896 individuals of dusky grouper, *Epinephelus marginatus*, in Copacabana, Rio
23 de Janeiro, from September 2013 to February 2019. The total weight of the catches was 6,065.57
24 kg, with an average of 1,442.50 kg/year and a std of 147.30 kg.

25 We integrated fishers in our study through citizen science (CS): individuals were trained
26 to monitor grouper gonads and supplied information on fishing spots and prices. After comparing
27 catch curves (based on weight) and curve prices (in the Brazilian monetary currency of reals),
28 our results showed that catches in the Copacabana fishery have been stable (the results of the
29 Kruskal-Wallis test showed no significant difference for either the weight of the catches or the
30 average prices of dusky groupers in the years compared). Copacabana has been a sustainable
31 fishery when considering its catches of dusky grouper. This is a very important result for
32 conservation and management, considering the importance of small-scale fisheries in terms of
33 their low fishing efforts and their possible effects on vulnerable species, as well as their
34 ecological and economic importance in developing countries. Citizen science, along with local
35 ecological knowledge, helps integrate research and fisheries as well as researchers and fishers
36 and allows for larger sampling efforts and management training for fishers.

38 **Introduction**

39 The dusky grouper, *Epinephelus marginatus*, inhabits rocky reefs and is a slow-growing,
40 protogynous hermaphroditic, late-maturing fish that can form spawning aggregations; since
41 2004, it has been considered an endangered fish by the IUCN Red List [1].

42

43 **Small-scale fisheries**

44 Small-scale fisheries (SSFs) can be sustainable; several examples of Caribbean and Latin
45 American SSFs are given by Salas et al. [2]. In Brazil, SSFs are of overwhelming importance,
46 providing protein for poor coastal communities and riverine inhabitants; SSFs provide
47 approximately half of the country's fish production, but in some regions, it can reach higher rates
48 [3]. However, for slow-growing and late-maturing species, SSFs can have an impact on
49 populations [4]. This study shows that, for dusky grouper caught in Copacabana, Rio de Janeiro,
50 there is no such impact, since production has been stable for years.

51 It is important to recall that SSFs are defined by several attributes [3,5,6]:

- 52 (a) Small-scale fisheries (SSFs) are important at the local, regional, national and
53 global levels;
- 54 (b) SSFs use less energy-intensive fishing and usually operate in inshore waters;
- 55 (c) SSFs discard little or no fish;
- 56 (d) SSFs employ 25 times more people, and provide a food source for millions; and

57 (e) SFFs lack infrastructure, often occur in remote areas and have low political
58 power.

59

60 **Citizen science, local knowledge and the Copacabana fishery**

61 Disciplines occupy different niches, and ecology came to be a separate niche (as did
62 human ecology) in the postwar period, altering its identity from a soft to a hard science;
63 however, the field of ecology has never lost its links to the physical and social sciences [7]. The
64 understanding of the complexities of fisheries management can help to re-establish the balance
65 between the physical and social sciences and conservation ecology by demonstrating that
66 scientific research could be aided in obtaining positive outcomes for fisheries management by
67 other forms of knowledge.

68 Currently, local knowledge (LEK) is still under scrutiny with respect to its usefulness and
69 its acceptance in biological or fisheries science [8]. Here, we argue that LEK is very important
70 for data-poor countries; through knowledge from fishers (i.e., LEK) or the public (i.e., CS), we
71 can reduce the costs of time and money by increasing the efficiency of ecological data collection.
72 Tropical countries, in particular, lack the infrastructure for data collection, and many have high
73 biodiversity with several species for which there is no knowledge at all. In Brazil, for example,
74 among the 65 marine species most often consumed by marine small-scale fisheries, 33% are
75 decreasing, and 54% have an unknown status [9]. In the freshwater fisheries of the Amazonian

76 rivers, among the 90 fish species mentioned by fishers as being consumed, 78% have an
77 unknown biological or ecological status [10].

78 Local, folk, ecological and traditional knowledge bases are sources of information from
79 local people. Such information is often empirically based and rich in ecological or biological
80 information, which is often acquired over several years or centuries (for definitions see: [11-13]).

81 This example, given for Brazil, reflects the reality of other countries in continents such as
82 South America and Africa: often, there is little systematic data collection, but studies of local
83 knowledge have been used to accumulate several important data points on local species. This is
84 the case for coastal fisheries and for the data collected for dusky grouper.

85 Since 1997, one of the authors has been studying the Copacabana SSF through many
86 research projects (FAPESP 1997, 2001, 2004, 2006, 2007 and 2014). A study was conducted by
87 Nehrer and Begossi [14] about the fishing activities in this fishery, where the main fishing
88 techniques were set gillnet followed by hook and line; in this period, diving was still not
89 dominant. Groupers, led by dusky grouper but also including *Mycteroperca acutirostris* [15],
90 were one of the notable species caught [16].

91 The first study conducted directly on dusky grouper in Copacabana was published by
92 Begossi and Silvano [17]; in this study, 40 individuals of dusky grouper were collected and their
93 stomach contents and gonads were quantified. Fishers helped by providing local knowledge (e.g.,
94 diet, habitat, and spawning) and citizen science (e.g., participation in fishing trips for information
95 on fishing spots).

96 In another study, fishers were active participants in a research project as citizen scientists
97 (besides local knowledge); the fishers were trained to observe the gonads of dusky groupers, and
98 during the 21-month study, 800 dusky groupers were observed [18]. We continued the study of
99 the Copacabana fishery, following catches and getting information through science and citizen
100 science with the objective of having more information and comparing yearly data to understand
101 if catches of dusky grouper were increasing, stable or decreasing in Copacabana. This
102 information is essential to predict the effect of fisheries and to formulate management strategies
103 for vulnerable species.

104

105 **Materials and methods**

106

107 **Study site**

108 The “Colônia de Pescadores do Posto 6” includes a small-scale fishing community in
109 Copacabana beach, created in 1923. Groupers have been, and are, a target fish because of their
110 high price [14]. Fishing is performed in small motorboats through set gillnets, hooks and lines
111 and by spear fishing [15]. Recently, spear fishing through diving has become important,
112 especially among young fishers.

113

114 **Procedures**

115 Fieldwork occurred from September 25, 2013, to February 11, 2019, at the landing point
116 of the Colonia de Pescadores Z-13 (“Posto 6”), in Copacabana. The landing point includes
117 “selling boxes” where fishermen sell the fish that is landed. Sometimes, this is not done by
118 fishers but by middlemen who receive the landings and sell the fish.

119 Two fishers were trained to use the same protocol as that in a previous study [18]:
120 measurement of the TL (total length in cm) and weight (kg) of the dusky grouper, and dissection
121 of the fish to observe its gonads (i.e., whether or not the fish was mature, and whether or not it
122 had visible eggs). The procedure of macroscopically observing the mature gonads of the fish was
123 previously used in studies with snook (*Centropomus undecimalis*) [19], bluefish (*Pomatomus*
124 *saltatrix*) [20] and dusky grouper [21,22]. “Macroscopic observation” means that the gonads
125 were observed by a naked eye. Monthly visits of approximately 3-5 days each were performed to
126 follow the study and the groupers; when possible, the Copacabana fishery was visited twice a
127 month for fieldwork. The two fishermen trained since the previous study [18] continued to
128 collaborate on this research; they are also “fish cleaners”, who clean and cut fish fillets.

129

130 **Comparing yearly catches**

131 We compared grouper catches from September 2013-September 2018 (4 full years) and
132 also from September 2013-February 2018 (6 partial years). We built two histograms of the
133 distributions for daily and monthly catches (in kg), which showed that the size distributions of
134 the catches are not normal. For this reason, we used the nonparametric Kruskal-Wallis test.

135 For the Kruskal-Wallis test, we used data of the monthly catches in kg.

136 Two versions of calculations were made: 1) for 4 full years and 2) for 6 years (including
137 full and partial years).

138 Thus, in the first version, we had 48 observations, and in the second version, we had 54
139 observations.

140 The sum of the ranks of the total observations in the first version is expressed as $R_j =$
141 $\frac{(N \times (N+1))}{2} = 1,176$; in the second version, R_j is 1,485. Please see the Supporting material for
142 details.

143

144 **Comparing yearly prices**

145 Normalized histograms were built for the grouper price distributions in the different years
146 (2016-2018, partial years) and showed non-normal distributions.

147 The Kruskal-Wallis test was chosen as a nonparametric statistical test of the similarity of
148 sample distributions when several variables (i.e., more than 2) are available. For the
149 implementation of this test, it is preferable not to have a very long sequence of data (i.e., less
150 than 60 samples) and to have samples with no more than two times the difference in length.

151 Considering the aforementioned, for our analysis, we used prices averaged per day and
152 divided the 2017 data into quarters. Thus, we obtained 5 independent samples with a similar
153 number of observations corresponding to time periods of approximately the same length. The
154 total number of observations was $n=128$.

155 The sum of the ranks of the total observations was $R_j = \frac{(N \times (N+1))}{2} = 8,256$.

156 For details, consult the Supporting material.

157

158 Results

159 We observed 1,896 individuals of dusky grouper, *Epinephelus marginatus*, in
160 Copacabana, Rio de Janeiro, from September 2013 to February 2019. The total weight of the
161 catches was 6,065.57 kg, with an average of 1,442.50 kg/year and a std of 147.30 kg. The
162 weight, per month, of the full years of sampling (i.e., 2014-2017) is shown in Fig 1. Our sample
163 from landings of dusky grouper in Copacabana showed an average weight of 3.20 kg (n=1,896;
164 std=2.74) and length of 54.47 cm (n=1,544; std=12.11).

165

166 **Fig. 1. Weight (Kg) per month of dusky grouper *Epinephelus marginatus* from Copacabana**
167 **small-scale fishery.**

168

169 Table 1. Kg per month: table with all years and total per year; averages and std¹ of dusky
170 grouper, *Epinephelus marginatus* at Copacabana, Rio, 2013-2019 (n=1,896 individuals)

171 ¹averages calculated for period of full years, 2014-2017.

172

Month	2013	2014	2015	2016	2017	2018	Total weight	Avg weight	St dev
Jan		70.6	222.1	42.4	134.3	124.5	593.9	118.8	69.1
Feb		91.1	87.3	88.6	244.9	30.4	542.3	108.5	80.4
Mar		61.3	86.9	70.2	55.5		273.9	68.5	13.7

Apr		84.7	118.2	26.0	139.5		368.4	92.1	49.5
Mai		214.6	75.4	111.7	50.2		452.0	113.0	72.3
Jun		39.6	145.2	311.5	208.8		705.2	176.3	114.0
Jul		172.3	150.0	150.6	74.3		547.2	136.8	42.9
Aug		94.4	136.4		64.1		294.9	98.3	36.3
Sep	14.0	177.0	128.9	179.1	57.5		556.4	111.3	73.5
Oct	70.4	197.9	172.2	226.4	78.7		745.5	149.1	70.8
Nov	50.8	281.9	71.5	122.4	66.3		593.0	118.6	95.2
Dec	5.5	49.7	68.3	215.0	54.4		392.9	78.6	79.8
Annual	140.7	1535.1	1462.7	1543.9	1228.4	155.0	6065.7	1,442.5	147.3

173

174 Statistical comparisons (i.e., the Kruskal-Wallis tests) showed that catches were stable
 175 among the years of sampling in Copacabana. The results of the statistical comparisons of 4 full
 176 years (a) (2014-2017, Table 1) and 6 partial years (b) are as follows:

177 (a) The total number of observations was $n=48$; the sum of the ranks of the total
 178 number of observations was $R_j = \frac{(N \times (N+1))}{2} = 1,176$ (S1 Table). The parameters are
 179 $\alpha=0.05$ and $df=4-1=3$; the χ^2 value is 7.81.

180 (b) The total number of observations was $n=54$. The sum of the ranks of the total
 181 observations in the first version was $R_j = \frac{(N \times (N+1))}{2} = 1,485$ (S2 Table). The
 182 parameters were $\alpha=0.05$ and $df=6-1=5$; the χ^2 value was 11.07.

183 The critical H value (H_c) was defined from the χ^2 criterion.

184 In both cases, the calculated values of the Kruskal-Wallis statistics were lower than the
185 H_c . Thus, we concluded that there were no significant differences between grouper catches of
186 different years.

187 The very productive months, whose productivity was calculated from the average weight
188 of the dusky grouper, were June and July (i.e., the winter) and October (i.e., the spring).

189

190 **Weight-length of dusky groupers**

191 The weight-length of groupers from the 6-year period (2013-2019) is shown in Fig 2.
192 Most groupers fall between 50 and 70 cm. The figure was based on 1,563 individuals, and the
193 curve is expressed by $W=0.0043*L^2-0.3122*L+6.9191$, $R^2=0.925$ ($n=1,563$; $df=1,561$)

194

195 **Fig.2. Weight-length (kg-cm) of dusky grouper *Epinephelus marginatus* from Copacabana small-**
196 **scale fishery.**

197 Fig 3 clearly demonstrates these results, with a peak between 50 and 60 cm, which
198 corresponds to 37% and 31% of the groupers caught, respectively ($n=1,544$ individuals).

199

200 **Fig. 3. Length (cm) of dusky grouper *Epinephelus marginatus* from Copacabana small-scale fishery.**

201

202 **Reproduction**

203 From 515 days of sampling of the dusky grouper in Copacabana, we observed 1,969
204 individuals, of which only 1,83% had visible gonads with eggs. The mean volume of the gonads

205 was 54.71 ml, and the fish had a mean weight of 5.96 kg and a mean length of 65.14cm (Table
 206 2). Approximately 10% of the fish with visible eggs or gonads occurred in the spring (October
 207 and November) and a few occurred in the summer and autumn (January-March and April,
 208 respectively). The peak of the dusky grouper catches is concentrated in the winter, when the fish
 209 are probably not in their reproductive period.

210 **Table 2. Month (summing up years 2013-2019): visible gonads, mean size and weight of**
 211 **fish with visible gonads. Including total number of individuals of dusky grouper,**
 212 ***Epinephelus marginatus*, sampled, total days sampling, total number of individuals with**
 213 **visible gonads**

214

Month	Days sampling	Number of individuals sampled	Fish with visible gonads	% fish with visible gonads	Mean gonads volume, ml	Mean Weight, kg	StDev Weight	Mean Lenth, cm	StDev Lenth
Jan	49	191	2	1.05	29.5	5.00	0.99	63.00	1.41
Feb	41	148	5	3.38	93.0	7.35	6.42	68.80	15.45
Mar	32	102	1	0.98	150.0	7.20	-	78.00	-
Apr	28	104	4	3.85	25.0	7.61	3.15	64.75	27.83
Mai	38	141		-					
Jun	57	254		-					
Jul	58	199		-					
Aug	36	97	1	1.03	20.0	7.61	-	77.00	-
Sep	49	187		-					
Oct	60	228	9	3.95	12.1	5.40	3.28	62.33	12.58
Nov	38	183	11	6.01	76.2	5.16	4.24	62.18	15.72

Dec	29	135	3	2.22	30.0	5.81	1.75	72.00	5.00
Total	515	1969	36	1.83	54.71	5.96	3.79	65.14	14.89

215

216 **Fishing spots**

217 Groupers were often caught in rocky shores, and some islands were of overwhelming
218 importance for catching dusky groupers. Table 3 shows the importance of the islands in the
219 Cagarras Archipelago (including the fishing in the vicinity of these islands, which fishers refer to
220 as “ao largo das cagarras” and “laje da cagarra”), and the Rasa and Redonda Islands (which
221 account for most of the biomass caught). From Cagarras, Redonda, and Rasa, groupers represent
222 42%, 13%, and 7% of the biomass caught, respectively; compared with Cagarras, Redonda and
223 Rasa are relatively distant islands. Fig 4 graphically shows the biomass of groupers per fishing
224 spot, and S1 Fig. shows a map with the fishing areas and fishing spots.

225

226 **Fig. 4. Fishing spots and production per spot (kg) of dusky grouper *Epinephelus marginatus***
227 **from Copacabana small-scale fishery.**

228 We had the opportunity to include some data from recreational fishers of the adjacent
229 Marimbás Club. Data from sixty-nine trips (in 2015 and 2016) were included, equaling 338,12
230 kg of dusky groupers caught at Cabo Frio in Northeast Rio de Janeiro state. The average weight
231 of dusky grouper was 4.9 kg, slightly above the average weight of dusky grouper from the main
232 spots used in Copacabana (Cagarras, Rasa and Redonda, where the approximate average weight

233 of dusky grouper was 3.3 kg). Distant locations, such as Angra, Maricá and Macaé, showed the
234 highest average weight per fishing spot (Table 4).

235 **Table 4. Fishing spots and kg per fishing spot at the fishery of Copacabana where dusky**
236 **grouper *Epinephelus marginatus* was caught.**

237

LOCAL	Weight (Sum), kg	individuals	Avg Weight of ind.	StDev- Weight
cagarras	2387.80	724	3.32	3.0
copa	1249.10	439	2.85	1.8
redonda	812.09	244	3.33	2.7
rasa	435.95	135	3.23	2.4
angra	251.00	53	4.74	4.7
ao largo das cagarras	126.24	45	2.81	2.4
baia guanabara	110.22	43	2.56	1.3
laje do forte	65.25	26	2.51	1.7
tijucas	84.21	23	3.66	3.7
costao da Niemeyer	30.28	14	2.16	0.8
posto 6	34.39	14	2.46	1.4
costao do vidigal	10.70	6	1.78	0.5
comprida	30.40	5	6.08	6.2
maricá	36.30	3	12.10	7.0
laje da cagarra	4.64	2	2.32	1.3
pai e mae	18.30	2	9.15	5.9

arpoador	5.53	1	5.53	-
costão	1.40	1	1.40	-
largo	2.79	1	2.79	-
macae	14.90	1	14.90	-
sd	354.21	118	3.00	2.6

238

239

240 **Gear used**

241 In Copacabana, spearfishing (by snorkeling and probably some diving) is the most
242 common method to fish dusky grouper (Fig 5).

243

244 **Fig. 5. Gear used to catch groupers at Copacabana.**

245

246 **Prices**

247 Data on prices are given in Figs 6 and 7 with details in S4 Table and S1 and S2 Figs. The
248 dusky grouper prices increased 2.774 reals per year. Considering that the average price was
249 approximately 34 reals/kg in 2016, the price increase corresponds to an increase of
250 approximately 8%, which is similar to the figure of inflation in Brazil, which was 6,29% in 2016,
251 2,95% in 2017, and 3,75% in 2018 ([https://g1.globo.com/economia](https://g1.globo.com/economia;);
252 <http://agenciabrasil.ebc.com.br>).

253

254 **Fig. 6. Prices (Reais, R\$) of dusky grouper *Epinephelus marginatus* from Copacabana**
255 **small-scale fishery.**

256 **Fig. 7. Average monthly price of dusky grouper *Epinephelus marginatus* for different years**
257 **(2016-2019) from the small-scale fishery of Copacabana. Price Regression analysis showed**
258 **that the average price of grouper (Reais, R\$, per kg) increases by about R\$ 2.774 per year**

259

260 We compared samples with the data on the grouper prices for three adjacent years, from
261 2016 to 2018. Note that sample sizes for different years are quite different. We have 71 price
262 values for the period from 28.09.2016 to 30.12.2016, 264 price values for the period from
263 03.01.2017 to 30.12.2017, and 50 price values for the period from 09.01.2018 to 10.02.2018.

264 S4 Fig shows that the normalized histograms of the price distributions look similar.
265 However, the data for 2016 and 2018 have wider and lower peaks shifted toward larger price
266 values. Considering the aforementioned, for our Kruskal-Wallis analysis, we used prices
267 averaged per day and divided the 2017 data into quarters. Thus, we obtained 5 independent
268 samples with a similar number of observations corresponding to time periods of approximately
269 the same length. The total number of observations is $n=128$.

270 The sum of the ranks of the total observations is $R_j = \frac{(N \times (N+1))}{2} = 8,256$.

271 The distribution of the number of observations and the rank sums for each sample is
272 given in S3 Table.

273 H_c was defined from the χ^2 criterion for the parameters $\alpha=0,05$ and $df=5-1=4$. The χ^2
274 value was 9.49.

275 The calculated value of the Kruskal-Wallis statistic was lower than the critical value
276 (H=8.42<H_c=9.49). Thus, we concluded that there were no significant differences between price
277 samples for different years.

278

279 **Discussion**

280 Compared with the results of a 2016 study on dusky grouper in Copacabana, we had
281 double the sample size and a more significant regression on the weight-length ratio (R²=0.83,
282 df=791 in the 2016 study; R²=0.92, df=1,561). Increasing the sample size also allowed us to
283 conclude that the catches in Copacabana included larger dusky groupers than the previous study
284 found. Diving continues to be the main method to catch dusky grouper, and the fishing spots
285 remain the same near the islands of Cagarras, Redonda and Rasa.

286

287 **Bottleneck**

288 Considering that the dusky grouper is an endangered species, analyzing the catches in
289 Copacabana relative to those in previous studies on its genetics from this area is worthwhile. The
290 population of groupers from the sites in Copacabana and Paraty, where the original catch data
291 used to perform genetic analyses was collected, showed a significant bottleneck, with a
292 population of 663 individuals [23].

293 Small populations show genetic effects such as bottlenecks and drifts (i.e., random
294 effects) as well as inbreeding depression (i.e., directional effects); bottlenecks indicate that the

295 population size declined [24]. When there is a sudden reduction in population size, the average
296 heterozygosity per locus is expected to decline [25]. Survivors carry a sample of the genetic
297 variance from the prebottleneck population; the minimum effective population sizes to minimize
298 the loss of variance and fitness were suggested to be 50 for short-lived individuals and 500 for
299 long-lived individuals [24].

300 The stock structure of most grouper species is not well understood [26]. However, data
301 from the Priolli et al. [23] study showed a bottleneck in the population of dusky groupers from
302 the sites in Copacabana and Rio-Paraty, in southern Rio de Janeiro. Considering our results and
303 the comparison of yearly catch data, we can conclude that there is a sustainable fishery of dusky
304 grouper from Copacabana, Posto 6, that has the capability of maintaining a stable population of
305 dusky groupers. Moreover, it is important to observe that studies of dusky grouper populations in
306 Malta have shown decreasing catches, with a mean length of 52 cm (n=84) and an average
307 weight of 3 kg (n=41) [27]. Our larger sample in Copacabana showed an average weight of
308 3,20 kg (n=1896; std=2,74) and length of 54,47 cm (n=1544; std=12,11).

309

310 **Prices**

311 Our price samples comprised 128 individuals of dusky grouper from throughout the year,
312 and showed a non-normal distribution. There were no significant differences among the years in
313 the price of dusky grouper in Copacabana, Rio de Janeiro.

314 Dusky grouper prices reflect the lack of variation in grouper catches over the years and
315 reinforce the stable availability of groupers in these years. In the Gulf of Mexico and the South
316 Atlantic areas, the prices of fishes of the snapper-grouper complex were analyzed using SIDS
317 (synthetic inverse demand system). While fishing probably responds to fish price incentives,
318 catches are not influenced by the probable random perturbation in the monthly fish price. In a
319 study about fish prices in India, Sathiadhas and Kumar [28] emphasized the important points
320 concerning marine fishery prices: marine fish prices are very uncertain due to the
321 unpredictability of production, fish are highly perishable, landing points and species are diverse,
322 there are spatial and temporal variations, and there are disequilibria of supply and demand,
323 among others. When they are stressed, fish fluctuate far more than agricultural products, and the
324 short-run supply is highly inelastic: an increase in catches will lower prices, and a low catch will
325 increase prices.

326 Fish show an inverse demand system: the prices reflect the quantities of fish in this
327 inelastic system where the producers tend to be those collecting the money (there is no fish
328 processing before the catches are landed in the local market) [29,30]. Gates [31] showed how
329 important fish size is for determining prices. In the case of groupers, the price is given per kg; of
330 course, this differs between fish species and groupers are considered a noble fish, with a high
331 price in the market of Copacabana [14]. As shown by optimal foraging models, noble species
332 tend to be less bony and, thus, require less manipulation time [21,32]. Thus, from these results,
333 we may assume that the stable average prices are due to stable catches throughout the years. This

334 is a very important result, since fishers have felt repressed from their fishing activities, especially
335 for noble species. Recent legislation (Portaria Ministerail 41, July 27, 2018) related to the fishing
336 of dusky grouper intends to provide management but without any participation of fishers.

337 As with marine fisheries from other developed countries, harvesting and marketing of
338 fish create employment opportunities [28]. This applies to the fishery of Copacabana, where
339 fishers have depended on the fishery for a living for several years [14,15]. Knowing that the
340 grouper fishery has been sustainable is very important, especially because it is a noble fish with
341 high market prices [14]. Unfortunately, another legislation, the Decree 8722 from May 11, 2016,
342 has been an obstacle to both small-scale fishers and researchers since it inhibits fishing and
343 collaborative processes between fishers and researchers.

344

345 **The future: systems of knowledge-citizen science and local ecological** 346 **knowledge and their importance for data-poor small-scale fisheries**

347 There are many instances in which local ecological knowledge has been useful. An
348 example of the different knowledge systems available for a cosmopolitan species is found in the
349 studies from Australia and Brazil on *Pomatomus saltatrix* (bluefish) [20, 33-35]; in this very
350 interesting example, the local knowledge of bluefish in Australia and in Brazil yields enhanced
351 data on its migration and reproduction, among other characteristics. In the eastern Australian
352 state of Queensland, Brodie et al. [33] conducted a tag-recapture CS study, and the
353 spatiotemporal movements of *P. saltatrix* were recorded; thus, important information for the

354 management of bluefish became available. In Brazil, [34,35] studies on the LEK of the same
355 species (*P. saltatrix*) were performed by comparing the LEK regarding feeding, habitat and
356 migratory movement direction of fishers from Buzios Island (SE Brazil) to the aboriginal fishers
357 of North Stradbroke Island in Moreton Bay (Queensland) (*Quandamooka* in the aboriginal
358 language); both sets of LEK were also compared to the information from the literature, showing
359 an astonishing correspondence. Reproduction data and other important ecological and biological
360 types of information were also obtained in the studies of LEK and CS. Brodie et al. [33]
361 observed that some species lack information regarding catch records because several factors
362 prohibit them from being targeted; however, recreational fishing programs are similar to
363 programs of citizen science in which members of the public participate in data collection, e.g., by
364 tagging and releasing fish.

365 Postuma and Gasalla [36] presented results from fishers' information (i.e., LEK) about
366 squid, which they used to cross-validate their analysis and provide important information about
367 the decrease in the concentration of squid in SE Brazil, and they gave the environmental
368 conditions of the areas where the best squid catches were known to occur in this region. Mapping
369 is also an important aspect in which LEK is very helpful and the knowledge of geographical
370 information related to fishing spots has been shown to be helpful in some studies. For example,
371 Léopold et al. [37] mapped mangrove and coral reef finfish and invertebrate fisheries in New
372 Caledonia (in the southwest Pacific). In Brazil, several species were mapped using GPS with the
373 help of local fishers [38]; in particular, in SE Brazil, important target species were mapped

374 through this method, including catfish, mackerel, snapper, croaker, sand drum, bluefish, cutlass
375 fish, grouper, weakfish, snook, mullet, bluerunner, shrimp and squid [15].

376 Information on food chain and feeding habits was also provided, with LEK as a source
377 among other relevant biological information [39-43]. This is especially important where there is
378 nonexistent information, or a few sources of information, on fish, such as on the coast of Brazil
379 [18]: there are certain species for which the only source of knowledge is LEK, such as
380 *Rhinobatos percellens*, *Sphoeroides dorsalis*, and *Dasyatis guttata*. It is important to note that
381 information is lacking for important target species and consumed species from both the coastal
382 and continental waters of Brazil [9,10]. Another area in which the fishers can help is the
383 monitoring of contaminants: as the study by Silvano and Begossi [44] shows, observations of
384 bioaccumulation, such as the mercury content in fish muscle, can be made by fishers and can be
385 very valuable.

386 Other information obtained through LEK provides insights for modeling and predicting
387 the distributions of species. This was shown in a study by Lopes [45] for the coast of Brazil
388 using Bayesian hierarchical spatial models and oceanographic variables, with which the author
389 was able to predict the distribution of grouper, *Epinephelus marginatus*; they used data from the
390 literature and from fishers, and the results showed a concordance between the models that
391 temperature predicts the distribution of this species and the reliability of the information from the
392 fishers. Duplisea [46], studying redfish (*Sebastes* spp.) catches, concluded after interviews with
393 fishers, that scientific reports underestimated catches, including those of small fish, which led to

394 a reinterpretation of the abundance of stocks. Fishers are also shown to provide helpful
395 information regarding the temporal abundance of fish and changes therein, based on CPUE [47]
396 and regarding different fishers' perceptions concerning MPAs. Other temporal changes were also
397 detected by Lima et al. [48] in the SE Atlantic Brazilian areas, such as a decrease in biomass of
398 the fish caught and a higher abundance of relatively small fish.nats

399

400 **LEK in freshwater fisheries**

401 In a recent study by Nunes et al. [49], LEK of migratory behaviors and other ecological
402 information from seven Amazonian fishes along a 550 km stretch of the Tapajos River was
403 studied through interviews with 270 fishers, who also provided information on the behavior of
404 this fish along the poorly known tributary rivers of the Amazon; this information was of great
405 importance considering dam building in these areas. Changes in fish abundance have also been
406 identified through LEK: Hallwass et al. [50] demonstrated this in the lower portion of the
407 Tocantins rivers by acquiring information from 300 fishers in 9 villages and 601 fish landings,
408 and concluding that, after impoundment of the river due to the Tucuruí dam, an important local
409 species (jaraqui, *Semaprochilodus brama*) had become locally extinct, and there had been
410 changes in the composition of fish catches and decreases in fish production.

411 In the Mekong River in Asia, studies by Valbo-Jørgensen and Poulsen [51] involving 355
412 expert fishermen along 2,400 km of the Mekong mainstream were used to develop migration
413 maps and obtain spawning information for 50 fish species.

414

415 **Citizen science: examples**

416 Citizen science (CS) (i.e., public scientific research, [52]) refers to the knowledge that
417 local people have about something or might refer to their collaboration to some ongoing research
418 ; it has been applied to ecological and biological knowledge and it can fulfill the research
419 demands from scientific points of view and incorporate rigorous research tools, as demonstrated
420 by the many examples given in this study by Cigliano et al. [52]. Bailey et al. [53] suggest that a
421 positive relationship between fishery scientists and lay people could bring positive results toward
422 integrative research as a “social activity”.

423 Other examples are given by Fairclough et al. [54] concerning citizen science projects
424 being a cost-effective form of data collection because of the opportunity to obtain volunteers and
425 increase the data sets and data coverage, among other effects. Spatiotemporal information was
426 obtained using citizen science, and researchers were able to train and use focal groups to study
427 inshore fisheries in Denmark [55]. The study of alien species [56] is another important aspect for
428 fisheries management where CS is able to help in gathering ecological data.

429

430 **A gradient for dusky grouper: local knowledge and citizen science**

431 Some research includes studies in which both local knowledge and citizen science are at
432 work: examples include research in which fishers are trained to look for mature gonads in fish
433 [19]. Where there are no data on fish, fishers are extremely helpful since they can gather data,

434 thereby increasing the reliability of sampling and results. Projects in Brazil and other studies
435 were performed in this way, especially with grouper (*Epinephelus* spp.) [57,58]. These are
436 studies in which both local knowledge and citizen science are involved; the local knowledge
437 comes from fishers who provide their own knowledge (such as the reproductive period or
438 knowledge on the aggregation of species), but the fishers also participate in a training program
439 within the research project. Thus, the two forms of knowledge are involved in a “dialogue
440 between different forms of knowledge”, for which Ruddle [59] provides several examples and
441 details.

442 Both methods and concepts, i.e., local knowledge and citizen science, can be helpful not
443 just for data-poor countries: management in the North Sea shows several weaknesses, indicating
444 that there is a need to integrate citizens because fishers can communicate as both citizens and
445 knowledgeable experts with defined interests at stake. Indonesia has high average shark landings,
446 but with very little local information [60]; this is another study conducted in a particularly data-
447 poor region where sharks are primarily targeted for their fins with the help of shark fishers.

448 These results are very important, especially considering that dusky grouper, *Epinephelus*
449 *marginatus*, is a flagship species for conservation that reaches large sizes and lives up to 60
450 years, with many MPAs (marine protected areas) established in Mediterranean waters [61]. It is a
451 very important food source for coastal communities that have livelihoods dependent on fishing
452 [9,18], and it is an ecological and cultural keystone species [10].

453

454 **Conclusions**

455 Our study shows that, despite the vulnerable features of dusky grouper, the small-scale
456 fisheries in Copacabana have been performing well, since grouper catches have been stable over
457 time. In data-poor fisheries such as those in the coastal communities of Brazil, an integration of
458 science and citizen science (including local knowledge) can turn viable scientific conclusions
459 into management practices.

460 The integration between the different types of knowledge has been put into practice by
461 the FAO [62], with a technical paper about the Latin American fisheries providing a toolkit for
462 an ecosystem-based management approach. Several years ago, in 1981, Johannes [63] explained
463 how important fishers could be for managing resources and data-poor fisheries; approximately
464 20 years have passed since the publication of classical papers on "ignoring fishers' knowledge
465 and missing the boat", among other topics [64,65].

466 As shown in this study, the dialog between other forms of knowledge and scientific
467 research can be used in the following ways to help in fisheries management, especially in data-
468 poor areas:

- 469 1. Increasing the possibility of monitoring aquatic species.
- 470 2. Increase sample size.
- 471 3. Organizing systematic data collection with the help of expert fishers or citizens.
- 472 4. Diminishing research costs in terms of sampling size (i.e., by making increasing
473 sampling possible) and monetary expenses.

- 474 5. Sharing knowledge with other nonscientific groups, such as expert fishers' and
475 the public.
- 476 6. Learning from other nonscientists who show empirically-based knowledge, such
477 as expert fishers and the public.
- 478 7. Increasing the possibility of knowing important factors, such as the period of fish
479 reproduction and reproductive aggregations, which are key factors for fisheries
480 management (and are unknown in several data-poor countries).
- 481 8. Increasing the knowledge of target species, such as dusky grouper.
- 482 9. Increasing the knowledge of vulnerable species, such as dusky grouper.

483 There are examples from Mexico that should be followed, showing how important the
484 participation of fishers is in the management of groupers [66]. Other examples for Latin
485 American and the Caribbean are found in Salas et al. [2].

486

487 **Acknowledgments**

488 I am thankful to FAPESP (#14/16939-7) and CNPq (301592/2017-9).

489 This research is approved and signed by B. R. Martins dos Santos, Comitê de Ética,
490 Universidade Santa Cecília, number 1.747.889 on September 27, 2016 (Plataforma Brasil). It is
491 approved under number 53824 at SISBIO and registered under number AB53669 at SISGEN,
492 MMA (Ministério do Meio Ambiente, Brasil). We are grateful for fishers Antonio, Elenilson
493 (“Jaguriçá”) and Raul; Ana was helpful with data from the Marimbás Club, Copacabana.

495

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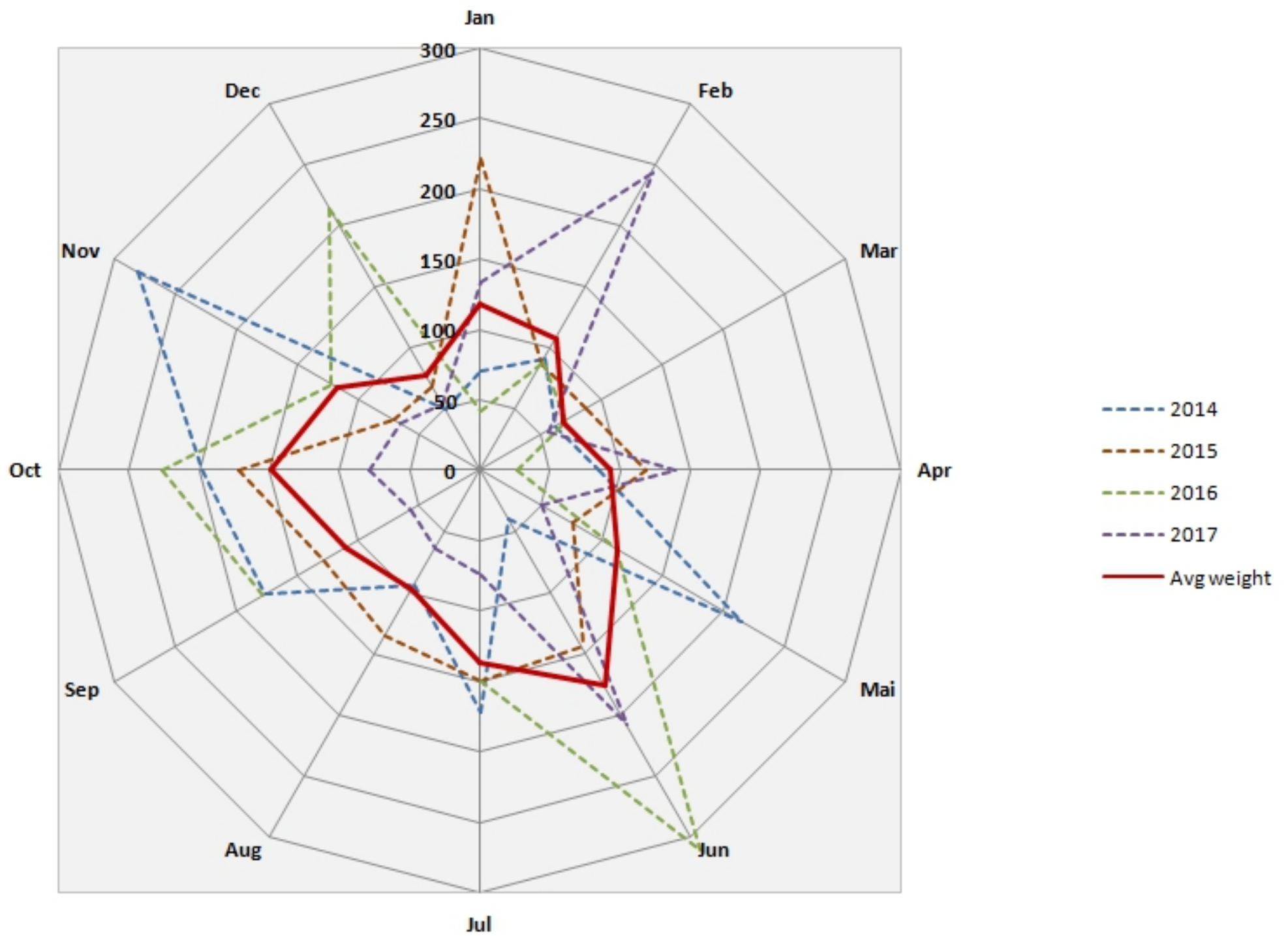


Figure 1

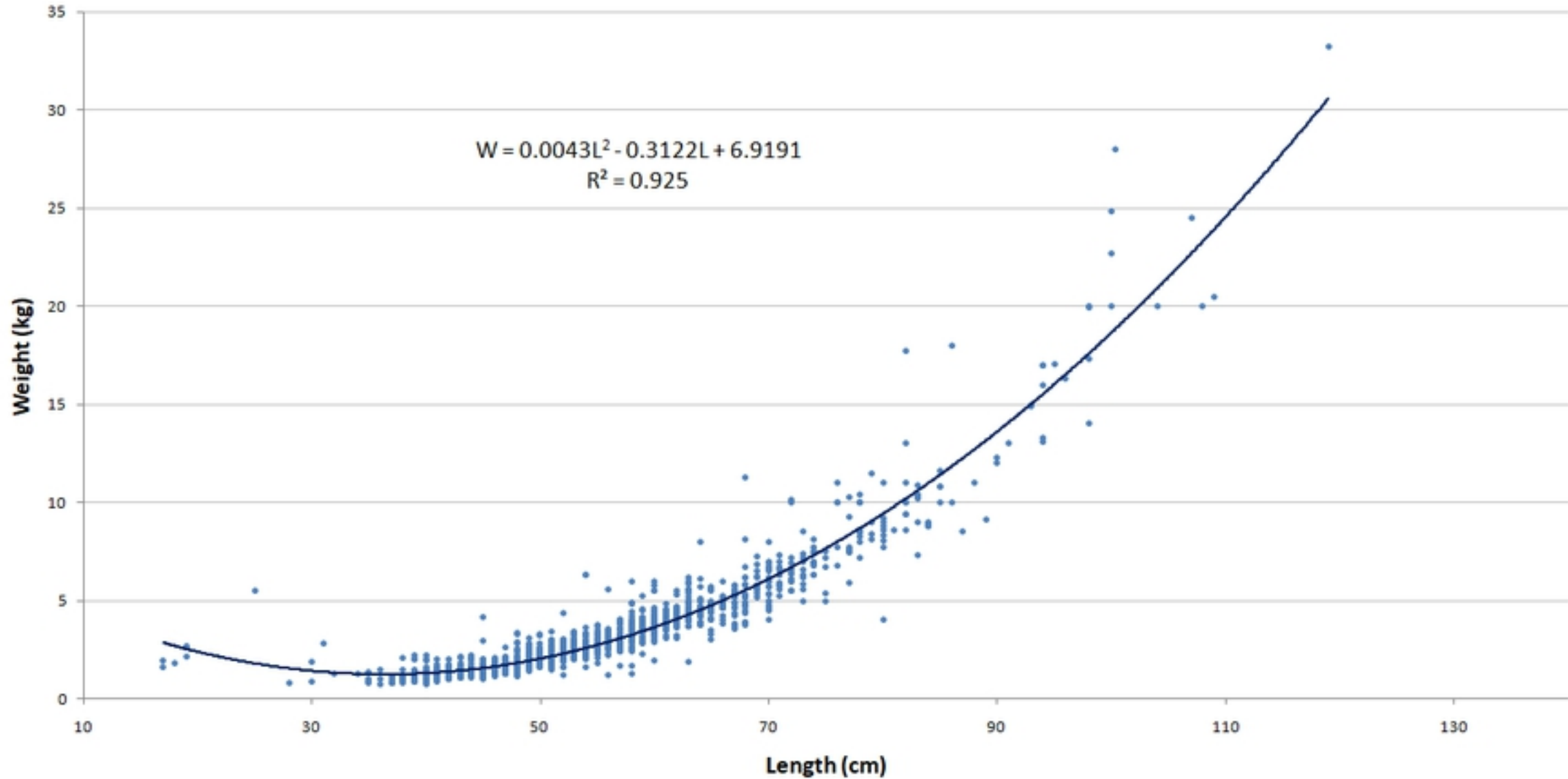


Figure 2

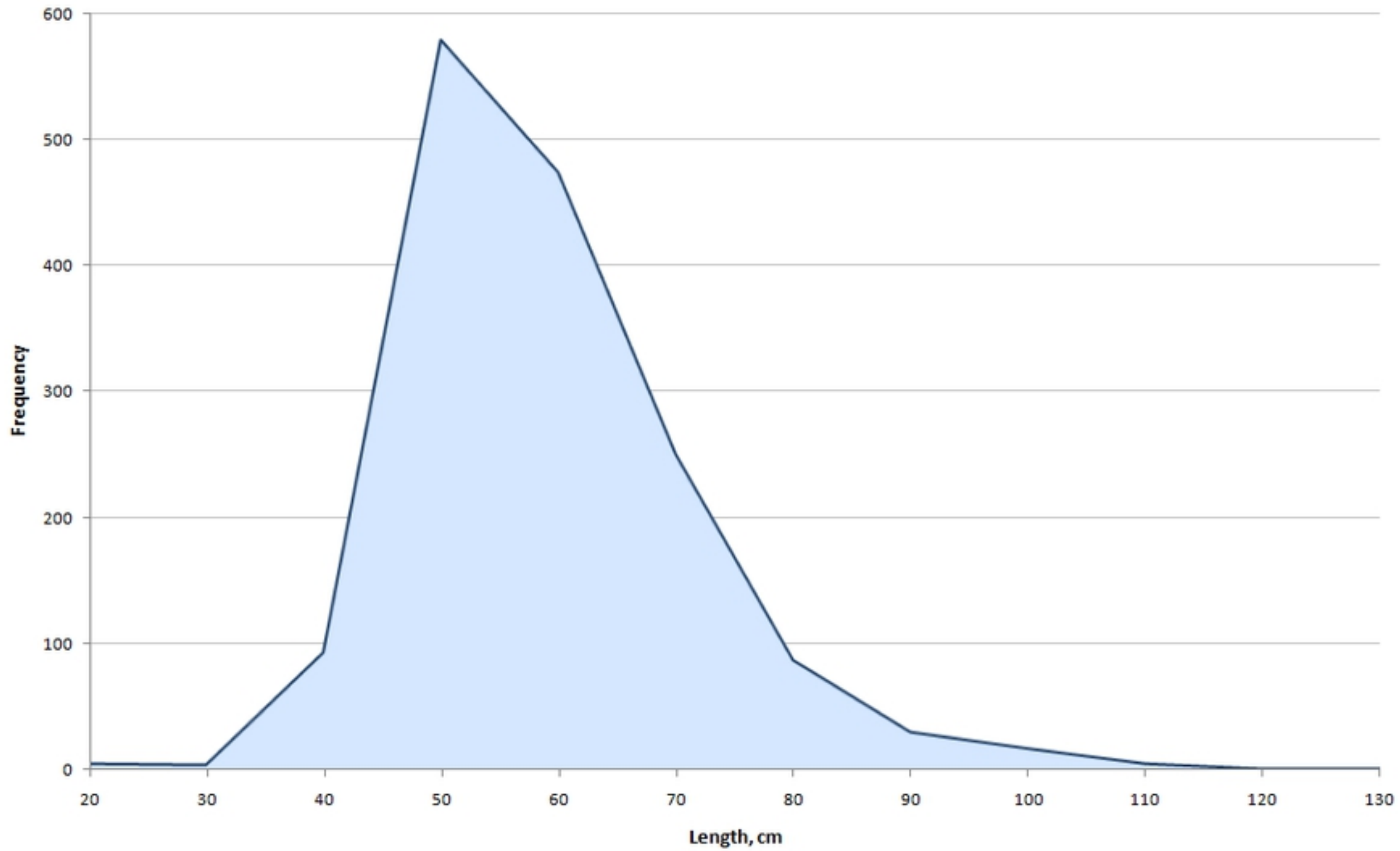


Figure 3

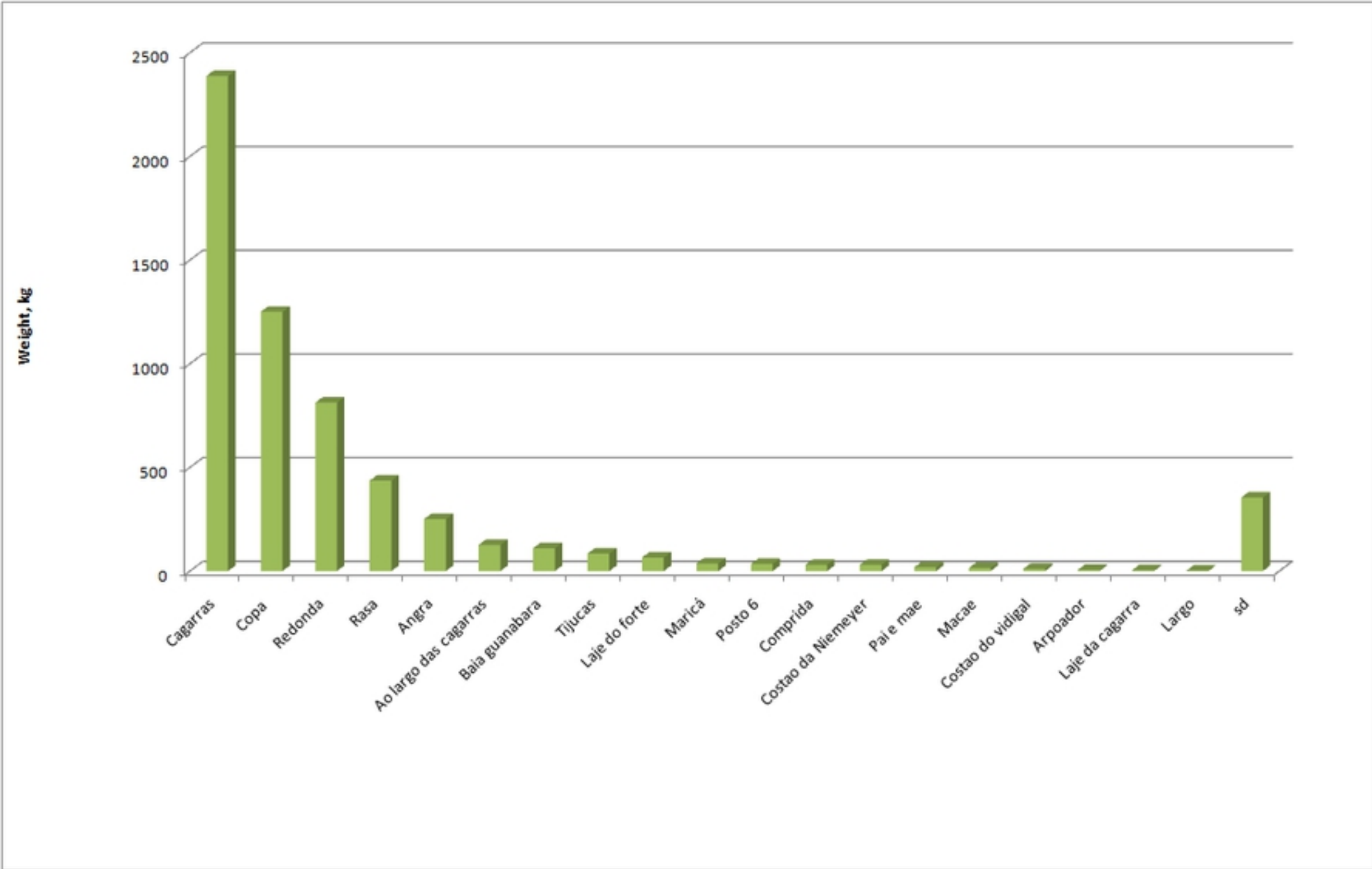


Figure 4

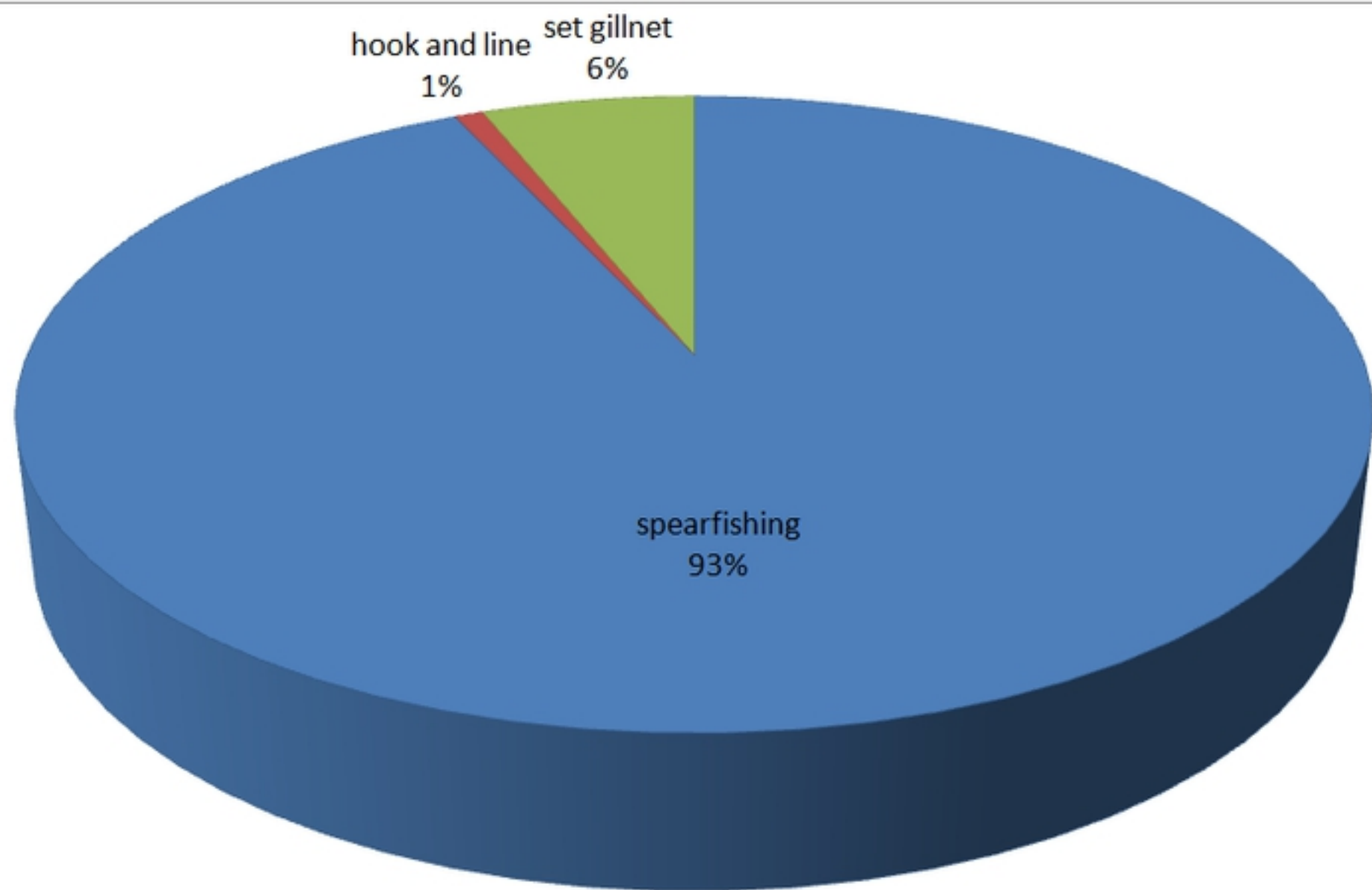


Figure 5

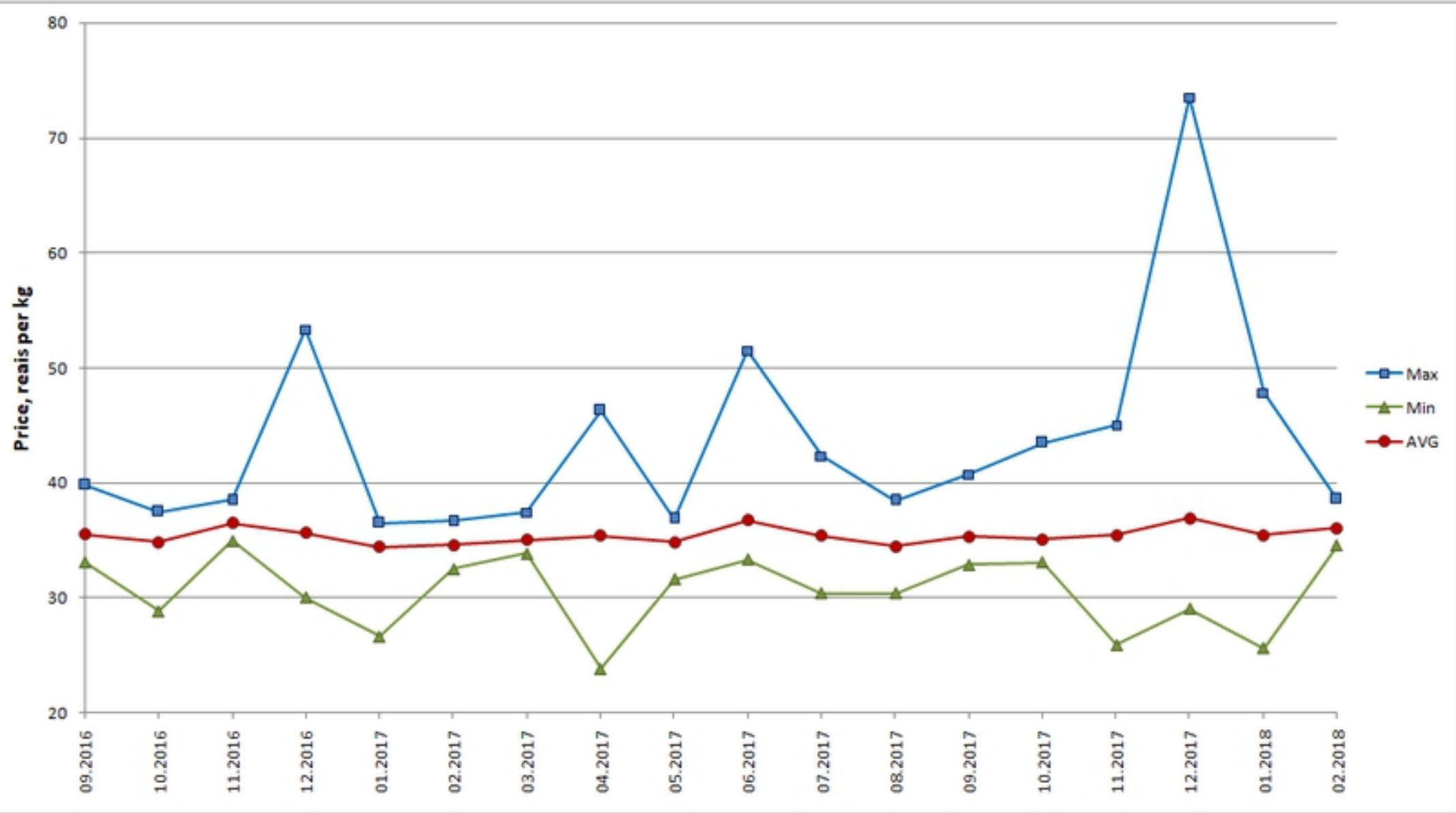


Figure 6

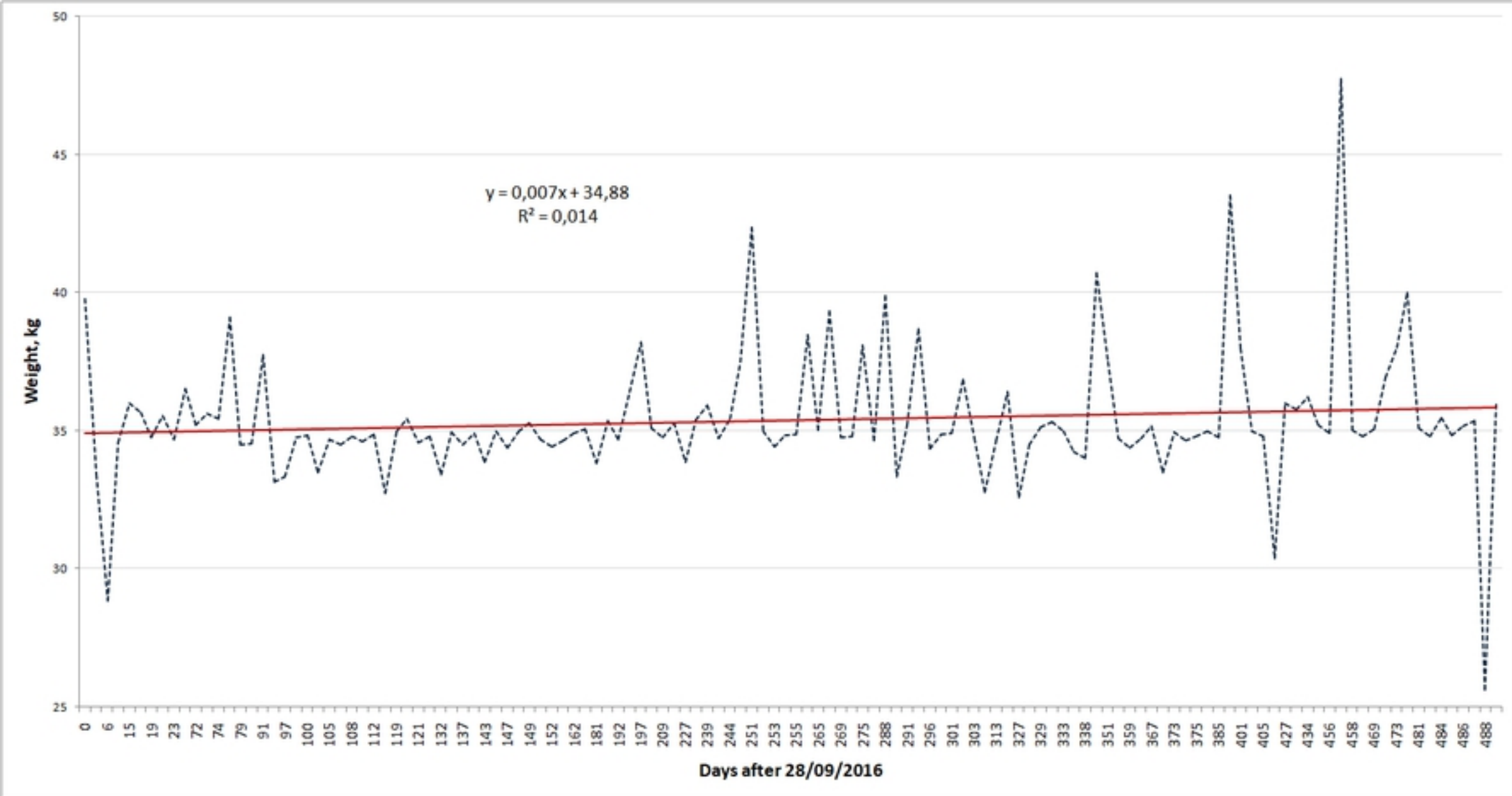


Figure 7