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33 **Keywords**

34 Blue shark, by-catch, longline, magnet, repellent, CPUE

35

36 **1. Introduction**

37

38 The blue shark *Prionace glauca* (Linnaeus, 1758) is a species with worldwide
39 distribution (Moreno, 2004). Like most of pelagic shark species, the blue shark presents
40 a low fecundity rate and a slow growth rate (Ferretti et al., 2008) and is therefore
41 particularly vulnerable to fishery exploitation.

42 In the northeastern Atlantic Ocean, one part of the Spanish and Portuguese longline
43 fleet targets swordfish *Xiphias gladius* Linnaeus, 1758, tuna (teleosts of the group
44 Thunini) and shortfin mako near Azores archipelago and between Azores archipelago
45 and Iberian Peninsula (Buencuerpo et al., 1998; Stevens et al., 2000; Baum and Myers,
46 2004). The bait is mackerel (*Scomber scombrus*). However, about 60% of the catch is
47 represented by blue shark (Xunta de Galicia. pers. comm.). The second part of the
48 longline fleet concerned by this study targets only blue shark (*Prionace glauca*) near
49 Iberian Peninsula. The bait is longfin inshore squid (*Doryteuthis pealeii*). Over 200 tons
50 of blue shark were landed each month in 2013 in Vigo (Xunta da Galicia, i.e. regional
51 government, pers. comm.). In both case, Spanish and Portuguese longline fishermen can
52 be interested by a repulsive system as if they catch more commercial species like
53 swordfish and tuna they may increase their profit. Moreover most pelagic sharks are on
54 top of the food web and play an important role in marine ecosystems as they contribute
55 to the management of healthy ocean ecosystems (Ferretti et al., 2010).

56 Elasmobranchs use the electric sense due to the ampullae of Lorenzini for the detection
57 of the bioelectric fields produced by prey organisms (Kalmijn, 1971). However the
58 chemoreception will be probably used on large distances to detect prey even if at a
59 small distance from the prey electric sense may influence their behaviour. According to
60 Hueter et al. (2004) *Prionace glauca* is attracted to an area by odor but preferentially
61 attacked an active dipole source that simulated the prey's bioelectric field rather than
62 the odor source of the prey. This electric sense is also related to their two modes of
63 navigation. In the passive mode, the elasmobranch simply measures the electric fields
64 are produced by the flow of ocean water through the Earth's magnetic field. In the
65 active mode, the elasmobranch measures the voltage gradients that are induced through

66 the animal's body due to its own swimming movements through the geomagnetic field
67 (Hueter et al., 2004).

68 Permanent magnets have been shown to have repellent effect on sharks by creating an
69 abnormally strong electrical stimulus to overwhelm the elasmobranchs' acute
70 electrosensory system (Stoner et al., 2008; Tallack and Mandelman, 2009; O'Connell et
71 al., 2011a, 2012; Hutchison et al., 2012). Magnets constitute therefore a possible means
72 to reduce the by-catch. Actually, among 20 pelagic shark species concerned by fisheries
73 and/or bycatch, three are now classified by the International Union for the Conservation
74 of Nature (IUCN, 2013) as endangered, namely *Mobula mobular* (Bonnaterre, 1788),
75 *Sphyrna lewini* Griffith & Smith, 1834, *Sphyrna mokarran* Rüppell, 1837, nine as
76 vulnerable, namely *Alopias pelagicus* Nakamura, 1935, *A. superciliosus* Lowe, 1841, *A.*
77 *vulpinus* (Bonnaterre, 1788), *Carcharodon carcharias* (Linnaeus, 1758), *Cetorhinus*
78 *maximus* (Gunnerus, 1765), *Isurus oxyrinchus* Rafinesque, 1810, *I. paucus* Guitart,
79 1966, *Lamna nasus* (Bonnaterre, 1788), *Sphyrna zygaena* (Linnaeus, 1758), and one, *P.*
80 *glauca*, as near threatened.

81 During the last years, many works tried to test the deterrent electromagnetic effect on
82 sharks (Annexe 1). They used permanent magnet composed by Barium (Ba), Boron (B),
83 Iron (Fe) and Neodymium (Nd) or electropositive metal (EPM) composed by
84 Lanthanides metal. Different EPM tested were Barium (Ba), Neodymium (Nd),
85 Praseodymium (Pr), Cerium (Ce), Cerium-Lanthanum (CeLa), Praseodymium-
86 Neodymium metal alloy (PrNdA), and Praseodymium-Neodymium mischmetal
87 (PrNdM) (Annexe 1).

88 The tests published were realized in laboratory (in experimental conditions) or in field
89 (in experimental conditions, in experimental fishing or in real fishing conditions). Many
90 species were used to test several magnet models or EPM. Some species have a pelagic
91 behaviour (Dasyatidae, Carcharhinidae, Lamnidae, Sphyrnidae and Triakidae) and
92 others, a benthic behaviour (Rajidae and Squalidae). The results show contrasted
93 effects. In laboratory, the results of experiments are sometimes positive (Brill et al.,
94 2009; Rigg et al., 2009; O'Connell et al., 2010; Jordan et al., 2011; O'Connell et al.,
95 2011b, 2014a, 2014c; Smith and O'Connell, 2014), and sometime, negative or partial
96 (Stoner and Kaimmer, 2008; Rigg et al., 2009; Jordan et al., 2011; McCutcheon and
97 Kajiura, 2013). Tests realized in field obtained both positive (Rice, 2008; Wang et al.,
98 2008; O'Connell et al., 2011a, 2014b, 2014d, 2015) and negative results (Robbins et al.,

99 2008; Tallack and Mandelman, 2009; O'Connell et al., 2011a; Hutchinson et al., 2012;
100 Godin Cosandey et al., 2013; Smith, 2013; O'Connell et al., 2014d).
101 Some species may have opposite behaviour in different conditions. For example,
102 smooth dogfish (*Mustelus canis*) in contact with Neodymium (Nd) metal can have a
103 repellent reaction in group but not alone (Jordan et al., 2011). *Carcharhinus plumbeus*
104 can have a repellent reaction in laboratory (Brill et al., 2009) but not in field (O'Connell
105 et al., 2011a). Globally, all the tests with electromagnetic dispositive obtained highly
106 contrasted results between laboratory and field experiments, between species and
107 according to the electromagnetic dispositive.
108 Repellent effects with EPM were proposed to be used to limit the intense fishing
109 activities especially for blue shark (*Prionace glauca*) and shortfin mako (*Isurus*
110 *oxyrinchus*). However, previous experiments realized in field and in real fishing
111 conditions with EPM, were negative for both species (Hutchinson et al., 2012; Godin
112 Cosandey et al., 2013).
113 The aim of this paper was to test the effects of neodymium magnets on catches of the
114 blue shark aboard a fishing vessel targeting pelagic species in the eastern Atlantic
115 Ocean. This is the first paper measuring and taking into account the physical properties
116 of the magnets and their effect on the hooks.

117

118 **2. Methods**

119

120 *Physical properties of the two magnet models*

121 The magnet is mainly composed of neodymium, a magnet element with high resistance
122 in time and magnet power. The magnets were of the N35-Ni and N35-NdFeB types.
123 The higher the grade (the number following the 'N'), the stronger the magnet. Ni
124 indicates the presence of traces of nickel. NdFeB indicates that the magnet is composed
125 of neodymium, iron and boron. Neodymium is a rare-earth magnet element with
126 degradation trends in sea water. However the experiment lasted only 3 days and there
127 was no degradation of the magnets. We did not measure the level of dissolution in
128 laboratory because as the lanthanides dissolve, the voltage (mV) remains unchanged
129 despite the decreasing mass (McKutcheon and Kajiura, 2013).

130 The dimensions of the two cylindrical magnet models with a central hole, tested were
131 26 mm x 11 mm x 12 mm (model 1, 0,885 tesla - from Ingeniera Magnética Aplicada,

132 Barcelona, Spain) and 20 mm x 13 mm x 15 mm (model 2, 0,464 tesla - from
133 Firstmagnetic, Roncq, France). The magnetic fields produced by the two types of
134 magnets, with the hook, were measured at several distances (between 7 and 70 cm). We
135 also measured the magnetic fields of two hooks after contact with the two types of
136 magnets and the magnetic fields of a hook which was never in contact with magnets.
137 As each model has always been composed of three magnets in experiments, we report
138 here the measurements for sets of three magnets. When magnets are stuck together, the
139 magnetic field produced by three magnets is not exactly equal to three times the field
140 produced by one as they are not physically at the same point (the more distant magnet
141 has a lower influence, due to the increasing discrepancy of magnetic field with
142 distance). But at a long distance in relation to the size of the magnet, the field can be
143 considered as approximately three times the field of each.
144 The hook used in the experiments is made of steel, a ferromagnetic material. In
145 consequence, it concentrates the magnetic lines and changes the map of the magnetic
146 field. Moreover, the size of the hook is much larger than the size of the magnets so that
147 very close to the hook, if the magnets are on the opposite side of the hook, the magnetic
148 field can be greater than what it would be with the magnets alone. To measure precisely
149 the field produced, we used a Gauss/Teslamètre Sypris 7030 F.W.Bell and recorded the
150 variation in the magnetic field in a figure that gives the magnetic field in tesla units
151 along the distance X in centimeters for a hook filled with respectively big magnet (big
152 circle) and small magnet (small circle) in a log-log scale. The measurements were made
153 from the position of the center of the magnet on the hook (approximate position when
154 magnet was absent). The magnetic fields of two hooks after contact with the two types
155 of magnets and the magnetic fields of a hook which was never in contact with magnets
156 were also recorded in the same figure.

157

158 *Experiments under real fishing conditions*

159 The experiments were carried out in the northeastern Atlantic Ocean ($8^{\circ} - 9^{\circ}$ W and 42°
160 $- 45^{\circ}$ N) (Figure 1) aboard a longline fishing vessel, during 3 days (October 2013). The
161 vessel, the *Pescalema*, was based in Muxía, a small port in Galicia (Spain). The vessel,
162 ~20 m long, carried 8 crew members, plus the scientific observer (SBP). The
163 experiments concerned 1076 shark individuals. We determined their sex and

164 approximate size. They belonged to the following size classes (cm): [90-100), [100-
165 110), [110-120), [120-130), [130-140), [140-150), [150-200), [>200.

166 The longline measured about 50 km with 1 300 hooks, about 40 m apart. Hooks were
167 located at about 20 m depth. The ring-shaped hooks (model 9202, Mustad™, Lilleaker,
168 Oslo area, Norway) measured 8 cm in total height and 2 cm in width.

169 The shape and size of the magnets were chosen to correspond to the size of the hook
170 (Figure 2).

171 A positive and encouraging aspect of the experiment was that the fishermen were able
172 themselves to place the magnets on the hooks without the assistance of the scientist
173 (SBP), who just passed them the magnets stored in a polystyrene box. Inserting the
174 hook within the magnet did not reduce the hectic speed of the immersion of the baited
175 hook and the supporting line, lasting 7-8 h, by night, during a real fishing operation.

176 The polarization of the magnets was randomly orientated so that the magnetic field N or
177 S corresponded to the hook axis. Fishermen had no difficulty in attaching the magnets
178 and removing them from the hook. The bait was located close to the magnet so that
179 sharks would feel the magnetic field when trying to feed. The fishermen used only
180 longfin inshore squid (*Doryteuthis pealeii*) (Lesueur, 1821) as bait. The longline carried
181 the same number of hooks during the three days of the experiment. We divided the
182 longline into 3 test zones with the same number of hooks (zone 1 at the beginning of the
183 longline, zone 2 in the middle of the line and zone 3 at the end) and the rest of the
184 longline was the zone 4 (Table 1; Figure 3). The reason for this partitioning is that zone
185 1 remained immersed for a longer time than zone 3 (approximately 7 hours) and this
186 may influence the catch values. Within each test zone, we used 5 hooks with magnets of
187 the first model, 11 hooks with magnets of the second model and 16 control hooks
188 without magnets (Figure 3). The aim of this strategy was to observe whether there was
189 any significant difference in the catch rate between test hooks and control hooks and
190 between the two types of magnet within test zones. The rate of catch per unit of effort
191 (CPUE) represents the relation between the number of individuals in catches and the
192 number of hooks.

193 The three days were considered as replicates. We compared catch values for the 144
194 hooks with magnets from test zones 1 to 3 with 144 control hooks under normal fishing
195 conditions (i.e. without magnets)(Table 1). Inside the test zones, we tested the influence

196 of different factors (size, sex, presence or absence of magnets and the models of
197 magnet) on the CPUE values.

198

199 *Data treatment*

200 Data were analyzed with Statistica 9.1. Normality and homogeneity of variance were
201 previously tested using Shapiro and Levene tests. One-way ANOVA was used in each
202 zone and for all the tested zones together to test the differences in CPUE values between
203 hooks with magnets and control hooks as well as between the two models of magnet.

204

205 **3. Results and discussion**

206

207 *Physical tests*

208 Figure 4 shows the measurement of the magnetic field in tesla (T) along the distance X
209 in cm for a hook carrying respectively big magnets (big black circles) and small
210 magnets (small grey circles) in a log-log scale. The lines correspond to the theoretical
211 variation of the magnetic field as X^{-3} . We note that despite the presence of the hook, for
212 a distance more than 10 cm, the magnetic field intensity varies like that of a dipole. At
213 these distances, the intensity of the large magnets was twice as high as that of the
214 smaller magnets.

215 The intensity of the magnetic field produced by the magnets has to be
216 compared with the additional intensity of the magnetic field of the Earth (between
217 0.00002 T and 0.00007 T, depending on the position on the Earth). From figure 4, we
218 note that the intensity of the magnetic field from the magnets was the same
219 intensity as that of the magnetic field of the Earth at a distance around 25 to 35 cm for
220 small magnets, and 30 to 45 cm for big magnets.

221 An important aspect to be considered is that hooks equipped with both big and small
222 magnets remained magnetized when removing the magnets and this phenomena is
223 permanent (Figure 4). For example, a hook magnetized after contact with a big magnet
224 at 6 cm distance induced the same magnetic field that a hook with a big magnet at 7 cm
225 distance. Moreover, a hook alone which was never in contact with a magnet shows also
226 a measurable magnetic field, even if it's lower than the magnetic field of hooks after
227 contact with a magnet. For example at 6 cm distance from the hook which was never in

228 contact with a magnet the magnetic field is equivalent to that of a hook with a big
229 magnet model 1 measured at 8 cm distance.

230

231 *Experiments under real fishing conditions*

232 During the fishing campaign, 1 076 blue shark *Prionace glauca* were caught by the
233 longline vessel (Figure 5; Table 2). In addition to the blue sharks, one small swordfish
234 *Xiphias gladius*, one albacore *Thunnus alalunga* (Bonnatere, 1788), 3 sunfish *Mola*
235 *mola* (Linnaeus, 1758), 6 pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832)
236 and one common thresher shark *Alopias vulpinus* were caught.

237 The total length of the captured blue sharks ranged from 70 to 240 cm, corresponding
238 mainly to juvenile individuals (Table 2). For the blue shark, sexual maturity is reached
239 at 180 cm in males and 200 cm in females (Moreno, 2004).

240 Sex ratio (% of males) was 0.52 - 0.55 in the tested zones 1 to 3 and 0.77 in the zone 4.

241 The total length and sex of the caught individuals did not differ significantly according
242 to whether they were caught with hooks equipped with magnets or not ($p=0.062$,
243 respectively $p=0.892$).

244 The presence of the magnets had a significant effect on the catch rate per unit of effort
245 (CPUE) only in the zones 2 ($F=10.48$; $p=0.014$) and 3 ($F=7.99$; $p=0.026$) with higher
246 CPUE values for hooks equipped with magnets in both areas (0.73 in zone 2 and 0.75 in
247 zone 3 for hooks with magnets compared to 0.52 and 0.38 respectively for hooks
248 without magnets) (Table 1; Figure 6). These values were significantly higher only for
249 the hooks equipped with the model 1 magnet (0.80) than for the control hooks in the
250 zone 2 (0.52) ($F=5.25$; $p=0.048$). In contrast, there were no significant differences in
251 CPUE between the two magnet models 1 and 2, between model 2 magnet hooks and the
252 control hooks in the zone 2, and between the two magnet models and the control hooks
253 in the zones 1 and 3.

254 Globally for all the tested areas CPUE values for hooks with magnets are higher than
255 those of hooks without magnets (mean 0.74, SD 0.15 and respectively mean 0.47, SD
256 0.17) ($F=18.29$, $p=0.000$). These values are also higher than those of CPUE in the zone
257 4 (mean 0.25, SD 0.43). However as the number of hooks is much higher in the zone 4
258 (1204 hooks x 3 days) than in the tested zones (48 hooks x 3 days) this might influence
259 the comparison between the mean CPUE values among these zones.

260 It remains unclear whether it is the absolute strength of the magnetic field in the water,
261 which at some level induces reaction behaviour of blue sharks, or whether it is the
262 magnitude of the change in magnetism with distance that elicits the response. However,
263 the presence of magnets near the hook did not provide the expected repellent effect. One
264 of the two tested models of magnet even increased the catch rate. Magnets would
265 therefore not appear to constitute an effective device to avoid by-catch for this species
266 in real fishing conditions. Our results would appear to contradict these promising
267 experimental previous results. However, several factors are to be considered. **(i)** Results
268 from the literature are mainly based upon laboratory experiments, and/or *in situ*
269 experiments more or less remote from the real conditions of a professional fishing fleet
270 (Stoner and Kaimmer, 2008; Tallack and Mandelman, 2009; O'Connell et al., 2011a,
271 2014; Robbins et al., 2011). **(ii)** Clearly, the results from previous authors evidence the
272 non-congruence of deterrent effects depending upon the species (Hutchinson et al.,
273 2012); for example, these authors showed the ineffectiveness of EPM with blue shark
274 and shortfin mako, although effective with another species (Annex 1). **(iii)** Our results,
275 together with similar results from the literature (e.g. Hutchinson et al., 2012), concern
276 juveniles. It is known that the electrosensory sensitivity, in many elasmobranchs,
277 increases with growth (e.g. Fishelson and Baranes, 1999; Tricas and Sisneros, 2004).
278 **(iv)** The repellent devices used in the literature are rather disparate. Their characteristics
279 and strength are often poorly described. In addition, the effectiveness of the magnet is
280 influenced by the parallelism, or non-parallelism, of the axis of polarization with the
281 axis of the hook (O'Connell et al., 2011a).

282 Most of the previously published papers on the deterrent effect on sharks tested the
283 effects of electropositive metals (Annex 1), excepting Rigg et al., (2009). This is the
284 first paper describing the magnetic effect on blue shark catch. Previous papers
285 concerning the blue shark analyzed only the electropositive effects (Godin Cosandey et
286 al., 2013; O'Connell et al., 2014d) (Annex 1). In our case, blue shark probably detects
287 by odour at a large distance the presence of bait on the longlines. However at a short
288 distance when swimming towards the bait it should feel the electric field induced by
289 both the magnet and the electropositive metal. We probably have a cumulated effect of
290 electric field induced the shark movement in the magnetic field and an electric field
291 generated by the electropositive metal in contact with seawater that we cannot dissociate

292 in field conditions. The measurements in laboratory concerned only magnetic field, but
293 in perspective we will try to develop a protocol to measure the electric field too.
294 Our results, as well as others experiments in real fishing conditions did not reduce the
295 by-catch of sharks (Godin Cosandey et al., 2013). Permanent magnet or electropositive
296 metal is actually not proved yet as a solution to limit by-catch or to reduce negative
297 impact of longline fisheries. As suggested by Jordan et al., (2013), we will have to
298 explore new approaches to reduce the by-catch of sharks, as magnets seem to even have
299 an attraction effect. Other management measures such as quotas or minimum catch
300 length may be more appropriate for blue shark fishery.

301

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303

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310

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312

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413 **Tables**

414

415 Table 1. Comparison of mean values of CPUE (catch per unit of effort, where the unit of effort was the
 416 number of hooks) for blue shark (*Prionace glauca*) between longline zones during the test period (3
 417 days). No=number. SD=Standard Deviation.

418

Blue shark catch tests	Zone 1			Zone 2			Zone 3		
	No of hooks	CPUE	SD	No of hooks	CPUE	SD	No of hooks	CPUE	SD
Magnet model n°1	3x5	0.87	0.35	3*5	0.80	0.45	3*5	0.80	0.41
Magnet model n°2	3x11	0.64	0.49	3*11	0.70	0.47	3*11	0.70	0.47
Hooks without magnets	3x16	0.52	0.51	3x16	0.52	0.50	3x16	0.38	0.49

419

420 Table 2. Total length (TL) of captured blue sharks. - = missing data, Min = Minimum, Max = Maximum,
 421 SD = standard deviation.
 422

Blue sharks catch	n	Min. and Max. TL	Mean length (SD)	Sex ratio (% of males)
Total caught individuals	1 076	70 to 240 cm	-	-
Individual caught by hooks equipped with magnets inside the zones 1, 2 and 3	94	100 to 200 cm	109 (18) cm	52%
Individual caught by control hooks inside the zones 1, 2 and 3	75	100 to 200 cm	112 (15) cm	55%
Individual caught by hooks without magnets in the zone 4	907	100 to 200 cm	-	77%

423

424 Table 3. References concerning tests of electropositive and magnetic effects on sharks in laboratory (Lab)
 425 and field.
 426

Species	Electromagnetic dispositive	Study	Detterent effect	References
<i>Prionace glauca</i>	NdFeB N35 – NdNi N35	Field	no	This study
<i>Sphyrna mokarran</i>	BaFe12O19	Field	yes	O’Connell et al., 2015
<i>Carcharhinus leucas</i>	BaFe12O19	Lab	yes	O’Connell et al., 2014a
<i>Negaprion brevirostris</i>	BaFe12O19	Lab	yes	O’Connell et al., 2014c
<i>Scyliorhinus canicula</i>	Nd2Fe14B	Lab	yes	Smith and O’Connell, 2014
<i>Raja clavata</i>	Nd2Fe14B	Lab	yes	Smith and O’Connell, 2014
<i>Carcharodon carcharias</i>	BaFe12O19	Field	yes	O’Connell et al., 2014b
<i>Squalus acanthias</i>	Electropositive metal	Field	yes	O’Connell et al., 2014d
<i>Amblyraja radiata</i>	Electropositive metal	Field	no	O’Connell et al., 2014d
<i>Dipturus laevis</i>	Electropositive metal	Field	no	O’Connell et al., 2014d
<i>Prionace glauca</i>	Electropositive metal	Field	no	O’Connell et al., 2014d
<i>Rhizoprionodon terraenovae</i>	Neodymium (Nd) metal	Field	partial	Smith, 2013
<i>Carcharhinus limbatus</i>	Neodymium (Nd) metal	Field	no	Smith, 2013
<i>Negaprion brevirostris</i>	Neodymium (Nd) metal	Lab	no	McCutcheon and Kajiura, 2013
<i>Sphyrna tiburo</i> – group	Neodymium (Nd) metal	Lab	no	McCutcheon and Kajiura, 2013
<i>Sphyrna tiburo</i> – individual	Neodymium (Nd) metal	Lab	no	McCutcheon and Kajiura, 2013
<i>Prionace glauca</i>	Electropositive metal	Field	no	Godin Cosandey et al., 2013
<i>Isurus oxyrinchus</i>	Electropositive metal	Field	no	Godin Cosandey et al., 2013
<i>Lamna nasus</i>	Electropositive metal	Field	no	Godin Cosandey et al., 2013
<i>Sphyrna lewini</i>	PrNdA	Field	yes	Hutchinson et al., 2012
<i>Carcharhinus plumbeus</i>	PrNdA	Field	no	Hutchinson et al., 2012
<i>Prionace glauca</i>	PrNdA	Field	no	Hutchinson et al., 2012
<i>Isurus oxyrinchus</i>	PrNdA	Field	no	Hutchinson et al., 2012
<i>Rhizoprionodon terraenovae</i>	Nd2Fe14B	Field	yes	O’Connell et al., 2011a
<i>Carcharhinus limbatus</i>	Nd2Fe14B	Field	no	O’Connell et al., 2011a
<i>Carcharhinus limbatus</i>	BaFe12O19	Field	yes	O’Connell et al., 2011a
<i>Carcharhinus plumbeus</i>	BaFe12O19	Field	no	O’Connell et al., 2011a
<i>Negaprion brevirostris</i>	BaFe12O19	Field	yes	O’Connell et al., 2011a
<i>Carcharhinus acronotus</i>	BaFe12O19	Field	no	O’Connell et al., 2011a
<i>Rhizoprionodon terraenovae</i>	Nd2Fe14B	Field	yes	O’Connell et al., 2011a
<i>Mustelus canis</i>	Nd2Fe14B	Field	yes	O’Connell et al., 2011a
<i>Squalus acanthias</i>	Nd2Fe14B	Field	no	O’Connell et al., 2011a
<i>Dasyatis americana</i>	BaFe12O19	Field	yes	O’Connell et al., 2011a
<i>Dasyatis americana</i>	Nd2Fe14B	Field	no	O’Connell et al., 2011a
<i>Raja eglanteria</i>	Nd2Fe14B	Field	no	O’Connell et al., 2011a
<i>Carcharhinus plumbeus</i>	Nd2Fe14B	Field	no	O’Connell et al., 2011a
<i>Carcharhinus limbatus</i>	Nd2Fe14B	Field	yes	O’Connell et al., 2011a
<i>Negaprion brevirostris</i>	BaFe12O19	Lab	yes	O’Connell et al., 2011b
<i>Mustelus canis</i> – group	Neodymium (Nd) metal	Lab	no	Jordan et al., 2011
<i>Mustelus canis</i> – individual	Neodymium (Nd) metal	Lab	yes	Jordan et al., 2011
<i>Dasyatis Americana</i>	BaFe12O19	Lab	yes	O’Connell et al., 2010
<i>Ginglymostoma cirratum</i>	BaFe12O19	Lab	yes	O’Connell et al., 2010
<i>Carcharhinus plumbeus</i>	Electropositive metal	Lab	yes	Brill et al., 2009
<i>Squalus acanthias</i>	Electropositive metal	Lab	partial	Tallack and Mandelman, 2009
<i>Squalus acanthias</i>	Electropositive metal	Field	partial	Tallack and Mandelman, 2009
<i>Sphyrna lewini</i>	Ferrite magnet	Lab	yes	Rigg et al., 2009
<i>Carcharhinus tilstoni</i>	Ferrite magnet	Lab	yes	Rigg et al., 2009
<i>Carcharhinus amblyrhynchos</i>	Ferrite magnet	Lab	yes	Rigg et al., 2009
<i>Rhizoprionodon acutus</i>	Ferrite magnet	Lab	yes	Rigg et al., 2009
<i>Glyphis glyphis</i>	Ferrite magnet	Lab	no	Rigg et al., 2009
<i>Squalus acanthius</i>	Nd2Fe14B	Lab	no	Stoner and Kaimmer, 2008
<i>Squalus acanthius</i>	Electropositive metal	Lab	no	Stoner and Kaimmer, 2008

<i>Squalus acanthias</i>	Neodymium (Nd) metal	Lab	yes	Jordan et al., 2008
<i>Mustelus canis</i>	Neodymium (Nd) metal	Lab	yes	Jordan et al., 2008
<i>Carcharhinus galapagensis</i>	Electropositive metal	Field	yes	Wang et al., 2008
<i>Carcharhinus plumbeus</i>	Electropositive metal	Field	yes	Wang et al., 2008
<i>Negaprion brevirostris</i>	Electropositive metal	Field	yes	Rice, 2008
<i>Carcharhinus galapagensis</i>	Neodymium (Nd) metal	Field	no	Robbins et al., 2008
<i>Carcharhinus galapagensis</i>	PrNdA	Field	no	Robbins et al., 2008

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428

429 **Figure legends**

430

431 Figure 1. Map of the marine area (northeastern Atlantic) and location of the fishing zone
432 (black oval) where magnet experiments were conducted.

433

434 Figure 2. a. Position of the magnet model 2 with a hook under real fishing conditions.
435 Photo: Sebastián Biton Porsmoguer. b. Position of magnet model 2 on a hook measured
436 for magnetic field in laboratory. Photo: Christophe Almarcha.

437

438 Figure 3. Position of hooks with magnet models 1, 2 and control hooks in the
439 tested zones 1, 2 and 3. The rest of the longline was the zone 4.

440 Figure 4. Measurement of the maximum magnetic field B in tesla (T) along the distance
441 X in cm for a hook filled with, respectively, big magnet for model 1 (big black circles),
442 small magnet for model 2 (small grey circles), a hook alone after contact with big
443 magnet model 1, a hook alone after contact with small magnet model 2 and a hook
444 alone which was never in contact with a magnets (white circles), in a log-log scale.

445

446 Figure 5. A blue shark *Prionace glauca* caught by the longline vessel during the fishing
447 campaign. Photo: Sebastián Biton Porsmoguer.

448

449 Figure 6. Comparison of the CPUE (catch per unit of effort) with mean values for blue
450 shark (*Prionace glauca*) between the two model of magnets (M1 = model 1, M2 =
451 model 2) and the control hooks inside the tested zones.

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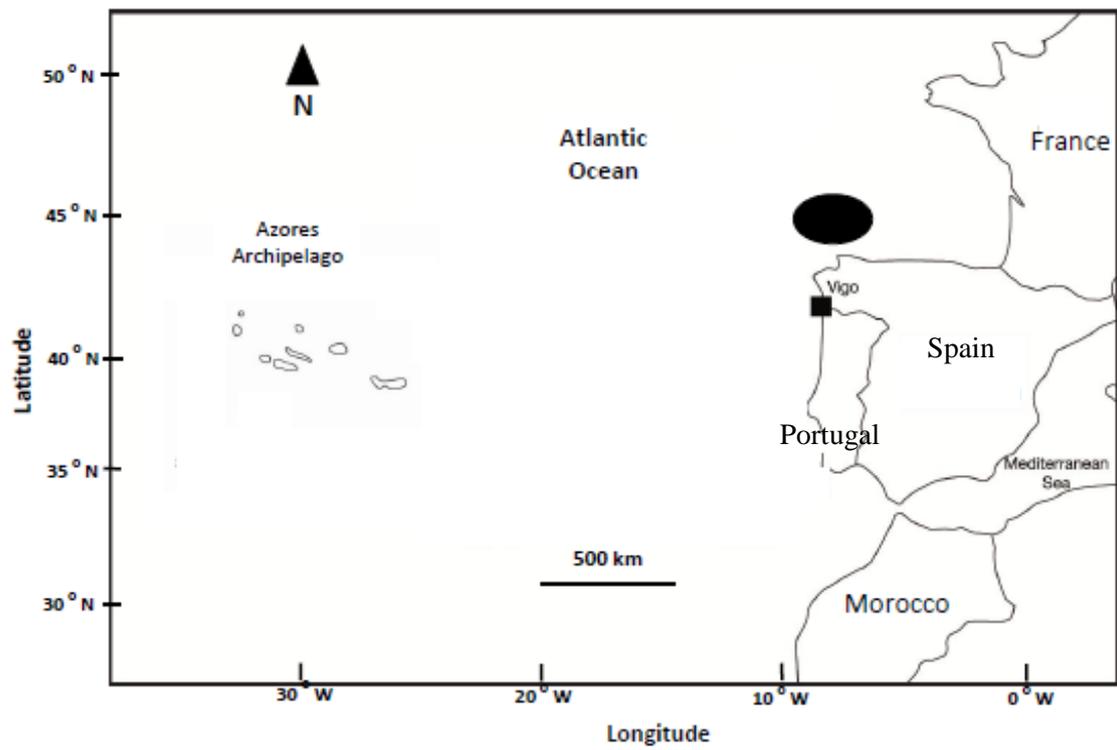


Figure 1.

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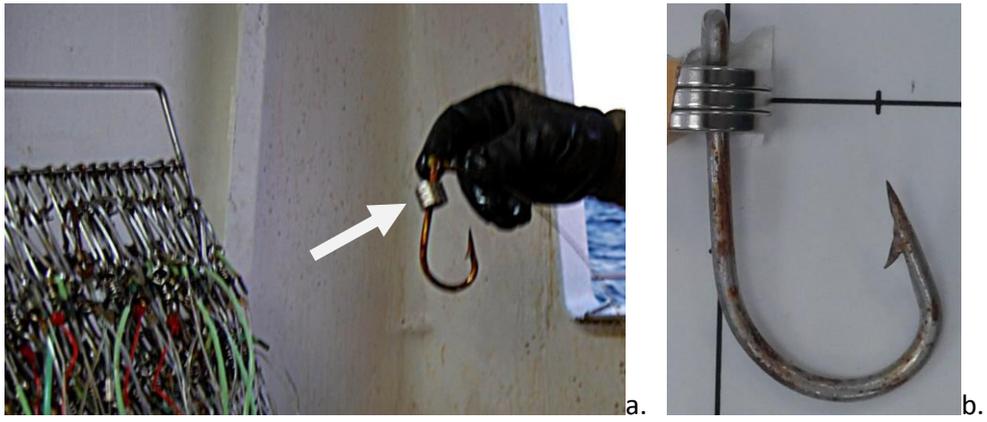


Figure 2.

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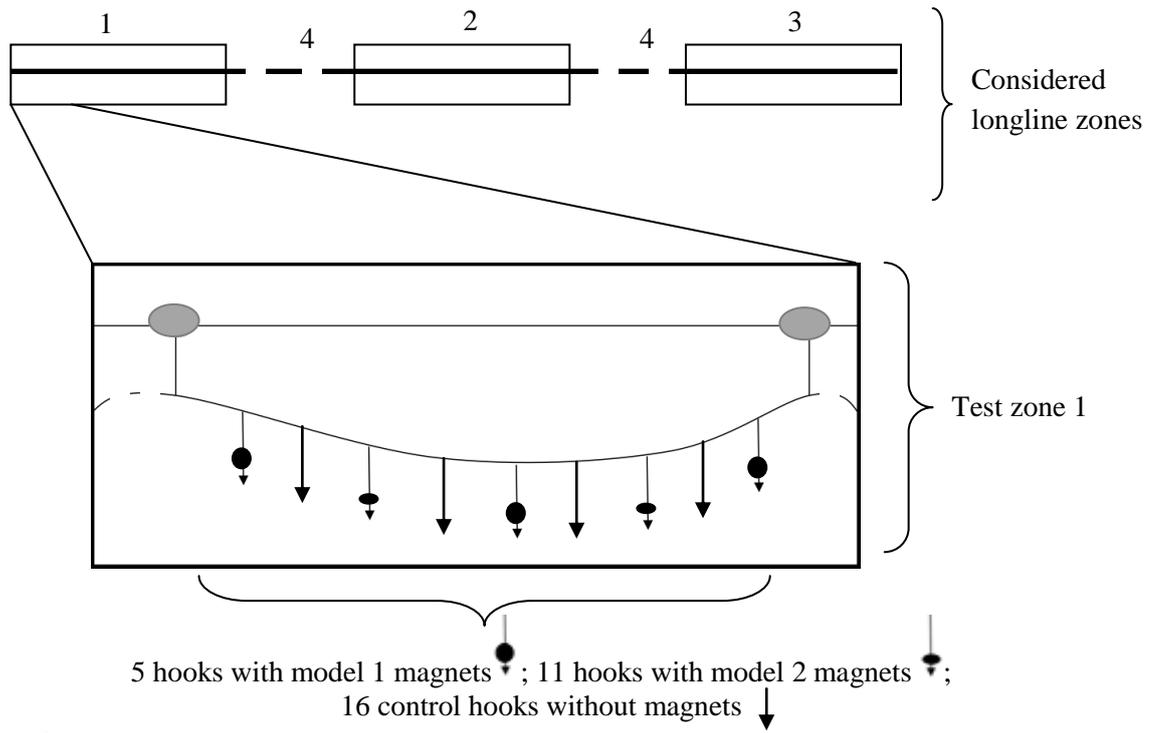
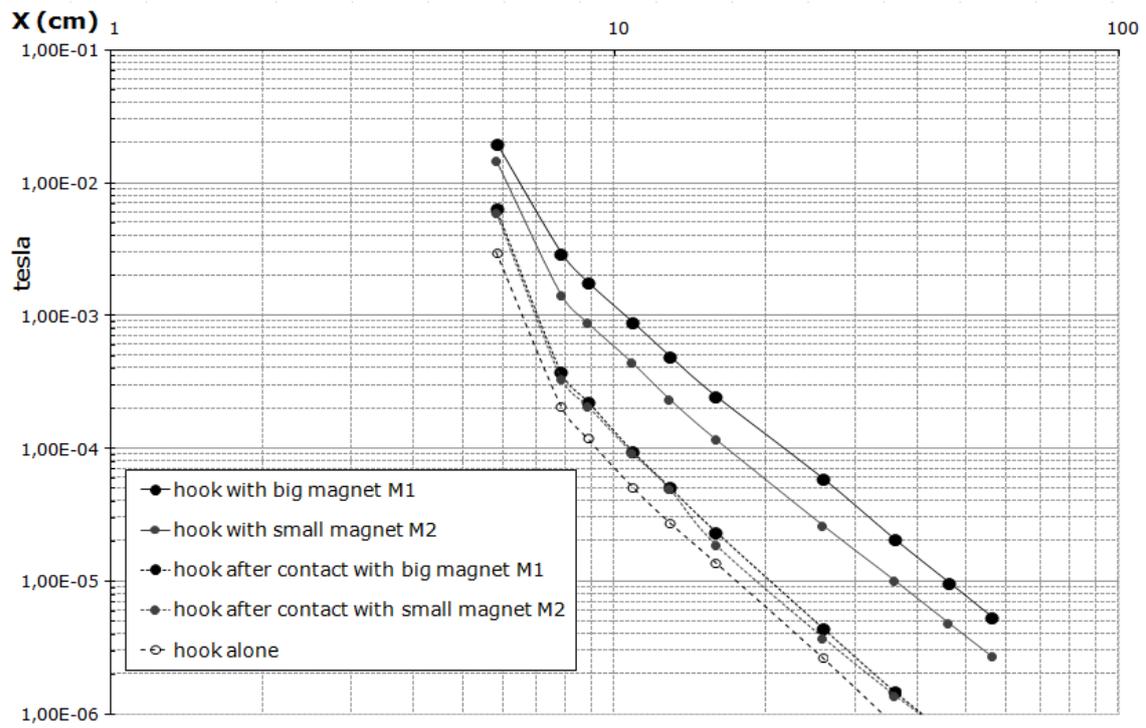


Figure 3.



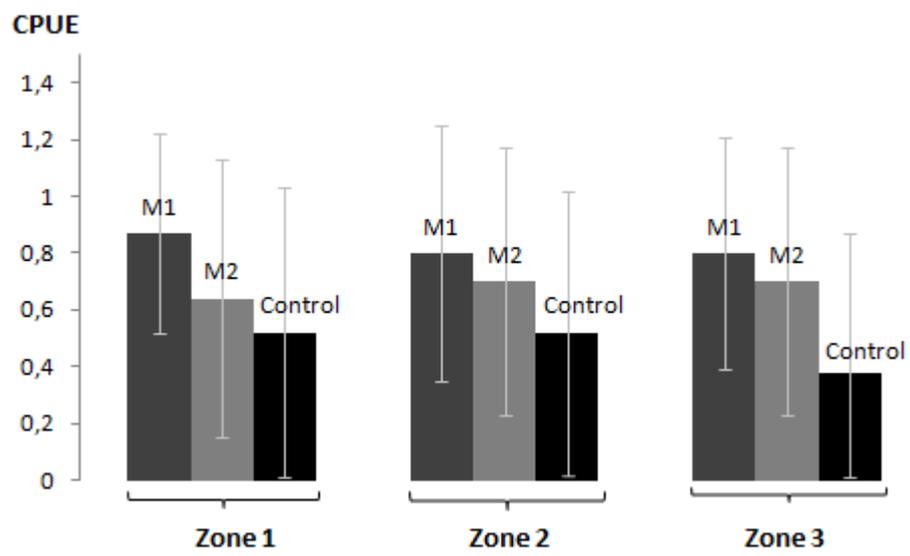
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Figure 4.



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Figure 5.



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528 **Figure 6.**