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**Resilience of inshore, juvenile snapper *Pagrus auratus* to angling and
release**

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Suggested running headline: Post-release mortality of *Pagrus auratus*

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Abstract

This study assessed the mortality of 157 snapper *Pagrus auratus* (9–29 cm L_T) after being conventionally angled and then released into cages (along with 48 controls) for 4 days off southeastern Australia. Fatalities were restricted to 12 angled fish (7.6%) and mostly attributed to the ingestion of hooks and especially their subsequent removal, which caused substantial blood loss and immediate death. Hook ingestion was significantly biased towards smaller fish (<21 cm L_T) and attributed to a lower chance of anglers initially detecting these individuals on the line (allowing them to consume more of the baits). While mortalities might be reduced in future via (1) choosing terminal rigs that promote mouth hooking and/or (2) cutting the line on any-hook ingested fish, the results nevertheless validate releasing unwanted angled inshore juvenile *P. auratus* as a means for managing their exploitation.

Key words: catch-and-release; hook ingestion; post-release mortality; Sparidae.

INTRODUCTION

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Sparidae encompasses more than 33 genera and 110 species, with a global distribution across tropical and temperate estuarine and coastal demersal areas (Carpenter & Johnson, 2002). Many sparids are economically important and form the basis of important artisanal, commercial and, in developed countries, recreational fisheries (Broadhurst *et al.*, 2005; Götz *et al.*, 2007; Alós *et al.*, 2008; Overton *et al.*, 2008; Veiga *et al.*, 2011).

At least ten sparids (six genera) occur in Australia (Carpenter & Niem, 2001; Grant, 2008); all of which are recreationally fished for an estimated annual catch of almost 17 million individuals (Henry & Lyle, 2003). The exact catch composition is unknown, but the most abundant species include *Acanthopagrus* spp. [especially yellowfin bream *A. australis* (Owen 1853) and black bream *A. butcheri* (Munro 1949); *c.* 50% of the total] and snapper *Pagrus auratus* (Bloch & Schneider 1801) (*c.* 20%) (estimated in 2000/01 by Henry & Lyle, 2003). Like most recreationally targeted sparids throughout the world (*e.g.* those described by Götz *et al.*, 2007; Alós *et al.*, 2008; Overton *et al.*, 2008; Veiga *et al.*, 2011), the Australian species are managed by legal sizes and personal quotas. Combined with voluntary non-consumptive fishing, these regulations result in *c.* 11 million sparids (65% of the total catch) being released per annum; which is among the greatest rate for any family of Australian teleosts (Henry & Lyle, 2003).

Recognition of the need to validate the assumption of few negative impacts to such large numbers of released fish has resulted in several relevant studies, and mostly for *A. australis* (Broadhurst *et al.*, 1999, 2005, 2007; Butcher *et al.*, 2007, 2008, 2010; Reynolds *et al.*, 2009) and *A. butcheri* (Haddy & Pankhurst, 1999, 2000; Grixti *et al.*, 2007, 2008). This

63 work estimated total short-term (<10 days) mortalities of <28% for both species and, like for
64 virtually all other studied sparids (e.g. Götz *et al.*, 2007; Rudershausen *et al.*, 2007; Overton
65 *et al.*, 2008; Alós *et al.*, 2009a; Veiga *et al.*, 2011), identified hook ingestion as a consistent,
66 key deleterious factor (Broadhurst *et al.*, 2005; Grixti *et al.*, 2008). Consequently, most
67 efforts at mitigating mortalities have concentrated on promoting shallow hooking, via
68 modifications to terminal rigs and/or fishing methods (Grixti *et al.*, 2007; Butcher *et al.*, 2008,
69 2010).

70

71 Much less information is available on the post-release fate of the remaining Australian
72 sparids, including the highly valued *P. auratus*. Such bias can be partially attributed to
73 comparatively lower catch and release, although species-specific distributions and the
74 logistics of assessing mortality are also important. For example, *A. australis* and *A. butcheri*
75 tolerate a wide range of salinities and occur in coastal rivers, estuaries and near shore areas in
76 large abundances and across all sizes (Grant, 2008). In contrast, *P. auratus* prefer marine
77 waters with juveniles and small adults (< c. 40 cm L_T) mostly located in shallow bays, while
78 larger fish are often distributed across the continental shelf down to 200 m (Sumpton *et al.*,
79 2003; Grant, 2008). The cheapest field-based experiments to assess short-term post-release
80 mortality involve angling fish and then ‘releasing’ and monitoring them in replicate, large
81 surface cages (termed ‘confinement’ studies; Pollock & Pine, 2007); which need to be moored
82 close to the fishing area, and in low flow with protection from waves. Such logistical
83 requirements have been more suited to the distributions of *Acanthopagrus* spp.

84

85 Notwithstanding the above, two short-term confinement studies involving *P. auratus*
86 have been published in the primary literature (Broadhurst *et al.*, 2005; Grixti *et al.*, 2010a).
87 Both have estimated mortalities to juveniles, but with various limitations. Specifically,

88 Broadhurst *et al.* (2005) t-bar tagged 72 angled fish (15–31 cm L_T) in Botany Bay, New South
89 Wales (NSW) and released them along with controls (caught by seining) into four floating 48
90 000 l cages for 10 days. Although catch histories were available for each angled fish, there
91 were insufficient numbers and/or data to attribute causality among the observed fatalities (c.
92 33%). Grixti *et al.* (2010a) followed a similar design in Port Phillip Bay, Victoria, but instead
93 of being tagged, 620 fish (15–26 cm L_T) were fin clipped according to intuitive *a priori*
94 treatments and monitored for either 1 h or 3 days. This experimental approach facilitated
95 relative mortality assessments (e.g. between shallow- and deep-hooked fish of 3 and 52%)
96 but, because individual fish could not be identified, precluded quantifying the full range of
97 contributing factors, including any random effects.

98
99 Isolating the key deleterious impacts associated with angling (and their mechanisms of
100 action) is important to prioritise resolution strategies. This study aimed to acquire such
101 information for inshore juvenile *P. auratus* by collecting detailed data describing their
102 conventional angling and handling across a sufficient sample size, and then immediately
103 releasing them individually (or at densities where they could be subsequently identified by
104 their L_T) into cages; most of which were rigid and submerged to the seabed (< 10 m depth)
105 where they were protected from tide and wave action.

106 107 **MATERIALS AND METHODS**

108
109 Twenty-four boat-based anglers were asked to target *P. auratus* between 06:00 and
110 14:00 on one day during January 2008 in Botany Bay, NSW (34.0° S; 151.2° E), and then
111 immediately place their fish into portable 110 l cylindrical cages (provided by researchers)
112 tethered to their boats. The cages were made from polyvinyl chloride (PVC) buckets with

113 lids, and comprised one top and two lateral ‘windows’ positioned at 300 mm above the base
114 (with a combined area of *c.* 1200 cm²) and covered by 6-mm PVC mesh. Depending on their
115 sizes, *P. auratus* were caged at densities of 1–10 so that the total weight was <5 kg 110 l cage⁻¹
116 ¹. Anglers completed a data sheet for each fish and placed it into the 110 l cage before
117 securing the lid and alerting researchers.

118

119 Researchers retrieved the 110 l cages and, after removing the datasheets and checking
120 for deaths, transported them to a monitoring site, comprising two 240 m lengths of 12 mm
121 diameter (∅) polyamide (PA) rope buoyed at the surface in a straight line (anchored at either
122 end). The 110 l cages were weighted (2 kg brick), tied to the 12 mm ∅ rope at 5 m intervals
123 and deployed to the sea bed (3 m). When all of the available 110 l cages (*n* = 78) were
124 stocked, angled *P. auratus* were still collected as above, but then transferred to one of three
125 2600 l cylindrical floating cages (made from 22 mm PA mesh attached to PVC frames)
126 deployed on the surface between the monitoring sites. All multi-stocked *P. auratus* were
127 identified by *L_T*.

128

129 After the angled fish were caged, 48 ‘control’ *P. auratus* that were previously trapped or
130 angled in shallow water off Coffs Harbour (30.3° S; 153.1° E), and housed in aquaria for three
131 months were distributed among 41 empty 110 l cages (at comparable stocking densities as the
132 angled fish) and similarly deployed at the monitoring sites on the same day. The controls
133 were handled, transported and housed according to the methods described by Broadhurst *et al.*
134 (1999).

135

136 All cages were retrieved after four days and any mortalities were recorded. At this
137 time, 10 angled and 11 control *P. auratus* were randomly selected from their cages and

138 sampled for blood within 1 min of initial disturbance following the methods outlined by
139 Broadhurst *et al.* (2005). Eleven *P. auratus* were also angled from Botany Bay and similarly
140 sampled (within 1 min of hooking).

141

142 DATA COLLECTED AND ANALYSES

143

144 The following general categories of data were collected for all angled *P. auratus*: angler
145 name; hook type and size (absolute; mm²); line strength (kg); trace length (cm); bait and rig
146 types; whether the boat was anchored or drifting; fishing depth (m); period between hooking
147 and landing (*i.e.* playing time in s); landing and restraint methods; period of air exposure
148 during unhooking and ‘release’ (s); anatomical hook location; whether or not the hook was
149 removed; L_T (cm); the presence or absence of fin damage, scale loss, bleeding or hook
150 damage; cage number; and whether they died or survived the experiment. Replicate water
151 temperature (°C) and dissolved oxygen (mg l⁻¹) were recorded on the fishing and monitoring
152 days using an Horiba U/10 water quality meter.

153

154 A Fisher’s exact test was used to test the hypothesis of no difference in the total
155 numbers of angled and control *P. auratus* surviving at the end of the experiment. All data
156 describing the capture and handling of each angled fish were collated as either fixed
157 ‘terminal-rig’, ‘fishing-and-landing’ or ‘angling-response’ factors. Design factors (considered
158 as being random) included ‘anglers’ and ‘cages’. These various terms were then considered
159 for inclusion in generalised linear mixed models (GLMMs) fitted using ASReml-R (Butler *et*
160 *al.* 2009) and via penalized quasi-likelihood (Breslow & Clayton, 1993) to the dichotomous
161 status (alive *v.* dead) of *P. saltatrix* at the end of the experiment. Total length was included as
162 a co-variate in all models.

163

164 After assessing the baseline model, two groups of GLMMs were separately fitted using a
165 forward selection approach to ascertain which of the (1) terminal-rig and fishing-and-landing
166 or (2) angling-response factors contributed towards fatalities. Where appropriate, significant
167 fixed effects identified in these analyses were then considered as response variables and
168 GLMMs fitted to isolate their causes. This sequential and structured modelling approach is
169 biologically plausible and avoids many of the statistical challenges and pitfalls associated
170 with variable selection in GLMMs for small data sets. But, the limited sample size and low-
171 frequency binary data mean that all modelling should be considered descriptive, rather than
172 predictive.

173

174 The *P*-values for the various GLMMs were derived via the asymptotic distribution of two
175 test statistics: (1) a pseudo *F*-to-enter based on a Wald value (from the GLMM), and (2) the
176 change in deviance from a generalised linear model obtained by excluding the random terms.
177 Both approaches were chosen to overcome inherent technical problems. In particular, the
178 Wald test suffers from the Hauck-Donner phenomenon (Hauck & Donner, 1977), while using
179 the change in model deviance to derive *P*-values can be anti-conservative if there is
180 significant extra-binomial variation induced by ignoring sources of variation from the random
181 terms.

182

183 The blood samples were analysed for concentrations of cortisol (ng ml⁻¹) and plasma
184 glucose (mM) by direct chemiluminescent immunoassay and using an enzymatic
185 spectrophotometric assay, respectively, according to the manufacturers' instructions. Owing
186 to low levels of both parameters (below the detectable range – see Results) among baseline
187 and control fish, formal statistical analyses were not done to test the hypothesis of no

188 differences among the groups of fish. Rather, the extent of censored data and mean levels of
189 both parameters for which there were recordable data are presented.

190

191

RESULTS

192

193 In total, 157 *P. auratus* (mean $L_T \pm$ S.D. of 18.4 ± 4.2 cm) were caught by 15 of the 24
194 anglers using various terminal rig configurations (but all comprising baited, J or circle hooks),
195 played for mostly <1 min, and then, within an additional 1 min, typically landed without a net,
196 restrained by hand while the hook was either removed (most fish) or the line cut, and released
197 into the cages (Table I). Of these fish, 150 were subsequently deployed and monitored
198 alongside the controls (25.8 ± 2.4 cm L_T). Water temperature (mean \pm S.D. of $22.5 \pm 0.4^\circ\text{C}$),
199 salinity (36.0 ± 0.0 psu) and DO (8.5 ± 0.4 mg l^{-1}) remained similar during the angling and
200 subsequent monitoring days.

201

FATALITIES AND CAUSES

202

203

204 There were no fatalities among the controls, but seven of the angled *P. auratus* died
205 immediately after being placed in the cages (and prior to their deployment—within 5 min of
206 capture), while another five fish were dead at the end of the monitoring period, providing a
207 total, non-significant anger-induced mortality of 7.6% (Fisher's exact test, $P > 0.05$). The
208 initial fatalities and solitary confinement of most fish precluded the coherent inclusion of
209 cages as a random term; restricting the baseline model to the intercept and random effect of
210 anglers.

211

212 Because nine of the 12 fatalities were caught by two of the 15 anglers, this term
213 explained nearly 30% of the total variation in the baseline model, although the residual also
214 clearly indicated the influence of other factors. The first GLMMs fitted to those fixed factors
215 describing the terminal rig and fishing and landing processes (and with L_T as a co-variate)
216 identified that only hook removal was significant, with both $P(\text{Wald and deviance}) < 0.01$
217 (Tables I and II). But this treatment was clearly confounded by anatomical hook location,
218 with hooks removed from all 142 mouth-caught individuals (with only two deaths), but left in
219 11 hook-ingested fish (of which six died) and removed from three (all died). No other
220 variables, including the L_T of fish were significant after hook removal was included as a term
221 and the model refitted ($P > 0.05$; Table II).

222
223 The importance of anatomical hook location in determining fatalities (*i.e.* nine of 14
224 hook-ingested v. two of 142 mouth-hooked fish; Table I) was subsequently explored in the
225 second group of GLMMs assessing the influence of just the angling-response factors. Both
226 this factor and bleeding were the only significant main effects; returning $P < 0.01$ for both the
227 Wald and change in deviance test statistics (Table II). However, all of the bleeding fatalities
228 (four of 12 inflicted fish; Table I) had ingested their hooks, suggesting some co-dependency
229 between anatomical hook location and the presence of blood. A GLMM refitted accounting
230 for anatomical hook location supports this conclusion, with a $P(\text{Wald}) < 0.05$, but a
231 $P(\text{deviance}) > 0.05$ for bleeding. Subsequent assessment of the interaction between bleeding
232 and anatomical hook location also returned conflicting levels of significance [$P(\text{Wald}) > 0.05$
233 and $P(\text{deviance}) < 0.05$]. These analyses, combined with a lack of any significant effects of
234 L_T or hook damage ($P > 0.05$; Table II), suggest that anatomical hook location was the most
235 important predictor of fatalities.

236

237 Based on these results, anatomical hook location was then considered as a binary
238 response variable (mouth *v.* ingested) and GLMMs fitted in an attempt to isolate explanatory
239 factors (Table III). The only significant factor was L_T , which returned a $P(\text{Wald}) < 0.01$, but a
240 highly non-significant $P(\text{deviance}) > 0.05$ (Table III). Because the $P(\text{deviance})$ ignores
241 random effects, such disparity in significance indicated a strong dependency on angler. This
242 relationship was explored in a conditional scatter (jittered) plot of anatomical hook location
243 against L_T for each angler, which revealed that for most of the anglers ($n = 9$) that caught
244 hook-ingested fish, there was a bias towards this occurring among smaller individuals (Fig.
245 1).

246

247 PHYSIOLOGICAL RESPONSE OF ANGLED FISH

248

249 The chemiluminescent immunoassay was unable to detect plasma concentrations of
250 cortisol $< 3.6 \text{ ng ml}^{-1}$ among either those *P. auratus* that were immediately sampled after
251 angling, or the caged controls ($n = 11$ for both). Similarly, four of the caged angled fish had
252 cortisol concentrations below the detectable range of the assay. The remaining six caged
253 angled fish had a mean (\pm S.D.) concentration of $4.3 \pm 0.4 \text{ ng ml}^{-1}$. Comparatively fewer
254 censored data were recorded for plasma glucose ($< 1.0 \text{ mM}$) among baseline ($n = 8$), controls
255 (4) and angled (4) fish using the enzymatic spectrophotometric assay. The remaining means
256 (\pm S.D.) were 1.7 ± 0.6 , 1.9 ± 0.3 and $2.2 \pm 0.6 \text{ mM}$, respectively.

257

258

DISCUSSION

259

260 The *c.* 8% mortality of *P. auratus* in this study is lower than the *c.* 33% recorded by
261 Broadhurst *et al.* (2005) for the same population, but comparable to Grixti *et al.*'s (2010a)

262 estimate of c. 11% (pooled across treatments) for more southern stocks. This estimate is also
263 within the range of other sparids angled from the same depths (<10 m), including *A. australis*
264 (5–28%; Broadhurst *et al.*, 2005; Butcher *et al.*, 2007), *A. butcheri* (8%; Grixti *et al.*, 2008),
265 black seabream *Spondylisoma cantharus* L. 1758 (2.8%; Veiga *et al.*, 2011), gilthead
266 seabream *Sparus aurata* L. 1758 (11.7%; Veiga *et al.*, 2011), two-banded seabream *Diplodus*
267 *vulgaris* (Geoffroy Saint-Hilaire 1817) (0%; 2011) and striped seabream *Lithognathus*
268 *mormyrus* L. 1758 (33%; Alós *et al.*, 2009a). Further, like for many assessed sparids,
269 including those angled from deep water and incurring the cumulative impacts of barotrauma
270 (e.g. *C. laticeps* – Götz *et al.*, 2007; *P. pagrus* – Rudershausen *et al.*, 2007; Overton *et al.*,
271 2008 and annular seabream *Diplodus annularis* L. 1758 – Alós *et al.*, 2009a), a large
272 proportion of the variability among mortalities to *P. auratus* here was explained by the
273 anatomical hook location (Broadhurst *et al.*, 2005; Butcher *et al.*, 2007; Grixti *et al.*, 2008,
274 2010a; Veiga *et al.*, 2011). This factor manifested as disproportionately greater deaths among
275 individuals that ingested hooks (64%) than those hooked in the mouth (1.4%); a relationship
276 comparable to that (52 v. 3%) observed by Grixti *et al.* (2010a).

277

278 There are at least two factors contributing towards such apparent consistency in the
279 importance of anatomical hook location in deciding the fate of sparids. First, in all of the
280 above cited experiments fish were angled on hooks with natural baits. It is well established
281 that such configurations typically are ingested at a greater rate than artificial baits or lures
282 (Bartholomew & Bohnsack, 2005). Second, juvenile sparids (*i.e.* typically comprising the
283 greatest proportion of released individuals) often school, which might increase competition
284 for baits as a perceived source of food and therefore contribute towards an aggressive hooking
285 response. Most sparids are targeted with constant tension on the line (termed ‘active fishing’,
286 but see Alós *et al.*, 2009a) which usually limits the depth of hooking (Bartholomew &

287 Bohnsack, 2005; Grixti *et al.*, 2007, 2010a), so presumably those that manage to ingest hooks,
288 do so with sufficient force to cause considerable damage. Such impacts are supported here by
289 most of the hook-ingested *P. auratus* dying within 5 min, (four of which bled profusely), and
290 similar rapid fatalities among hook-ingested *A. australis* angled across comparable space and
291 time (Broadhurst *et al.*, 2005; Butcher *et al.*, 2007).

292

293 While anatomical hook location (and associated bleeding) explained most of the
294 fatalities in this study, the deaths of two mouth-hooked *P. auratus* indicates the influence of at
295 least some other impacts; albeit nowhere near the extent observed by Broadhurst *et al.* (2005).
296 Two unexamined factors that might have contributed to more *P. auratus* dying during this
297 earlier work were (1) relatively warmer water temperatures (mean \pm S.D. of 24.1 ± 1.5 v. 22.5
298 $\pm 0.4^\circ\text{C}$ here) and (2) tagging. More specifically, previous research has identified positive
299 relationships between temperature and post-release mortality for several species (reviewed by
300 Bartholomew & Bohnsack, 2005; Arlinghaus *et al.*, 2007) which are often attributed to a
301 range of physiological disturbances, including a greater metabolic rate and demand for
302 oxygen (Pörtner, 2002). Further, although tagging did not cause mortalities among the
303 controls monitored by Broadhurst *et al.* (2005) or similar-sized *P. auratus* in other studies
304 (*e.g.* Quartararo & Kearney, 1996; Sumpton *et al.*, 2003), undoubtedly this would have had
305 some cumulative impact on angling stressors. Either of the above factors ultimately could
306 have contributed towards mortality. The potential for such effects illustrates the need to
307 carefully design experiments and to collect sufficient data to attribute causality.

308

309 Irrespective of differences in results between the present and the earlier studies, it is
310 clear from the data presented here and by Grixti *et al.* (2010a), that limiting hook ingestion in
311 juvenile *P. auratus* would concomitantly reduce fatalities. In addition to actively fishing the

312 line (discussed above), several factors have been identified to affect hook ingestion among
313 sparids, including L_T , the hook type (circle v. J-hooks) and mass/size, trace length and bait
314 type (Götz *et al.*, 2007; Grixti *et al.*, 2007, 2008, 2010a,b; Alós *et al.*, 2008, 2009b,c; Butcher
315 *et al.*, 2008; Veiga *et al.*, 2011). Of these variables, L_T had the greatest influence here. But,
316 unlike for many other teleosts (discussed by Grixti *et al.*, 2010b), including the sparids, *A.*
317 *australis* (Butcher *et al.*, 2008), *C. laticeps* (Götz *et al.*, 2007), *D. annularis* (Alós *et al.*,
318 2008) and *S. aurata* (Veiga *et al.*, 2011) and, contrary might be considered intuitive, hook
319 ingestion was biased towards smaller *P. auratus* (Fig. 1).

320

321 The few data mean that the above relationship between anatomical hook location and L_T
322 should be treated with caution. Nevertheless, one plausible explanation is that even though
323 the lines were actively fished, smaller fish may have been able to consume baits before the
324 anglers could detect their presence, which could have allowed some of them to be hooked
325 more deeply. Additional trials would be required to validate this hypothesis and to more
326 closely investigate the importance of other, more controllable, factors affecting hook ingestion
327 so that coherent mitigation strategies can be implemented. In particular, previous studies have
328 shown that changes to terminal rigs, including larger hooks and or subtle modifications (*e.g.*
329 Butcher *et al.*, 2008) are effective in promoting mouth hooking among sparids (Butcher *et al.*,
330 2008; Alós *et al.*, 2009b; Grixti *et al.*, 2010b).

331

332 Irrespective of any modifications to terminal rigs to increase mouth hooking, a
333 concomitant strategy that also should be promoted is to release all hook-ingested fish with
334 their line cut (Broadhurst *et al.*, 2007; Butcher *et al.*, 2007; Alós *et al.*, 2009a; Grixti *et al.*,
335 2010a). Broadhurst *et al.* (2007) and Butcher *et al.* (2007) demonstrated that such a practice
336 was appropriate for improving the fate of *A. australis*, with up to 85% of line-cut hook-

337 ingested individuals surviving (over up to three months); most of which subsequently ejected
338 their hooks. More recently, McGrath *et al.*, (2011) observed 25% mortality among 108 hook-
339 ingested *P. auratus* monitored in aquaria tanks for six weeks, with 77% of survivors ejecting
340 their hooks over an average of *c.* 9 days. By comparison, there were 100% fatalities among
341 fish ($n = 3$) that had their ingested hooks removed here.

342

343 The results from this study indicate minimal post-release mortalities to *P. auratus* after
344 being angled and released during conventional fishing in shallow water. Furthermore, the
345 impacts to survivors appeared to be fairly limited with few differences in blood plasma
346 glucose and cortisol between treatments and controls at the end of monitoring, and
347 immediately sampled wild-caught individuals. Both parameters (across all groups) were
348 within the ranges for unstressed *P. auratus* (*e.g.* Cleary *et al.*, 2000). However, these data are
349 limited to the conditions examined. Like several other sparids (*e.g.* *C. laticeps* – Götz *et al.*,
350 2007, *D. annularis* – Alós *et al.*, 2009a; and *P. pagrus* – Stephen & Harris, 2010) larger *P.*
351 *auratus* inhabit deeper water, where they are extensively targeted by anglers. In addition to
352 any impacts of terminal rigs, are the ancillary effects of barotrauma. This factor has been
353 implicated as contributing towards high mortalities among angled *C. laticeps* (Götz *et al.*,
354 2007) and *P. pagrus* (Stephen & Harris, 2010), and trap-caught *P. auratus* (Stewart, 2008).

355

356 Clearly, the occurrence of barotrauma, along with associated impacts and methods by
357 which these might be mitigated for angled *P. auratus*, need to be assessed to more
358 comprehensively describe the post-release fate of this species and facilitate its future
359 management. Based on the uniformity among known factors affecting the mortality of
360 sparids angled-and-released from shallow water, it is likely that any such assessments would
361 have broader application across the entire family.

362

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367

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485

486 TABLE I. Summary of categorical and, where applicable, mean (\pm S.D.) continuous random
 487 and fixed ('terminal-rig', 'fishing-and-landing' and 'angling-response') factors collected for
 488 the live and dead angled-and-released *Pagrus auratus*. ¹seven fish died immediately and
 489 were not caged.

490

491 Variables	Alive	Dead
---------------	-------	------

492 *Design/random factors*

493 Angler		
------------	--	--

494 1	20	5
-------	----	---

495 2	21	0
-------	----	---

496 3	20	0
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497 4	16	4
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498 5	18	0
-------	----	---

499 6	11	1
-------	----	---

500 7	11	1
-------	----	---

501 8	8	0
-------	---	---

502 9	7	1
-------	---	---

503 10	6	0
--------	---	---

504 11	3	0
--------	---	---

505 12	1	0
--------	---	---

506 13	1	0
--------	---	---

507 14	1	0
--------	---	---

508 15	1	0
--------	---	---

509

510 Cages ¹		
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511	110-l individual	69	4
512	110-l mixed 1	10	0
513	110-l mixed 2	5	0
514	110-l mixed 3	4	0
515	110-l mixed 4	4	0
516	110-l mixed 5	4	0
517	110-l mixed 6	3	0
518	110-l mixed 7	2	0
519	110-l mixed 8	2	0
520	110-l mixed 9	2	0
521	2600-l mixed 1	19	0
522	2600-l mixed 2	18	0
523	2600-l mixed 3	3	0
524			
525	<i>Terminal-rig factors</i>		
526	Hook type		
527	J	98	7
528	Circle	46	5
529			
530	Absolute hook size (mm ²)	312.7 (117.0)	356.4 (65.9)
531			
532	Line strength (kg)	2.8 (0.7)	2.6 (0.6)
533			
534	Trace length (cm)	73.2 (42.9)	63.6 (24.4)
535			

536	Bait type		
537	<i>Trachurus</i> sp	10	0
538	<i>Mugil cephalus</i>	7	0
539	<i>Sardinops neopilchardus</i>	11	0
540	<i>Metapenaeus macleyi</i>	58	6
541	<i>Loliginidae</i>	59	6
542			
543	Rig type		
544	Hook only	36	5
545	>50-cm trace	33	2
546	<50-cm trace	14	0
547	Paternoster	50	5
548	Sinker on hook	5	0
549			
550	<i>Fishing-and-landing factors</i>		
551	Fishing method		
552	Anchored	86	5
553	Drifting	59	7
554			
555	Fishing depth (m)	7.4 (2.2)	7.3 (2.2)
556			
557	Playing time (s)		
558	<10	63	5
559	11–30	79	7
560	31–60	2	0

561	>61	1	0
562			
563	Landing method		
564	Knotless net	2	0
565	Knotted net	4	0
566	No net	139	12
567			
568	Restraint method		
569	Dry bare hand	26	1
570	Wet bare hand	117	11
571	Towel	1	0
572	Not restrained	1	0
573			
574	Air exposure (s)		
575	<15	41	3
576	16–30	98	7
577	31–60	5	2
578			
579	Hook removed		
580	No	5	6
581	Yes	140	6
582			
583	<i>Angling response factors</i>		
584	Hook location		
585	Ingested	5	9

586	Mouth	140	2
587	Body	0	1
588			
589	Hook damage		
590	No	137	10
591	Yes	8	2
592			
593	Bleeding		
594	No	137	8
595	Yes	8	4
596			
597			

598 TABLE II. Wald- and deviance-derived P -values, and variance component ratios for the
 599 random effect of angler, associated with fixed variables tested in generalized linear mixed
 600 models (GLMMs) for their independence on the mortality of angled-and-released *Pagrus*
 601 *auratus*. Two groups of models were applied: the first to just the terminal-rig and fishing-
 602 and-landing variables; and the second to only those data describing the angling responses of
 603 fish. L_T was fitted as a co-variate in all GLMMs, and in all cases returned $P(\text{Wald})$ and
 604 $P(\text{deviance}) > 0.05$.

606	607 Variables	606 P		606 Variance component ratio 607 for angler
		607 Wald	607 Deviance	
608	608 <i>Terminal-rig and</i>			
609	609 <i>fishing-and-landing GLMMs</i>			
610	610 Hook type	0.980	0.695	1.711
611	611 Absolute hook size	0.480	0.246	0.692
612	612 Line strength	0.696	0.418	1.597
613	613 Trace length	0.499	0.466	1.539
614	614 Bait type	0.879	0.298	2.868
615	615 Rig type	1.000	0.342	2.145
616	616 Playing time	0.999	0.917	1.516
617	617 Water depth	0.447	0.921	1.883
618	618 Fishing method	0.279	0.171	1.523
619	619 Landing net	0.991	0.623	1.266
620	620 Restraint method	0.976	0.746	1.404
621	621 Air exposure	0.132	0.382	2.308
622	622 Hook removed	0.000	0.000	0.412

623

624 *Angling-response GLMMs*

625	Hook location	0.000	0.000	0.210
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626	Hook damage	0.146	0.192	1.407
-----	-------------	-------	-------	-------

627	Bleeding	0.004	0.006	1.478
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628

629 TABLE III. Wald- and deviance-derived P -values, and variance component ratios for the random effect
 630 of angler, associated with fixed variables tested in generalized linear mixed models for their
 631 independence on the anatomical hook location of angled *Pagrus auratus*

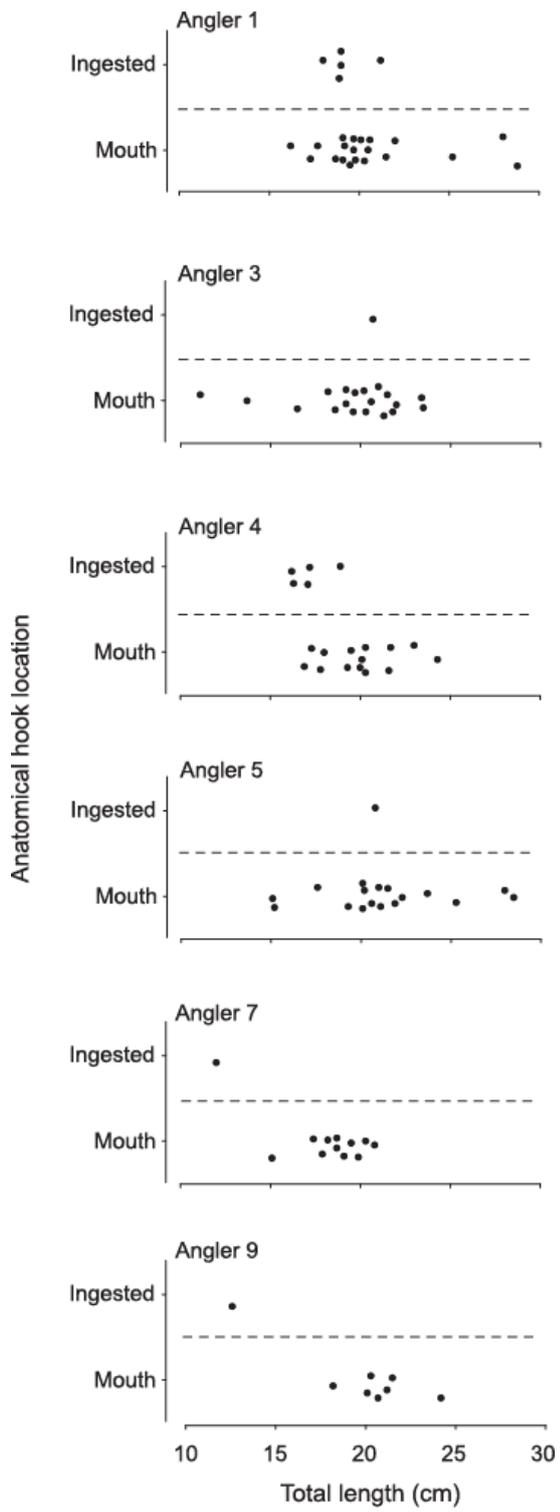
633		P		Variance component ratio
634	Variables	Wald	Deviance	for angler
635	Hook type	0.904	0.653	0.768
636	Absolute hook size	0.868	0.673	0.340
637	Line strength	0.541	0.352	0.708
638	Trace length	0.992	0.611	0.938
639	Bait type	0.927	0.454	1.545
640	Rig type	0.856	0.105	0.537
641	L_T	0.046	0.501	1.617

642
 643

644 **Caption to Fig**

645 Fig. 1. Jitter plots of the total length of *Pagrus auratus* v. anatomical hook location for each of the
646 six anglers that caught hook-ingested fish.

647



648