

1 **Responses to predator's chemical cue reveal coexisting mechanism of exclusive related species**

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18 **Running Head:** Effect of predator chemical cue on caddisfly case making

19

20 **Keywords:** Trichoptera; construction behaviour; chemical cue; trophic interaction; competitive

21 exclusion; coexisting mechanism

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24 **Response to predator's chemical cue reveals coexisting mechanism of exclusive related species**

25

26 **Abstract**

27 Coexisting mechanism of the multiple species shearing same niche is often puzzling issues. Biased

28 predation is possible factors that allow competitive coexistence. Two species of case-bearing

29 caddisfly larvae *Perissoneura paradoxa* and *Psilotreta kisoensis* (Odontoceridae, Trichoptera) have

30 closely similar natural history other than body size. In natural field, the two species of caddisfly

31 larvae can coexist only where predatory fish inhabit. In this study, we examined triangle species

32 interactions to reveal the coexisting mechanism of closely similar caddisfly species. The result of

33 sympatric incubation experiment confirmed that the two odontocerid caddisfly larvae could not

34 coexist without predatory fish as larger species *Pe. paradoxa* outcompeted smaller *Ps. kisoensis*

35 population. This indicates that the larger species strongly exploits small species. Next, we measured

36 the case repair speed of two species with/without chemical cue of predatory fish. The result showed

37 that larger *Pe. paradoxa* with chemical cue reconstructed their cases faster than that without cue.

38 Whereas *Ps. kisoensis* did not exhibit significant response to fish chemical cue. This result indicates

39 that larger species showed defensive response as they are more vulnerable to predatory fish. Taken

40 together, two closely related odontocerid species can coexist since predatory fish weaken the

41 exploitation relation between the two. Our present study demonstrates that the protective response of

42 prey to predators' chemical cues can be a useful clue to estimate potential tripartite trophic
43 interactions.

44

45 **Introduction**

46 A major challenge in ecology is to understand how numerous species coexist and affect each others'
47 population. Especially, the coexisting mechanism of the multiple species shearing same niche is
48 often puzzling issues (contrary to Gause's law of competitive exclusion, Gause 1934; Hardin 1960).

49 Presence of predators is one of the most prevailing factors that permit competitive coexistence
50 (Dayton 1971; Vance 1978; McPeck 2014). Thus, evaluating predation pressure is important to
51 reveal the coexisting mechanism. To understand the strength of prey-predator relationships, the
52 protective responses of preys appeared would be useful indicators because they would be expressive
53 of the evolutionary history of species specific prey-predator interaction. Indeed the magnitude of the
54 response of prey is often related to predation risk (Eklöv 2000; McCarthy & Fisher 2000; Mowles et
55 al. 2011). Although numerous studies have been examined protective plasticity with the view of
56 simple bilateral prey-predator interaction or its multiple combinations, there are few literatures
57 considering more than triangular trophic interactions.

58 Generally, protective response of prey is classified into anatomical (e.g, prickles on body
59 surface, bulgy body) and behavioural ones (e.g, pause, drift, refuge). Anatomical changes often take

60 long time to develop the traits and irreversible. Otherwise behavioural responses are temporal but
61 their response is quick and reversible. On the contrary, protective external structures (e.g., nests,
62 burrows, retreats and cases) built by organisms can be treated as anatomical traits that are extended
63 by behavioural phenotype. Such intermediate phenotype can be quickly developed and also long
64 lasting. Therefore, it may be able to easily estimate trophic interaction by evaluating responses of
65 construction behaviour. The larvae of many caddisfly species (order Trichoptera) construct portable
66 cases in a variety of forms and shapes using materials from the sediment. Some species of
67 case-bearing caddisfly are known to immediately switch their case material from soft material to
68 more rigid material under the presence of predators (Boyero et al 2006; Boyero 2011). In addition,
69 these studies claimed that the degree of switching rate and the speed of case construction vary
70 depending on predator species that have different nature. These indicate the possibility that we can
71 estimate the potential strength of trophic interaction with the predator by evaluating the responses of
72 prey appeared as phenotype of their cases.

73 Two species of the case-bearing caddisfly larvae *Perissoneura paradoxa* and *Psilotreta*
74 *kisoensis*, these belong to same family Odontoceridae, are widely distributed all over the Honsyu
75 Island of Japan. Their biology is closely similar, but clearly different in body size (about four times
76 in body dry weight). We have empirically known that the two species of caddisfly larvae can coexist
77 in habitat only where predatory fish inhabit. Therefore, we predict that the presence of fish is

78 important key of the coexisting mechanism. In this study, 1. we firstly surveyed the distribution of
79 natural habitat in relation to fish presence/absence. In addition, we determine the strength of
80 triangular trophic interactions by 2. sympatric incubation experiment of two caddisfly species under
81 predator free condition (interaction between two caddisfly species) and 3. measuring the speed of the
82 case repair of two caddisfly in response to chemical cue of predatory fish (interactions between fish
83 and two caddisfly species respectively). Based on these evaluations, we finally discuss the possible
84 coexisting mechanism of closely similar species of caddisfly larvae.

85

86 **Materials & Methods**

87 *Study organisms*

88 Two species of the case-bearing caddisfly larvae *Perissoneura paradoxa* and *Psilotreta kisoensis*,
89 these belong to same family Odontoceridae, are widely distributed all over the Honsyu Island of
90 Japan. Their biology is closely similar including habitat (confined to spring fed and pool of
91 headwater stream), life cycle (one to two years voltine, emergence on April to June, Okano
92 unpublished), feeding habit (cannibalistic scavenger), life style of sinking in the sediment, case
93 shape (simple cylindrical case constructed from sediment sand), criterion of case material choice
94 (Okano et al. 2011). But body size of *Pe. paradoxa* is clearly larger than that of *Ps. kisoensis*
95 (maximum body weight is 20 DW mg in *Pe. paradoxa* and 5 DW mg in *Ps. Kisoensis*, Okano et al.

96 2011).

97 *Natural habitat*

98 To survey the distribution of natural habitat in relation to fish presence/absence, we listed up the
99 habitat of odontocerid two species where we could surely confirm the presence/absence of predatory
100 fish to the best of our knowledge.

101 *Sympatric incubation experiment*

102 To evaluate the interaction between two odontocerid species without predators, we measured larval
103 survivability and growth under sympatric and singularly incubation in laboratory setting. Here the
104 procedures are described above, but the details of the incubation conditions (larval localities,
105 individual number, sediment sand types) other than sympatric/singularly condition were set for the
106 aims of other study plan and so not fundamental one for this study. On the middle of May 2014, we
107 collected pupae of *Pe. paradoxa* from Mt. Tsukuba (Site 2 in Table 1) and pupae of *Ps. kisoensis*
108 from Mt. Maya (Site 4) and Mt. Gozen (Site 5). After bringing to laboratory, each pupal population
109 was incubated in 40 × 45 × 20 biggest aquarium tank separately. From the emerged adults from the
110 pupae, we got eggs on the end of May (egg number: 23 of *Pe. paradoxa* from site 2, 7 of *Ps.*
111 *kisoensis* from site 4 and 13 of *Ps. kisoensis* from site 5). Larvae of next generation were hatched on
112 the middle of June. They were incubated in 28 × 20 × 8 containers, paved with natural sediment sand
113 from Site 5, submerged in the biggest tanks for 2 weeks. We started incubation experiment on June

114 28th; immature larvae of each population were randomly divided into $13 \times 13 \times 5$ cm containers
115 according to setting conditions (details of conditions are described in Table 2). In each container, we
116 paved either of the two types of artificial sand (1.7 l of glass or ceramic sand) that prepared in
117 similar way as described in Okano et al (2011, 2012). These containers were submerged in the
118 biggest tanks. During the incubation, 0.2 mg per an individual of fish meal (Tetra Fin; Tetra Co.,
119 Melle, Germany) was fed to larvae once every three days. We did not adjust food amount according
120 to decreasing in individual number. On July 30, we measured larval survivability and aperture
121 diameter of the anterior end of the case in each container. The data of aperture diameter (A.D) was
122 transformed to larval body weight (DW mg) using previously known relationship between them (see
123 figure 2 in Okano et al. 2011). The conversion equations are

124 Body weight of *Pe. paradoxa* = $0.111 \times \text{A.D.}^{2.96}$

125 Body weight of *Ps.kisoensis* = $0.323 \times \text{A.D.}^{2.15}$

126 ***Case repair experiment in response to predatory fish***

127 To evaluate the interaction between fish and two similar odontocerid species respectively, we
128 conducted case repair experiment under presence/absence of predator's chemical cue in laboratory
129 setting. On August 13th, 2014, we collected larvae of *Pe. paradoxa* (nine individuals) and *Ps.*
130 *kisoensis* (ten individuals), and a predatory fish *Salvelinus leucomaenis* (one individual) from
131 Akashio River (Site 8 in Table 1). At the same time, river water was sampled in two plastic bags. The

132 fish was soaked in water of one of the two bags for four hours. We used the soaked water as

133 predator's chemical cue to induce the caddisflies' protective behaviour afterward.

134 After bringing three species separately to laboratory, length and aperture diameter of the
135 anterior end of the larval case was measured under binocular scope. Then larvae were divided for
136 two experiment treatments so as to prevent unevenness of larval size; one is for absence of predator
137 condition (N = 5 for *Pe. paradoxa*; N = 5 for *Ps. kisoensis*) and another is presence of predator (N =
138 4 for *Pe. paradoxa*; N = 5 for *Ps. kisoensis*). The anterior portion of the larval case was removed
139 (one-fourth of the case length) to induce larval motivation for case construction. Each larva
140 separately placed in 3.5 diameter and 1cm depth of container where 2-ml of artificial glass sand was
141 provided as case material. After that, we provided 10-ml of intact river water into containers of
142 control condition (absence of predator), and 4-ml of intact river plus 6-ml of fish soaked river water
143 into containers of treatment condition (presence of predator). All containers were placed under the
144 eaves of laboratory building. The experiment started at 6:00 PM and ended at 13th to 4:00 PM on
145 14th. Larvae could repair their case with provided material for 22 hours. After the experiment, we
146 counted the number of glass sand that larvae used for case repair after preserving in 100 % alcohol.

147

148 **Statistical analysis**

149 To assess the sympatric effect on larval survivability, we used generalized linear model (GLM)

150 analysis with binomial errors and a logit link. We statistically compared binominal data of [survived
151 individual number after one month] against [initial individual number] between sympatric and
152 singularly incubation condition. Other than sympatric effect, we also considered the effects of
153 incubation sediment type (glass or ceramic) and population locality (Site 4 or 5 for *Ps. kisoensis*).
154 The statistical significance of each correlation model was tested by calculating the deviance of the
155 model with and without explaining the terms. The deviance was assumed to have a chi-square
156 distribution. In similar fashion, to assess the sympatric effect on larval growth, we used generalized
157 linear model (GLM) analysis with poisson errors and a logit link. Explanatory variables are same as
158 survivability analysis.

159 We used t-test to detect the differences of the length and aperture diameter of the anterior end of
160 the case, and the number of glass sand that larvae used for case repair.

161

162 **Results**

163 ***Larval Natural habitat***

164 Table 1 shows the presence or absence of two odontocerid larvae and predatory fish in natural
165 habitat. We can clearly recognize that two species of caddisfly larvae can coexist only where
166 predatory fish inhabit (Site 4, 8 & 9). On the other hand, either of two odontocerid species existed in
167 fish free habitat (Site 1, 2, 3, 5, 6 & 7).

168 ***Sympatric incubation experiment***

169 Figure 1-a&b show the survivability of two species of odontocetid larvae under sympatric/singularly
170 condition without predatory fish. For *Pe. paradoxa*, there were no significant effects of sympatry
171 (GLM, $z = 0.816$, $p = 0.45$, Fig. 1-a) and sediment sand type ($z = 1.372$, $p = 0.17$), indicating that
172 this species was not negatively affected by *Ps. kisoensis*. On the other hand, survivability of *Ps.*
173 *kisoensis* significantly decreased when *Pe. paradoxa* coexist (86-96 % dropped down to 7-30 %;
174 GLM, $z = -9.059$, $p < 0.00001$, Fig. 1-b), but there were no significant effects of sediment sand type
175 ($z = 0.815$, $p = 0.415$) and population locality ($z = 0.202$, $p = 0.840$), indicating that this species was
176 negatively affected by *Pe. kisoensis*.

177 Figure 1-c&d shows the body weight of two species of odontocetid larvae after one month
178 incubation. For both species, larval body weight was higher in sympatry condition than in singularly
179 condition (GLM, *Pe. paradoxa*: $z = 3.384$, $p < 0.00001$, Fig. 1-c; *Ps. kisoensis*: $z = 4.004$, $p <$
180 0.00001 , Fig. 1-d). There were no significant effects of sediment sand type (*Pe. paradoxa*: $z = 1.044$,
181 $p = 0.296$; *Ps. kisoensis*: $z = 1.519$, $p = 0.129$) and population locality (*Ps. kisoensis*: $z = 0.509$, $p =$
182 0.610).

183 ***Case repair speed in response to predatory fish***

184 Figure 2-a,b,c & d shows length and aperture diameter of the natural cases sacrificed for repair
185 experiment. Between with and without chemical cue condition, there were no significant differences

186 in case length (t-test, *Pe. paradoxa*: d.f. = 7, $t = 1.2$, $p = 0.45$, Fig. 2-a; *Ps. kisoensis*: d.f. = 8, $t =$
187 0.35 , $p = 0.47$, Fig. 2-b) and case diameter (*Pe. paradoxa*: d.f. = 7, $t = 0.05$, $p = 0.48$, Fig. 2-c; *Ps.*
188 *kisoensis*: d.f. = 8, $t = 0.18$, $p = 0.43$, Fig. 2-d).

189 Figure 2-e & f shows the number of glass sand used for case repair under presence/absence of
190 predator's chemical cue. For *Pe. paradoxa*, larvae exposed to chemical cue added higher number of
191 sands to their case than these without cue (d.f. = 7, $t = 2.7$, $p = 0.015$, Fig. 2-e). As a result, larva
192 with chemical cue enlarged the case clearly longer than that without cue (Fig. 3). On the other hand,
193 larvae of *Ps. kisoensis* show no significant difference of case repair speed between with and without
194 chemical cue (d.f. = 8, $t = 0.75$, $p = 0.24$, Fig. 2-f).

195

196 **Discussion**

197 The protective response of prey to predators' chemical cues can be a useful clue to estimate potential
198 trophic interaction since response strength of prey reflects underlying connections with other traits
199 related to vulnerability (Dewitt et al. 1999; Boyero 2011). However, such a prey-predator interaction
200 generally does not exist solely in natural field but is modified by interactions with other organisms.

201 Our aim of this study is revealing the coexisting mechanism of closely similar two odontocerid
202 larvae in relation to the presence of predators by evaluating protective response strength to chemical
203 cues.

204 In natural habitat, either of two odontocerid species existed in predatory fish free habitat (Table
205 1). In particular at Site 5 and 6, habitats of two species were segregated even within 1-km. These
206 habitat segregations strongly indicate that two odontocerid have exclusive relation that cannot
207 coexist when their predator is absent. Sympatric incubation experiment supports this natural
208 distribution pattern. Smaller species *Ps kisoensis* larvae drastically decreased their survivability
209 when they coexist with *Pe. paradoxa*. Whereas survivability of larger species *Pe. paradoxa* did not
210 differ between singularly and sympatry incubation. In addition, *Pe. paradoxa* grew faster in
211 sympatric than singularly condition, while maintaining their population. These results indicate that
212 both species cannot coexist since *Pe. paradoxa* exploit *Ps. kisoensis* (Fig. 4-a). On the contrary, two
213 species of caddisfly larvae can coexist where predatory fish inhabit (Table 1). Case repair
214 experiment proposes the possible answer to this nonconformity. When larvae were exposed to
215 predator chemical cue, response appeared as case repair speed was much higher in *Pe. paradoxa*
216 than *Ps. kisoensis* (Fig. 2-e&f). With the assumption that response strength of prey reflects strength
217 of trophic interaction with the predator, *Pe. paradoxa* is more vulnerable to predatory fish than *Ps.*
218 *kisoensis*. Taken together, we can explain the possible coexisting mechanism of them. Both species
219 cannot coexist under predator free condition since *Pe. paradoxa* strongly exploit *Ps. kisoensis*. But
220 under the presence of fish predator, the exploitation becomes weak since *Pe. paradoxa* receive
221 predation pressure from the fish (Fig. 4-b). As a result, the two species would be able to coexist in

222 same habitat.

223 The biology of these two odontocerid species is closely similar but only their body size is much
224 different (about four times in body dry weight). Body size difference of related species can facilitate
225 coexistence by resource partitioning according to food size (Radloff & Du Toit 2004) and/or
226 reproductive isolation due to size-assortative mating (Boughman et al. 2005; Okuzaki et al. 2009). In
227 our study case, resource partitioning seems not to contribute to the coexisting of two odontocerid
228 species since larger species outcompeted without predatory fish which means they are competitive
229 for resources. However, in addition to resource competition, predation may also contribute to defeat
230 of smaller species with considering very short period (one month) to cause extreme imbalance of
231 populations. Although the two caddisfly species are basically scavengers that eat fallen seeds and
232 dead animals, they also often cannibalise conspecifics (probably size-structured cannibalism, Okano
233 et al. 2011). Thus, larger species *Ps. paradoxa* may predates smaller species *Ps. kisoensis* in similar
234 fashion of cannibalism. By such exploitation, *Ps. paradoxa* can assimilate good quality food (i.e.,
235 related species would have similar nutrient balance) and gain exclusive use of entities that serve as
236 food and habitat resources.

237 Large body size of *Pe. paradoxa* may have a disadvantageous effect on defense against
238 predatory fish in turn. Two caddisfly species usually inhabit on sand sediment of pools or stream
239 edges, and so their cases would have camouflage devise. However, *Pe. paradoxa* are more

240 vulnerable since large body size may be easily found by fish. Indeed we can find the larger species
241 easier than the small one in natural habitat. The predation pressure of fish may accompany also
242 non-consumptive effect. The cases provide protection from predators and/or accidental damage
243 (Ross 1956; Otto and Svensson 1980) and increase the efficiency of undulatory behaviors associated
244 with respiration (Wiggins 1996; Okano & Kikuchi 2009). To protect from predators, larvae must
245 increase the case size of by extending its anterior end to accommodate growth as quick as possible.
246 On the other hand, elaborate case material choice is critical factor to promote respiratory efficiency
247 (Okano et al. 2010, 2011, under review). Thus, presence of predators facilitates case making speed
248 but may decrease the case function connecting to respiration, being a competitive disadvantage
249 compared to the related species. Therefore, two odontocerid species can coexist probably by
250 suppression of exploitive relation between them. It is well known that presence of predator permit
251 coexistence of competitive consumers theoretically (Levin 1970; Vance 1978; McPeck 2014) and
252 empirically (Paine 1966; Menge 1995; McPeck 1998). In addition, size-selective predation can be
253 proximate factor to maintain the coexisting stability (Sprules 1972; Stoks & McPeck 2003).

254 Many organisms exhibit defensive behaviour by detecting predators' chemical cue especially in
255 aquatic systems (e.g., snail, Bourdeau 2013; tadpole, Takahara et al. 2008; crayfish, Shave et al.
256 1994; insects, Miyasaka & Nakano 2001). Such responses have been treated as important key to
257 understand the evolutionary history of preys in relation to predators. Additionally, in recent years,

258 protective responses itself could significantly affect trophic cascades through their non-consumptive
259 effects (Schmitz et al. 1997; Reyea 2000; Trussell et al 2003; Reynolds & Bruno 2013). These
260 suggest, conversely, that prey protective responses can be useful indicators to estimate even complex
261 trophic and competitive interactions. Indeed, Mowles et al. (2011) showed that predator chemical
262 cue reversed the competitive superiority between two snail species as they differed in degree of
263 anti-predator response depending on their susceptibility. However, unfortunately, their life histories
264 and habitat distributions in relation to predators in natural field are unexamined. In this study, by
265 evaluating the strengths of protective response, we could explain possible coexisting mechanism of
266 closely related species in natural habitat. Our results indicate that the prey response to predator
267 chemical cues can be a useful clue to estimate more than triangle trophic interactions. Further studies
268 to confirm their actual vulnerability and effect of predator cue on their population dynamics will
269 determine validity of our hypothesis of coexisting mechanism.

270

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277

278

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356

357 **Figure Legends**

358

359 **Figure 1.** The survivability (a & b) and body weight (c & d) of two species of odontocerid larvae
360 after one month incubation without predatory fish (a & c: *Perissoneura paradoxa*; b & d: *Psilotreta*
361 *kisoensis*). Open circles show incubation under singularly condition and grey circles show
362 incubation under sympatric condition. Each circle corresponds to each incubation deme (mean body
363 weight of a deme is indicated in c & d).

364

365 **Figure 2.** The length (a & b), aperture diameter (c & d) of the natural cases sacrificed for repair
366 experiment, and number of glass sand used for case repair (e & f) of two odontocerid species (a, c &
367 e: *Perissoneura paradoxa*; b, d & f: *Psilotreta kisoensis*). Open circles show incubation without fish
368 chemical cue and grey circles show incubation with cue. Each circle corresponds to each individual.

369

370 **Figure 3.** Photo image of *Perissoneura paradoxa* after case repair experiment: larvae with fish
371 chemical cue (right) repaired faster than these without cue (left).

372

373 **Figure 4.** (a) interaction between two related caddisfly species Odontoceridae without predatory fish,
374 and (b) possible triangle interactions among two caddisfly species and predatory fish.

Table 1. Presence or absence of two Odontocerid larvae and predatory fish in natural habitat. *Site1–7 correspond to site number in Okano et al. (2011). SSS of Site5 means habitat where is same stream

Site Name	Site Number	lat/long	<i>Pe.paradoxa</i>	<i>Ps.kisoensis</i>	Fish	Major Fish Species
Mt. Aoba	Site 1*	38°15'N/140°49'E	×	○	×	
Mt. Tsukuba	Site 2	36°10'N/140°7'E	○	×	×	
Mt. Yokone	Site 3	38°4'N/139°43'E	×	○	×	
Mt. Gozen	Site 5	36°32'N/140°19'E	○	×	×	
Mt. Gozen	SSS of Site 5**	(600m from Site 5)	×	○	×	
Sekigahara	Site 6	35°22'N/136°27'E	×	○	×	
Sekigahara	1.SSS of Site 6	(85m from Site 6)	○	×	×	
Sekigahara	2.SSS of Site 6	(900m from Site 6)	○	×	×	
Kakita	Site 7	35°6'N/138°54'E	○	×	○	Amur minnow, Sculpin, Goby
Mt. Maya	Site 4	34°43'N/135°11'E	○	○	○	Dark chub Sculpin, Goby
Hiramizo ***	Site 8	35°82'N/139°19'E	○	○	○	Char, Landlocked salmon
Akashio	Site 9	35°87'N/137°67'E	○	○	○	Char
* Site1-7 correspond to site number in Okano et al. (2011).						
** 'SSS of Site5' means habitat where is same stream system of Site5.						
*** Information was obtained from Nozaki (personal communication)						

Table 2. Incubation conditions of two Odontocerid larvae.				
Species	singularly/sympatry	Individual number	Sand type	N
<i>Pe. paradoxa</i>	singularly	55	Glass	1
<i>Pe. paradoxa</i>	singularly	55	Ceramic	1
<i>Pe. paradoxa</i>	singularly	110	Glass	1
<i>Pe. paradoxa</i>	singularly	110	Ceramic	1
<i>Ps. kisoensis</i> (Site 4)	singularly	110	Glass	1
<i>Ps. kisoensis</i> (Site 4)	singularly	110	Ceramic	1
<i>Ps. kisoensis</i> (Site 5)	singularly	110	Glass	1
<i>Ps. kisoensis</i> (Site 5)	singularly	110	Ceramic	1
<i>Pe. paradoxa</i> + <i>Ps. kisoensis</i> (Site 4)	Sympatry	55 : 55	Glass	1
<i>Pe. paradoxa</i> + <i>Ps. kisoensis</i> (Site 4)	Sympatry	55 : 55	Ceramic	1
<i>Pe. paradoxa</i> + <i>Ps. kisoensis</i> (Site 4)	Sympatry	55 : 55	Glass	1
<i>Pe. paradoxa</i> + <i>Ps. kisoensis</i> (Site 4)	Sympatry	55 : 55	Ceramic	1

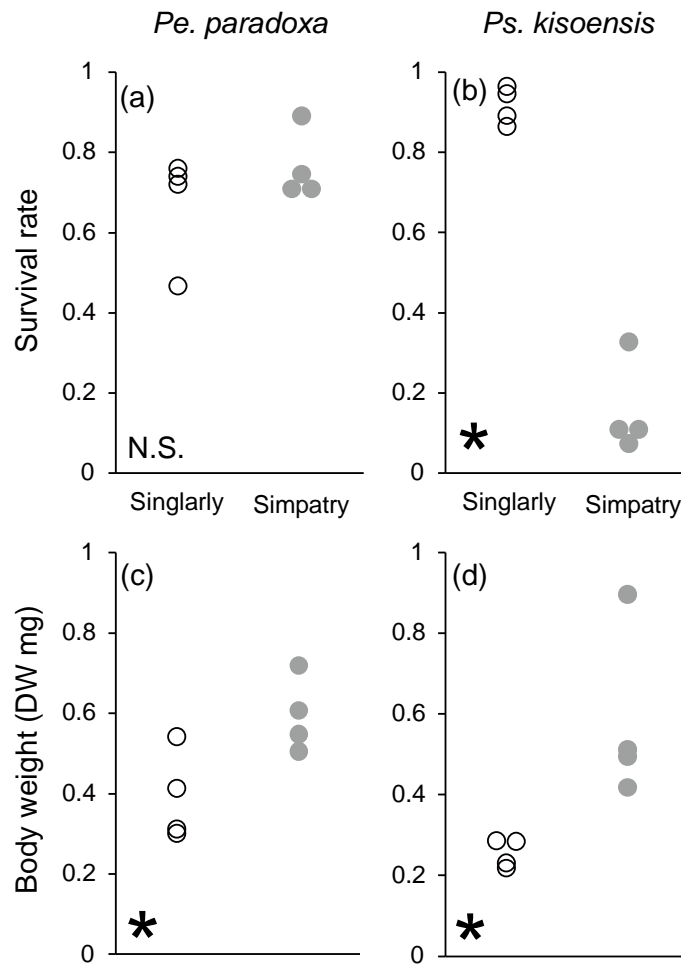


Figure 1. The survivability (a & b) and body weight (c & d) of two species of odontocerid larvae after one month incubation without predatory fish (a & c: *Perissoneura paradoxa*; b & d: *Psilotreta kisoensis*). Open circles show incubation under singularly condition and grey circles show incubation under sympatric condition. Each circle corresponds to each incubation deme (mean body weight of a deme is indicated in c & d).

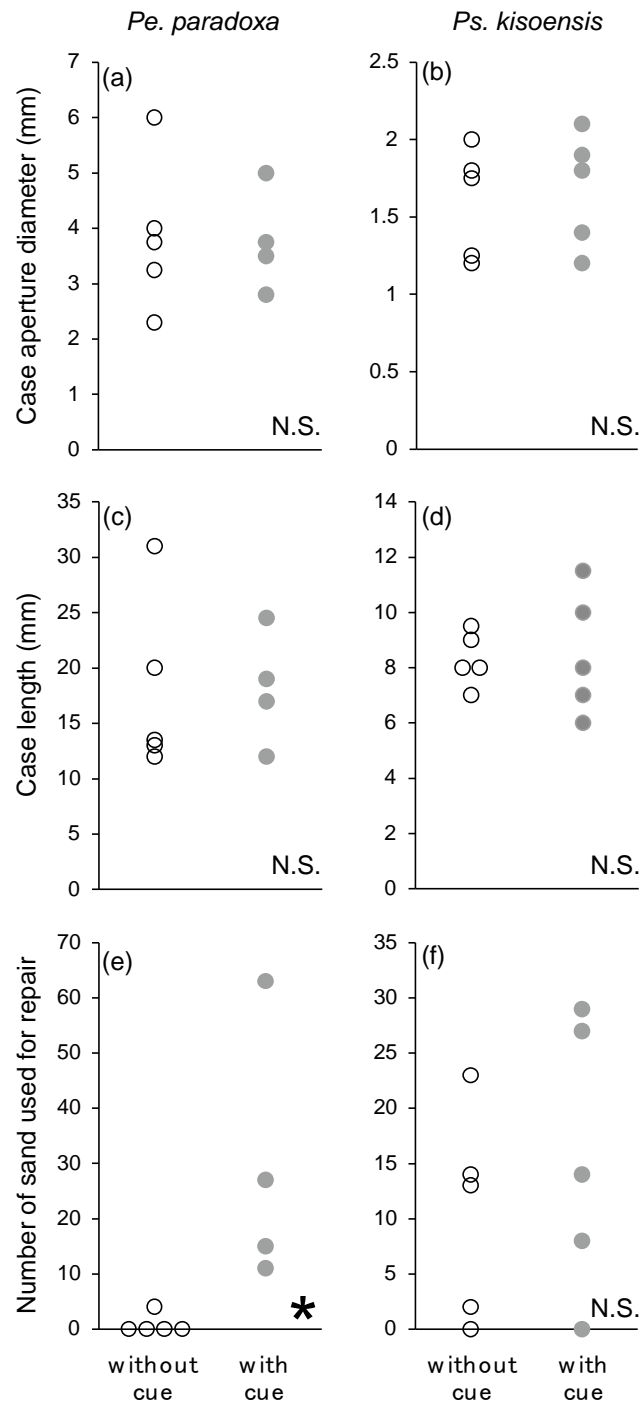
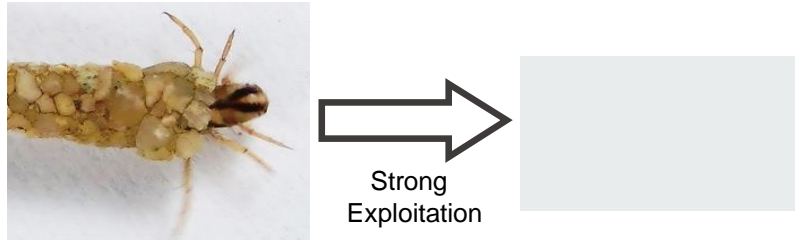


Figure 2. The length (a & b), aperture diameter (c & d) of the natural cases sacrificed for repair experiment, and number of glass sand used for case repair (e & f) of two odontocerid species (a, c & e: *Perissoneura paradoxa*; b, d & f: *Psilotreta kisoensis*). Open circles show incubation without fish chemical cue and grey circles show incubation with cue. Each circle corresponds to each individual.



Figure 3. Photo image of *Perissoneura paradoxa* after case repair experiment: larvae with fish chemical cue (right) repaired faster than these without cue (left).

(a) absence of predator



(b) presence of predator

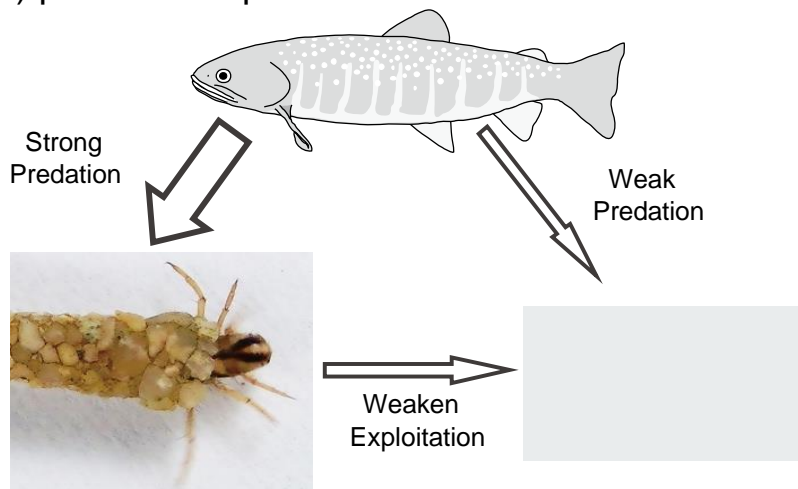


Figure 4. (a) interaction between two related caddisfly species *Odontoceridae* without predatory fish, and (b) possible triangle interactions among two caddisfly species and predatory fish.