

1 **Diel changes in the vertical distribution of larval cutlassfish *Trichiurus japonicus***

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3 DAICHI UEHARA¹, JUN SHOJI¹, YUICHIRO OCHI², SHUHEI YAMAGUCHI²,

4 KAZUMITSU NAKAGUCHI², JUN-YA SHIBATA³ AND TAKESHI TOMIYAMA^{1*}

5

6 ¹Graduate School of Biosphere Science, Hiroshima University, Higashi-Hiroshima,

7 Hiroshima 739-8528, Japan

8 ²School of Applied Biological Science, Hiroshima University, Higashi-Hiroshima, Hiroshima

9 739-8528, Japan

10 ³Environmental Research and Management Center, Hiroshima University, Higashi-Hiroshima,

11 Hiroshima 739-8513, Japan

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13 Running head: Vertical distribution of cutlassfish larvae

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15 *Corresponding author: Takeshi Tomiyama

16 Email: tomiya@hiroshima-u.ac.jp

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18

19 **Abstract**

20 *Diel vertical migration of the cutlassfish Trichiurus japonicus larvae were investigated by*
21 *consecutive 24-h collections at 3-h intervals at a station in the central Seto Inland Sea, Japan*
22 *in June and September. Only one larva was collected in June 2017, while 224 and 40 larvae*
23 *were collected in September 2016 and 2017, respectively. Larvae were present only at depths*
24 *of ≥ 11 m during the day, whereas they were present at depths of 1, 6, 11, and 16 m during the*
25 *night. Migration was observed in larvae in which the swim bladder formation was completed.*
26 *Similar pattern, namely nocturnal occurrence at shallow depths only of the developed larvae,*
27 *was observed in another 24-h survey, suggesting that the swim bladder regulates the upward*
28 *movement of larvae at night.*

29

30 **Key words:** developmental stage; ontogenetic change; swim bladder; Trichiuridae; vertical
31 movement

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34 INTRODUCTION

35

36 In marine fish larvae, vertical distribution governs the maintenance of geographic position
37 (Pearre, 2003), opportunity to encounter prey (Murphy *et al.*, 2011) and escape from predators
38 (Yamashita *et al.*, 1985; Scheuerell & Schindler, 2003); it is one of the important ecological
39 subjects related to the growth and survival of fish larvae. The diel vertical migrations (DVM)
40 of larvae are roughly classified into two types: one in which the larvae move up to the surface
41 at night, and the other in which they move down to the middle or bottom at night (Neilson &
42 Perry, 1990). The former is noted in many fishes, including the anchovy *Engraulis*
43 *encrasicolus* (Olivar *et al.*, 2001), red seabream *Pagrus major* (Tanaka, 1985), haddock
44 *Melanogrammus aeglefinus* (Perry & Neilson, 1988), walleye Pollock *Theragra*
45 *chalcogramma* (Olla & Davis, 1990), and Japanese Spanish mackerel *Scomberomorus*
46 *niphonius* (Shoji *et al.*, 1999). The latter is reported in black seabream *Acanthopagrus*
47 *schlegelii* (Kinoshita & Tanaka, 1990), Japanese sand lance *Ammodytes japonicus* (formerly *A.*
48 *personatus*; Yamashita *et al.*, 1985), and pinfish *Lagodon rhomboides* (Lewis & Wilkens,
49 1971). Moreover, the day-night patterns in larval distribution varies in the same species of the
50 pilchard *Sardina pilchardus* (Olivar *et al.*, 2001; Santos *et al.*, 2006). Thus, the patterns of
51 larval DVM are variable and should be elucidated for deeper understandings of the early life
52 history traits of each species.

53 The family Trichiuridae is widely distributed in oceans worldwide and includes many
54 commercially important species. To our knowledge, no study has revealed the DVM of larvae
55 of species belonging to this family, although some collection records of Trichiuridae larvae at
56 various depths were observed only during the daytime (Loeb, 1979; Hayashi, 1990).

57 This study aimed to elucidate diel patterns of the vertical distribution of the larvae of
58 *Trichiurus japonicus*, the most dominant Trichiuridae species in the western North Pacific.

59 This species had been confused with *T. lepturus*, but genetic difference between these two
60 species was confirmed (Chakraborty *et al.*, 2006a, b). *Trichiurus japonicus* spawns from June
61 to September (Munekiyo, 1991) or May to October (Sakamoto, 1976). In this study,
62 consecutive day–night collections were carried out in September and June.

63

64 MATERIALS AND METHODS

65

66 **Study site and sample collection**

67

68 The vertical distribution of *T. japonicus* larvae was investigated at a sampling station during
69 17–18 September 2015, 5–6 September 2016, 27–28 June 2017, and 20–21 September 2017.

70 This station, located near the southern coast of Hiuchi-Nada in the central Seto Inland Sea
71 (34° 01' N; 133° 20' E; 25 m deep; Figure 1), Japan, was chosen because of the high
72 concentration of larval fishes in this area (Shoji & Tanaka, 2005).

73 In 2015, diurnal distribution patterns were investigated at 0900 and 1000 h on 17
74 September and at 1100 h on 18 September (Supplementary Table S1). In September 2016 and
75 June 2017, diel distribution patterns were investigated by consecutive 24-h collections at 3-h
76 intervals from 1500–1200 h in 2016 (eight collections in total) or from 1500–1500 h in 2017
77 (nine collections). In September 2017, larval collections were carried out six times (1500,
78 1800, 2100, 0000, 0600, and 0900 h). For larval collections, ring nets (called the MTD net;
79 mouth diameter: 56 cm, mesh size: 335 μm ; Horiki, 1981) were towed simultaneously at four
80 depths (1, 6, 11, and 16 m) for 10 min at a speed over the water of 2 knots by the training and
81 research vessel Toyoshiomaru (256 tons). Water volume filtered per net was estimated to be
82 $116 \pm 36 \text{ m}^3$ (mean \pm SD, $n = 35$) and $128 \pm 51 \text{ m}^3$ ($n = 24$) in June and September 2017,
83 respectively, by using a flow meter attached to the net. Samples collected were immediately

84 preserved in 5% seawater formalin onboard.

85 Water temperature and salinity were measured at each collection by using a
86 conductivity-temperature-depth sensor (SBE-9plus, SeaBird). The vertical structure of water
87 temperature and salinity did not change greatly between day and night (Supplementary
88 Figures S1, S2 & S3). Water temperature ranged from 26.0–27.4°C, 18.9–23.5°C, and
89 25.4–26.2°C, and salinity ranged from 31.6–32.1, 31.9–33.1, and 30.1–32.3 in September
90 2016, June 2017, and September 2017, respectively. Times of sunset were 1828 h (5
91 September 2016), 1924 h (27 June 2017), and 1810 h (20 September 2017), and times of
92 sunrise were 0543 h (6 September 2016), 0500 h (28 June 2017), and 0557 h (21 Sep 2017).

93 We also sorted out *T. japonicus* larvae from specimens collected in the past 24-h survey
94 (Shoji *et al.*, 1999). In this survey, larvae were collected from four depths (0, 5, 10, and 20 m)
95 by using a net with 1.3-m mouth opening in Hiuchi-Nada in 3–4 June 1997. Larvae including
96 *T. japonicus* were preserved in 10% seawater formalin (Shoji *et al.*, 1999). Water volume
97 filtered per net was estimated to be $219 \pm 93 \text{ m}^3$ (mean \pm SD, $n = 22$).

98

99 **Laboratory observation and data analyses**

100

101 *Trichiurus japonicus* larvae were sorted in the laboratory. The abundance of larvae at each
102 depth was standardised to the number per 1000 m^3 . Because the water volume filtered by each
103 net was not measured in 2015 and 2016, the average value in September 2017 (128 m^3) was
104 commonly used instead.

105 Total length (TL) was measured to the nearest 0.1 mm by using a digital calliper under a
106 microscope. The developmental stages were determined according to Munekiyo (1991) as
107 follows (Supplementary Figure S3). No juveniles were collected.

108 Pr1 (Prelarva 1); yolksac is retained, the mouth is not opened, and the swim bladder

109 is not formed.

110 Pr2 (Prelarva 2): yolksac is retained, the mouth is opened, and the swim bladder is
111 formed.

112 Po (Postlarva): yolk is absorbed, and three serrated dorsal spines are present on the
113 anterior dorsal fin.

114 To test the difference in the collection depth of the larvae between day and night, the
115 Mann-Whitney *U* test was used for the data in September 2016, September 2017, and June
116 1997.

117 To test whether thermoclines and/or pycnoclines were formed at each survey, vertical profiles
118 of average water temperature and average seawater density were described.

119 RESULTS

120

121 In 2015 and 2016, 98 and 224 *T. japonicus* larvae were collected, respectively. Their size
122 ranged from 4.2–26.9 mm (stage: Pr1–Po) and 3.6–11.3 mm TL (stage: Pr1–Po) in 2015 and
123 2016, respectively (Table 1). In June 2017, only one larva (5.7 mm TL, stage Pr2) was
124 collected from the 16 m layer at 0600 h. In September 2017, 40 *T. japonicus* larvae (stage:
125 Pr1–Po; size: 3.5–11.1 mm) were collected.

126 Larvae of *T. japonicus* were not observed at 1 and 6 m depths, but were collected at 11
127 and 16 m depths during the daytime (0900–1100 h) in 2015 (Figure 2). Similarly, the larvae
128 were collected only at 16 m (at 1500 and 1800 h) or at 11 and 16 m depths (at 0600, 0900, and
129 1200 h) during the daytime in 2016 (Figure 3). In September 2017, one larva of *T. japonicus*
130 at stage Po was collected at 6 m during the daytime (1500 h), but other individuals were
131 collected at 11 and 16 m depths during the daytime (Figure 4). Conversely, *T. japonicus* larvae
132 were collected from all depths during the night from 2100–0300 h in 2016 and from depths of
133 6–16 m during the night in September 2017. However, larvae of stage Pr1 were not present in

134 samples collected from depths of 1 or 6 m irrespective of day and night in 2015 and 2016
135 (Figures 2, 3). Similarly, the larvae of stage Pr1 were not collected from 1 m depth in 2017,
136 although four individuals were collected from a depth of 6 m during the night (Figure 4). In
137 September 2016, significant differences in the collection depth between day and night were
138 observed for stages Pr2 ($U = 2033, P < 0.001$) and Po ($U = 1901.5, P < 0.001$), while no
139 significant differences were observed for stage Pr1 ($U = 54.5, P = 0.33$). In September 2017,
140 no significant differences in the collection depth between day and night were observed for
141 each stage (Pr1: $U = 1, P = 0.62$; Pr2: $U = 7, P = 0.88$; Po: $U = 67, P = 0.92$).

142 Water temperature was higher at shallower depths except for in September 2017 (Figure
143 5). Seawater density was lower at shallower depths. Differences in both water temperature
144 and seawater density between 1 and 20 m depths were the greatest in June 2017. No clear
145 thermoclines or pycnoclines were observed.

146 In 1997, 36 *T. japonicus* larvae were collected. Their size ranged 4.1–7.5 mm TL (stage:
147 Pr1–Po). The larvae were collected from 5–20 m depths during the daytime, while some
148 larvae except of stage Pr1 were collected from the surface layer (0 m) at the night (Figure 6).
149 No significant difference in the collection depth between day and night was observed (Pr1: U
150 $= 6, P = 0.17$; Pr2: $U = 32, P = 0.18$; Po: not applicable because of small sample sizes),
151 although presence of larvae at surface was observed only during the night.

152

153 DISCUSSION

154

155 This is the first study to describe the vertical distribution of Trichiuridae larvae during the
156 night and to clarify their DVM. The daytime patterns in the vertical distribution of *T.*
157 *japonicus* larvae corresponded with those reported previously: the larvae did not appear at the
158 surface, but were mostly found at depths of around 50 m (Okiyama, 1965; Horiki, 1981;

159 Munekiyo & Kuwahara, 1986; Hayashi, 1990).

160 The absence of stage Pr1 larvae near the surface throughout the surveys indicates that the
161 DVM of *T. japonicus* larvae depends on the developmental stage. The formation of the swim
162 bladder, as observed at stage Pr2, is likely related to the vertical migration, because the swim
163 bladder plays important roles in changing the depth or acquiring neutral buoyancy (Kanwisher
164 & Ebeling, 1957). Swim bladder inflation at night has been observed in larvae of other
165 species, including Clupeidae (Uotani, 1973; Hoss & Phonlor, 1984; Landaeta & Castro, 2013),
166 the red seabream *P. major* (Kitajima *et al.*, 1985), and Japanese Spanish mackerel (Shoji *et al.*,
167 1999). Thus, the formation of the swim bladder enables the larvae to adjust their buoyancy
168 and to move up towards the surface at night, as well as to reduce offshore advection
169 (Landaeta & Castro, 2013). However, another possibility should be considered for the timing
170 of swim bladder inflation. The swim bladder seemed to connect to the alimentary canal in the
171 larvae at stages Pr2 and Po, indicating that they are physostomous, at least during larval
172 stages. If so, the larvae has to ascend to the surface to ingest gas bubbles to inflate their swim
173 bladder. Further observation is necessary to elucidate this.

174 The swim bladder development begins before the yolk-sac absorption in *T. japonicus*
175 (Munekiyo, 1991). It is different from other species. For example, the swim bladder begin to
176 inflate from the larvae after yolk-sac absorption in Pacific bluefin tuna *Thunnus orientalis*
177 (Ina *et al.*, 2014). The yolk-sac larvae of Pacific bluefin tuna use yolk-sac and oil globule to
178 acquire buoyancy. Similarly, Japanese Spanish mackerel larvae that complete yolk absorption
179 show DVM, but yolk-sac larvae do not (Shoji *et al.*, 1999). The absence of DVM was also
180 observed in preflexion (yolk-sac) larvae of many other species (Rodriguez *et al.*, 2015).
181 Relationships between the presence/absence of DVM and the larval developmental stages in
182 relation to yolk absorption and swim bladder formation should be further investigated in other
183 species.

184 The stage Pr1 larvae appeared chiefly around the bottom layers, although *T. japonicus*
185 spawns pelagic eggs. It is likely to be related to the egg distribution of this species. Eggs of
186 early developmental stages are scarce around surface and are abundant around middle layers
187 ≥ 10 m depth (Horiki, 1981; Munekiyo & Kuwahara, 1986). Developed eggs are more
188 abundant at deeper layers around 50 m compared to eggs of early developmental stages
189 observed at a depth of 20 m (Horiki, 1981). Thus, larvae would hatched around
190 middle-bottom layers and spend a little until their swim bladders are formed.

191 The vertical distribution of larvae is often affected by the hydrographic stratification.
192 Thermoclines and/or pycnoclines may limit the distribution of larvae (Olivar *et al.*, 2014). In
193 an offshore environment, larvae of some species show diel movement between above and
194 below the pycnocline formed at depths ranging from 36–108 m, and others remained above
195 the pycnocline (Sakuma *et al.*, 1999). However, the DVM is often not observed in well-mixed
196 environments (Rodriguez *et al.*, 2015). Clear thermoclines or pycnoclines were absent,
197 especially in September, in our study (Figure 5) probably because of the shallow water depth
198 of the sampling site. Nonetheless, larval appearance at depths with relatively low seawater
199 density during the night may reflect the DVM.

200 The ecological significance of the nocturnal migration of *T. japonicus* larvae is unclear.
201 Since these larvae feed during the day (Munekiyo & Kuwahara, 1985), their upward
202 movement to the surface might not likely increase their foraging success at night. One
203 possible explanation is that inflation of the swim bladder at night reduces the energy required
204 for maintaining a position in the water column and also reduces predation by predators
205 responding to prey activity (Hunter & Sanchez, 1976). However, it is not yet known whether
206 the upward movement of larvae is advantageous or not. Because not all larvae of *T. japonicus*
207 at stages Pr2 and Po moved up to the surface, other factors such as the condition of larvae
208 (Sclafani *et al.*, 1993) could affect the larval distribution. Further observations on the energy

209 expense or survival at various depths are necessary to elucidate the role of the vertical
210 migration of *T. japonicus* larvae.

211

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217

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221

222 REFERENCES

223

224 **Chakraborty A., Aranishi F. and Iwatsuki Y.** (2006a) Genetic differentiation of *Trichiurus*
225 *japonicus* and *T. lepturus* (Perciformes: Trichiuridae) based on mitochondrial DNA
226 analysis. *Zoological Studies* 45, 419–427.

227 **Chakraborty A., Aranishi F. and Iwatsuki Y.** (2006b) Genetic differences among three
228 species of the genus *Trichiurus* (Perciformes: Trichiuridae) based on mitochondrial DNA
229 analysis. *Zoological Studies Ichthyological Research* 53, 93–96.

230 **Hayashi S.** (1990) Seasonal abundance and vertical distribution of fish eggs and larvae in
231 Toyama Bay, the Japan Sea. *Bulletin of Toyama Prefectural Fisheries Experiment Station*
232 2, 1–17. [in Japanese with English abstract]

233 **Horiki N.** (1981) Vertical distribution of fish eggs and larvae in the Kii Channel.

- 234 *Suisanzoshoku* 29, 117–124. [in Japanese]
- 235 **Hoss D.E. and Phonlor G.** (1984) Field and laboratory observations on diurnal swim bladder
236 inflation-deflation in larvae of gulf menhaden, *Brevoortia patronus*. *Fishery Bulletin* 82,
237 513–517.
- 238 **Hunter R.J. and Sanchez C.** (1976) Diel changes in swim bladder inflation of the larvae of
239 the northern anchovy, *Engraulis mordax*. *Fishery Bulletin* 74, 847–855.
- 240 **Ina Y., Sakamoto W., Miyashita S., Fukuda H., Torisawa S. and Takagi T.** (2014)
241 Ontogeny of swim bladder inflation and caudal fin aspect ratio with reference to vertical
242 distribution in Pacific bluefin tuna *Thunnus orientalis* larvae. *Fisheries Science* 80,
243 1293–1299.
- 244 **Kanwisher J. and Ebeling A.** (1957) Composition of the swim-bladder gas in bathypelagic
245 fishes. *Deep Sea Research (1953)* 4, 211–217.
- 246 **Kinoshita I. and Tanaka M.** (1990) Differentiated spatial distribution of larvae and juveniles
247 of the two Sparids, red and black sea bream, in Shijiki Bay. *Nippon Suisan Gakkaishi* 56,
248 1807–1813.
- 249 **Kitajima C., Tsukashima Y. and Tanaka M.** (1985) The voluminal changes of swim bladder
250 of larval red sea bream *Pagrus major*. *Nippon Suisan Gakkaishi* 51, 759–764.
- 251 **Landaeta M.F. and Castro L.R.** (2013) Vertical distribution and gas bladder
252 inflation/deflation in postlarval anchoveta *Engraulis ringens* during upwelling events.
253 *Journal of the Marine Biological Association of the United Kingdom* 93, 321–331.
- 254 **Lewis R.M. and Wilkens E.P.H.** (1971) Abundance of Atlantic menhaden larvae and
255 associated species during a diel collection at Beaufort, North Carolina. *Chesapeake*
256 *Science* 12, 185–187.
- 257 **Loeb V.J.** (1979) Vertical distribution and development of larval fishes in the North Pacific
258 central gyre during summer. *Fishery Bulletin* 77, 777–793.

- 259 **Munekiyo M. and Kuwahara A.** (1985) Food habits of ribbon fish in the western Wakasa
260 Bay. *Nippon Suisan Gakkaishi* 51, 913–919. [in Japanese with English abstract]
- 261 **Munekiyo M. and Kuwahara A.** (1986) Eggs and larvae distribution of ribbon fish in the
262 western Wakasa Bay. *Nippon Suisan Gakkaishi* 52, 805–810. [in Japanese with English
263 abstract]
- 264 **Munekiyo M.** (1991) Fishery biology of ribbon Fish, *Trichiurus lepturus* in western Wakasa
265 Bay. *Kyoto Institute of Oceanic and Fishery Science Special Report* 3, 1–78 [in Japanese
266 with English abstract]
- 267 **Murphy M.H., Jenkins P.G., Hamer A.P. and Swearer E.S.** (2011) Diel vertical migration
268 related to foraging success in snapper *Chrysophrys auratus* larvae. *Marine Ecology*
269 *Progress Series* 433, 185–194.
- 270 **Neilson D.J. and Perry I.R.** (1990) Diel vertical migrations of marine fishes: an obligate or
271 facultative process? *Advances in Marine Biology* 26, 115–168.
- 272 **Okiyama M.** (1965) A preliminary study on the fish eggs and larvae occurring in the Sado
273 strait, Japan Sea, with some remarks on the vertical distribution of some fishes. *Bulletin*
274 *of the Japan Sea Regional Fisheries Research Laboratory* 15, 13–37. [in Japanese with
275 English abstract]
- 276 **Olla B.L. and Davis M.W.** (1990) Effects of physical factors on the vertical distribution of
277 larval walleye pollock *Theragra chalcogramma* under controlled laboratory conditions.
278 *Marine Ecology Progress Series* 63, 105–112.
- 279 **Olivar M.P., Salat J. and Palomera I.** (2001) Comparative study of spatial distribution
280 patterns of the early stages of anchovy and pilchard in the NW Mediterranean Sea.
281 *Marine Ecology Progress Series* 217, 111–120.
- 282 **Olivar M.P., Sabatés A., Alemany F., Balbín R., Fernández de Puelles M.L. and Torres,**
283 **A.P.** (2014) Diel-depth distributions of fish larvae off the Balearic Islands (western

284 Mediterranean) under two environmental scenarios. *Journal of Marine Systems* 138,
285 127–138.

286 **Pearre S.** (2003) Eat and run? The hunger/satiation hypothesis in vertical migration: history,
287 evidence and consequences. *Biological Reviews* 78, 1–79.

288 **Perry I.R. and Neilson D.J.** (1988) Vertical distributions and trophic interactions of age-0
289 Atlantic cod and haddock in mixed and stratified waters of Georges Bank. *Marine*
290 *Ecology Progress Series* 49, 199–214.

291 **Rodríguez J.M., Cabrero A., Gago J., Guevara-Fletcher C., Herrero M., Hernandez de**
292 **Rojas A., Garcia A., Laiz-Carrion R., Vergara A.R., Alvarez P., Piñeiro C. and**
293 **Saborido-Rey F.** (2015) Vertical distribution and migration of fish larvae in the NW
294 Iberian upwelling system during the winter mixing period: implications for cross - shelf
295 distribution. *Fisheries Oceanography* 24, 274–290.

296 **Sakamoto T.** (1976) Age and growth of the ribbon fish in the Kii Channel. *Nippon Suisan*
297 *Gakkaishi* 42, 1–11. [in Japanese with English abstract]

298 **Sakuma K.M., Ralston S. and Roberts D.A.** (1999) Diel vertical distribution of postflexion
299 larval *Citharichthys* spp. and *Sebastes* spp. off central California. *Fisheries*
300 *Oceanography* 8, 68–76.

301 **Santos A.M.P., Ré P., Dos Santos A. and Peliz Á.** (2006) Vertical distribution of the
302 European sardine (*Sardina pilchardus*) larvae and its implications for their survival.
303 *Journal of Plankton Research* 28, 523–532.

304 **Scheuerell M.D. & Schindler D.E.** (2003) Diel vertical migration by juvenile sockeye
305 salmon: empirical evidence for the antipredation window. *Ecology* 84, 1713–1720.

306 **Shoji J. and Tanaka M.** (2005) Distribution, feeding condition, and growth of Japanese
307 Spanish mackerel (*Scomberomorus niphonius*) larvae in the Seto Inland Sea. *Fishery*
308 *Bulletin* 103, 371–379.

- 309 **Shoji J., Maehara T. and Tanaka M.** (1999) Diel vertical movement and feeding rhythm of
310 Japanese Spanish mackerel larvae in the central Seto Inland Sea. *Fisheries Science* 65,
311 726–730.
- 312 **Sclafani M., Taggart C.T. and Thompson K.R.** (1993) Condition, buoyancy and the
313 distribution of larval fish: implications for vertical migration and retention. *Journal of*
314 *Plankton Research* 15, 413–435.
- 315 **Tanaka M.** (1985) Factors affecting the inshore migration of pelagic larval and demersal
316 juvenile red sea bream *Pagrus major* to a nursery ground. *Transactions of the American*
317 *Fisheries Society* 114, 471–477.
- 318 **Uotani I.** (1973) Diurnal changes of gas bladder and behavior of postlarval anchovy and other
319 related species. *Nippon Suisan Gakkaishi* 39, 867–876. [in Japanese with English
320 abstract]
- 321 **Yamashita Y., Kitagawa D. and Aoyama T.** (1985) Diel vertical migration and feeding
322 rhythm of the larvae of the Japanese sand-eel *Ammodytes personatus*. *Nippon Suisan*
323 *Gakkaishi* 51, 1–5.
- 324

325 **Table 1.** The number and body size (total length, TL) of collected larvae of *Trichiurus*
 326 *japonicus* at each developmental stage.

| Developmental stage | N | TL (mm) |
|----------------------------|----------|----------------|
| June 1997 | | |
| Pr1 | 12 | 4.1–6.4 |
| Pr2 | 15 | 5.2–7.5 |
| Po | 9 | 5.5–7.4 |
| September 2015 | | |
| Pr1 | 3 | 4.16–4.21 |
| Pr2 | 2 | 5.0–5.2 |
| Po | 90 | 4.4–26.9 |
| September 2016 | | |
| Pr1 | 24 | 3.6–4.9 |
| Pr2 | 104 | 4.2–5.5 |
| Po | 96 | 4.7–11.3 |
| June 2017 | | |
| Pr2 | 1 | 5.7 |
| September 2017 | | |
| Pr1 | 4 | 3.5–4.2 |
| Pr2 | 13 | 4.0–5.6 |
| Po | 23 | 4.9–11.1 |

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328

329

330 Figure captions

331

332 **Fig. 1.** Map of the study area in Hiuchi-Nada, the central Seto Inland Sea, Japan. Sample
333 collections were conducted at stations shown by solid (in 2015–2017) and open (in
334 1997) circles.

335

336 **Fig. 2.** Diurnal distribution of *Trichiurus japonicus* larvae at (A) 0900 h on 17 September, (B)
337 1000 h on 17 September, and (C) 1100 h on 18 September 2015. The number of
338 collected larvae per 1000 m³ is shown. Developmental stages (Pr1–Po) were
339 identified.

340

341 **Fig. 3.** Diel changes in the vertical distribution of *Trichiurus japonicus* larvae in September
342 2016. The number of collected larvae per 1000 m³ is shown. Detailed information on
343 larval total length by year and developmental stage is shown in Table 1.
344 Developmental stages (Pr1–Po) were identified. Open and closed bars indicate
345 daylight (day) and dark (night) periods, respectively.

346

347 **Fig. 4.** Diel changes in the vertical distribution of *Trichiurus japonicus* larvae in September
348 2017. The number of collected larvae per 1000 m³ is shown. Detailed information on
349 larval total length by year and developmental stage is shown in Table 1.
350 Developmental stages (Pr1–Po) were identified. Open and closed bars indicate
351 daylight (day) and dark (night) periods, respectively.

352

353 **Fig. 5.** Vertical profiles in average water temperature and seawater density (σ_t) in (A)
354 September 2015, (B) September 2016, (C) June 2017, and (D) September 2017. Solid

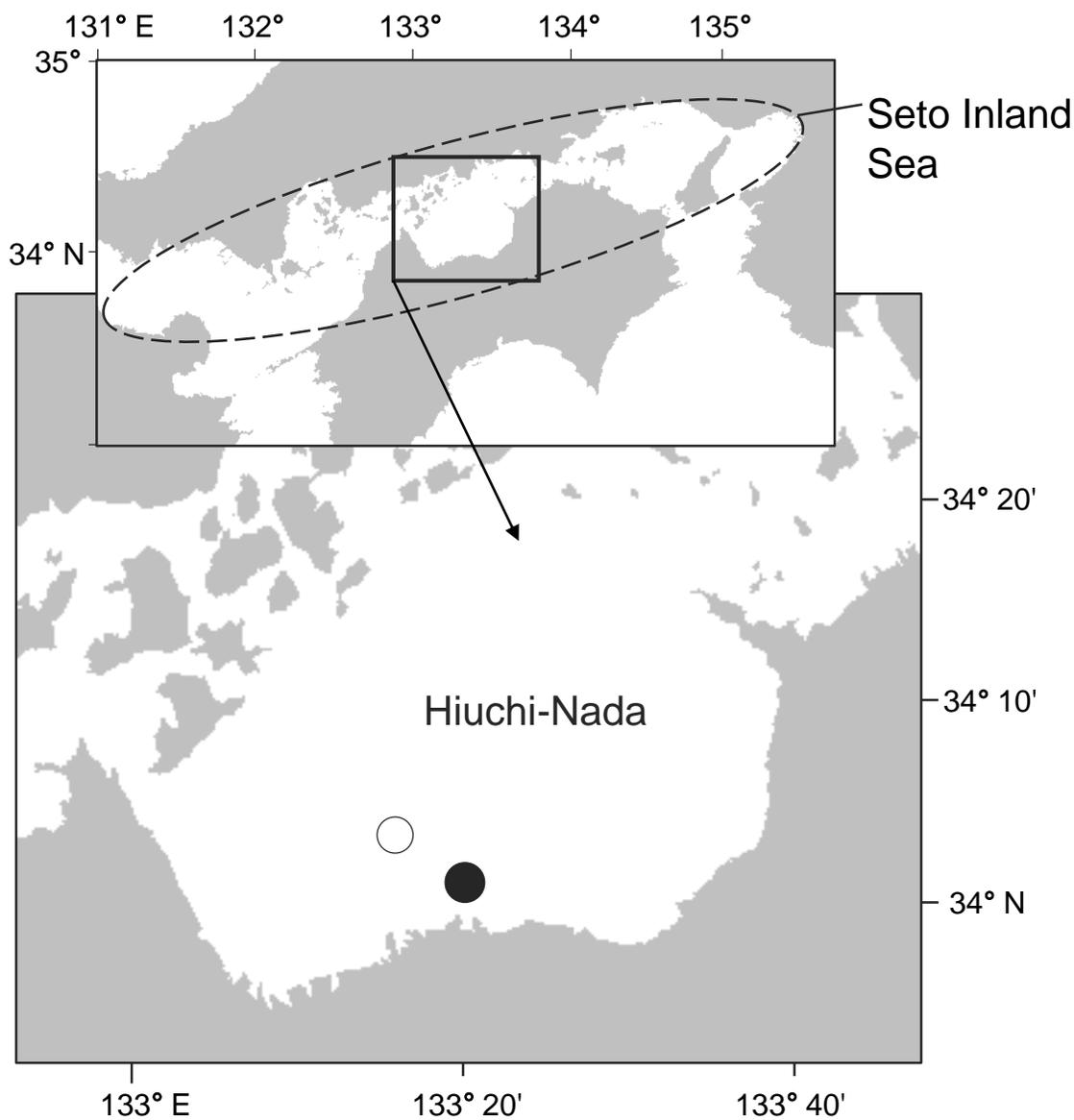
355 and dashed lines indicate water temperature and σ_t , respectively. Diel changes in
356 vertical profiles in temperature and salinity are shown in the supplemental figures.

357

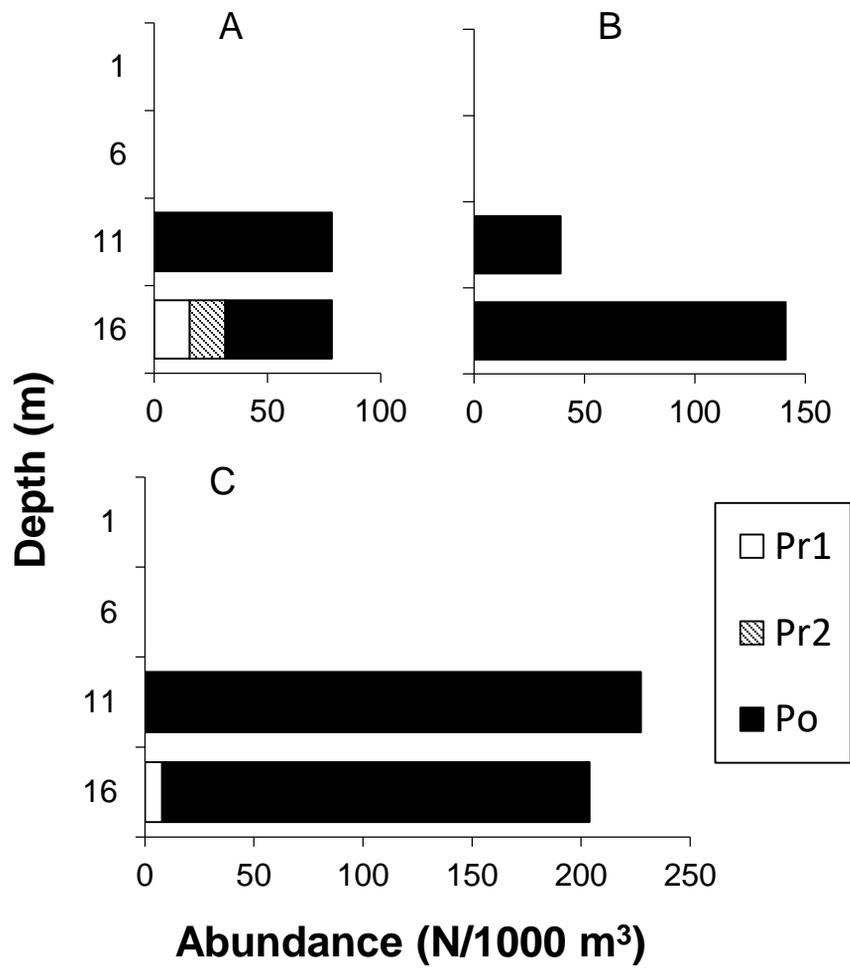
358 **Fig. 6.** Diel changes in the vertical distribution of *Trichiurus japonicus* larvae in June 1997.

359 The number of collected larvae per 1000 m³ is shown. Detailed information on larval
360 total length by year and developmental stage is shown in Table 1. Developmental
361 stages (Pr1–Po) were identified. Open and closed bars indicate daylight (day) and dark
362 (night) periods, respectively.

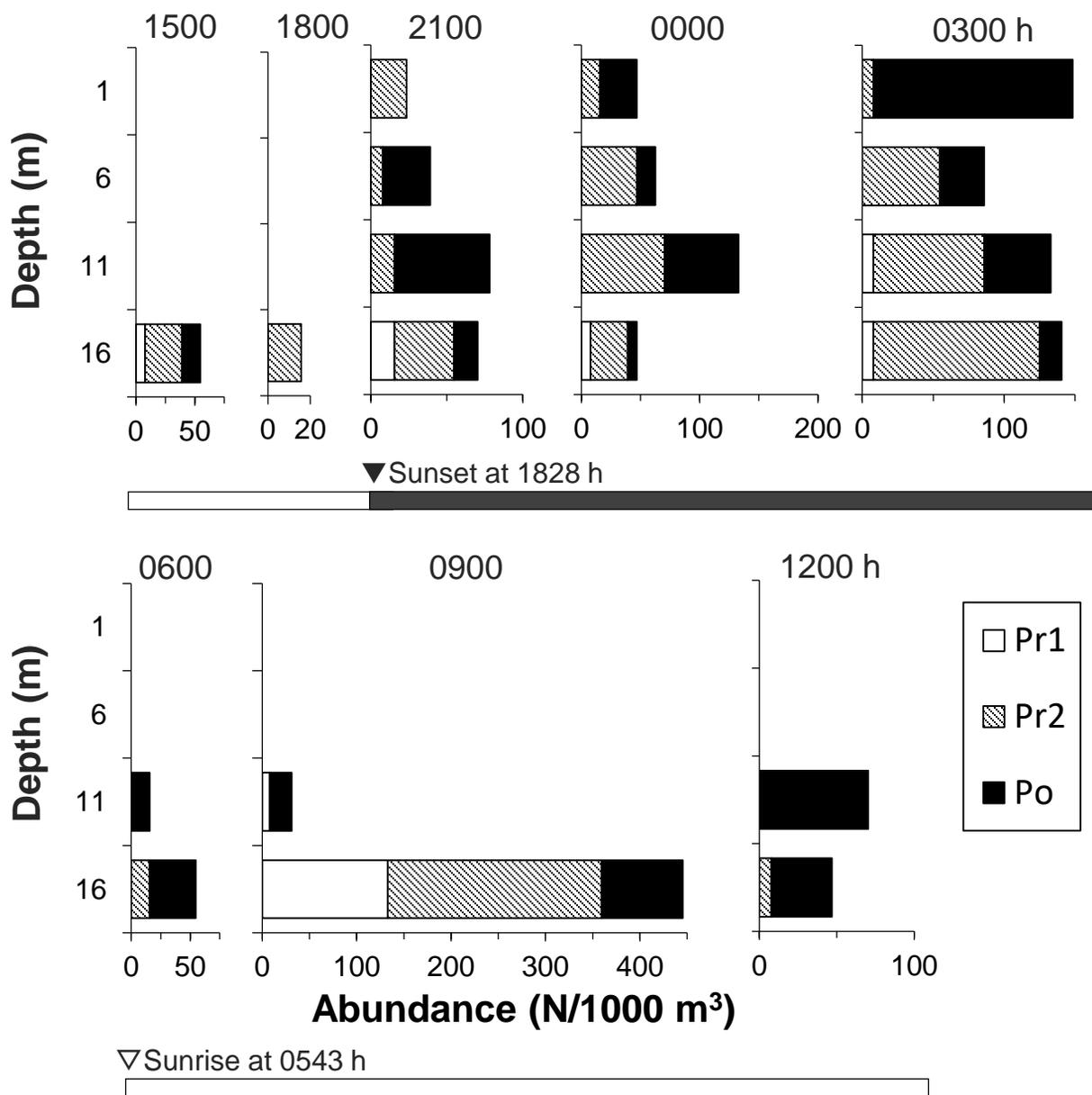
(Fig. 1)



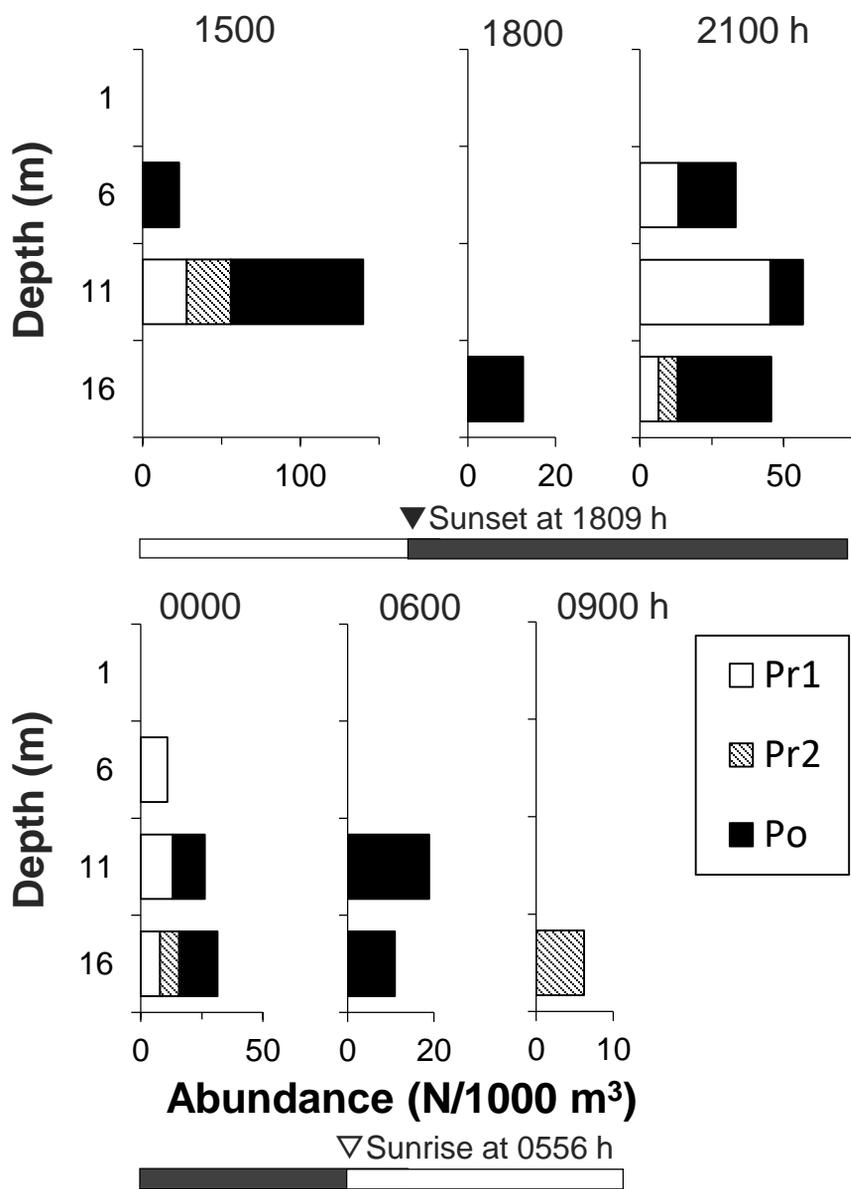
(Fig. 2)



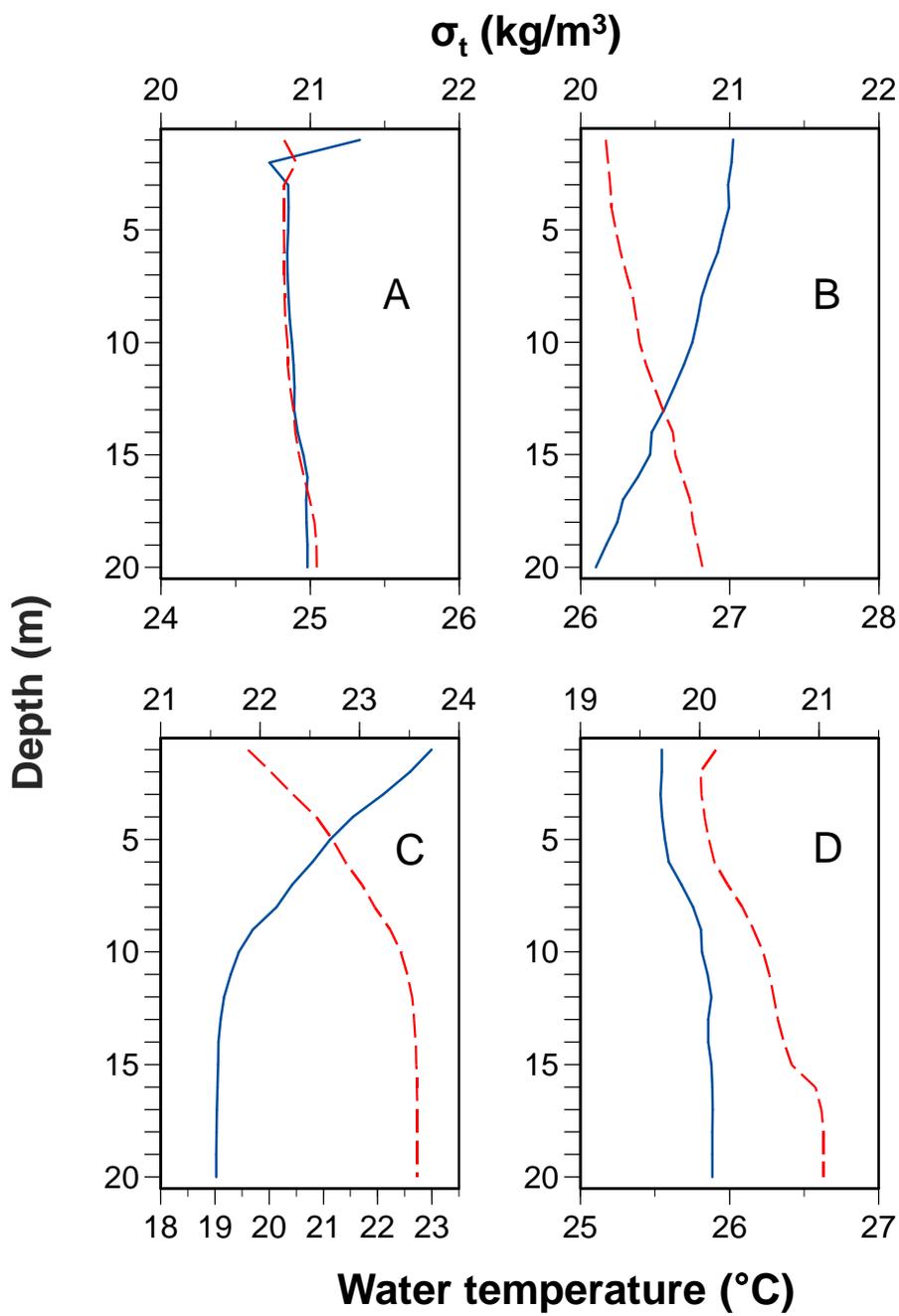
(Fig. 3)



(Fig. 4)



(Fig. 5)



(Fig. 6)

