広島大学学術情報リポジトリ
Hiroshima University Institutional Repository

Title	Diel changes in the vertical distribution of larval cutlassfish Trichiurus japonicus
Author(s)	Uehara, Daichi; Shoji, Jun; Ochi, Yuichiro; Yamaguchi, Shuhei; Nakaguchi, Kazumitsu; Shibata, Jun-Ya; Tomiyama, Takeshi
Citation	Journal of the Marine Biological Association of the United Kingdom , 99 (2) : 517 - 523
Issue Date	2018-04-02
DOI	10.1017/S002531541800019X
Self DOI	
URL	https://ir.lib.hiroshima-u.ac.jp/00049225
Right	© Marine Biological Association of the United Kingdom 2018. This article has been published in a revised form in Journal of the Marine Biological Association of the United Kingdom, https://doi.org/10.1017/S002531541800019X. This version is free to view and download for private research and study only. Not for re-distribution or re-use. This is not the published version. Please cite only the published version. この論文は出版社版ではありません。引用の際には出版社版をご確認、ご利用ください。
Relation	

Hiroshima University Institutional Repository

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

2

3 DAICHI UEHARA[1], JUN SHOJI[1], YUICHIRO OCHI[2], SHUHEI YAMAGUCHI[2],

4 KAZUMITSU NAKAGUCHI[2], JUN-YA SHIBATA[3] AND TAKESHI TOMIYAMA[1*]

5

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

7   Hiroshima 739-8528, Japan

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

9   739-8528, Japan

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

11   Hiroshima 739-8513, Japan

12

13 Running head: Vertical distribution of cutlassfish larvae

14

15 *Corresponding author: Takeshi Tomiyama

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

17

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

32

33

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 ± 36 m^3 (mean $\pm$ SD, n = 35) and 128 ± 51 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 ± 93 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;

7

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

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.

10

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. *Transections 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

327

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 m^3 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 m^3 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 m^3 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)

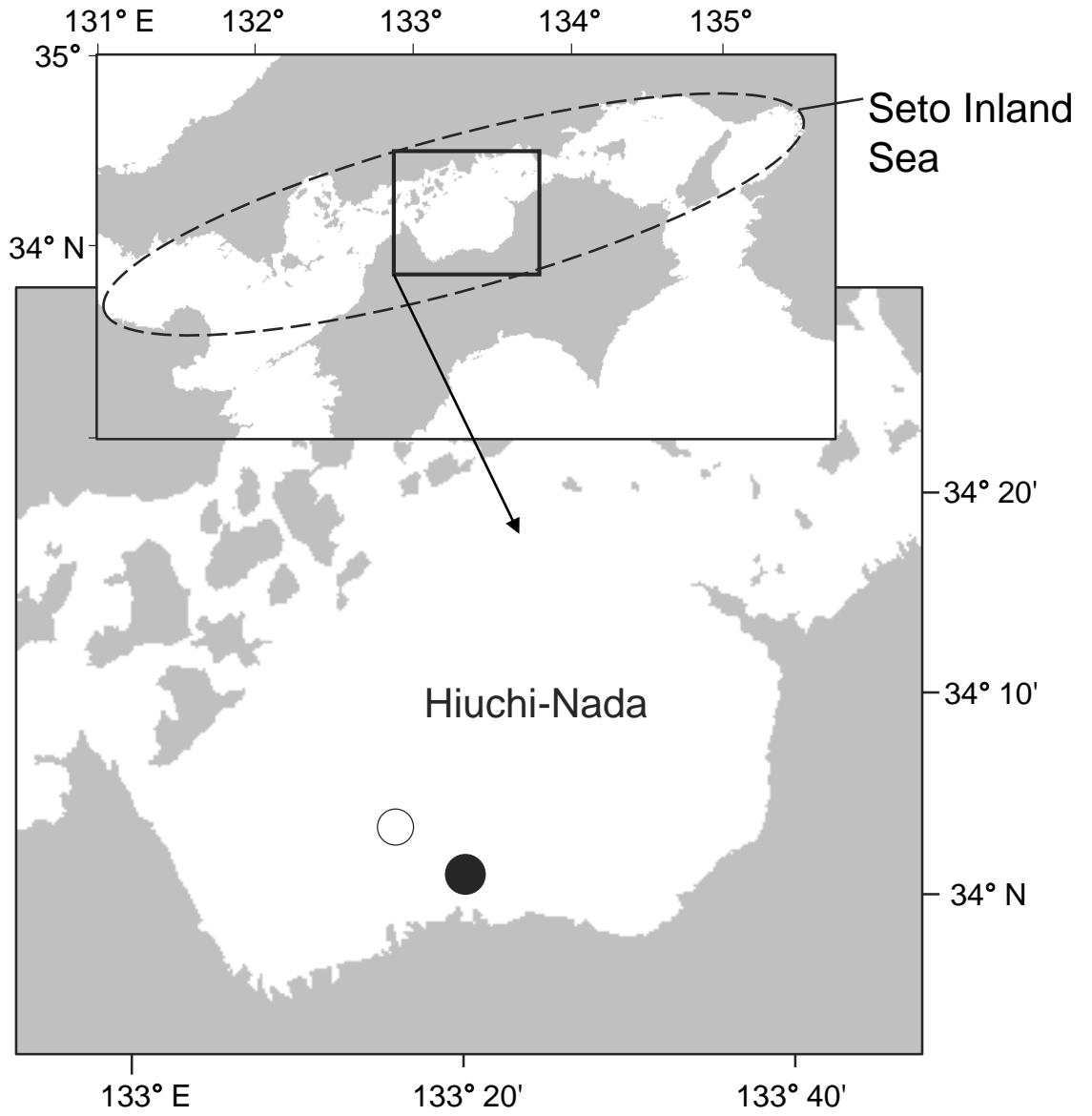354   September 2015, (B) September 2016, (C) June 2017, and (D) September 2017. Solid

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.
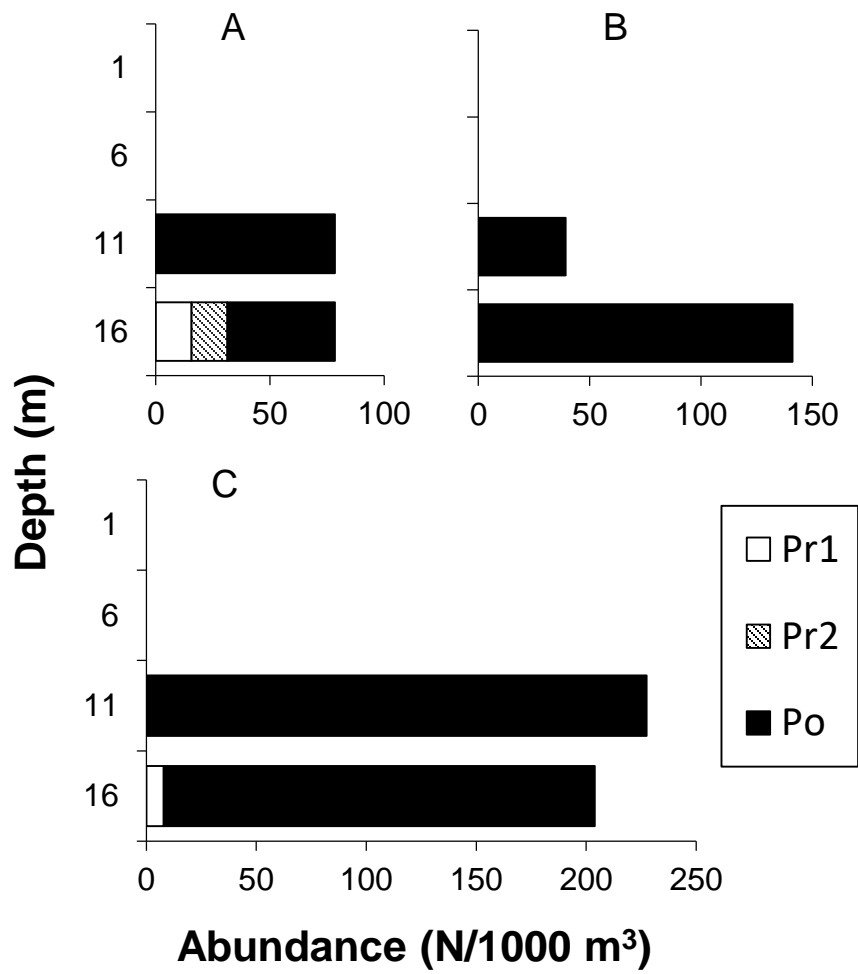
357

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

359   The number of collected larvae per 1000 m^3 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
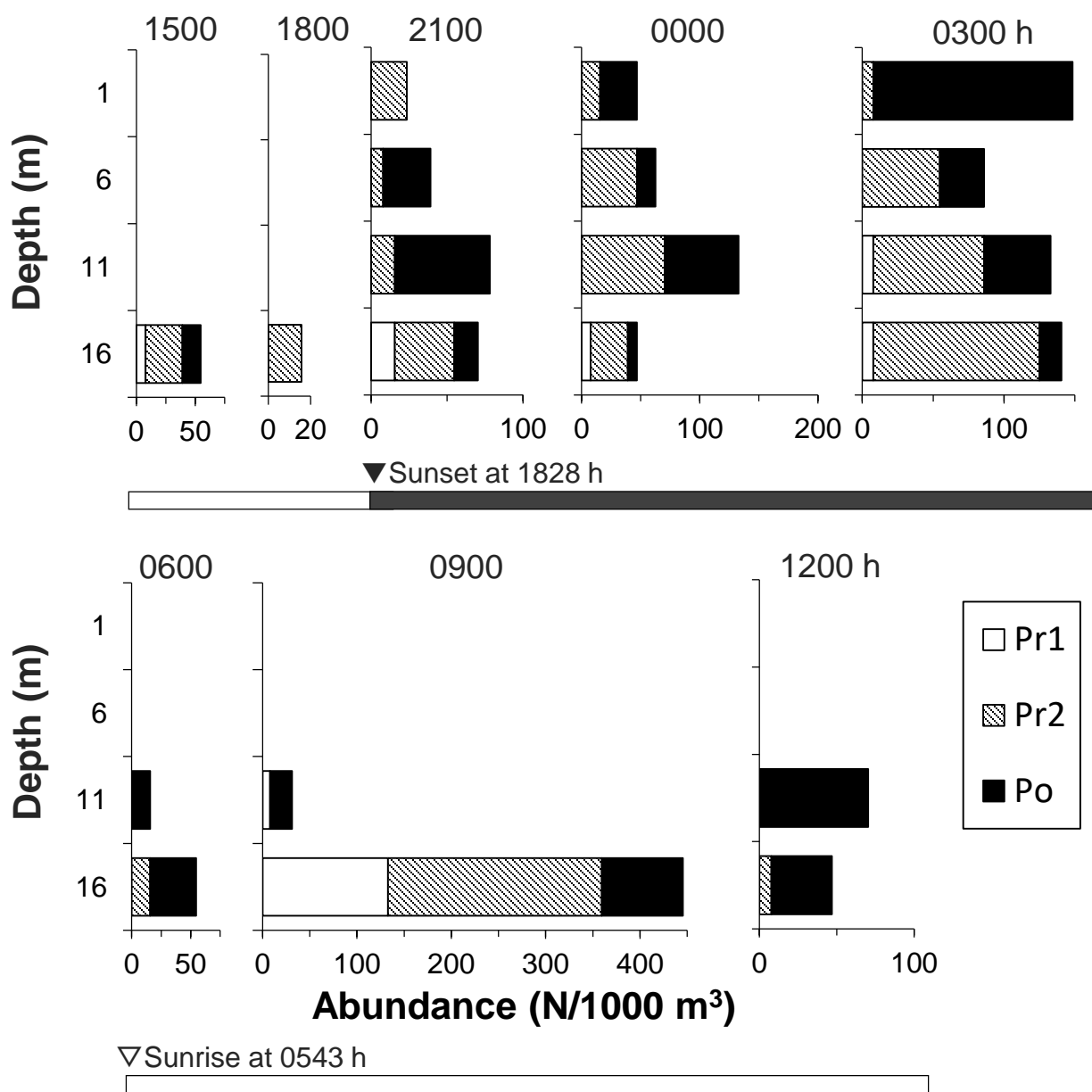
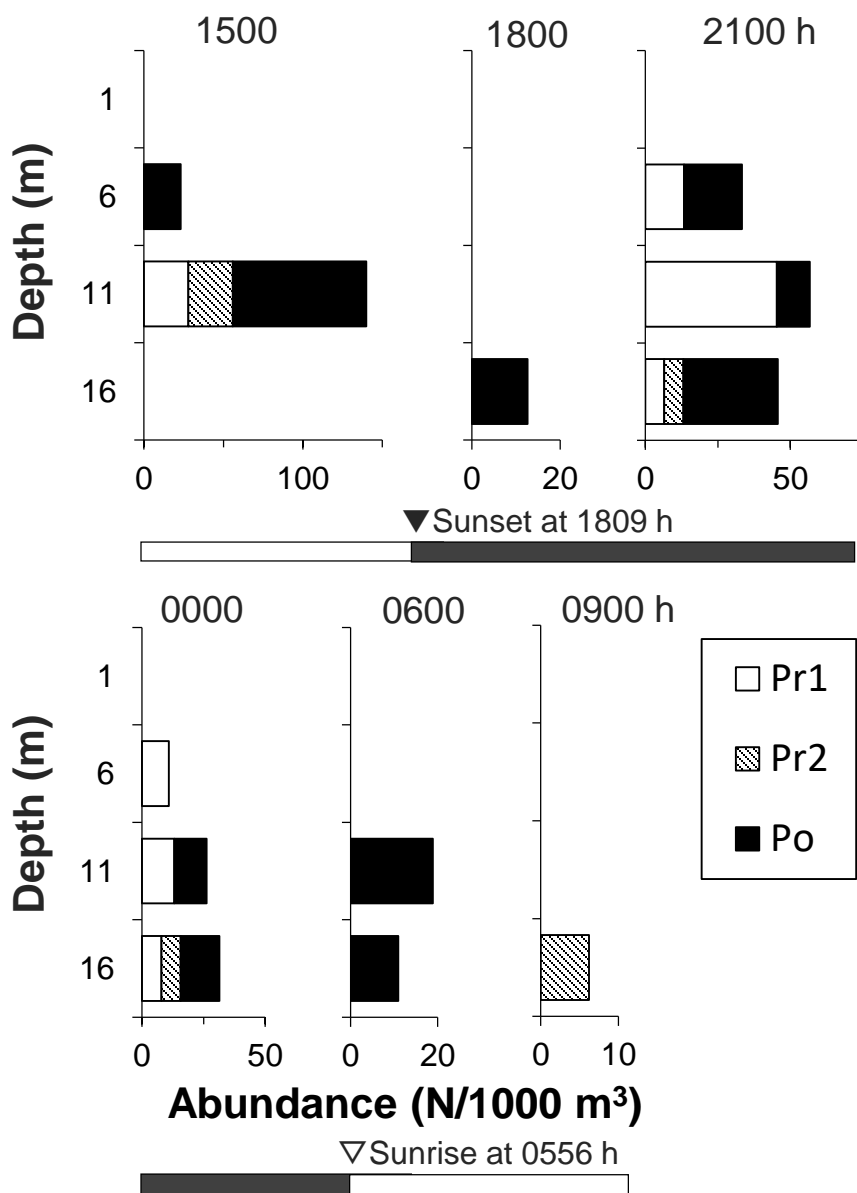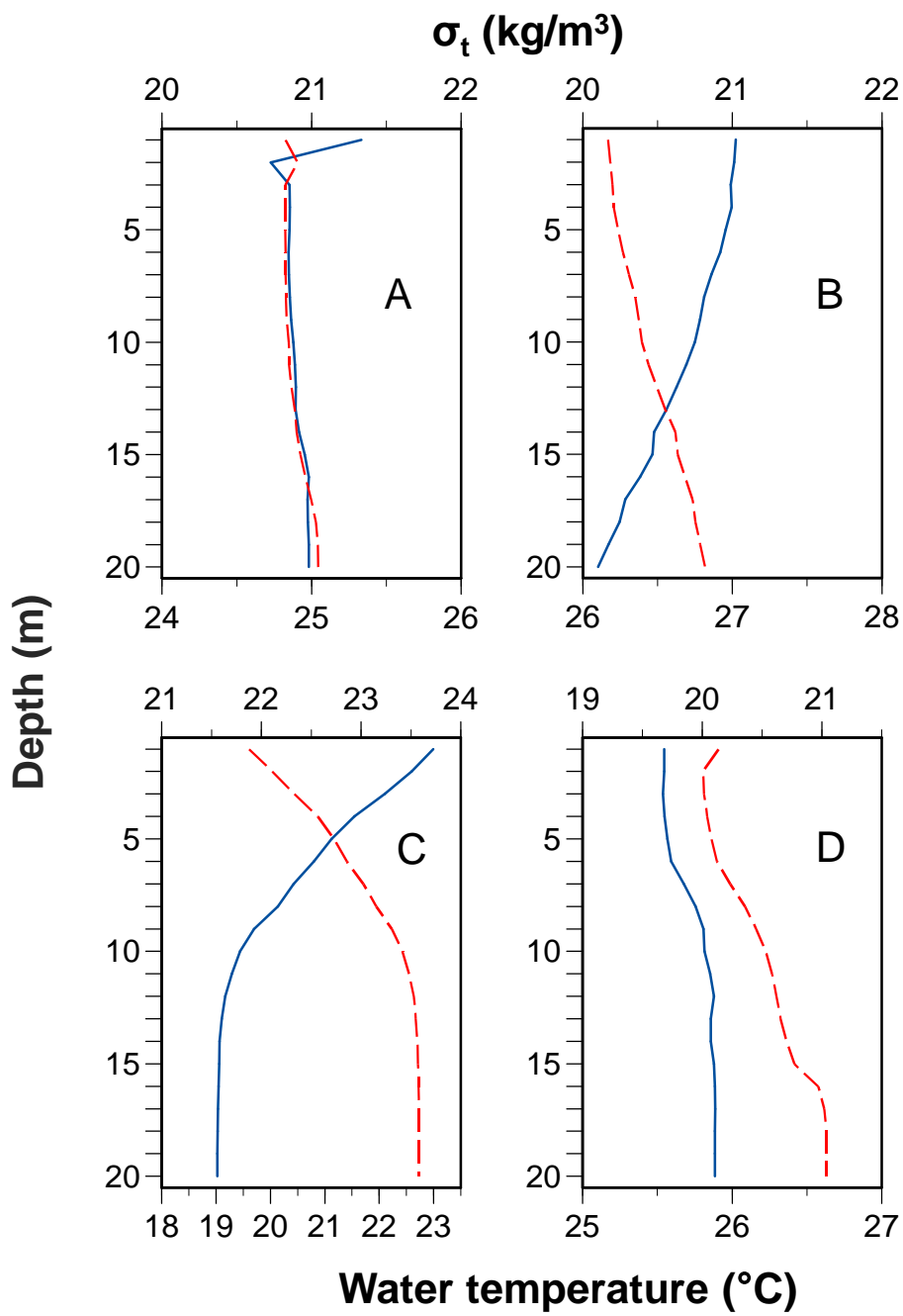362   (night) periods, respectively.

(Fig. 1)

Seto Inland Sea

131° E   132°   133°   134°   135°

35°

34° N

133° E   133° 20'   133° 40'

34° 20'

34° 10'

34° N

Hiuchi-Nada

(Fig. 2)

(Fig. 3)

(Fig. 4)

1500   1800   2100 h

0000   0600   0900 h

Depth (m)

▼Sunset at 1809 h

∇Sunrise at 0556 h

Abundance (N/1000 m³)

☐ Pr1
▨ Pr2
■ Po

(Fig. 5)

(Fig. 6)

Depth (m)

1030   1400   1600   1900   2100   2330 h

▼Sunset at 1914 h

0200   0430   0700   1000 h

Abundance (N/1000 m³)

Pr1
Pr2
Po

▽Sunrise at 0455 h