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Title	Validation of otolith daily increments for larval and juvenile Japanese halfbeak Hyporhamphus sajori
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Abstract: To understand the survival processes in Pacific saury during the early life stages, growth histories were compared between individuals that died and those that survived under laboratory conditions. The morphology of Pacific saury drastically changed by 40 days after hatching (DAH) under 20 ºC, and during this period most individuals reached the juvenile stage (40 mm knob length (KnL)). From hatch to this period, high levels of mortality were observed. The back-calculated growth rates analyzed from otolith microstructure were compared among individuals that died and those that survived this period of metamorphosis. Growth rates of individuals that died were significantly lower since 1 DAH than surviving individuals. Factors contributing to mortality are considered to be cumulative effects of their delayed growth and other unfavorable body conditions (growth dependent survival). The body size (40 mm KnL) that is currently used to estimate the recruitment is concluded to be valid for evaluating the recruitment in the field.

1 **Verification of growth dependent survival in early life history of Pacific saury**

2 *Cololabis saira* **using laboratory experiment**

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Abstract   To understand the survival processes in Pacific saury during the early life stages, growth

histories were compared between individuals that died and those that survived under laboratory

conditions.   The morphology of Pacific saury drastically changed by 40 days after hatching (DAH)

under 20 ℃, and during this period most individuals reached the juvenile stage (40 mm knob length

(KnL)).   From hatch to this period, high levels of mortality were observed.   The back-calculated growth

rates analyzed from otolith microstructure were compared among individuals that died and those that

survived this period of metamorphosis.   Growth rates of individuals that died were significantly lower

since 1 DAH than surviving individuals.   Factors contributing to mortality are considered to be

cumulative effects of their delayed growth and other unfavorable body conditions (growth dependent

survival).   The body size (40 mm KnL) that is currently used to estimate the recruitment is concluded

to be valid for evaluating the recruitment in the field.

Keywords   Growth dependent survival • Metamorphosis • Pacific saury • Survival

37 **Introduction**

38 The Pacific saury *Cololabis saira* (Brevoort) is an important pelagic commercial fish. Although the

39 stock is currently at a high level（Tian *et al*., 2003: Annual catches of Pacific saury in Japan have

40 fluctuated from 572,000 metric tons (t) in 1958 to 63,000t in 1969 with an annual average of about

41 257,000t over the last half century）, landings in Japan and the body size distribution of catch have

42 fluctuated from year by year (Fukushima *et al.,* 1990; Watanabe *et al.,* 1997). To determine the factors

43 causing the fluctuations, at first we need to get information about the life history, age and growth, and

44 reproduction process. Hotta (1964) and Kosaka (2000) outlined the life history, and sampling continues

45 to clarify details of the life history. However reasons for the dramatic fluctuations in the stock are still

46 not clear, this being partly due to the broad distribution of this species in the northwestern Pacific (Hubbs

47 and Wisner, 1980).

48 The sampling of eggs, larvae, and juveniles using plankton nets has also continued since the 1950's.

49 For nearshore Japan, many studies have been carried out on the growth and survival of Pacific saury in

50 the early life stages (Watanabe *et al*.; 1988, 1997, 2003), and it is estimated that the body size when

51 high levels of mortality stabilize is approximately 40 mm knob length (KnL: a special unit of body length;

52 detailed below). In addition, catch efficiency of Pacific saury larger than this size by existent sampling

53 gears show much fluctuation presumably due to gear avoidance. Thus, currently the abundance of 40

54 mm KnL is used as an index of the recruitment for each cohort. Nonetheless minimal evidence has been

55 obtained to examine how differences in growth between individuals that fail to survive and individuals

56 that are able to survive metamorphosis in the field.

3

57   The cause of early life mortality of fish is due to various incremental factors ,and predation is generally

58   the final factor (Bailey and Houde, 1989). To clarify these factors, comparison of the growth rate

59   between individuals that survive and those that die during the period of high mortality (generally related

60   to metamorphosis) is one potential method.   In the case of Japanese anchovy, the growth rates analyzed

61   by otolith microstructure have directly been compared between larvae from the stomach contents of

62   predators and otoliths from the larvae taken by sampling nets in the field, and consequently, the

63   growth-selective predation hypothesis has been proposed (Takasuka *et al.,* 2003).   However, this is only

64   a rare case, for most fish species including Pacific saury, non-surviving larvae and juveniles have not

65   been sampled in the field, and therefore comparison of the growth rates between non-surviving and the

66   surviving individuals has not been carried out.   During the period of metamorphosis, high mortality due

67   to dramatic changes of the body is often observed (e.g. Tanaka *et al.,* 1989).   Metamorphosis was

68   defined using the full completion of fins and morphometric ratio change (Kendall *et al.,* 1984).   In this

69   study, we observed the metamorphosis process, and then the growth rates were compared between

70   individuals that died and those that survived (growth dependent survival) by otolith microstructure

71   analysis.   Using the above results, we verified whether the criterion of body size (40 mm KnL) as an

72   index of recruitment is appropriate for estimates of abundance or not.   The research assesses the: (1)

73   growth and survival processes in the early life stage, (2) processes of morphological change, and (3)

74   growth comparison of individuals that survived and those that died during the high level mortality

75   periods.

76

4

77 Methods

78

79 Egg collection

80

81 Fertilized eggs of the Pacific saury, attached to drifting brown algae, were collected by RV 'Tankai'

82 offshore of Kushiro, Hokkaido Prefecture on August 5, 2004 (1st Batch: 1B) and RV 'Asama' in

83 Kumano-nada, Mie Prefecture, Pacific Ocean, Japan on March 4 (2nd Batch: 2B), April 21–23 (3rd Batch:

84 3B), and April 25 (4th Batch: 4B), 2005. The eggs were kept in plastic bags containing 10 liters of

85 ambient seawater (17 ℃) with oxygen and then transported to Hokkaido National Fisheries Research

86 Institute, Fisheries Research Agency, Akkeshi by vehicle and plane. The eggs were stocked and then

87 incubated with running seawater (exchange rate of 120 % / day) in 500 liters black colored polyethylene

88 circular tanks or a 20,000 liters green color painted concrete rectangular tank at temperatures of

89 approximately 17 ℃ until hatching.

90

91 Rearing of larvae

92

93 Hatched larvae (initial stock density of batches 1–4 were 0.9, 2.5, 5.0, and 2.9 inds. / liter, respectively)

94 were reared in the same tank at a temperature of approximately 20°C, which has been shown to produce

95 the best growth and survival for Pacific saury (for larvae and juvenile (Oozeki and Watanabe, 2000), and

96 from larvae to adult (Tsuzaki, 2000a, b, 2001a, b)). Illumination of the tank was via natural daylight and

5

97　light intensity was reduced by covering the tank with a black plastic sheet.　The fish were fed to almost

98　satiation (rotifers *Brachionus* spp. and *Artemia* sp. nauplii: two times a day (08:00–09:00, 15:00–16:00) ,

99　frozen copepods (Miyabi　No. 1 (300–700μm), and No. 2 (1000–1500μm): JCK Co. Ltd): three times a

100　day (08:00–09:00, 11:00–12:00, 15:00–16:00) , and artificial feed (Otohime A, B1, and B2: Marubeni

101　Nishiin Feed Co., well mixed): 15–22 times a day (depending on their appetite using a self feeding

102　machine) during 06:00–17:00).　Details of the feeding and environmental conditions are shown in Table

103　1.　From 08:00 to 09:00, the bottom of the tanks was cleaned, dead individuals collected, and then the

104　water temperature was measured.

105

106　Sampling of fish

107

108　Samples of over 20 individuals were collected randomly every 5 days from 0 to 40 days after hatching

109　(DAH), and then 20–30 individuals were collected randomly at 10 days intervals, twice on 50 and 60

110　DAH.　The sampling was undertaken at feeding time when the fish could be caught easily without

111　causing excess stress.　During feeding, when the fish were swimming at the surface of the tank, is a

112　period when they are least wary.

113　　The samples were preserved in 80% ethanol after being anaesthetized with FA-100 (Dainippon

114　Pharma)(50–100ppm).　　Knob length (KnL: a special unit of body length represented by the length

115　from the anterior edge of the lower jaw to the posterior edge of the silver flesh which is protruded on the

116　base of the tail fin; the measurement with least bias for Pacific saury (Kimura, 1956)) were measured to

6

117 the nearest 0.1mm.   According to Oozeki et al. (1991), for fish preserved in 80 % ethanol we used a

118 correction factor of 1.08 for fish smaller than 9.9 mm KnL and 0.98 for those larger than 10.0 mm KnL.

119 Body weight (BW) of the individuals was measured to the nearest 0.01g.   In addition, their total length

120 (TL), head length (HL), pre-anal length (PAL), eye diameter (ED), lower jaw length (LJL), body depth

121 (BD), and head depth (HD) were measured, and also their fin rays (pectoral (P1), pelvic (P2), anal (A),

122 dorsal (D), and caudal (C)) were counted for each sample.   Thereafter the otoliths were extracted under a

123 stereomicroscope.

124

125 Growth analysis

126

127 The left (primarily) or the right (if the left one was lost or broken) otolith was mounted on a glass slide

128 using epoxy enamel.   The mounted otolith was allowed to set for over 24 hours.   Thereafter, the

129 proximal side of the otolith was polished with lapping films of grit sizes of 1, 3, and 9 μm.   Since the

130 posterior otolith radius is more suitable for back-calculation of KnL (Oozeki and Watanabe, 2000), the

131 number of otolith increments and the otolith increment widths were measured for the posterior part.

132 The image data for measuring the number of otolith increments and the otolith increment widths were

133 obtained using a light microscope (400–1000 x) with a camera connected.   They were analyzed on a

134 monitor of a computer using image-analyzing software (Adobe Photoshop 7.0).   These measurements

135 were repeated at least three times by different researchers without knowledge of the previous results.

136 These data were adopted when two or more counts agreed.   The first growth increment for Pacific saury

137 has been reported to begin at 4 to 6 days before hatching (Watanabe and Kuji, 1991): 4–5, mean 4.81;

138 Suyama *et al.* (1996), middle North Pacific Ocean: mean 6.1, western North Pacific Ocean: mean 5.6;

139 Oozeki and Watanabe (2000): mean 6.37) and posterior radius of hatching check are 20–35 μm (Watanabe

140 *et al.* (1988), about 27μm; Watanabe and Kuji, (1991), 31μm; Suyama *et al.* (1996), 25.8 ± 3.9μm

141 (western North Pacific Ocean); Suyama (2002), 28.1 ± 5.0μm (middle North Pacific Ocean)).   Therefore,

142 we measured the width of the hatching check as 20–35μm distant from the center of the focus and

143 counted the daily growth increments to the last distinct increment (posterior radius).   KnL and daily

144 growth rate at each age were back-calculated by the biological intercept method (Campana 1990) in order

145 to obtain the growth trajectories and histories of individual larvae.   Average KnL on 0 DAH was 7.33

146 mm.

147

148 Numerical value analysis

149

150 Death of Pacific saury were recorded daily during the experiment.   Daily instantaneous mortality rate

151 (IMR) were derived (Ricker 1958) at 5 day intervals.   Mortality rates were calculated using the

152 following equation.

153 $IMR = (LnN_i - LnN_{i+1}) / 5$

154 where N_i, N_{i+1} are the number of survivors at the first date of time intervals.   Specific mortality rates

155 (SMR) were calculated as IMR x 100.

156   In order to calculate the morphometric variation at 5 mm KnL intervals, the morphometric characters

8

157 (TL, HL, PAL, ED, LJL, BD, and HD) per KnL of Pacific saury were made on 1000 data chosen

158 randomly from the available samples.   This operation was repeated 1000 times (Bootstrap method), and

159 the mean value of the morphometric character per KnL composition was estimated for each 5 mm KnL

160 interval.   This calculation involved the use of Microsoft Excel software.   Morphometric variations

161 (MV) among 5 mm KnL intervals (e.g. 10.0–14.9, 15.0–19.9 mm) were calculated using the following

162 equation.

163 $MV = ((MC / KnL)_i - (MC / KnL)_{i+1}) / \Sigma(MC / KnL) / n$

164 where MC is the morphometric character, $(MC / KnL)_i$, $(MC / KnL)_{i+1}$ are the mean values of 5mm KnL

165 size intervals i and i+1, respectively.   n is the number of 5 mm KnL size intervals.

166

167 Statistical analysis

168

169 One-way ANOVA was used to detect differences in the growth speed among surviving and dead

170 individuals.   If the variances determined were heteroscedastic as shown by a F_{max}-test, the values were

171 log transformed.   When a significant difference was detected, Scheffe's test was used for comparisons

172 thereafter.   The level of significance was set at 1%.

173

174 **Results**

175

176 Growth and survival processes

177

178   Growth of larval and juvenile Pacific saury is shown in Fig. 1.   Their KnL at 20, 40, and 60 DAH was

179   16.1 ± 1.90, 39.3 ± 4.31, and 65.9 ± 10.51 (mean ± SD), respectively.   The number of dead individuals

180   until 9 DAH could not be counted accurately because of their small and weak bodies which decomposed

181   rapidly.   Consequently, specific mortality rates (SMR) (% / day) are shown using data from individuals

182   that died from 10–60 DAH (Table 2).   After 10 DAH, a high mortality rate usually started from 11 DAH,

183   and continued until 20 DAH (the highest mean SMR time interval: 15–19 DAH).   Then the mortality

184   rate stabilized, however it increased again and continued until 33 DAH (the second highest mean SMR

185   time interval: 25–29 DAH).   After 40 DAH, the SMR decreased drastically.   Such a mortality process

186   pattern was observed regardless of the different batches of eggs and rearing conditions.   Therefore this

187   process probably reflects changes in internal physiological factors during the early life history of Pacific

188   saury.

189

190   Metamorphosis

191

192   Relationships between DAH and number of fin rays are shown in Fig. 2.   In the case of the caudal (C)

193   and dorsal (D) fins, notable increases were observed 0–5 DAH.   Such increases were also observed for

194   the anal (A) fin 0–10 DAH, pectoral (P1) fin 5–10 DAH, and pelvic (P2) fin 20–30 DAH.   Almost all

195   them had already reached their stable ray number by 40 DAH (D: 12–15, A: 18–21, P1: 12–16, P2: 6, C:

196   19–21 as detailed by Nakabo (2000), and Nakaya *et al.* (2007)).   Relationships between KnL and percent

10

197   that had reached a stable number for each fin rays are shown in Table 3.   By 15.0–19.9 mm KnL the

198   number of D rays had already reached a stable number.   P1 and P2 rays reached the stable number of

199   rays during 20.0–24.9 mm KnL.   By 35.0–39.9 mm KnL the number of A and C rays was stable.   All

200   fin rays reached the stable number before reaching 40.0 mm KnL.

201   Fig. 3 shows the relationships between DAH and the proportion of total length (TL), head length (HL),

202   pre-anal length (PAL), eye diameter (ED), lower jaw length (LJL), body depth (BD), and head depth

203   (HD) to KnL.   Morphometric variations (MV) among 5 mm KnL intervals are shown in Fig. 4.   For all

204   body proportions, the highest two MV values were observed by the KnL size range 35.0–39.9mm KnL,

205   after that the MV showed less fluctuation.   Over 40 mm KnL, fluctuations in body proportions tended to

206   be more gradual.

207   Before 39 DAH, the larvae swam only near the surface in the daytime, and were not observed to form

208   schools in the tank.   After 39 DAH, they swam not only near the surface but also in the middle to near

209   bottom sections of the tank, and were observed to form a school.

210

211   Comparison of growth between survived and dead individuals

212

213   During 10–60 DAH, two periods of high mortality were observed.   We compared the back-calculated

214   growth rate among dead individuals during these periods (the highest mean SMR time interval: 15–19

215   DAH (D1) , the second   highest mean SMR time interval: 25–29 DAH (D2)), and surviving individuals

216   collected at 60 DAH (SV) using otolith microstructure analysis (Fig. 5).   As a result, there were

11

217 significant differences (One-way ANOVA, $P<0.01$) among them since 1 DAH.   Although no significant

218 difference was observed between D1 and D2 (Scheffe's test, $P=0.82$), there were significant differences

219 (Scheffe's test, $P<0.01$) between SV and D1, D2 since 1 DAH.   These (D1, D2) lower growth continued

220 until death.

221

222 **Discussion**

223

224 Natural mortality rates of fish are generally highest in early life.   Fishes may die from many causes

225 (endogenous factors (maternal effects: e.g. Solemdal (1997)) such as insufficient endogenous nutrition

226 and physical disorders, and exogenous factors such as poor-nutrition, disease, and unfavorable

227 environmental conditions), nonetheless predation is usually the critical agent for mortality (Houde, 1997).

228 In general, the mortality rate is high until the end of metamorphosis and after that tends to be more

229 gradual.   Metamorphosis was defined using the full completion of fins and morphometric ratio change

230 (Kendall *et al.,* 1984).   In this study, we observed the development of fin rays and the relative growth of

231 each body part.   The first inflection point was observed at 5–9 DAH (<10 mm KnL).   This point

232 corresponds to the period when a change of nutrition from endogenous to exogenous occurs (20°C:

233 Nakaya *et al.,* 2009).   The second inflection point was observed at about 30 DAH, and most of the fin

234 rays were completely formed before 40 DAH (over 40 mm KnL).   Consequently, the second inflection

235 point (about 30 DAH) was considered to be the end of the metamorphosis period for this species.   We

236 directly examined the growth process between surviving and dead individuals of larval and juvenile

237   Pacific saury in laboratory conditions by otolith microstructure analysis, and observed significant

238   differences among them already at 1 DAH.　Though newly hatched Pacific saury can survive for 5–10

239   days (50% mortality period) without feeding in 10–25°C (Nakaya *et al.,* 2009), if larvae of Pacific saury

240   can not encounter appropriate environmental conditions by 5–9 DAH, their survival rate may be low in

241   the field as they will become more prone to predation.　Survival in this species in the early life stage may

242   be determined soon after hatching, although predation effects should also be considered further for

243   precise evaluations of natural mortality rates.

244   The relationship between growth rates and larval duration (to metamorphosis) has been a focus of study

245   especially for a variety of coral reef fishes (Victor, 1986; Victor and Wellington, 2000; McCormick *et al.,*

246   2002; Shima and Findlay, 2002) and for flatfishes (Hovenkamp, 1992; Bertram *et al.,* 1997) that are

247   characterized by settlement through metamorphosis.　Takasuka *et al.* (2004) suggested that a growth

248   selective survival mechanism might apply to pelagic fish (Japanese anchovy), and our present results are

249   consistent with their study.　In general, the critical period for fishes is species specific, and in cold water

250   species, tends to be long and gradual (e.g. in Japanese anchovy *Engraulis japonicus*: the growth and

251   developmental rate-dependent mortality occurred at 50–60 days (Takahashi and Watanabe, 2004), and in

252   Atlantic cod *Gadus morhua*, growth selective mortality occurred at 41–80 days (Meekan and Fortier,

253   1996)).　On the other hand, the period of warm water species tends to be short (e.g. in bluefish

254   *Pomatomus saltatrix* at 10–15 days (Hare and Cowen, 1997), at 0–5 days in the common coral wrasse

255   *Halichoeres bivittatus* (Searcy and Sponaugle, 2001), at 7–10 days in damselfish *Stegastes partitus*

256   (Wilson and Meekan, 2002), and within 2 weeks of hatching was crucial for survival to recruitment in

13

257　Pacific bluefin tuna *Thunnus orientalis* (Tanaka *et al.,* 2006)).　The present study suggests that the body

258　conditions and environmental conditions at the start of the feeding period in Pacific saury may be more

259　related to survival than for other warm water species reported previously.　We could compare directly

260　between individuals that died during the metamorphosis period and the surviving individuals, and thus,

261　obtained evidence that growth dependent survival strategy occurs in Pacific saury.　Maternal effects and

262　the environmental conditions (variance in feed and temperature conditions) at the start of the feeding

263　period might be closely related to survival during the metamorphosis period (e.g. Houde, 1997).

264　Hereafter we need to further study the relationships between maternal effect and the growth-survival for

265　larval and juvenile stages.

266　　According to Watanabe and Kuji (1991), Pacific saury starts schooling behavior when they attain

267　45–50 mm KnL.　The density of juveniles after mass mortality can be used as a quantitative index of the

268　recruiting cohort, therefore the 40 mm KnL juvenile density has been used as an index of recruitment.

269　The present study found that the high rate of mortality stabilized after 40mm　KnL for Pacific saury

270　under non-predation conditions.　Therefore, we consider that using density of 40 mm KnL of Pacific

271　saury collected by net is valid for estimating the wild recruitment amount.

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281

282   **References**

283   Bailey KM, Houde ED   (1989)   Predation on eggs and larvae of marine fishes and the problem of

284   recruitment.   Adv Mar Biol   25: 1–83

285   Bertram DF, Miller TJ, Leggett WC   (1997)   Individual variation in growth and development during

286   the early life stages of winter flounder, *Pleuronectes americanus*.   Fish Bull US   95: 1–10

287   Campana SE   (1990)   How reliable are growth back-calculations based on otolith?   Can J Fish

288   Aquat Sci   47: 2219–2227

289   Fukushima S, Watanabe Y, Ogawa Y   (1990)   Correspondence of spawned season to large, medium,

290   and small size Pacific saury exploited in the northwestern Pacific Ocean.   Bull Tohoku Natl

291   Fish Res Inst   52: 17–27

292   Hare JA, Cowen RK   (1997)   Size, growth, development, and survival of planktonic larvae of

293   *Pomatomus saltatrix* (Pisces: Pomatomidae).   Ecology   78: 2415–2431

294   Hotta H   (1964)   Biological studies and fisheries of the saury, *Cololabis saira* (Brevoort).

295   Suisanshigensousyo, 4, Resources of saury, Japan Fisheries Resources Conservation Association,

296   Tokyo

297   Houde ED   (1997)   Mortality.   In: Chambers RC, Trippel A (ed), Early Life History and

298   Recruitment in Fish Populations.   Chapman & Hall, London, pp. 64–87

299   Hovenkamp F   (1992)   Growth-dependent mortality of larval plaice *Pleuronectes platessa* in the

300   North Sea.   Mar Ecol Prog Ser 82: 95–101

16

301   Hubbs CL, Wisner RL　(1980)　Revision of the sauries (Pisces, Scomberesocidae) with description

302   of two new genera and one new species.　Fish Bull US 77: 521–566

303   Kendall AW, Ahlstrom EH, Moser HG　(1984)　Early life history stages of fishes and their characters.

304   In: Moser HG, Richards WJ, Cohen DM, Fahay MP, Kendall AW, Richardson SL (ed), Ontogeny

305   and systematics of fishes.　American Society of Ichthyologists and Herpetologists, Special

306   publications Vol. 1, Allen Press Inc, Lawrence, pp11–22

307   Kimura K　(1956)　The standard length of the Pacific saury, *Cololabis saira* (Brevoort).　Bull

308   Tohoku Reg Fish Res Lab　7: 1–11

309   Kosaka J　(2000)　Life history of the Pacific saury *Cololabis saira* in the northwest Pacific and

310   considerations on resource fluctuations based on it.　Bull Tohoku Natl Fish Res Inst　63: 1–96

311   McCormick MI, Makey L, Dufour V　(2002)　Comparative study of metamorphosis in tropical reef

312   fishes.　Mar Biol　141: 841–853

313   Meekan MG, Fortier L　(1996)　Selection for fast growth during the larval life of Atlantic cod *Gadus*

314   *morhua* on the Scotian Shelf.　Mar Ecol Prog Ser　137: 25–37

315   Nakabo T　(2000)　Fishes of Japan with pictorial keys to the species 2nd edition.　Tokai University

316   Press, Tokyo

317   Nakaya M, Morioka T, Fukunaga K, Murakami N, Ichikawa T, Sekiya S, Jinbo T, Suzuki S, Nishiki A

318   (2007)　Growth and survival of Pacific saury *Cololabis saira* under laboratory conditions.

319   Annual Report of the Research Meeting on Saury Resources　55: 246–259

320   Nakaya M, Morioka T, Fukunaga K, Murakami N, Ichikawa T, Sekiya S, Suyama S　(2009)

321   Relationships between survival period and temperature of newly hatched Pacific saury *Cololabis*

322   *saira* under starvation conditions.   Aquaculture Sci   57: 625–626

323   Oozeki Y, Watanabe Y, Kuji Y, Takahashi S   (1991)   Effects of various preservatives on the body

324   length of saury larvae.   Bull Tohoku Natl Fish Res Inst   53: 15–21

325   Oozeki Y, Watanabe Y   (2000)   Comparison of somatic growth and otolith increment growth in

326   laboratory-reared larvae of Pacific saury, *Cololabis saira*, under different temperature conditions.

327   Mar Biol   136: 349–359

328   Ricker WE   (1958)   Handbook of computations for biological statistic of fish populations.   Bull

329   Fish Res Board Can   119: pp300

330   Searcy SP, Sponaugle S   (2001)   Selective mortality during the larval - juvenile transition in two

331   coral reef fishes.   Ecology   82: 2452–2470

332   Shima JS, Findlay AM   (2002)   Pelagic larval growth rate impacts benthic settlement and survival of

333   a temperate reef fish.   Mar Ecol Prog Ser   235: 303–309

334   Solemdal P   (1997)   Maternal effect- a link between the past and the future.   J Sea Res   37:

335   213–227

336   Suyama S, Sakurai Y, Shimazaki K   (1996)   Maturation and age in days of Pacific saury *Cololabis*

337   *saira* (Brevoort) in the Central North Pacific Ocean during the summer.   Nippon Suisan

338   Gakkaishi   62 (3): 361–369

339   Suyama S   (2002)   Study on the age, growth, and maturation process of Pacific saury *Cololabis*

340   *saira* (Brevoort) in the North Pacific.   Bull Fish Res Agen   5: 68–113

341   Takahashi M, Watanabe Y (2004) Growth rate-dependent recruitment of Japanese anchovy

342   *Engraulis japonicus* in the Kuroshio-Oyashio transitional waters. Mar Ecol Prog Ser 266:

343   227–238

344   Takasuka A, Aoki I, Mitani I (2003) Evidence of growth-selective predation on larval Japanese

345   anchovy *Engraulis japonicus* in Sagami Bay. Mar Ecol Prog Ser 252: 223–238

346   Takasuka A, Aoki I, Mitani I (2004) Three synergistic growth-related mechanisms in the short-term

347   survival of larval Japanese anchovy *Engraulis japonicus* in Sagami Bay. Mar Ecol Prog Ser

348   270: 217–228

349   Tanaka M, Goto T, Tomiyama M, Sudo H (1989) Immigration, settlement and mortality of flounder

350   (*Paralichthys olivaceus*) larvae and juveniles in a nursery ground, Shijiki bay, Japan. Neth J

351   Sea Res 24: 57–67

352   Tanaka Y, Satoh K, Iwahashi M, Yamada H (2006) Growth-dependent recruitment of Pacific

353   bluefin tuna *Thunnus orientalis* in the northwestern Pacific Ocean. Mar Ecol Prog Ser 319:

354   225–235

355   Tian Y, Akamine T, Suda M (2003) Variations in the abundance of Pacific saury (*Cololabis saira*)

356   from north western Pacific in relation to oceanic climate changes. Fish Res 60: 439–454

357   Tsuzaki J (2000a) Breeding and display of Pacific saury I. Aquamarine Fukushima News 2 (2):

358   2–3

359   Tsuzaki J (2000b) Breeding and display of Pacific saury II. Aquamarine Fukushima News 2

360   (3): 1–2

19

361   Tsuzaki J   (2001a)   Breeding and display of Pacific saury III.   Aquamarine Fukushima News   3

362   (1): 1–2

363   Tsuzaki J   (2001b)   Breeding and display of Pacific saury IV.   Aquamarine Fukushima News   3

364   (2): 1–2

365   Victor BC   (1986)   Duration of the planktonic larval stage of one hundred species of Pacific and

366   Atlantic wrasses (family Labridae).   Mar Biol   90: 317–326

367   Victor BC, Wellington GM (2000)   Endemism and the pelagic larval duration of reef fishes in the

368   eastern Pacific Ocean.   Mar Ecol Prog Ser   205: 241–248

369   Watanabe Y, Butler JL, Mori T   (1988)   Growth of Pacific saury, *Cololabis saira*, in the northeastern

370   and northwestern Pacific Ocean.   Fish Bull US   86: 489–498

371   Watanabe Y, Kuji Y   (1991)   Verification of daily growth increment formation in saury otoliths by

372   rearing larvae from hatching.   Jpn J Ichthyol   38: 1–15

373   Watanabe Y, Oozeki Y, Kitagawa D   (1997)   Larval parameters determining preschooling juvenile

374   production of Pacific saury (*Cololabis saira*) in the northwestern Pacific.   Can J Fish Aquat Sci

375   54: 1067–1076

376   Watanabe Y, Kurita Y, Noto M, Oozeki Y, Kitagawa D   (2003)   Growth and survival of Pacific saury

377   *Cololabis saira* in Kuroshio-Oyashio transitional waters.   J Oceanogr   59: 403–414

378   Wilson DT, Meekan MG   (2002)   Growth-related advantages for survival to the point of

379   replenishment in the coral reef fish *Stegastes partitus* (Pomacentridae).   Mar Ecol Prog Ser

380   231: 247–260

381

382   Fig. 1   Relationships between days after hatching (DAH) and knob length (KnL) of Pacific saury.

383   Open circles and closed squares show the individual score and mean value at each date, respectively.

384   Fig. 2   Relationships between days after hatching (DAH) and number of fin rays for each fin of Pacific

385   saury.   Open circles and closed squares show the individual scores and the mean value at each date,

386   respectively.   The stable number of rays for each fin is shown with oblique lines area and / or dashed

387   lines.

388   Fig. 3   Relationships between days after hatching (DAH) and relative length of body parts (% KnL) of

389   Pacific saury.   Open circles and closed squares show the individual scores and the mean value at each

390   date, respectively.

391   Fig. 4   Morphometric variation (MV) in early life stage of Pacific saury among 5 mm KnL size intervals.

392   Fig. 5   Relationships between days after hatching (DAH) and estimated knob length (KnL) using otolith

393   microstructure data for three kinds of individuals (dead individuals during their periods (15–19 DAH

394   (D1) , 25–29 DAH (D2)) and surviving individuals collected at 60 DAH individuals (SV)) of Pacific

395   saury.   Vertical lines show the standard deviation (SD).

table Table. 1 Feeding and rearing conditions at each batch

DAH	Temperature (C)				Water exchange rate (%)				Rotifer (inds/ml)				Artemia nauplius (inds/ml)				Frozen copepods (g/t)				Artificial feed (g/t)			
	1B	2B	3B	4B	1B	2B	3B	4B	1B	2B	3B	4B	1B	2B	3B	4B	1B	2B	3B	4B	1B	2B	3B	4B
0	19 5	16 2	16	16 5	100	120	150	120	5															
1	19 4	15 6	16	17	100	120	150	120	7	4	4	4												
2	20	16 3	17	17	100	120	150	120	7	6	4	4			0 3	0 3								
3	19 6	16	18	17 5	100	120	150	120	7	7	4	4	0	0 2	0 5	0 5	3							
4	19 8	17	19	18	100	120	150	120	7	8	4	4	1	0 5	0 5	0 5	3							
5	19 8	17 2	20	18	100	120	150	120	7	8	4	4	2	0 5	1	1	3	6			2			
6	19 9	19	20	18 5	100	120	150	120	7	8	4	4	2	1	1	1	3	6			4			
7	19 3	18 9	20	19	100	120	150	120	7		4	4	2	1	1	1	10	6			4		4	
8	19 5	20	20	19 5	100	120	150	120					3	1	1 5	1 5	10	6			8 4		4	
9	19 6	20	20	19 5	230	120	150	120					4	1	1 5	1 5	10	6			9		4	
10	19 2	20	20	20	230	120	150	120					5	1	1 5	1 5	10	6			9		4	
11	19	20 3	20	20	360	120	150	120					5	2	2	2	10	6			10		8	
12	19 2	20 2	20	20	360	150	150	120					5	2	2	2	10	6			12		8	
13	19 3	20 2	20	20	360	150	150	120					5	2	2	2	10	6			14		8	
14	18 9	20 1	20	20	490	150	150	120					5	2	2	2	10	6			16		8	
15	19	20	20	20	490	150	200	150					5	2	2	2	10	6		5	16	8	8	2 5
16	18 8	20 3	20	20 5	490	180	200	150					5	2	2	2	10	6		5	18	8	10	2 5
17	19 5	20 2	20	20 6	490	180	200	150					5	3	2	2	10	6		5	20	10	10	2 5
18	19 9	20 5	20	19 8	480	300	200	150					5	3	2	2	10	6		5	20	10	10	2 5
19	20 3	20	20	19 7	480	300	200	150					5	3	2	2	10	6		5	22	10	10	2 5
20	19 8	20 5	20	20 1	480	300	200	150					5	3	2	2	10	6		10	24	10	10	2 5
21	19 8	20	20	19 7	480	300	200	150						3 6	3	3	10	6		10	26	10	10	2 5
22	19 8	20 5	20	19 6	600	300	200	150						3 6	3	3	10	6		10	28	10	10	2 5
23	19 7	20 4	20	20	600	300	200	150						3 6	3	3	10	6		10	28	10	10	2 5
24	19 6	20 5	20	19 8	600	300	200	150						3 6	3	3	10	6		10	30	10	10	2 5
25	19 7	20 4	20	19 6	820	300	200	150						3 6	3	3	10	6		10	30	10	12	2 5
26	19 7	20 3	20	20	820	300	250	150						3 6	3	3	10	6		10	30	12	12	2 5
27	19 5	20 2	20	20 4	820	300	250	150						3 6	3	3	10	6		10	32	12	12	2 5
28	19 7	20 7	20	20 3	820	300	250	150						3 6	3	3	10	6		10	32	12	12	2 5
29	19 8	20 2	20	20 3	820	460	250	150						3 6	3	3	10	6		10	32	12	12	2 5
30	19 7	20 2	20	20 6	820	460	250	150						3 6	3	3	10	6		10	34	12	12	2 5
31	19 6	20 2	20	19 6	820	460	250	150						3 6	3	3	10	6			34	12	12	2 5
32	19 7	19 8	20	19 8	820	460	250	150						3 6	3	3	10	6			34	12	12	2 5
33	19 8	20	20	20 3	820	460	250	150						3 6	3	3	10	6				12	12	2 5
34		20 2	20	20 3		460	250	150						3 6	3	3	10	6				12	12	2 5
35		19 7	20	19 7		460	250	150						3 6	3	3	10	6				12	12	2 5
36		20 6	20	19 6		460	250	200						3 6	3	3	10	6				12	12	2 5
37		20	20	20 2		460	250	200						3 6	3	3	10	6				12	12	2 5
38		19 6	20	19 7		460	250	200						3 6	3	3	10	6				12	12	2 5
39		20 2	20	20 1		460	250	240						3 6	3	3	10	6				12	12	3 8
40		20	20	20 1		460	250	240						3 6	3	3		6				12	20	8 3
-																								
50		19 6	20	20		780	300	300												10		20	20	20
-																								
60		20 2	20	20		900	300	480														20	20	20

Table. 2 Specific mortality rate (%/day) of Pacific saury for different batch treatments and time intervals

Time interval (days after hatching)	Batch treatment				
	1st	2nd	3rd	4th	Mean
10–14	6.74	0	11.96	1.24	4.98
15–19	32.16	12.25	7.93	3.86	14.05
20–24	0	5.24	3.54	2.04	2.70
25–29	8.18	10.23	0.66	2.56	5.41
30–34	13.65	0	2.11	0.49	4.06
35–39	–	0	6.00	0.27	2.09
40–44	–	0	0.51	0.07	0.19
45–49	–	0	1.05	0.14	0.40
50–54	–	0	0.55	0.38	0.31
55–59	–	0	0.56	0.14	0.23

Table. 3 Percent of reached the stable number for each fin (%) of Pacific saury

| KnL size interval (mm)	Anal (A)	Caudal (C)	Dorsal (D)	Pectoral (P1)	Pelvic (P2)	No. samples
5.0–9.9	0	0	3	0	0	50
10.0–14.9	0	0	12	0	0	34
15.0–19.9	0	0	100	0	0	28
20.0–24.9	0	0	100	100	100	20
25.0–29.9	8	0	100	100	100	13
30.0–34.9	75	92	100	100	100	12
35.0–39.9	100	100	100	100	100	19
40.0–44.9	100	100	100	100	100	11
45.0–49.9	100	100	100	100	100	10
50.0–54.9	100	100	100	100	100	6
55.0–59.9	100	100	100	100	100	7
60.0–64.9	100	100	100	100	100	5
65.0–69.9	100	100	100	100	100	2
70.0–74.9	100	100	100	100	100	6
75.0–79.9	100	100	100	100	100	2
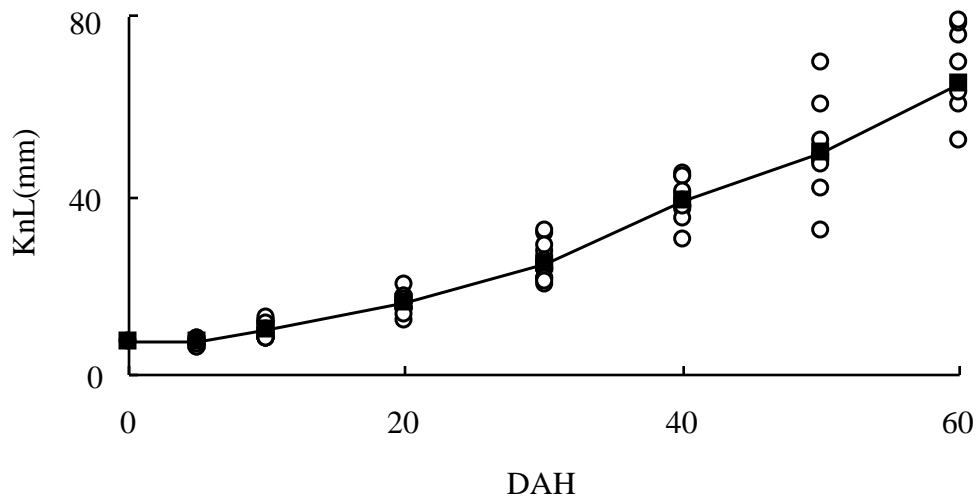
Fig. 1 Nakaya *et al.*
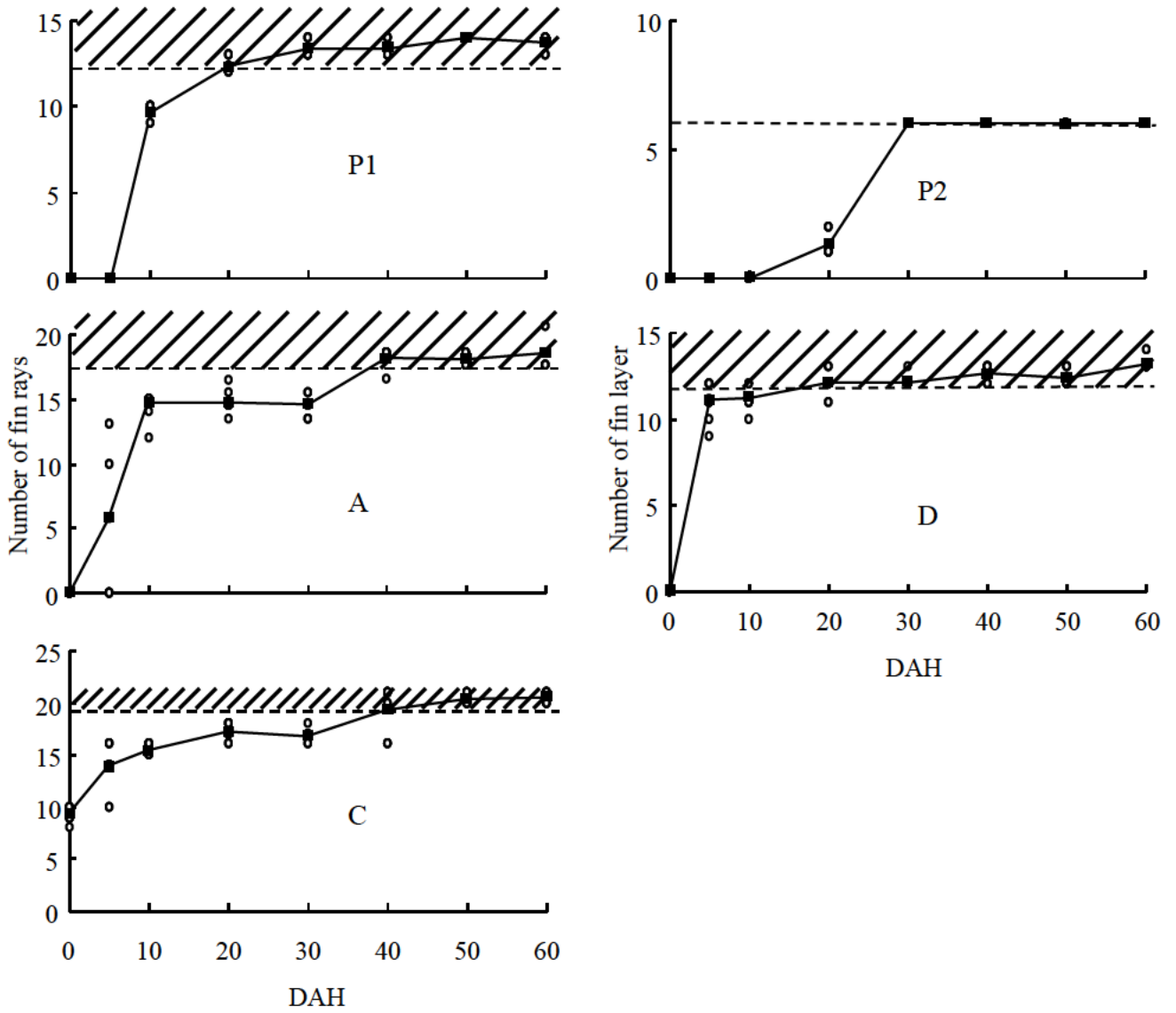
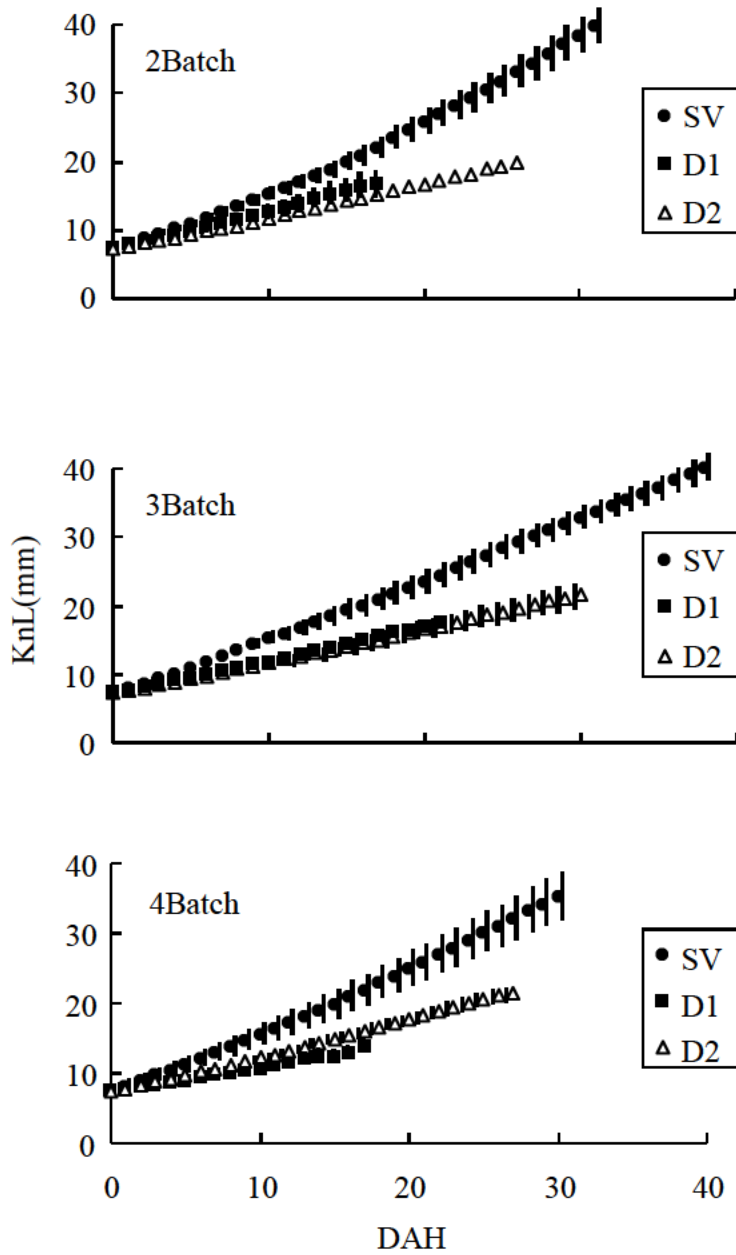Fig. 2 Nakaya *et al.*
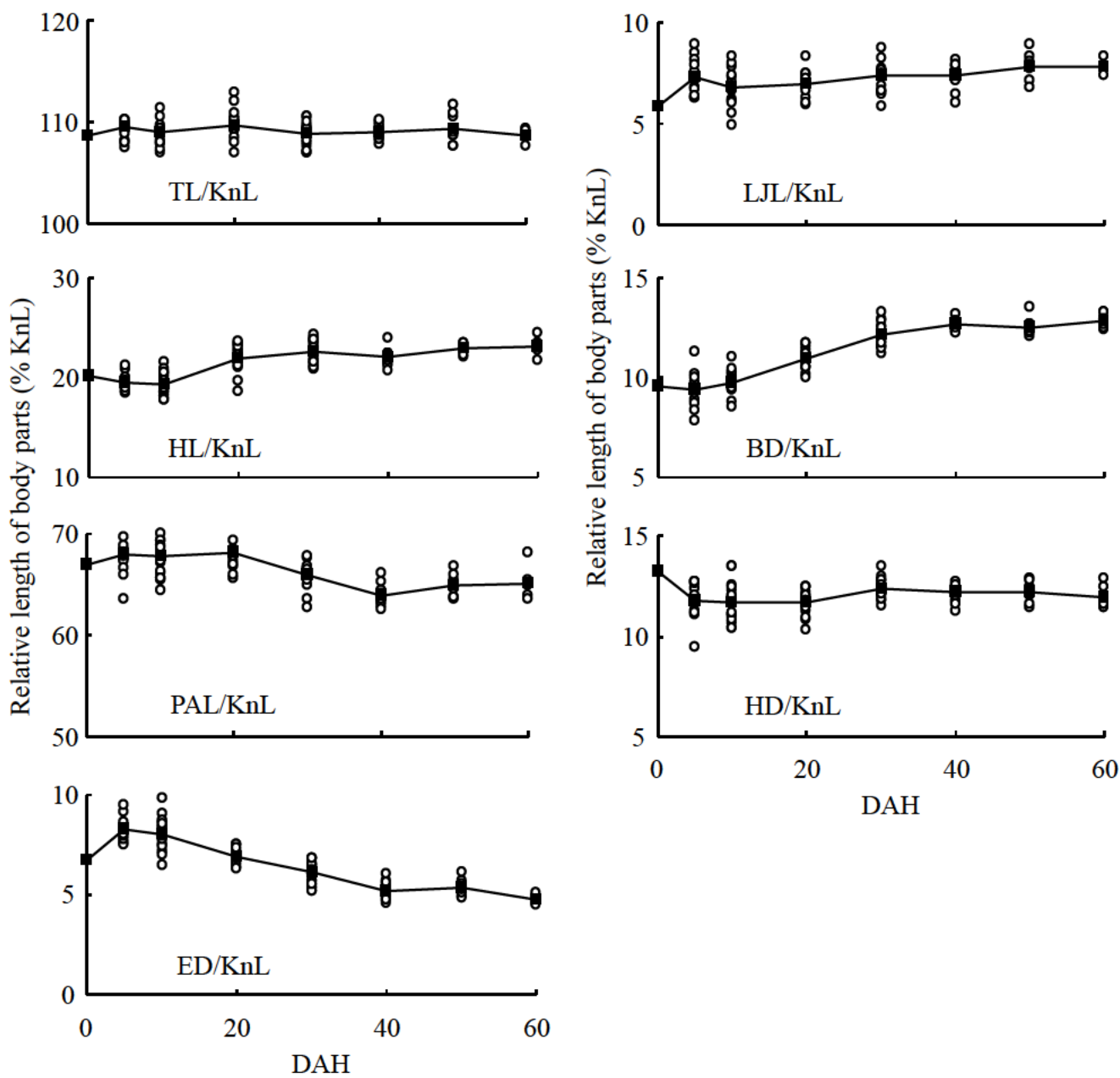
Fig. 3 Nakaya *et al.*
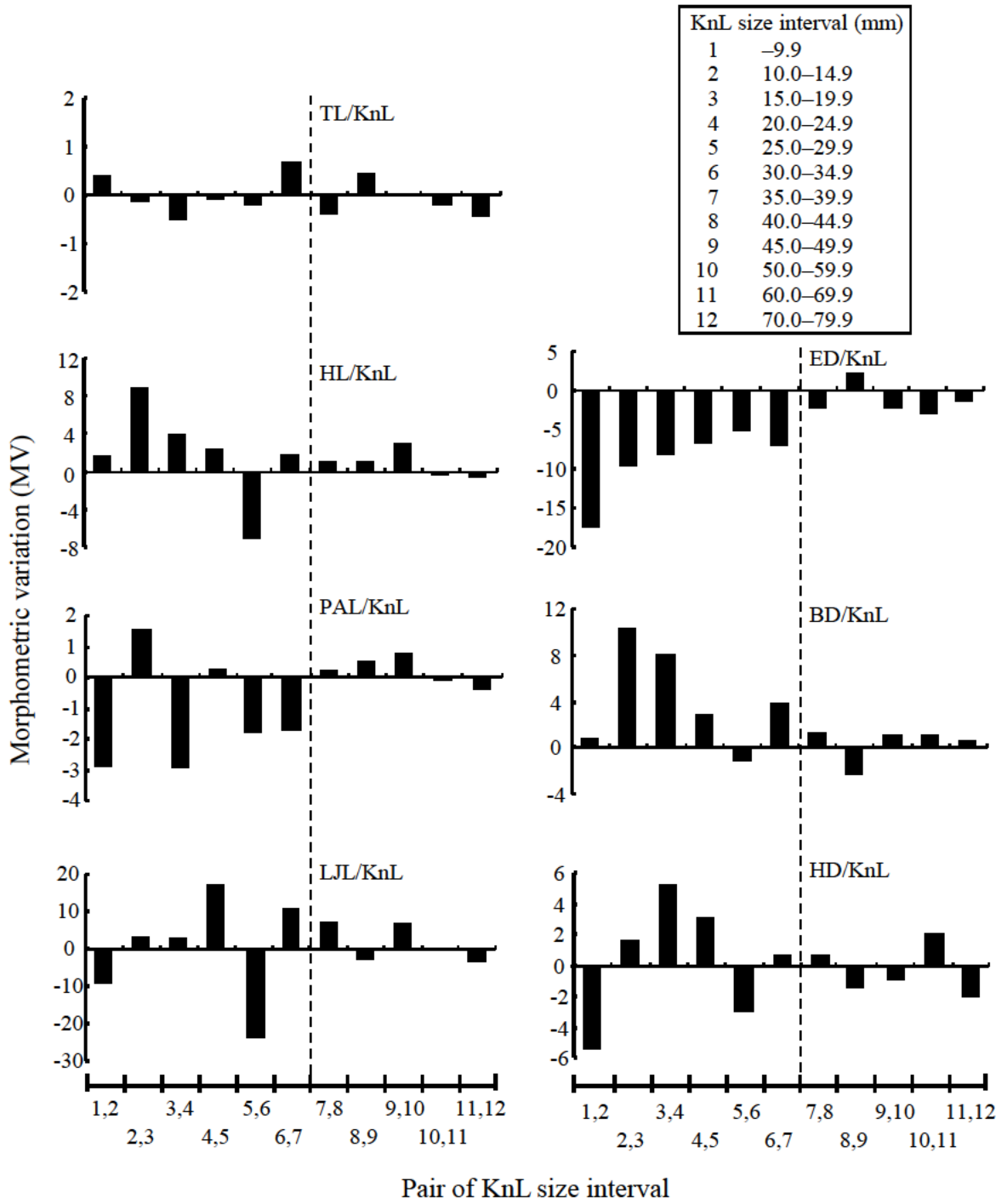
Fig. 4 Nakaya *et al.*

Fig. 5 Nakaya *et al.*