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Freshwater migration and feeding habits of juvenile temperate seabass *Lateolabrax japonicus* in the stratified Yura River estuary, the Sea of Japan

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1 **TITLE**

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3 Freshwater migration and feeding habits of juvenile temperate seabass *Lateolabrax*

4 *japonicus* in the stratified Yura River estuary, the Sea of Japan

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ABSTRACT: Juveniles temperate seabass *Lateolabrax japonicus* were sampled along the Yura River estuary from April to July 2008 to determine their distribution and feeding habits during migration within a microtidal estuary. Juveniles were distributed not only in the surf zone, but also in the freshwater zone and they were particularly abundant associated with aquatic vegetations in the freshwater zone, throughout the sampling period. This distribution pattern suggests that the early life history of the temperate seabass depends more intensively on the river than previously considered. Small juveniles in the freshwater zone fed on copepods and chironomid larvae, and then from ca. 20 mm standard length (SL) on mysids. In contrast, juveniles (ca. 17-80 mm SL) in the surf zone fed mainly on mysids.

KEY WORDS: “estuary”, “feeding habits”, “fresh water”, “juvenile”, “*Lateolabrax japonicus*”, “migration”, “salt wedge”, “Yura River”

29 INTRODUCTION

30 Temperate seabass *Lateolabrax japonicus* is a euryhaline fish distributed in
31 temperate coastal waters of Japan and Korea [1]. The temperate seabass is often dominant
32 in coastal areas, and is thus commercially important. The temperate seabass is one of the
33 handful species whose landing has been increasing in the recent 20 years in Japan, while
34 many other species of fish have decreased [2]. The fluctuation of fish stocks is largely
35 dependent on survival during the early life stages [3,4]. Therefore, clarification of the early
36 life history of temperate seabass may enable verification of the mechanism of the recent
37 increase in its landing.

38 In general, during the early part of the juvenile period, this species migrates from
39 open water areas into estuaries, surf zones, and/or coastal areas to feed on copepods, mysids,
40 amphipods, decapods, or fish larvae [5,6]. The life history of migratory juveniles has been
41 thoroughly investigated in the Chikugo River estuary and the Shimanto River estuary,
42 Japan. The Chikugo River estuary is characterized by its large tide and subsequent

43 productivity [7]. In the Chikugo River estuary, some early juveniles (ca. 20 mm SL) ascend
44 the river in March then inhabit the upper estuary, including the freshwater zone [8-11],
45 while others reside in the lower estuary [8,9] or in the littoral zone [12]. For early juveniles
46 of temperate seabass, migration to the freshwater zone was only been reported in the
47 Chikugo River estuary. There are two possible reasons; first, in the upper Chikugo River
48 estuary, strong tidal currents form the estuarine turbidity maximum (ETM) [7], where prey
49 items are abundant [13,14]. Second, temperate seabass in the Ariake Bay including the
50 Chikugo River estuary is a hybrid between *L. japonicus* and Chinese seabass *Lateolabrax* sp.
51 [15]. The Chinese seabass has higher performance for osmoregulation to freshwater than
52 temperate seabass [16]. This would lead juveniles in the Chikugo River estuary to ascend
53 the river to the freshwater zone [16]. On the other hand, no ETM is observed in the
54 Shimanto River estuary, although there are some seagrass beds [17]. Early juveniles occur
55 and aggregate in the seagrass beds in brackish waters in the Shimanto River estuary from
56 February, then they inhabit there at least until May [17]. The seagrass beds are therefore

57 regarded to important nursery areas for juveniles in the Shimanto River estuary [17].

58 In the Tango Sea, which is located in the western Wakasa Bay, temperate seabass
59 is one of the most important fisheries resources. Temperate seabass spawns offshore from
60 December to February [18] (Fig. 1). It was determined that eggs and larvae are transported
61 to inshore areas within a few months [19], but migration pattern after the larval stage is
62 unknown. It is not clarified whether juveniles migrate to upstream of the Yura River, which
63 is the largest river flowing into the Tango Sea, or remain in the littoral zone after
64 aggregation around the river mouth [19]. In addition, feeding habits of temperate seabass in
65 the Yura River estuary are unknown, even though it is of foremost ecological importance.

66 The Tango Sea is a part of the Sea of Japan, so that the tides are considerably
67 weaker than in the East China Sea and along the Pacific coast [20]. The hydrographic
68 conditions in the Tango Sea and Yura River estuary are therefore apparently different from
69 the aforementioned large-tide estuaries (i.e. the Chikugo and Shimanto River estuaries).
70 The small tides restrict the mixing of seawater and freshwater, and the water thus tends to

be stratified in the estuary [20]. Remarkably strong turbidity maximum zones, which are formed by the strong tidal currents in the upper Chikugo River estuary [7], are not observed in the estuaries facing to the Sea of Japan [20]. These differences in environmental conditions may lead to different migration and/or feeding habitats of the juveniles. However, no surveys have been previously conducted on the distribution and feeding habits of the juveniles in the rivers along the Sea of Japan side. The main objective of this study was therefore to determine the temporal distributions of juvenile temperate seabass in the microtidal Yura River estuary. We conducted ca. weekly surveys along the estuary to investigate the upstream migration. In addition, gut contents of juveniles were observed to investigate their feeding habits.

MATERIALS AND METHODS

Study site

Observations and samplings were conducted along the lower reaches of the Yura River and adjacent surf zone during the spring-summer seasons of 2008 (Fig. 1). The Yura

85 River flows into the Sea of Japan, where the tides are generally small. The typical tidal
86 range in the estuary is less than 0.5m [20], so that the effect of the tide on the fish
87 distributions and environmental conditions were neglected in this study. The river discharge
88 of the Yura River shows typical seasonal variations, which is large in winter and spring due
89 to melting snow, while small in summer and autumn [20]. In winter, freshwater occupied the
90 whole estuary and the water is homogeneous. Seawater starts to intrude into the lower layer
91 of the estuary from early spring and then lower layer is occupied by sea water until ca. 20km
92 upstream from the river mouth in summer, leading to strong stratification [20].

93 Five stations were set up along the lower reaches of the river from the mouth to
94 15km upstream (R1-R5, Fig 1c). The distances from river mouth were 0.5, 3.0, 6.5, 9.0 and
95 15.0 km at R1, R2, R3, R4 and R5, respectively. Almost riversides of the stations are free
96 from bank protection. There are dense aquatic vegetations mainly composed of
97 *Ceratophyllum demersum* close to an embankment at R3. Another station (S1) was set on
98 the sand beach adjoining the river mouth (1.0 km from the river mouth, Fig. 1c). The bottom

99 was sandy at S1, R1 and R2, while muddy at R3, R4 and R5.

100 **Field sampling**

101 In order to collect temperate seabass juveniles, a seine net (0.8 m×10 m, 1.0 mm
102 mesh aperture at the cod end) was towed along the bank or shoreline every week from 18
103 April to 17 July, 2008. A few minutes tow was performed two or three times at each station.
104 Sampling depth was 0.3 – 1.2 m at every station. Bottom water temperature and salinity
105 were measured with an environmental monitoring system (YSI 556 MPS, YSI Inc., U.S.A.)
106 at the same time as seine net towing. Collected juveniles were sorted and frozen using dry
107 ice immediately after seining. These samples were transported to the laboratory and kept in
108 a freezer until further analyses.

109 **Laboratory analysis**

110 The standard length (SL) and wet body weight (BW) of samples were measured.
111 Ingested gut contents were removed from randomly selected specimens at each station. Gut
112 contents were identified to the lowest possible taxonomic category and counted under a

113 dissecting microscope. The feeding incidence was calculated as the percentage of the number
114 of fish with food in relation to the total number analysed. Randomly selected organisms of
115 each prey item were dried at 60 °C for over 24 h and individual dry weight measured to the
116 nearest 0.001 mg after cooling to the air temperature with Mettler Toledo AT21 Comparator
117 (Mettler Toledo Inc, Mississauga, ON, Canada). The composition of each prey item for each
118 size class of fish was evaluated by calculating the percentage numerical composition (%N),
119 percentage frequency of occurrence (%F) and percentage of dry weight composition (%W) as
120 follows:

121
$$\%N = \frac{N_i}{N} \times 100,$$

122 where N_i is the number of prey i species and N is the total number of prey.

123
$$\%F = \frac{F_i}{F} \times 100,$$

124 where F_i and F are the number of fish fed on prey i species and total number of fish that had
125 stomach content on each prey, respectively.

126
$$\%W = \frac{N_i \times W_i}{\sum (N_i \times W_i)} \times 100,$$

where W_i is the individual dry weight of prey item i species.

The contribution of a prey item to the diet was determined using the index of relative importance (IRI) [21]. The equation used was:

$$IRI = (\%N + \%W) \times \%F.$$

The IRI was standardized to $\%IRI$.

$$\%IRI = \frac{IRI}{\sum IRI} \times 100.$$

RESULTS

Hydrographic conditions

Temperature increased from 12.6°C to 29.0°C during the sampling period (Fig. 2a).

There was no clear difference in temperature among the river stations. However, temperature at S1 was mostly lower than those at the other stations after May. Salinity fluctuated from 12.8 to 34.0 (mostly over 25.0) at S1, while it remained low (0.0 to 6.0) at the other river stations (Fig. 2b). Salinity was usually lower than 1.0 in the upper estuaries (R3, R4 and R5), indicating the sampling stations were mostly occupied by fresh water during the

141 sampling period.

142 **Distribution and size of the temperate seabass juveniles**

143 A total of 1906 juveniles (15.0 – 77.9 mm SL) of temperate seabass were collected
144 by the seine surveys from April to July 2008 (Fig. 3). Juveniles were widely distributed in
145 both marine and freshwater environments, although the abundance varied among the
146 stations. The catch at S1 showed a wide variation; 266 ind. were caught on 6 June, while
147 only one fish on 13 June. On the other hand, individuals were consistently sampled at R3, at
148 least until mid June. A relatively small number of juveniles were caught at the other
149 stations. Judging from differences in environmental conditions and larger catches, we
150 hereafter paid more attention to the three stations (S1, R3 and R4). We categorized S1, R3
151 and R4 as the surf zone, freshwater zone with aquatic vegetations, and freshwater zone
152 without aquatic vegetations, respectively.

153 The median SLs of fish at S1 were 20.9 mm on 18 April, 28.2 mm on May 8, 40.6
154 mm on 6 June and 76.1 mm on 17 July (Fig. 4). At R3, the median SLs were 20.7 mm on 18

155 April, 23.6 mm on 8 May, 30.4 mm on 6 June and 55.8 mm on 17 July (Fig 4). Juveniles at
156 R4 had median SLs of 17.6 mm on 18 April, 23.1 mm on 8 May and 34.9 mm on 6 June (Fig.
157 4).

158 **Feeding habits**

159 The feeding incidence kept high values of more than 80 % in all sizes at all three
160 stations (Fig. 5). The diet of the juvenile of temperate seabass was composed of 9 types of
161 prey items (Table 1). The dry weight of mysids in fish stomach (0.024 – 0.755 mg/ind.) was
162 considerably heavier than other prey items (0.001 – 0.152 mg/ind.) except for that of
163 polychaetes (5.335 mg/ind.; Table 2). The dry weight of ingested mysids increased with fish
164 growth and mysids in the river were heavier than those in the surf zone at every fish size
165 class (Table 2).

166 Mysids, composed of *Orientomysis japonica*, *Archaeomysis* spp., and
167 *Nipponomysis* spp. (Table 1), were the most important prey item for all SL classes at S1 (Fig.
168 6). Amphipods and polychaetes were secondary important prey item for 20 – 60 mm SL

classes and 60 – 80 mm SL, respectively, but their contributions were low. The main prey items at R3 were copepods, chironomid larvae and mysid *Neomysis awatschensis* (Table 1, Fig. 6). Copepods were the most important prey item for < 20 mm SL fish, followed by chironomid larvae. In the larger size classes (≥ 20 mm SL), mysid represented more than 55 % of total *IRI*, while contributions of copepods and chironomid larvae were comparatively low. Chironomid larvae was the dominant prey item for smaller size class (< 20 mm SL) at R4, followed by cladocerans, mysid *Neomysis awatschensis* and copepods (Table 1, Fig. 6). The %*IRI* of prey items for larger size classes (≥ 20 mm SL) showed similar pattern to that of R3; mysids were the most important prey item, while contributions of copepods, chironomid larvae and amphipods were low.

DISCUSSION

The temperate seabass juveniles occur in various environments in diverse waters [5,6]. Therefore it is important to investigate and compare the ecology of this species among the different conditions.

183 **Distribution**

184 This study first determined that a certain number of early juveniles of ca. 20 mm

185 SL migrate into the freshwater zone of the stratified Yura River estuary in April, while other

186 juveniles reside in the surf zone (Fig. 3). The two migratory pathways of early juveniles of

187 the temperate seabass are similar to those observed in the well-mixed Chikugo River

188 estuary [10,12], although hydrographic conditions and genetic characteristics of fish

189 populations are considerably different between the two estuaries [7,15,20]. This indicates

190 that the two migratory pathways are the native ecology of juveniles of *L. japonicus* and

191 common for temperate seabass juveniles in other estuaries. This also suggests that the early

192 life history of this species depends more intensively on the river water than previously

193 considered. No previous studies on temperate seabass early juveniles have been conducted

194 in the freshwater zone. It is thus necessary to investigate the distribution in the other

195 estuaries to confirm the generality of the migration of juveniles into freshwater as well as

196 residence in the sea water and brackish water.

197 Some studies showed that juveniles select the flood tide to achieve effective
198 upstream transport in the Chikugo River estuary [6,9]. A similar migrating mechanism was
199 also reported for other fish species in the other estuaries [22,23]. In the Yura River estuary,
200 however, the tidal range is considerably small and strong tidal current is not induced [20].
201 Therefore juveniles may ascend the Yura River through the bottom layer which is occupied
202 by sea water rather than the tidal stream transport. The timing of salt wedge intrusion in
203 the Yura River estuary varied annually according to the river discharge in winter [20]. This
204 suggests that the timing of river ascending of juveniles would fluctuate from year to year.
205 The long term investigations are needed to determine this hypothesis.

206 Ohmi [19] indicated the distribution of juveniles in the coastal area around the
207 Yura River mouth in March with the size range from ca. 10 to ca. 14 mm SL. This study
208 showed some juveniles were already distributed in the freshwater zone in mid April with the
209 size range of ca. 15 to 25 mm SL. The distribution of juveniles was determined in the Yura
210 River from 8 March in 2009 (Fuji T, unpubl. data, 2009). These results suggest that juveniles

211 ascend the river in March in the Yura River estuary at the size of ca. 15 mm SL. Also in the
212 Chikugo River estuary, juveniles begin to gather and ascend the river in March with the size
213 of ca. 15 mm SL [8], corresponding to the case in the Yura River estuary. The spawning
214 season of this species is from December to February and common in various waters in Japan
215 [5], but the distance from spawning areas to the river mouth is farther in the case of
216 enclosed bay (e.g. ca. 40 km from the Chikugo River estuary of the Ariake Bay) than the
217 open bay (e.g. ca. 20 km from the Yura River estuary in the Wakasa Bay) [6]. Despite the
218 difference in the distance of spawning areas from river mouths the corresponding of the
219 river ascending season may come from the difference in the process of the transport
220 mechanism of larvae [24].

221 In this study, juveniles with the size range from 15 to 77.9 mm SL were collected
222 from April to July both in the freshwater zone and the surf zone. Given the lower number of
223 collected juveniles over 40 mm SL in this study, many larger juveniles (> 40 mm SL) would
224 escape from the net, although some larger juveniles were occasionally collected. However,

225 the distribution of larger juveniles (> 40 mm SL) in the freshwater and surf zone was
226 demonstrated after May in this study. In addition, ca. 900 large juveniles at the size of ca. 80
227 mm SL were collected in July by the fixed net at the mouth of the Yura River (Ohmi H,
228 unpubl. data, 1995). This indicates that a part of large juveniles would have remained in the
229 freshwater zone or surf zone. Therefore, both the surf zone and freshwater zone are utilized
230 by various sizes of this species juvenile for long time in the Yura River estuary. This
231 indicates that both zones provide sufficient environmental conditions (e.g. ambient prey
232 abundance or low predation) of these habitats for juveniles of various sizes. Suzuki et al [10]
233 also reported juveniles use the lower salinity area (salinity < 10) from March to August in
234 the Chikugo River estuary. Arayama and Imai [25] reported the short residence (less than a
235 month) of temperate seabass juveniles in the surf zone of the outer part of the Tokyo Bay,
236 although Hibino et al. [26] and this study reported the longer utilization (ca. several
237 months) of the surf zone by juveniles. Kinoshita [27] showed that many species use the surf
238 zone in short periods in their juvenile stage. He considered that the surf zone plays an

239 important role for these species juveniles as a place for their metamorphosis. This study
240 showed that the surf zone would have functions not only as a place for their metamorphosis
241 but also as a nursery area for temperate seabass juveniles. It is necessary to investigate the
242 ecology of temperate seabass juveniles in the surf zone in the other waters to determine the
243 importance of the surf zone for this species. This would lead to determine the other aspects
244 of the surf zone for juveniles.

245 **Feeding habits**

246 Copepods, chironomid larvae, polychaetes and mysids were the important food for
247 juveniles in the Yura River estuary and adjacent surf zone (Table 1, Fig. 6). The importance
248 of these prey items for this species juvenile is reported in many studies [5]. However, the
249 timing of ontogenetic changes of feeding habits varies with waters. In the Chikugo River
250 estuary, juveniles change their main food from copepods to mysids at the size of 40 mm SL
251 [28]. On the other hand, juveniles shift their main prey items from copepods to mysids at 20
252 mm SL in the Kumihama Bay, adjacent to the Tango Sea [18]. In this study, juveniles at S1

253 fed on mysids from < 20 mm SL. In the freshwater zone (R3 and R4), smaller juveniles (< 20
254 mm SL) had mainly copepods, chironomid larvae, and cladocerans, while larger juveniles ($\geq$
255 20 mm SL) consumed mainly mysids. These differences in the timing of food change would
256 reflect the ambient prey environment as reported in Japanese flounder *Paralichthys*
257 *olivaceus* [29]. The earlier dependence on mysids in the surf zone in this study would derived
258 from the high density of some mysid species occurring in shallow waters around the Yura
259 River mouth from March to June (Tane S, unpubl. data, 1992). It is considered that juveniles
260 of this species change their feeding habits flexibly according to the ambient prey
261 environments. Therefore, the ambient prey environment in the Yura River estuary and
262 adjacent surf zone should be investigated to determine the relationship between ontogenetic
263 change of feeding habits and prey environment. It is also important to examine the feeding
264 ecology of this species in various waters with various ambient prey environments to
265 determine the survival strategies of this species.

266 **The aquatic vegetations as a nursery area in the freshwater zone**

267 In the freshwater zone, juveniles were considerably abundant associated with
268 aquatic vegetations (Fig. 3), indicating the aquatic vegetations play an important role in the
269 freshwater zone in the Yura River estuary. This is consistent with the previous studies
270 showing the temperate seabass juveniles intensively depend on seagrass beds in lower
271 salinity waters [5,6]. In the Shimanto River estuary, although there was no difference in %N
272 of food items and feeding incidence between seagrass beds and non-seagrass beds, juveniles
273 in seagrass beds fed on more food by weight [17]. In this study, feeding habits for juveniles
274 smaller than 20 mm SL were different between the freshwater zone with and without
275 aquatic vegetations (Fig. 6); copepods were the most important prey item in the aquatic
276 vegetations, while chironomid larvae were most important in the freshwater without
277 aquatic vegetations. The aquatic vegetations in the freshwater zone would give some effects
278 on feeding habits, although some more quantitative surveys for feeding habits are necessary
279 for examining this idea exactly.

280 Shoji et al. [30] indicated the importance of seagrass beds as a refuge from fish

281 predators for red sea bream *Pagrus major* juveniles. The aquatic vegetations in the
282 freshwater zone may be also important for temperate seabass juveniles as refuges from
283 predators. These functions of the aquatic vegetations in the freshwater zone would
284 correspond to those of ETM in the Chikugo River estuary [31]. The aquatic vegetations or
285 seagrass beds may play important roles in place of ETM in the river without ETM (e.g. the
286 Shimanto River estuary and the Yura River estuary).

287 Determining the relative value of the freshwater zone and surf zone as nursery
288 areas is important for understanding the ecological strategy of this species juvenile. Stable
289 isotopes and otolith Sr/Ca ratio as migration markers are considered to be necessary for
290 analysing the detailed migration pattern of juveniles [32,33]. In addition, it is also
291 important to measure the width of otolith increments for more information about
292 growth records.

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400 **FIGURE CAPTIONS**

401 **Fig. 1** Sampling stations along the Yura River. Hatched sea area indicates the spawning
402 area of temperate seabass in this water [18]

403 **Fig. 2** Temporal changes in (a) temperature and (b) salinity

404 **Fig. 3** Number of temperate seabass juveniles collected at each station. n.d. indicates
405 that no surveys were conducted at the station on the date

406 **Fig. 4** Weekly changes in the frequency of standard length (SL) of juvenile temperate
407 seabass at S1, R3 and R4. N, M and R indicate the number of fish analysed,
408 the median SL, and the range of SL, respectively. n.d. indicates no data

409 **Fig. 5** Feeding incidence of juveniles (< 60 mm SL) for each size class at S1, R3 and
410 R4

411 **Fig. 6** Composition of diet of temperate seabass at S1, R3 and R4 among size classes,
412 based on the percentage index of relative importance (*%IRI*) values of each
413 prey groups. Numbers above the bars show the numbers of stomachs

414

analysed in each size classes

Table 1 Diet composition of juvenile temperate seabass at S1, R3 and R4

Station	Prey item	Size class (mm SL)											
		< 20			20–40			40–60			60–80		
		%N	%F	%W	%N	%F	%W	%N	%F	%W	%N	%F	%W
S1	Copepods	0.0	0.0	0.0	11.1	23.4	0.1	0.0	0.0	0.0	0.8	25.0	0.0
	Mysids	100.0	71.4	100.0	74.9	78.1	95.0	64.3	72.2	78.5	89.9	100.0	24.8
	<i>Neomysis awatschensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Orientomysis japonica</i>	0.0	0.0	0.0	17.6	15.6	16.6	6.1	9.1	3.2	1.4	40.0	0.4
	<i>Archaeomysis</i> spp.	0.0	0.0	0.0	0.2	1.6	0.2	0.0	0.0	0.0	38.5	100.0	10.6
	<i>Nipponomysis</i> spp.	62.5	42.9	62.5	14.7	20.3	15.1	3.1	18.2	5.3	2.0	40.0	0.6
	Unidentified mysids	37.5	57.1	37.5	49.4	62.5	63.1	55.1	100.0	70.0	48.0	100.0	13.3
	Chironomid larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Insect larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Amphipods	0.0	0.0	0.0	9.5	29.7	4.8	35.7	45.5	21.5	1.4	40.0	0.4
	Cladocerans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tanaids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isopods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	40.0	0.7
	Polychaetes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	80.0	74.1
	Unidentified	+	28.6		+	10.9		0.0	0.0	0.0	0.0	0.0	
No. fish with empty gut		1			5			0			0		
No. fish examined		8			69			11			5		

Table 1 continued

Station	Prey item	Size class (mm SL)											
		< 20			20–40			40–60			60–80		
		%N	%F	%W	%N	%F	%W	%N	%F	%W	%N	%F	%W
R3	Copepods	62.5	91.7	13.1	66.2	64.9	2.4	16.9	26.3	0.2	0.0	0.0	0.0
	Mysids	9.6	16.7	47.0	13.4	63.6	87.9	80.5	100	91.0	100.0	100.0	100.0
	<i>Neomysis awatschensis</i>	0.0	0.0	0.0	10.9	44.2	71.2	57.9	78.9	64.9	38.5	100.0	38.5
	<i>Orientomysis japonica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Archaeomysis</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Nipponomysis</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unidentified mysids	9.6	16.7	47.0	2.5	29.9	16.8	22.6	47.4	26.2	61.5	100.0	61.5
	Chironomid larvae	11.0	66.7	30.0	8.7	51.9	4.1	1.7	21.1	0.3	0.0	0.0	0.0
	Insect larvae	0.7	8.3	5.9	0.2	5.2	0.3	0.9	15.8	0.4	0.0	0.0	0.0
	Amphipods	0.0	0.0	0.0	0.1	3.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	Cladocerans	14.7	25.0	0.8	10.8	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Tanaids	1.5	16.7	3.2	0.4	10.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	Isopods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Polychaetes	0.0	0.0	0.0	0.1	2.6	4.8	0.0	0.0	0.0	0.0	0.0	0.0
	Unidentified	0.0	0.0		+	5.2		0.0	0.0		0.0	0.0	
	No. fish with empty gut	1			4			0			0		
	No. fish examined	13			81			11			1		

Table 1 continued

Station	Prey item	Size class (mm SL)											
		< 20			20–40			40–60			60–80		
		%N	%F	%W	%N	%F	%W	%N	%F	%W	%N	%F	%W
R4	Copepods	4.8	66.7	0.8	44.9	77.3	0.7	38.6	64.3	0.6	0.0	0.0	0.0
	Mysids	6.8	33.3	27.3	36.0	86.4	95.1	58.8	100	85.6	100.0	100.0	100.0
	<i>Neomysis awatschensis</i>	2.7	33.3	10.9	16.9	41.3	44.8	17.7	85.7	27.5	46.7	100.0	46.7
	<i>Orientomysis japonica</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Archaeomysis</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Nipponomysis</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unidentified mysids	4.1	33.3	16.4	19.1	60.9	50.4	41.2	92.9	58.1	53.3	100.0	53.3
	Chironomid larvae	31.3	66.7	69.5	14.8	32.6	2.8	1.2	28.6	0.2	0.0	0.0	0.0
	Insect larvae	0.0	0.0	0.0	0.8	6.5	0.4	0.6	14.3	0.3	0.0	0.0	0.0
	Amphipods	0.0	0.0	0.0	1.3	6.5	0.7	0.3	7.1	0.2	0.0	0.0	0.0
	Cladocerans	57.1	66.7	2.4	1.6	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tanaids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isopods	0.0	0.0	0.0	0.5	2.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	Polychaetes	0.0	0.0	0.0	0.0	0.0	0.0	0.6	14.3	12.1	0.0	0.0	0.0
	Unidentified	0.0	0.0		+	6.5		0.0	0.0		0.0	0.0	
	No. fish with empty gut	1			7			0			0		
	No. fish examined	7			53			14			1		

“+” indicates uncountable

Table 2 Dry weight of each prey item (mean $\pm$ S.D.)

Prey item	Area	N	Dry weight (mg/ind.)
Mysid from < 20 mm SL juveniles	S	9	0.024 $\pm$ 0.012
	F	7	0.094 $\pm$ 0.121
Mysid from 20 – 30 mm SL juveniles	S	19	0.256 $\pm$ 0.556
	F	31	0.710 $\pm$ 0.842
Mysid from 30 – 40 mm SL juveniles	S	17	0.418 $\pm$ 0.485
	F	14	0.755 $\pm$ 0.548
Mysid from 40 – 50 mm SL juveniles	S	10	0.406 $\pm$ 0.450
	F	22	0.455 $\pm$ 0.318
Mysid from > 50 mm SL juveniles	S	16	0.121 $\pm$ 0.110
	F	16	0.294 $\pm$ 0.126
Polychaetes	S&F	10	5.335 $\pm$ 2.828
Fish larvae	S&F	10	0.096 $\pm$ 0.036
Insect larvae	S&F	10	0.152 $\pm$ 0.148
Cladocerans	S&F	10	0.001 $\pm$ 0.000
Tanaids	S&F	10	0.042 $\pm$ 0.016
Isopods	S&F	10	0.149 $\pm$ 0.132
Copepods	S&F	10	0.004 $\pm$ 0.003
Chironomids larvae	S&F	14	0.052 $\pm$ 0.024
Amphipods	S&F	10	0.140 $\pm$ 0.138

S; surf zone. F; freshwater zone. N; the number of samples analysed

Copepods, chironomid larvae and mysids from < 20 mm SL juveniles were pooled to measure their dry weights because of their small sizes

Fig. 1 Fuji et al.

Fig.2 Fuji et al.

Fig.3 Fuji et al.

Fig. 4 Fuji et al.

Fig. 5 Fuji et al.

Fig. 6 Fuji et al.