Sedentary behaviour establishment in 0-group common sole *Solea solea*: a laboratory video-tracking study

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Abstract:

Spontaneous swimming activity of 0-group common sole (*Solea solea*) was evaluated using a video-tracking system under laboratory conditions. An experiment was conducted during two consecutive days on individuals sampled in June, July, September and November (2004) in a coastal nursery ground (Pertuis Charentais, Bay of Biscay, France). The measured behavioural variables were: distance travelled and frequency of occurrence of burying, swimming and immobility. 0-group sole showed a relatively clear circadian activity in line with the artificial light conditions (day, twilight and night). Swimming activity of 0-group sole decreased drastically from June to July, thereafter remaining at a very low level in September and November. Such important changes reflect the transition between the exploratory behaviour of the post-colonization period and a well established sedentary behaviour remaining until the onset of winter. These results highlight the potential limitation in habitat use capacities of 0-group sole once settled in coastal nursery grounds.

Keywords: behaviour; flatfish; juvenile; swimming activity; video-tracking

35 **Introduction**

36 Juveniles of many marine fishes and especially flatfishes inhabit coastal areas (*e.g.* estuaries

37 and shallow water bays) where they find generally more abundant food, lower predation risks

38 and higher temperatures than in offshore areas (Gibson, 1994). However, in these essential

39 habitats, fish juveniles have also to face highly variable environmental factors and

40 superimposed anthropogenic activities that may jeopardize survival and influence recruitment

41 into the adult population (Beck *et al.*, 2001). Fish habitat utilization reflects trade-offs

42 between spatial distribution of essential resources, the internal state of the organism, and

43 tolerance to ambient conditions (Huntingford, 1993). In order to achieve habitat conservation

44 and sustainable fisheries management, it is therefore critical to understand fish juveniles

45 behaviour in term of spatio-temporal dynamics within these coastal habitats (Rice, 2005).

46

47 Common sole, *Solea solea* (L.) is a widely distributed and most economically important

48 flatfish species of the North East Atlantic region. Most common sole stocks are reported to be

49 overexploited (ICES, 2005). Previous both field and laboratory studies have focused on the

50 behavioural processes occurring in 0-group juveniles during the short colonization phase

51 (Champalbert & Koutsikopoulos, 1995, Amara *et al.*, 2000). Once settled in shallow coastal

52 areas individuals have to face a variety of natural and anthropogenic stressors that may impact

53 their survival. However, apart from field studies that have focused on their spatio-temporal

54 distribution till autumn (Dorel *et al.*, 1991, Rogers, 1992, Jager *et al.*, 1993) and some other

55 rare studies that have inferred indirectly about their movements capacities using conventional

56 (Coggan & Dando, 1988) or natural (Vinagre *et al.*, 2008) tags, little is known on 0-group

57 sole behavioural activities during the post-colonization period.

58

59   Therefore, the present study aimed at bringing new insights on 0-group sole swimming

60   behaviour during the sensitive post-colonization period in order to better understand

61   dynamics of individuals in shallow coastal areas. A laboratory video-tracking system was

62   developed to measure the spontaneous swimming and burying activity. Since behavioural

63   patterns in fishes generally vary on a diel cycle, experimental set up was designed to measure

64   behavioural activities during two consecutive days according to light period of the day (day-

65   twilight-night). 0-group common sole were caught throughout four different months after

66   colonization until the onset of winter (*i.e.* June to November) in an Atlantic nursery ground

67   (Pertuis Charentais, Bay of Biscay, France). In this region, colonization is centred around

68   May so that, it is likely that individuals belong to the same cohort. Therefore, it was

69   hypothesized that sampling month may be used as proxy of age / ontogenetic status. The

70   objectives were to establish the baseline levels of these natural activities in 0-group sole (*i.e.*

71   normal/spontaneous behaviour) and test the effect of the ontogenetic status (sampling month)

72   on these activities according to light periods under constant experimental conditions

73   throughout the post-colonization period.

74

75   ## Materials and methods

76   This study was conducted under the approval of the Animal Care Committee of France under

77   the official licence of M.L. Bégout (17-010).

78

79   **Fish origin and maintenance**

80   Thirty-one wild 0-group juveniles were caught in the Pertuis Charentais, a main sole nursery

81   ground for the Bay of Biscay (Le Pape *et al.*, 2003), in June, July, September and November

82   2004 in a mussel pole-culture area (46° 15' 80''N, 1° 13' 40''W) using a push net to avoid

83   injuries to the fish (Durieux *et al.*, 2007). At the video-tracking laboratory, fish were

84   maintained in aerated tanks (45x30x35 cm) with filtered sea water (temperature: 20 ± 1 °C;

85   salinity: 35 ± 1; oxygen concentration: 100 % air saturation) and a sand substratum (light

86   colour). Both temperature and salinity were set to constant value as a mean of disconnecting

87   the experiment from field conditions in a consistent way for all the fish. Fish were fed daily

88   with frozen *Tubifex*. They were maintained under these conditions for at least 10 days

89   acclimatization prior experimentation in order to avoid tidal rhythm effects (Gibson, 1973,

90   Burrows, 1994) that could eventually prevent comparisons between months. An artificial

91   photoperiod was applied: daylight period (8:00 – 21:00), a twilight transition period (7:00 –

92   8:00 and 21:00 – 22:00) and a night period (22:00 – 07:00).

93

94   **Video-tracking set-up and experimental protocol**

95   In the video tracking laboratory (isolated from external disturbances): three black circular

96   arenas of 60 cm diameter, with walls drilled regularly with 5 mm diameter holes to allow

97   water circulation, were placed individually in a 400 l tank with aeration and water filters that

98   maintained a continuous water flow around the arena. A 5 cm deep layer of black sand (100

99   to 300 µm) was placed on the bottom of the arena in order to allow sole to bury and to

100   provide an adequate colour contrast to allow fish detection by the image analysis system.

101   Water was maintained at temperature around 20 ± 1 °C (by an air conditioning system in the

102   laboratory); salinity at around 35 ± 1 psu (by regularly changing sea water and when needed

103   adjusting salinity with freshwater to compensate for evaporation); and oxygen concentration

104   at around 100% air saturation (using air aerator systems). The arenas were illuminated

105   laterally by artificial light with the same photoperiod used during maintenance of the fish:

106   daylight period (8:00 – 21:00; white light: 0.3×10^{15} Q.cm^{-2}.s^{-1}), a twilight transition period

107   (7:00 – 8:00 and 21:00 – 22:00; white light: 0.3×10^{14} Q.cm^{-2}.s^{-1}) and a night period (22:00 –

108   07:00; infrared light (PAR38 IR 175): 0.14 x10^{14} Q.cm^{-2}.s^{-1}). Since fish are not sensitive to

109   infrared light (Douglas & Hawryshyn, 1990), nocturnal behaviour was considered un-altered

110   by the artificial lighting used to assess nocturnal swimming. Fish were not fed the day before

111   the experiment nor during the subsequent video recordings.

112   Above each arena, a digital black and white high sensitivity camera (Sony XCD-X700, XGA)

113   linked to a computer equipped with Visilog 6.2 software (NOESIS, France) was mounted.

114   Image acquisition proceeded with cyclic sub-sampling of each arena with 33 s duration

115   sequences of 1 image s^{-1} and each image was saved in .jpeg format. Successive sequences

116   relative to a same arena were separated by a time lag of 2 min because of a 7 s delay between

117   each sequence acquisition. The resulting sub-sampling factor (SSF) was 1/3.6. For each

118   month, at 11:00, the day of the beginning of recording, one fish was introduced per arena, so

119   that three fish were recorded at a time. Videos were then recorded for 48 hrs duration. After

120   video recording, fish were individually measured (to 1 mm, standard length SL) (Table 1). To

121   complete each month group, successive recordings took up to 8 days.

122   Fish detection was based on the colour contrast between the fish (appearing in white) and the

123   black sandy bottom using image analysis (Visilog 6.2). The XY coordinates (mm) of the

124   barycentre of the detected fish shape were extracted for each image / time. An integrated

125   VBA module to Visilog 6.2, developed by NOESIS for this experiment, allowed automation

126   of the acquisition and image treatment process.

127

128   **Data analysis**

129   Five to ten individuals per month (June, July, September, November) *i.e.* around 1, 500 hrs of

130   video-tracking were analysed (Table 1). Based on XY coordinates, four behavioural

131   endpoints could be obtained: the distance travelled between consecutive images (D_i) and the

132   frequency of occurrence of three different activities: swimming (S_i), burying (B_i), and

133   immobility (I_i). When the fish was not detected, XY coordinates equalled 0, and the fish was

134   considered buried. When fish was detected but distance travelled between two consecutive

135   images was ≤ 5 mm s^{-1} (limit of motion detection of distance travelled between two

136   consecutive images) fish was considered immobile. Alternatively when distance travelled was

137   > 5 mm s^{-1} fish was considered swimming. Distance travelled were transformed in body

138   length (Bl) to avoid any effect of size on swimming speed (Peck *et al.*, 2006). For each

139   individual fish, hourly values of the four variables were calculated:

140   $$D_h = \frac{1}{SSF} \sum_{i=1}^{n} D_i$$

141   $$S_h = \frac{1}{n} \times 100 \sum_{i=1}^{n} S_i$$

142   $$B_h = \frac{1}{n} \times 100 \sum_{i=1}^{n} B_i$$

143   $$I_h = \frac{1}{n} \times 100 \sum_{i=1}^{n} I_i$$

144   with SSF: sub-sampling factor; n: number of observations per hour; i: individual observation

145   per sec.

146   D_h is expressed in Bl h^{-1} and S_h, B_h and I_h are expressed in percentage.

147

148   Using all 48 hrs observations, individual data were averaged for specific light periods (day,

149   twilight and night) prior analysis. Given the nature of the data, *i.e.*, non-independent light

150   periods, one-way repeated measures ANOVAs was used to test differences for each

151   behavioural variable (D, S, B and I) between month groups (between-subject factor: June,

152   July, September, October) and light periods (within-subject factor: day, night, twilight) as

153   well was interaction of both factors. Data were tested for normality with a Shapiro-Wilk test

154   and for homoscedasticity with a Bartlett's test. Since data could not meet assumptions they

155   were ranked prior analysis (Kane *et al.*, 2004). Homogeneous groups were determined with

156   the *a posteriori* multiple comparisons Newman and Keuls tests. Results are given as averages

157   ± SE (Standard Error). Statistical tests were performed using XLStat software and Systat.

158   Tests were considered significant at $p < 0.05$.

159

160   For derived instantaneous swimming speeds, only values > 5 mm s^{-1} (limit of motion

161   detection of distance travelled between two consecutive images) were considered. Swimming

162   speed frequencies were calculated for the different month groups with individual speed

163   classes of 2 cm s^{-1} and a range of 0.5 to 20 cm s^{-1}.

Results

165   Significant differences were detected for both factors (*i.e.* sampled months and light periods)

166   for all measured behavioural variables D, B, S and I (Table 2; Figure 1). Independently of the

167   light periods, D and S decreased significantly between June and July, while B increased

168   significantly. Between July and September, D, S and I decreased significantly, while B

169   increased significantly. The pattern observed for these four variables was independent from

170   the light periods. Between September and November, B decreased significantly and I

171   increased significantly independently of the light periods for both variables whereas no

172   difference was detected for D and S. D and S were significantly higher at night and twilight

173   than during the day, B was significantly lowest at night, intermediate at twilight and highest

174   during the day independently of sampled months. I was significantly highest at night

175   independently of sampled months.

176   For fish sampled in June, swimming speed frequencies displayed a bimodal distribution

177   (Figure 2). The first mode for speed comprised between 0.5-2 cm s^{-1} (0.4 Bl s^{-1}) and a second

178   for speed of 8-10 cm s^{-1} (2.2 Bl s^{-1}), each representing 25% of the overall swimming speeds.

179   For fish sampled in July, September and November, swimming speed frequencies displayed a

180   unimodal distribution with 50-60 % of swimming speeds between 0.5-2 cm s^{-1}.

181

Discussion

183   Our data were obtained under experimental conditions using a video tracking system at a

184   scale of observation enabling the assessment of daily spontaneous swimming activities

185   (levels, rhythms) of 0-group common sole for the first time. This method appears to be one of

186   the only non-harmful methods of quantifying free activity of 0-group sole. However, caution

187   should be applied in extrapolating these data to field observations. Swimming activity over

188   two days showed relatively high inter individual variability as often observed for fish (Bourke

189   *et al.*, 1997, Salvanes & Hart, 1998, Mehner, 2006). Body size is well known to influence fish

190   swimming activity so that in our study we used relative distance travelled in proportion of

191   body size in order to minimize size effect within and between sampled months. Alternatively

192   it is important to consider that the low sample size routinely employed in behavioural studies

193   (here five to ten replicates per sampled month) and often due to technical constraints might

194   also have the effect of rising the variability. Nevertheless, some clear temporal trends in the

195   behavioural activities form the post-colonization period till autumn were observed.

196

197   0-group sole showed a relatively clear circadian activity in line with the artificial light

198   conditions of the experiment, with higher swimming activity at night and twilight than during

199   the day and alternatively more burying activity during the day than during the night. This

200   nocturnal activity pattern is consistent with previous studies on young 0-group sole

201   (Macquart-Moulin *et al.*, 1991, Champalbert & Marchand, 1994, Champalbert &

202   Koutsikopoulos, 1995), older 2-group (Lagardère *et al.*, 1988, Laffargue *et al.*, 2006) and in

203   general in other flatfishes (Gibson, 1973, Burrows, 1994, Hurst & Duffy, 2005). Champalbert

204 et al. (1991) demonstrated that sole > 30 mm were photonegative at most light intensities

205 except at twilight. In the field, in addition to circadian rhythms, flatfishes display tidal

206 rhythms in swimming activity which has been shown for juveniles to correspond to a trade-

207 off between foraging, predator avoidance and the selection of suitable environmental

208 conditions (Burrows, 1994, Gibson *et al.*, 1998). In our study, fish were acclimatize for ten

209 days prior experiment in order to prevent any confounding effect of tidal rhythms between

210 sampled months.

211

212 Burying behaviour represented 80% of the activity in autumn months (September and

213 November). This behaviour is linked to a strategy for predation avoidance (Gibson, 1997) but

214 also energy saving with lower basal metabolism while buried (Howell & Canario, 1987). Sole

215 from June and July buried clearly less than fish from September and November. The later

216 were often immobile at the surface of the substratum, especially at night. As burying capacity

217 of juvenile flatfish is a strong logistic function of body size relative to the sediment grain size

218 (Gibson & Robb, 1992), June and July fish, due to their relatively small size, are likely to

219 have been limited by the size of the sand grains used in the experiment (100-300 µm).

220

221 The 0-group sole showed a strong decline in swimming activity from June to July (around 8

222 fold in distance travelled and 4 fold in % swimming), with very low activity remaining until

223 November. This drastic change was also observed in term of swimming speed frequency

224 distributions. Individuals sampled in June displayed a high proportion of fast swimming

225 speeds (around 10 cm s^{-1} or 2 Bl s^{-1}) that typically corresponds to off bottom swimming with

226 large scales movements (Champalbert & Koutsikopoulos, 1995, Hurst & Duffy, 2005)

227 whereas from July onwards the majority of swimming speeds were lower than 2 cm s^{-1} which

228 is characteristic of the foraging behaviour of juvenile flatfish searching for benthic prey

229   (Lagardère *et al.*, 1994, Hill *et al.*, 2000, Hill *et al.*, 2002). Both environmental (i.e. current,

230   salinity, light, and food availability) and endogenous factors are considered to play a

231   determinant role in nursery colonization (Champalbert & Koutsikopoulos, 1995). Here,

232   experimental conditions where the same for all sampled months so that we assume that our

233   observations reflect an ontogenetic change in swimming activity. 0-group sole juveniles in the

234   Bay of Biscay colonize nursery grounds around May (Amara *et al.*, 2000). Around one month

235   post-colonization, 0-group sole juveniles still demonstrate a relatively high swimming

236   activity. This behaviour may be a relic of an exploratory behaviour associated with

237   colonization of new habitat (Hurst & Duffy, 2005). Low activity from July onwards may

238   reflect the transition to a well established sedentary behaviour. From an ecological point of

239   view, this behaviour may be interpreted as giving a relatively high resiliency of 0-group sole

240   in confined areas of the shallow coastal habitat. This is consistent with field observations of

241   potential 0-group sole movements in different nursery grounds based on density distributions

242   (Dorel *et al.*, 1991, Rogers, 1992, Jager *et al.*, 1993), recapture of tagged individuals (Coggan

243   & Dando, 1988) and use of natural tags (Vinagre *et al.*, 2008).

244

245   In the field it has been reported that 0-group sole operate migration to deeper waters prior to

246   winter in order to avoid very low water temperature occurring in shallow part of the habitat at

247   this time (Dorel *et al.*, 1991, van der Veer *et al.*, 2001). Since we did not observed any

248   increase in swimming activity at this time under constant experimental conditions, this

249   suggest that such migratory behaviour prior to winter is mainly influenced by hydro climatic

250   factors.

251

252   In conclusion, using a laboratory video-tracking system this study provides a quantified

253   spontaneous swimming activity baseline levels of 0-group common sole through their first

254   period of life in coastal shallow areas. 0-group sole showed a clear ontogenetic change in

255   swimming activity between June and July, demonstrating the transition between the

256   exploratory behaviour of late colonization and the well established sedentary behaviour till

257   the onset of winter. These results highlight the potential movements limitation of 0-group sole

258   in coastal areas during this highly critical period.

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268

268   **References**

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372

372   Fig. 1. Average distance travelled (Bl h^{-1}) (A) and frequency occurrence (%) for the three

373   different types of activity swimming (B), burying (C) and immobility (D) per sampled month

374   and light period for 0-group common sole *Solea solea* captured in 2004 in the Pertuis

375   Charentais area (France). Artificial light time period was set as: Day: 8:00 – 21:00; Twilight:

376   7:00 – 8:00 and 21:00 – 22:00; Night: 22:00 – 7:00. Values were calculated on the total 48

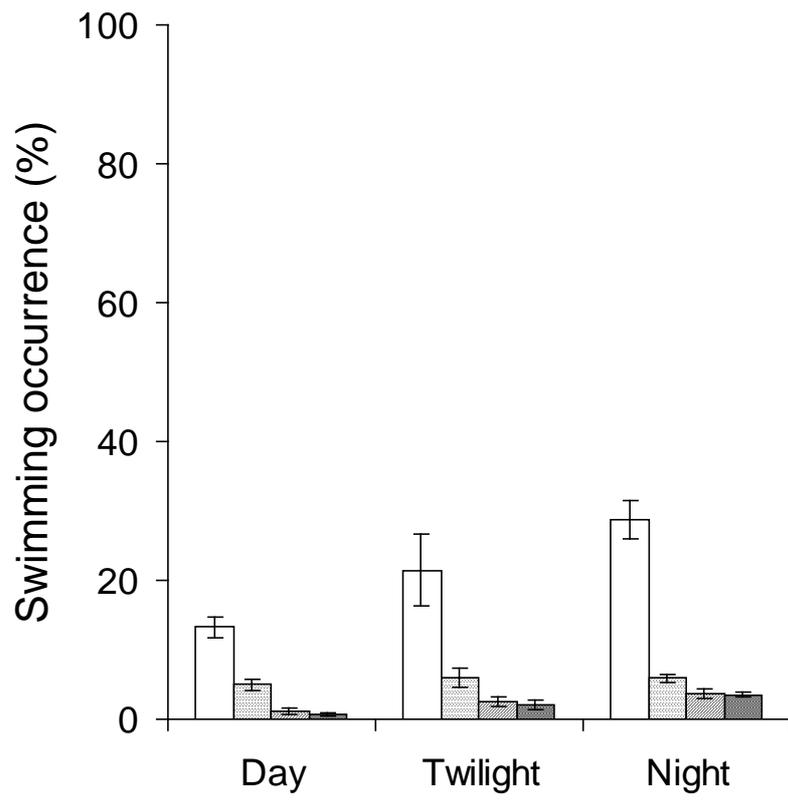377   hours observation period.

378

379   Fig. 2. Swimming speed (cm s^{-1}) frequency distribution calculated on the total 48 hours

380   observation period for each sampled month of wild-caught individuals captured in the Pertuis

381   Charentais area (France). 10 cm s^{-1} corresponds to 2.2, 2.0, 1.4 and 0.9 Bl s^{-1} in June, July,

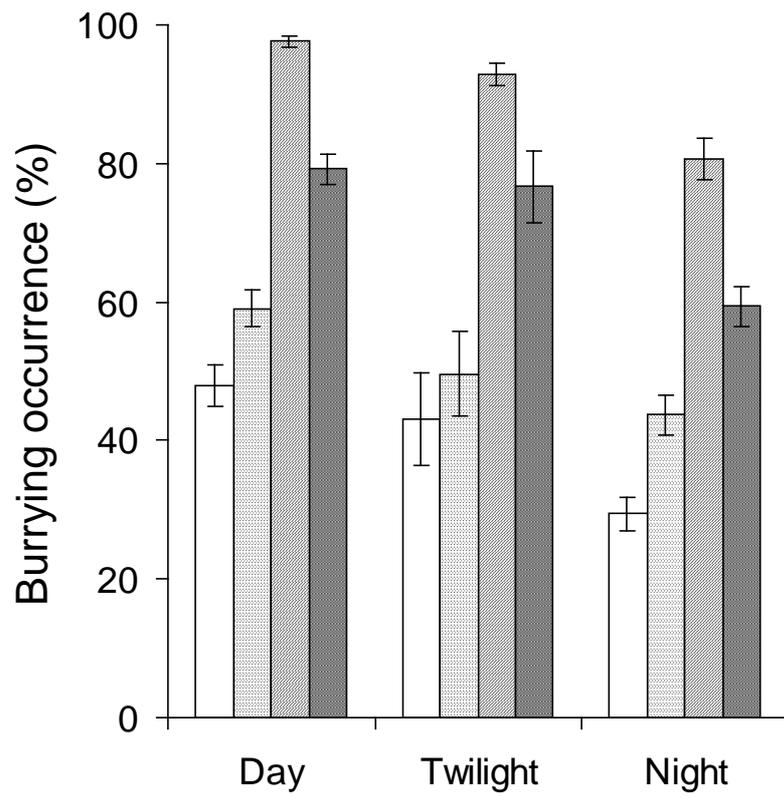382   September and November respectively.
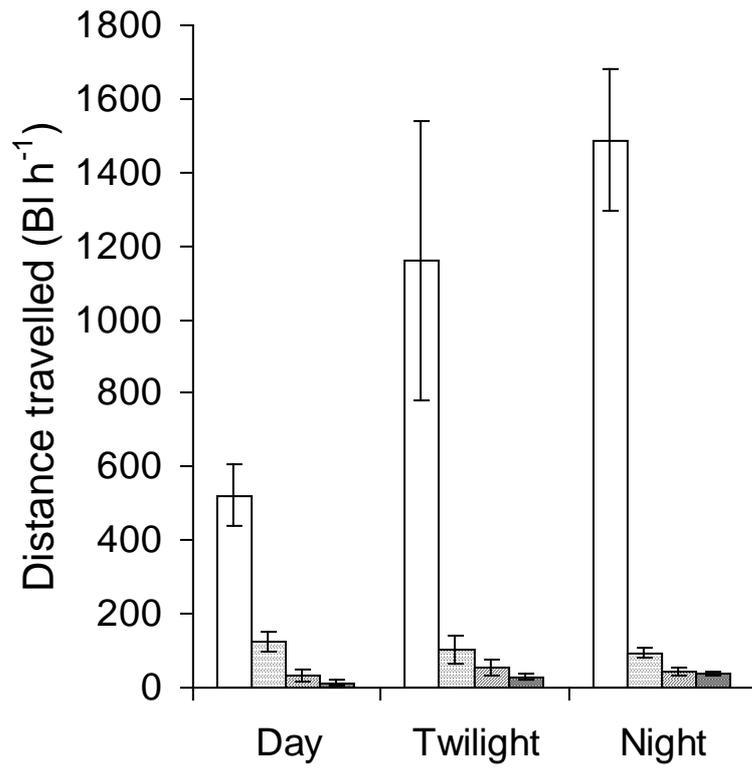
383

384   Fig. 1A.

385
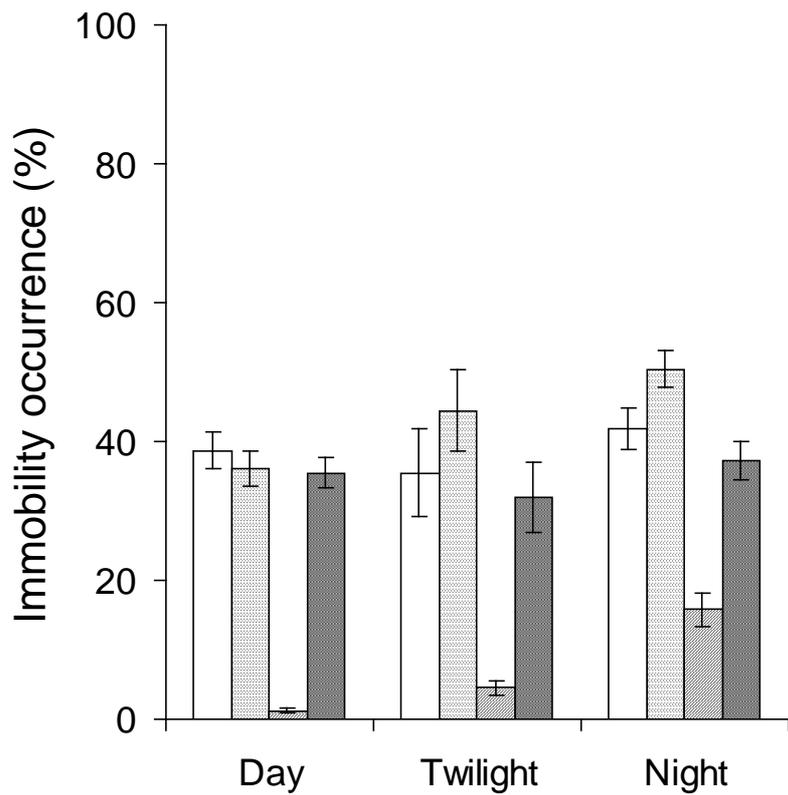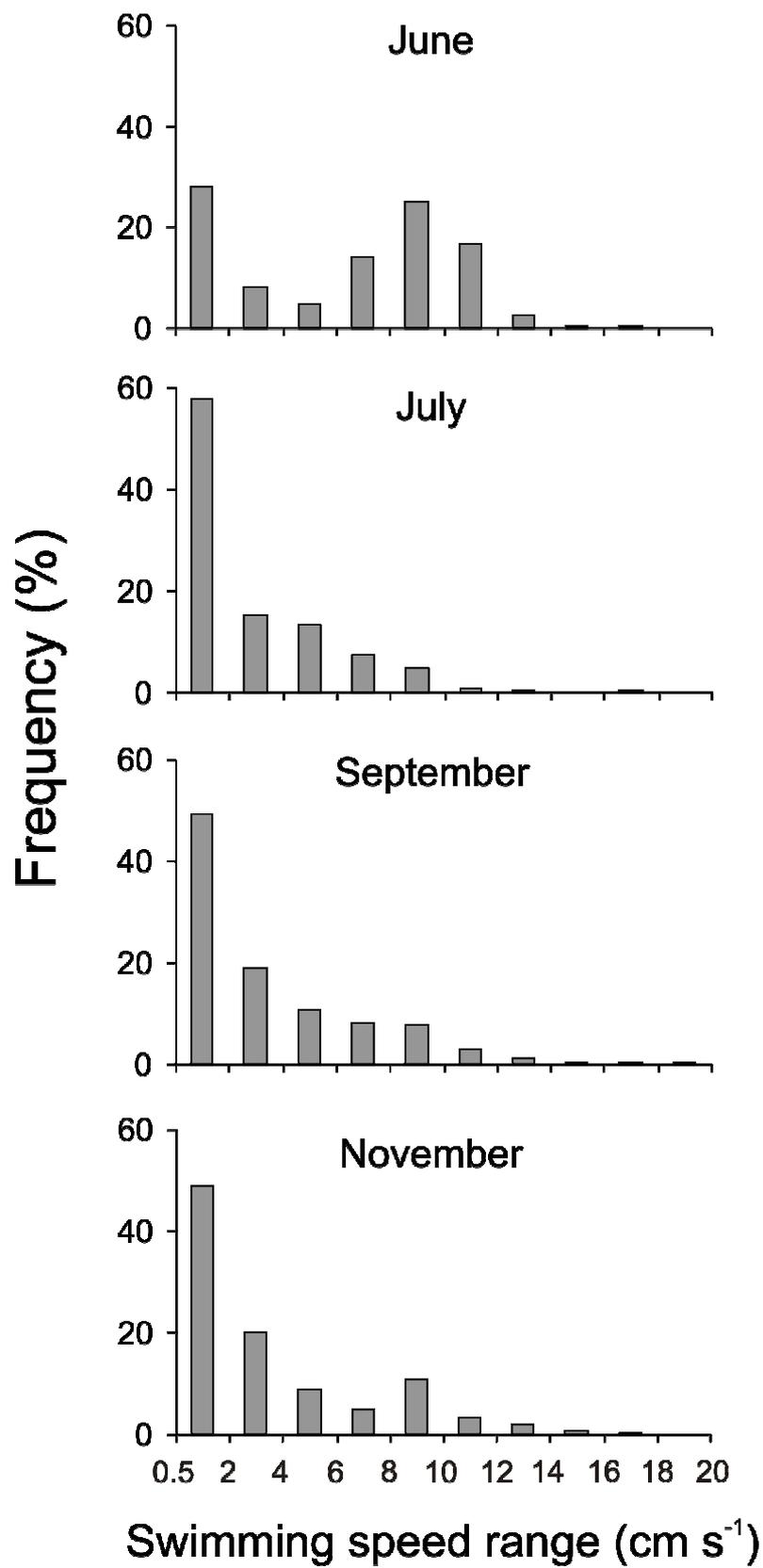
385

386   Fig. 1B.

387

388   Fig. 1C.

389

390   Fig. 1D.

392   Fig. 2.

393 Table 1. Sample size (n), mean standard length (SL ± SE (mm)), and size range of 0-group

394 common sole, *Solea solea* sampled in 2004 in the Pertuis Charentais nursery ground (France)

395

Sampled month	n	SL ± SE (mm)	Range (mm)
June	7	46.00 ± 1.23	41 - 50
July	9	51.22 ± 1.97	44 - 63
September	5	72.20 ± 1.43	69 - 76
November	10	108.80 ± 3.21	96 - 125

396

397 Table 2. Results of one-way repeated measures ANOVAs testing differences in mean behavioural variables (Distance travelled and Swimming,

398 Burying and Immobility occurrences; ranked transformed data) between months (between-subject factor), light periods (within-subject factor)

399 and interaction of both factors for 0-group common sole, *Solea solea* sampled in the Pertuis Charentais nursery ground (France). Multiple

400 comparisons Newman and Keuls tests posthoc Abbreviations are as follows: Jn: June, Jl: July, Sept: September, Nov: November; Twi: Twilight

401 period.

	Distance travelled (Bl h^{-1})				*Swimming occurrence* (%)			
Source	df	F	P > F	Newman and Keuls	df	F	P > F	Newman and Keuls
Month	3 - 27	10.48	<0.001	Sept = Nov < Jl < Jn	3 - 27	12.37	<0.001	Sept = Nov < Jl < Jn
Period	2 - 54	5.72	0.006	Day < Twi = Night	2 - 54	11.99	<0.001	Day < Twi = Night
Month x Period	6 - 54	1.14	0.354	ns	6 - 54	1.38	0.236	ns

	Burying occurrence (%)				*Immobility occurrence* (%)			
Source	df	F	P > F	Newman and Keuls	df	F	P > F	Newman and Keuls
Month	3 – 27	7.33	0.001	Jn < Jl < Nov < Sept	3 - 27	5.11	0.006	Sept < Nov < Jl = Jn
Period	2 - 54	17.54	<0.001	Night < Twi < Day	2 - 54	11.54	<0.001	Day = Twi < Night
Month x Period	6 - 54	0.46	0.834	ns	6 - 54	1.49	0.200	ns

402