Age, growth and maturation of the Sakhalin flounder
Limanda sakhalinensis of the northern Sea of Okhotsk

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Abstract. Sakhalin flounder abounds in the northern part of the Sea of Okhotsk and is currently a commercial fishing resource. Thus, the data needed for scientifically based management of this resource was obtained in the frame of a study carried out on the sampling of 1229 specimen caught in August–September of 2013 and 2019, determining age composition, growth and maturity of the fish. The otoliths were studied to reveal the age. The largest male with a credibly estimated age of 17 years was 27.0 cm TL and, weighted 184 g, while a 21 years old female was 35.0 cm TL and 408 g respectively. The measured data confirmed by the von Bertalanffy growth function calculations indicated that the growth of the female specimens is higher than that of the male. However, male specimens are faster in achieving their maximum length and reproductive maturity. Males start maturing at the age of 3 as they attain the length of 12.5 cm TL, while females mature at the age of five being 16.0 cm TL. The calculations indicate that for 50% of Sakhalin flounder, the males’ age of maturity is 4.1 years upon attaining TL 15.2 cm. Females mature in bulk at 7.5 years, attaining the length of 19.6 cm.

1. Introduction
Sakhalin flounder Limanda sakhalinensis Hubbs, 1915, is a widespread fish species of the northern part of the Pacific Ocean (from the Sea of Japan in the South and to the Chukchi Sea in the north) [1-17].

Despite being so widely distributed, the Sakhalin flounder's biology remains poorly studied. When analysing the fish fauna of such relatively well studied water area as the West Bering Sea, Balykin [18] stated that being a smaller flounder variety the Sakhalin flounder does not play a distinguished role in commercial fishing probably because almost nothing is known about it. This statement can be applied in full to the Sakhalin flounder occupying the northern shelf of the Sea of Okhotsk.

Still, due to its relatively high abundance, the biology of the Sakhalin flounder shall be studied not only by theoretical reasons, in the frame of the species biological diversity assessment in different habitats, but also practically, as this species of flounder fish has a potential for commercial fishing being currently the reserve of the northern part of the Sea of Okhotsk. Thus the aim of this work was to study such important aspects of the species biology as age, growth and maturity.

2. Research materials and methods
The bottom trawl survey samples collected by Akvaresurs research vessel in August–September 2013 were used as material for this study. Out of 110 trawls, the Sakhalin flounder was found in 46 stations...
in common coordinates 58° 00’–58° 47’ N and 146° 58’–150° 47’ E in the depth range of 97-300 m (figure 1). The study covered 1142 specimens of the Sakhalin flounder from this trawl catch. TL (total length) was used as a linear parameter of the study. Sex and maturity stage were assessed visually. In addition, 478 specimens were weighted and their otoliths were collected to define the age.

Figure 1. The trawl survey area in the northern part of the Sea of Okhotsk in 2013.

In addition, in early September 2019, sampling was made in the near-shore area south-west to Spafaryev Island, where the fish was caught by nets, and hook and line gear. All 87 fishes collected here were biologically analysed and their otoliths were taken. The otoliths were treated by the break-and-burn method [19, 21, 22]. The annual growth rings were observed using MBS-10 Stereo Microscope in incident light. The fish linear growth was studied based on direct observation of the average fish length in certain age groups and using the Von Bertalanffy growth formula (VBGF) adjusted by Mena and Klevesal [23] for fish application as follows $L_t = L_\infty - (L_\infty - L_0) e^{-k(t-t_0)}$: The linear growth calculations were based on n=565 sampling, the age of the specimens in the sampling was defined by the otoliths. $L_0$ at $t_0 = 0$ is the size of the alevins at the moment of breaking from eggs. There are no publications on the exact size of newly hatched alevins of the Sakhalin flounder. Based on the taxonomic similarity in size of the Sakhalin flounder eggs to those of the Yellowfin sole *L. aspera*, Pertseva-Ostroumova [24] suggested that the alevins of the Sakhalin flounder are at least 3 mm long. Taking this information as a reference we assumed that the size of the newly hatched alevins of the Sakhalin flounder is 2.75 mm (0.275 cm), which is similar to the size of newly hatched alevins of the Yellowfin sole, which we defined by experiment in study [13].

3. Results and discussions

The distinct sexual dimorphism by maximum size and age is characteristic of the majority of the northern Pacific Pleuronectidae. Regardless of geographic variation of these features, females in all the studied regions attain much bigger maximum length and age as compared to males [2, 27].

Diakov [27] prepared a systematic summary of all the available publications on the Sakhalin flounder and found that the specimens of the eastern part of the Sea of Okhotsk reach the longest lifespan (their males' maximum age is 18 years, females’ – 22 years). The lifespan of the specimens in Karaginsky and Olyutorsky Gulfs of the Kamchatka Peninsula Pacific coastline is no longer: 14 and 16 years respectively [28].

In the frame of our survey, the catch in the shelf of the northern part of the Sea of Okhotsk contained the Sakhalin flounder specimen from 19 generations. The otoliths of the biggest specimens of these flounders were collected and the results of the measurements were as follows: the longest male – 27.0 cm weighted 184 g and reached the age of 17 years; the longest female – 35.0 cm weighted 408 g and reached the age of 21 years (figure 2). In general, the power law equations describe the relationship
between the size and the age sufficiently well: $TL = 9.1754t^{0.3891}$ ($r = 0.93$) – for males and $TL = 8.8207t^{0.4005}$ ($r = 0.88$) – for females, where $TL$ – length, cm; $t$ – age, years. The obtained dependencies were used to define the theoretical age of the specimen for which only the body length was measured. This survey revealed inter alia that, in the total male sampling, the age of the biggest specimen (28.0 cm long and weighing 206 g) the theoretical age may reach 18 years.

![Figure 2. Otoliths of the Sakhalin flounder: left – a male 27.0 cm, 184 g, 17 years; right – female 35.0 cm, 408 g, 21 years.](image)

The total age composition of the Sakhalin flounder revealed a slightly positive asymmetry (the bar graph peaks in the left part at age value of 8.9). It indicates that the older fish generation prevails over the total number of the juveniles and the fish at their first maturity. The flounder of 7–10 age category were most numerous in the catches (63.8%) table 1.

Most obviously the positive asymmetry of the age class distribution was identified among the males. The total sampling of the collected males (including the specimens with the estimated age) comprised 16 fish generations of 3–18 years old, with the average value of 8.5 years. The males of 7–9 age group prevailed (56.2%) in this sampling. The females’ age range was wider: 3–21 years with the average age of 9.0 years. The total sampling of the collected females comprised 19 generations, 55.1% of which were from the 8–10 age group.

### Table 1. Age structure of Sakhalin flounder in catches of 2013 and 2019.

| Gender | Age, year | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Male | 3 | 0.3 | 1.6 | 6.5 | 9.6 | 14.7 | 29.7 | 27.9 | 11.8 | 8.0 | 5.2 | 4.4 | 4.3 | 1.8 | 1.1 | 0.5 | 0.3 | 0.2 | - | - | - |
| Female | 4 | 0.2 | 1.4 | 3.6 | 5.2 | 8.4 | 12.1 | 26.2 | 16.8 | 9.6 | 7.4 | 5.1 | 1.8 | 1.2 | 0.4 | 0.2 | - | - | 0.2 | 0.2 | 0.2 |
| In total | 5 | 0.3 | 1.5 | 5.3 | 7.7 | 12.0 | 22.2 | 18.0 | 11.7 | 7.1 | 5.7 | 4.6 | 1.8 | 1.1 | 0.4 | 0.3 | 0.1 | - | 0.1 | 0.1 |

The flounder fish (as many other fish species) are characteristic of the second type of size-sex relationship as per Zamakhaev classification [29]. For such fish populations, the males prevail among mature small-sized specimen, while among large-sized specimen, there are more females. According to [27], in the Sakhalin flounder catches from the eastern part of the Sea of Okhotsk, the numbers of males and females are almost equal with only slight overbalance by females.

In our survey, the catches in the northern part of the Sea of Okhotsk contained more males (57.3% of the total sampling). But such prevalence was not observed for all size groups. All smaller and less than 13 cm specimens were all males, the size group of 13–15 cm contained 80.0% of males, while size group of 21–23 cm contained almost equal number of both sexes, the fishes bigger than 28.0 cm were all females.

Using the Von Bertalanffy growth formula and the direct observation data on the sizes of the Sakhalin flounder in different age groups, we calculated the linear growth. The linear growth formulas are as follows: $L_t = 28.8 - (28.8 - 0.275)e^{-0.15t}$ for males and $L_t = 35.6 - (35.6 - 0.275)e^{-0.11t}$ for females. These calculations confirmed the outcomes of the direct observation identifying the sexual
dimorphism of the Sakhalin flounder, manifesting in quicker growth of the females. The delay in males
growth starts in their 7th year of life and, upon reaching the maximum age of 18 years, their length is
3.9 cm less than the length of females. At the same time, the males reach their maximum size quicker.
This is confirmed by the Walford plot logarithm slope: -0.15 for males and -0.11 for females.

When studying the sexual maturity issues of the Sakhalin flounder in Far-Eastern seas, Diakov [38]
analysed the data he obtained by himself and the data from publications [14, 18, 28, 31-36, 38]. He
concluded that in the studied area the length of the male specimens when they start maturing is 12.5 cm,
while the length of females at the beginning of the maturing varies between 13.5 and 16.0 cm. The age
of the mass males’ maturing is 3 years, and 2–4 years for females. Half of the males become mature
when they attain the length of 15.0 cm at 3.2 years, and females – when reaching 19.0 cm at 4.2 years.

The Sakhalin flounder in the western waters of the Kamchatka Peninsula matures much quicker than
the other species of Pleuronectidae [36]. Here, specimens of both sexes start maturing upon reaching the
length of 13.5 cm. The long-time average annual data indicate that the mass maturing size and age for
females is 19.0 cm and 4.2 years, and 15.0 cm and 3.2 years for males. Some specimens remain immature
up to their maximum length.

The observations in the frame of our study in the northern part of the Sea of Okhotsk revealed that
the smallest mature males were 12.5 cm long and 3 years old. In the bigger size groups, the percentage
of mature males increases: up to 49.3% in the 13.0–15.0 cm size group, and 93.6% in the 23.0–25.0 cm
and 11–15 years size-age groups. All males become fully mature upon attaining the length of 26.3 cm
and the age of 15 years.

All Sakhalin flounder females become mature upon attaining the length of 16.0 cm and the age of 5
years. The rate of maturing in the studied size-age classes is also rather high. In the 19.0–21.0 cm size
group (6–8 years old) the mature females constitute 47.7%, and all the females reach 100% maturity
upon attaining the length of 27.7 cm and the age of 16 years.

The second-order polynomial clearly describes the dependency of the fish size and maturity:
y = −0.1958x^2 + 12.322x − 92.108 for males and y = −0.237x^2 + 16.307x − 178.830 for females,
where x – body length TL, cm; y – percentage of mature specimens, %. The calculations indicate that,
for 50% of the Sakhalin flounder males, the age of maturity is 4.1 years upon attaining the length of
15.21 cm. The females mature in bulk at 7.5 years attaining the length of 19.64 cm.

We compared the data on the Sakhalin flounder maturity obtained in the frame of our survey and the
data on the same species populating the waters of the western Kamchatka Peninsula available in
publications [38], and made the conclusion that in the northern part of the Sea of Okhotsk the Sakhalin
flounder mature upon attaining the similar size but at an older age, which is probably due to their
comparatively slow growth rate.

4. Conclusion
The survey of 2013 and 2019 has shown that the Sakhalin flounder in the northern part of the Sea of
Okhotsk is one of the biggest and most long-living species by habitat. The males grow up to 28 cm and
live up to 18 years, the females – up to 35 cm and 21 years. Their linear growth is characteristic of the
sexual dimorphism manifesting in quicker growth of the females. The comparative analysis of our
survey outcomes and the data from publications revealed the similar growth rates of the Sakhalin
flounder from the northern shelf of the Sea of Okhotsk and the populations from the western Kamchatka
Peninsula and the eastern part of the Sea of Okhotsk. While the linear growth rates of the fish at the first
maturity are similar, the mass and the complete maturity of the Sakhalin flounder population from the
northern part of the Sea of Okhotsk is attained later due to a comparatively slow growth rate.

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