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Characteristics of Distribution and Ecology of the Whitespotted Greenling *Hexagrammos stelleri* (Hexagrammidae) in the Sea of Okhotsk Waters around Kamchatka

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Abstract—Bottom trawl survey conducted in the Sea of Okhotsk waters around Kamchatka during the summer-fall period in 1999–2019 demonstrated that the whitespotted greenling *Hexagrammos stelleri* is a common component of the benthic ichthyofauna. The densest aggregations have been reported from northern part of the West Kamchatka Shelf, which is determined by specific hydrological regime in this area. The spawning peak falls on August, when the species is observed in considerable quantities at the depths < 20 m, considering the dynamics of catches, frequency of occurrence, and bathymetric distribution of the greenling in June–October. In fall, the fish young transitions to the near-bottom layers and concentrates within the 31–40 m range of depths. In the study area, *H. stelleri* is represented in catches by the individuals 7–37 cm in length with weights of 10–680 g. When compared with the Sea of Okhotsk waters, findings of the length–weight relationship analysis at the western coast of Kamchatka suggest different patterns of growth rate in the whitespotted greenling within the confines of the Sea of Okhotsk.

Keywords: whitespotted greenling *Hexagrammos stelleri*, distribution, length composition, weight, the Sea of Okhotsk

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Hexagrammos spp. ubiquitously occur in Kamchatka waters. Due to inconsiderable aggregations, fishes of this group are not used for commercial harvesting, while being, however, the potential objects of coastal fishing and acquiring increasing importance in game fishing segment (Yusupov et al., 2006; Tokranov, 2018). Of these species, whitespotted greenling *H. stelleri* is the most widely distributed across the northern part of the Pacific Ocean from Peter the Great Gulf of the Sea of Japan and the Pacific coast of Hokkaidó Island at the Asian to the North Coast of California (Rutenberg, 1962; Lindberg and Krasyukova, 1987; Allen and Smith, 1988). Additionally, it is recorded from the contiguous Arctic areas, namely, the Chukchi Sea and western part of the Beaufort Sea (Mecklenburg et al., 2002; Antonenko 2010).

Currently, life cycle of *H. stelleri* across the range this vast is extremely poorly understood. In Russian waters, distribution, biology, and state of the stock of whitespotted greenling have been extensively studied in water of the northern Sea of Okhotsk (Chernyshev et al., 2001; Shestakov and Nazarkin, 2006; Yusupov et al., 2006; Shestakov, 2019) and in Peter the Great Gulf of the Sea of Japan (Antonenko and Vdovin, 2001; Antonenko and Gnobkina, 2001; Vdovin and Antonenko, 2001; Antonenko and Pushchina, 2002). At the same time, investigations of life cycle in this species are reported based on very limited material (Zolotov, 2012), at the Sea of Okhotsk coast, in particular, where it occupies dominant position among *Hexagrammos* spp. both based on the abundance and biomass. One exception is studies on the state of the stock and feeding in *H. stelleri* in this water area (Chetvergov, 2000; Napazakov, 2010, 2015).

The goal of the study is to analyze and characterize frequency of occurrence, distribution, and distinctive features of the ecology of *H. stelleri* in the Sea of Okhotsk waters around Kamchatka.

MATERIALS AND METHODS

The material was collected at the western coast of Kamchatka during the summer-fall period (June–October) 1999–2019 in the course of carrying out the trawl surveys (Table 1). Trawling was conducted with the *DT* 27.1 bottom trawl at vessel speed of three knots. The analysis only involved trawling conducted within the range of depths to 300 m, since whitespotted greenling is a sublittoral species and does not occur in

Table 1. List of bottom trawl surveys at the western coast of Kamchatka, which materials were employed by the study

Vessel	Year	Date	Depth covered, m	Number of trawls and measured fish		
				N	N_R/n	N_T
RV *Professor Kaganovskii*	1999	05.07–04.08	14–206	141	21/161	21
MFFST *Pogranichnic Petrov*	2000	19.07–03.09	12–300	156	28/659	25
Same	2001	02.07–13.08	12–201	206	43/522	43
MTF *Sopochnoe*	2002	14.07–12.08	8–206	179	32/–	18
MFFST *Pankara*	2003	03.09–22.10	14–300	235	96/–	–
RV *Professor Probatov*	2005	02.07–21.08	15–296	213	46/43	46
RV *Professor Kaganovskii*	2005	15.06–22.07	13–202	284	65/–	65
MFFST *Pogranichnik Kerdishchev*	2006	04.07–25.07	15–151	59	15/111	–
RV *Professor Kaganovskii*	2007	07.07–09.08	14–200	196	56/858	–
Same	2008	05.07–29.07	11–201	198	45/–	1
RV *Professor Kizevetter*	2009	23.07–27.08	14–284	241	49/27	–
Same	2010	05.07–08.08	13–262	208	54/794	54
RV *TINRO*	2011	08.07–11.08	13–300	218	51/266	–
RV *Professor Probatov*	2012	05.07–22.07	9–102	124	20/–	–
Same	2013	15.06–21.08	13–261	200	51/–	51
RV *TINRO*	2014	09.06–18.07	14–299	226	65/14	64
RV *Professor Kizevetter*	2015	06.06–13.07	14–300	239	58/14	–
RV *TINRO*	2016	02.06–06.07	13–298	226	68/16	68
Same	2017	22.06–01.08	12–298	241	73/1499	65
"	2017	05.10–12.10	15–255	41	13/–	–
"	2018	01.06–03.07	12–204	185	66/44	66
RV *Professor Kaganovskii*	2019	11.06–12.07	11–275	218	73/381	73
Total				4234	1088/5409	660

(RV) research vessel, (MTF) medium-sized fishing trawler, and (MFFST) medium-sized fishing freezer stern trawler. Number of repeated trawls: (N) total, (N_R) effective (with whitespotted greenling recorded in catches), (N_T) with measuring the near-bottom layer temperature; (n) the number of measured fish.

the upper regions of the continental slope. The catches from each trawl survey were sorted using the generally adopted method (Borets, 1997).

Spatial and bathymetric distribution, length structure of catches, and temperature preferences of whitespotted greenling were analyzed based on materials from the 2000–2019 surveys. (4093 trawls, 5248 ind.); dependence of the body weight (W) on total length (TL) based on data collected in 1999 (141 trawls, 161 ind.). Frequency of occurrence (FO, %) was determined as ratio of the number of effective repeated trawling to their total number. Spatial distribution of catches was mapped using ArcView GIS 3.3 program. Density based on bathymetric ranges was calculated using the area method (Aksyutina, 1968) with some modifications (Lapko, 2002; Davin, 2012). This parameter was further depth–averaged. Catching capacity coefficient of 0.4 was adopted for the considered species (Borets, 1997; Il'inskii, 2007). Whitespotted greenling distribution was analyzed dependent on temperature of the near-bottom layer during the summer period by mean density values (ind./km^2).

RESULTS AND DISCUSSION

During the period of the trawling operations, whitespotted greenling was persistently recorded in catches from within the boundaries of the surveyed area, stretching from Cape Lopatka in the south to Cape Yuzhnyi in the north (Fig. 1). In this species, FO varied between 14.9 and 40.9% (25.4% on average) over the years. Therefore, *H. stelleri* is a common component of benthic ichthyofauna of the West Kamchatka Shelf.

Catches were recorded to be the highest north of 54° N, which does not contradict the earlier studies (Chetvergov, 2000). Both in summer and fall, catches of *H. stelleri* were relatively low and did not exceed 100 ind./h of trawling at the Kamchatka southwesternmost point. Spatial distribution of whitespotted greenling confirms assumption of Zolotov (2012) that

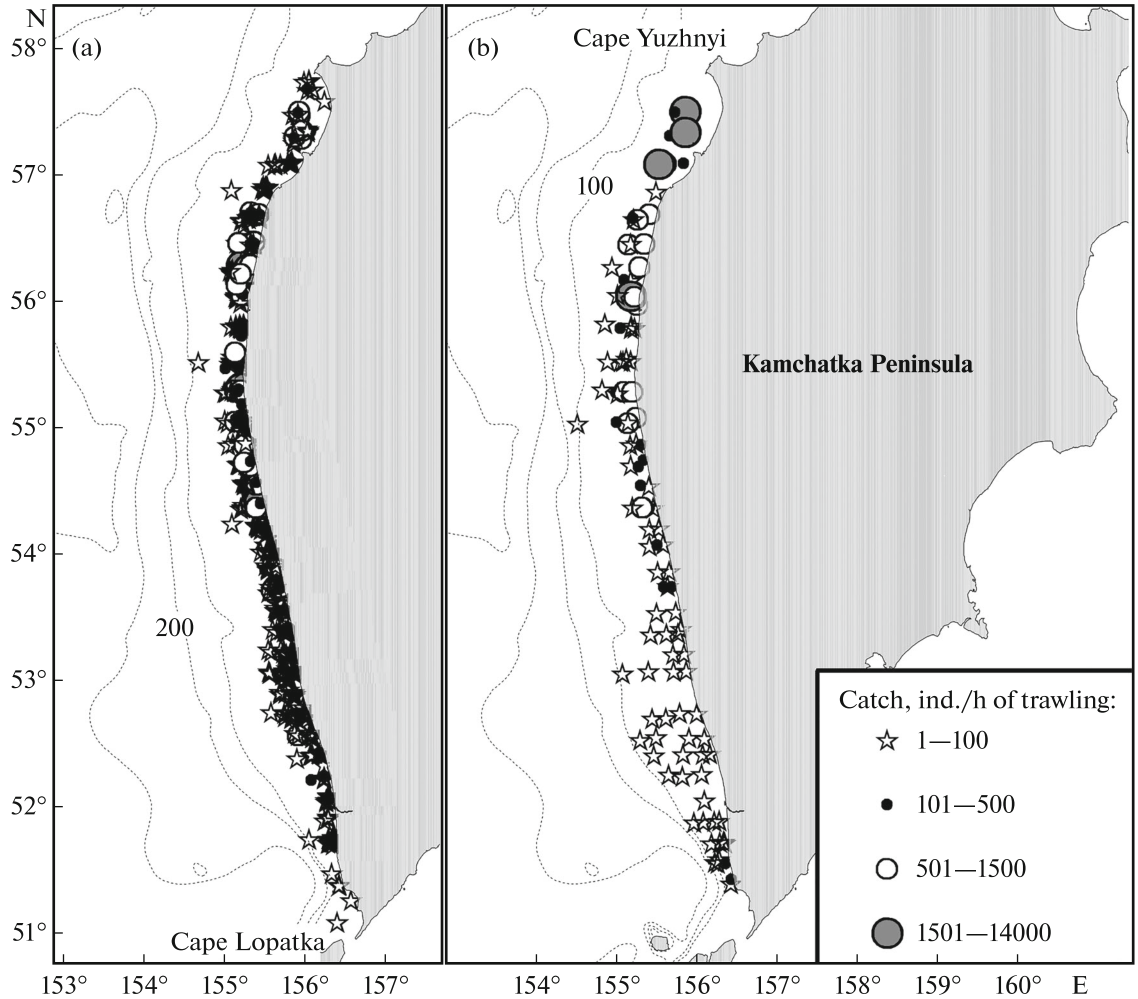

Fig. 1. Distribution of whitespotted greenling *Hexagrammos stelleri* at the western coast of Kamchatka during the (a) summer and (b) fall periods of 2000–2019; (···) isobath.

this species prefers the modified subarctic water masses of the Sea of Okhotsk with lower values of temperature and salinity.

Size of catches and frequency of occurrence in whitespotted greenling is subject to seasonal dynamics at the Kamchatka western coast during the considered period (Fig. 2). Mean values of catches were recorded to be the maximum in July in summer and September in fall, while the minimum in August and October, respectively. Most frequently, *H. stelleri* was recorded in June (30.3%) and October (27%), while the FO parameter was the lowest in August (15.9%). The identified dynamics of these parameters appears to be associated with peculiarities of *H. stelleri* distribution at different stages of the life cycle. As is known (Gorbunova, 1962), spawning in this species occurs during summer-fall period, while being reported to occur later in southern areas compared to the northern. Thus, whitespotted greenling spawns in September–October in the Peter the Great Gulf area of the Sea of Japan (Antonenko and Pushchina, 2002); from the late June until September in Taui Bay in the northern Sea of Okhotsk (Shestakov and Nazarkin, 2006; Shestakov, 2019); but in October–December at the Pacific Coast in the Puget Sound area and in October–December in the San Juan archipelago (Patten, 1980; DeMartini, 1986). Declines in catches and frequency of occurrence in *H. stelleri* at the western coast of Kamchatka in a second half of summer appears to indicate the onset of the spawning season, peaking in August. *H. stelleri* reproduces in the littoral zone within a range of depths of 2.5–8 m (DeMartini, 1986; Antonenko and Gnyubkina, 2001; Yusupov et al., 2006), where no inventory trawling was carried out. Therefore, size of catches does not reflect the actual abundance of the species. Minimum catches in October appear to be governed by two reasons. First, this is the time when sexually mature fishes gradually withdraw from spawning grounds located in shallow waters without forming the dense aggregations. Second, the minimum value of average catches may be determined

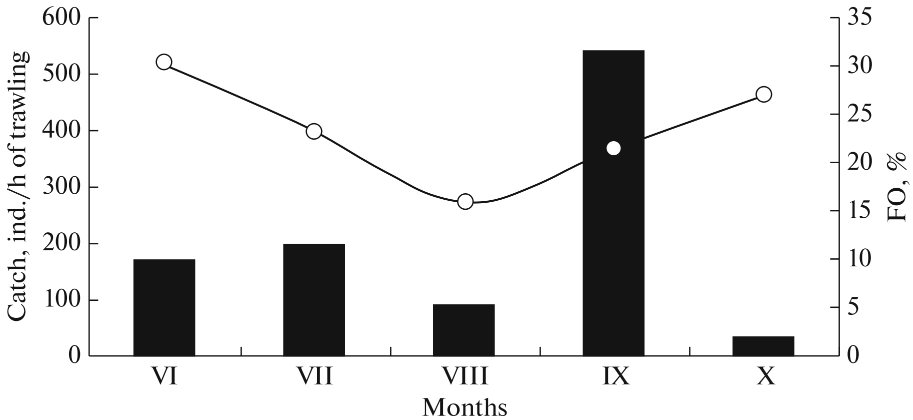

Fig. 2. Dynamics of (□) mean catches and (–○–) frequency of occurrence (FO) of whitespotted greenling *Hexagrammos stelleri* by months at the western coast of Kamchatka during the summer-fall period in 2000–2019.

by a considerably less trawling done in October compared to other months.

Whitespotted greenling represents the sublittoral ichthyocoen and occurs throughout the entire range of the shelf depths at various stages of its life cycle. Lower boundary of vertical distribution is limited by the specific features of particular habitat. Thus, it constitutes 175 m for the eastern Bering Sea (Allen and Smith, 1988) and 308 m for the Russian waters of the Sea of Japan (Panchenko et al., 2016). For the Sea of Okhotsk waters around Kamchatka, Zotov (2012) indicates the depths of 151–200 m. In our catches, *H. stelleri* was recorded from within the 10–117 m range during summer-fall period of 2000–2019. In the summer months, this species most frequently occurred at depths <20 m, where its mean distribution density peaked at 6833 ind./km^2 (941.3 kg/km^2) (Table 2). Formation of whitespotted greenling aggregations of such a great density in shallow waters might be attributed to the onset of its spawning season. In fall, whitespotted greenling largely concentrated at the depths of 31–40 m with 29944 ind./km^2 (490.1 kg/km^2). Reasons for these high values of density by abundance and low by weight can be explained in a following way.

The embryonic period in whitespotted greenling lasts ~1 mo.; hatched fish larvae inhabit the pelagic zone, while commonly occurring far away from shore (Gorunova, 1962; DeMartini, 1986; Yusupov and Yusupov, 2019). According to Tokranov and Safronov (2004), in the near-surface layer of the Sea of Okhotsk (0–5 m), single encounters with *H. stelleri* larvae *TL* 9–13 mm happen in August, their numbers in ichthyo-neiston dramatically increase by September–October, which points to the large-scale hatching. The

Table 2. Bathymetric distribution of whitespotted greenling *Hexagrammos stelleri* at the western coast of Kamchatka during the summer and autumn periods of 2000–2019

Depths, m	Summer (June–August)				Autumn (September–October)			
	FO, %	*P*		*n*	FO, %	*P*		*n*
		ind./km^2	kg/km^2			ind./km^2	kg/km^2	
<20	85.2	6833	941.3	495	85.7	6765	187.6	28
20–30	62.3	4137	766.4	665	87.8	10210	571.3	49
31–40	27.8	2191	451.2	335	87.5	29944	490.1	16
41–50	7.4	446	68.3	336	55.0	1490	342.5	20
51–60	1.6	522	158.1	375	44.0	346	65.0	25
61–70	1.0	112	22.5	204	27.3	244	21.7	11
71–80	0.5	57	18.1	415	7.1	57	6.3	28
81–90	–	–	–	125	–	–	–	13
91–100	–	–	–	172	–	–	–	27
>100	–	–	–	694	1.6	94	32.8	61

(FO) frequency of occurrence, (*P*) mean density, (*n*) the number of repeated trawling, (–) no information available

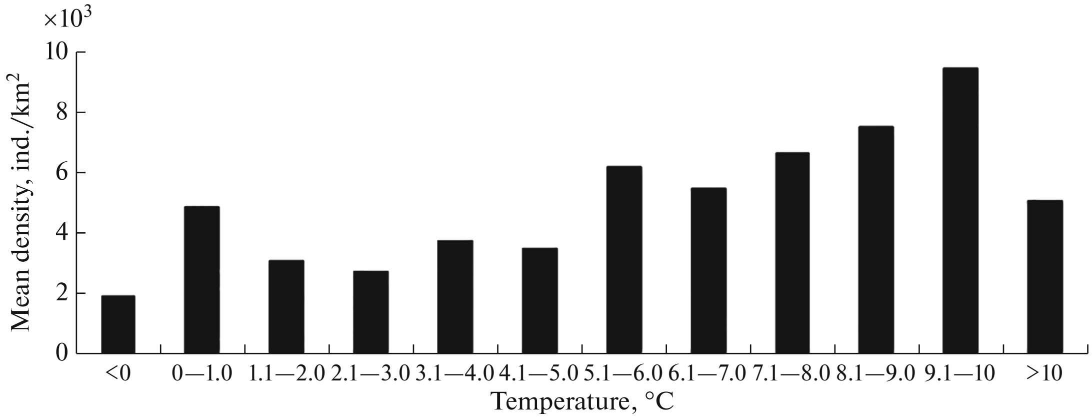

Fig. 3. Distribution of whitespotted greenling *Hexagrammos stelleri* dependent on the near-bottom water layer temperature at the western coast of Kamchatka during the summer period in 2000–2019.

larval greenlings reach *TL* 7–22 mm at this time. Length of the fingerlings varies between 24 and 43 mm in June next year, FO begins to decline, and subsequently, they are no longer recorded from the near-surface layer due to their transition to the epipelagic zone. As reported by Gorbunova (1962), length of the greenling fingerlings in this layer reaches 30–70 mm in July. Beginning a first half of fall, young of the whitespotted greenling in the study area might be assumed to change the lifestyle from the pelagic to benthic, considering dynamics of catches, frequency of occurrence by months, and the likelihood of peak of the *H. stelleri* spawning in the Sea of Okhotsk waters around Kamchatka falling on August. Appearance of the significant number of smaller-sized individuals additionally explains substantial catches at the western coast of Kamchatka in September (Fig. 2) and high levels of frequency of the occurrence at the depths of 31–40 m.

According to Antonenko and Vdovina (2001), in Peter the Great Gulf, young of whitespotted greenling transitions to the benthic lifestyle in August–September. This takes place one to two months later In the Sea of Okhotsk waters around Kamchatka. Differences of this kind appear to be caused by hydrological regime of the study area, which significantly affects growth rates in *H. stelleri*.

Whitespotted greenling occurs within rather wide temperature range of the near-bottom waters from –2 to 11.7°C (Napazakov, 2010; Zolotov, 2012; Love et al., 2016); in other words, it is a eurythermic species. According to the materials collected during the summer months in 2000–2019, *H. stelleri* was recorded at the bottom temperatures, ranging from –0.2 to 12.6°C with 7–10°C being the most preferred range (Fig. 3). It should be emphasized that distribution of the greenling dependent on near-bottom temperature is rather consistent with the ones across ranges of depths during the summer period, since precisely at this time the studied species begins its spawning migration to warmed-up nearshore areas.

Of the *Hexagrammos* spp., whitespotted greenling is characterized by comparatively small sizes. The maximum *TL* 48 cm has been recorded in the North California area of the United States (Miller and Lea, 1972). According to Rutenberg data (1962), there were cases of the fish finds in the Asian part of the range with *TL* 45 cm near Kamchatka coast, however, without indicating the catch area; *H. stelleri* can attain *TL* 42 cm in Peter the Great Gulf (Antonenko and Pushchina, 2002). Our catches at the western coast of Kamchatka contained individuals of *TL* 7–37 cm with the dominant size group (29.4%) of 20–23 cm (Fig. 4); maximum parameter was recorded only from one individual. Presence of the fish with *TL* 7–10 cm suggests that as they reach these lengths, young of the whitespotted greenling proceeds with benthic lifestyle. Nevertheless, this does not exclude occasional catching of small-sized individuals in the pelagic zone during bringing up the trawl aboard the vessel. Note that in southern habitat, e.g., Peter the Great Gulf, change of the species lifestyle occurs after reaching the somewhat larger sizes (*TL* 12–13 cm) (Antonenko and Vdovin, 2001).

Maximum weight of whitespotted greenling of 680 g has been recorded in catch in 1999; specifically, female of *TL* 36 cm. Similar indicators were obtained in the northern Sea of Okhotsk, that is, female *TL* 35.3 cm weighted 659 g (Yusupov et al., 2006). Relationship between the body length and weight of the whitespotted greenling from the Sea of Okhotsk waters around Kamchatka, which were calculated for 161 ind. (*TL* 10–36 cm, weigh 10–680 g), is described with equation $W = 0.0076TL^{3.1552}$, $R^2 = 0.964$ (Fig. 5). The only other data on the length–weight relationship in *H. stelleri* is available for the littoral zone of Magadan Region (Yusupov et al., 2006). Compared to the waters around Kamchatka, value of power coefficient

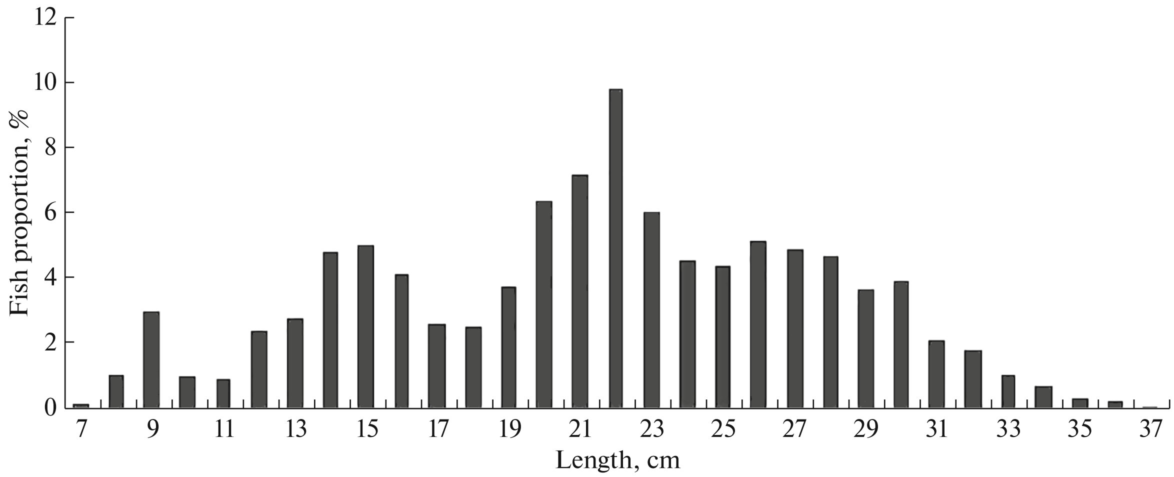

Fig. 4. Length composition of whitespotted greenling *Hexagrammos stelleri* in trawl catches at the western coast of Kamchatka during the summer-fall period in 2000–2019 (5248 ind., $TL = 21.44 \pm 0.08$ cm).

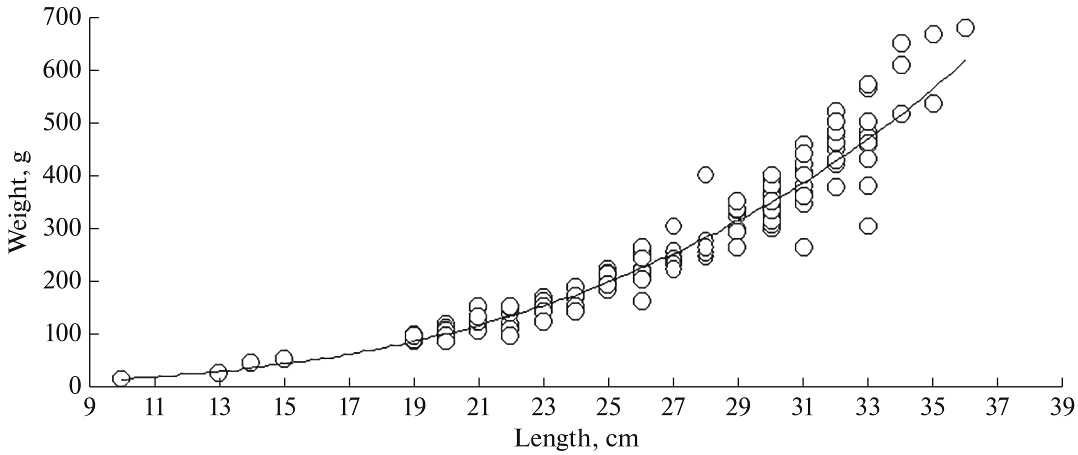

Fig. 5. Body length–weight relationship in whitespotted greenling *Hexagrammos stelleri* at the western coast of Kamchatka in 1999: $W = 0.0076TL^{3.1552}$, $R^2 = 0.964$, $n = 161$ ind.

of the given equation in the latter area is significantly higher (3.5873), which may suggest different growth patterns in whitespotted greenling from within the confines of the Sea of Okhotsk.

CONCLUSIONS

1. Whitespotted greenling is a common representative of the bottom ichthyofauna of the Sea of Okhotsk waters around Kamchatka. The major aggregations in this water area were reported north of 54° N, which is governed by a distinctive hydrological regime of the northern part of the West Kamchatka Shelf.

2. In whitespotted greenling, dynamics of catches and frequency of occurrence by months suggests that spawning peak in this species at the western Kamchatka coast falls on August. Additionally, it is presumed that individuals *TL* 7–10 cm change their lifestyle from the pelagic to benthic in a first half of fall.

3. In the study area, bathymetric range in *H. stelleri* is 10–117 m. Whitespotted greenling forms the major aggregations during the summer period at a depth < 20 m, which is associated with the onset of spawning migration and during the fall period at a depth of 31–40 m, which results from transition of the young down to the bottom and their subsequent distribution.

4. In the Sea of Okhotsk waters around Kamchatka, whitespotted greenling is recorded both under the negative values of the near-bottom water temperature and from warmed-up nearshore sites.

5. In the study area, length of *H. stelleri* in catches varies between 7 and 37 cm with the weight of 10–680 g. When compared with the northern Sea of Okhotsk,

findings of the length–weight relationship analysis at the western coast of Kamchatka may suggest different growth patterns in whitespotted greenling within the limits of the Sea of Okhotsk.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The author declares that he has no conflicts of interest.

Statement on the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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