Temporal variations in size-at-age of the western Bering Sea herring

Nikolay I. Naumenko
Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO), 18 Naberezhnaya Street., Petropavlovsk-Kamchatsky, 683600, Russia. E-mail: nnaumenko@kamniro.kamchatka.ru

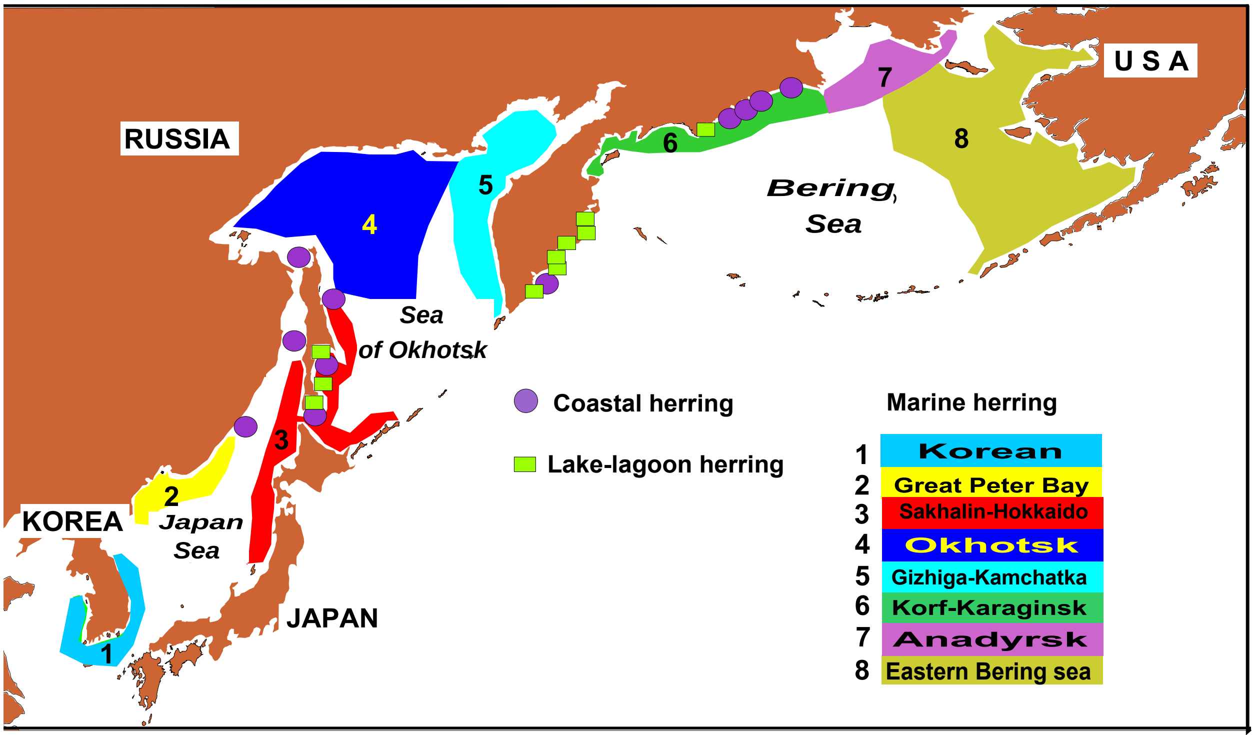

Fig. 11 Distribution of herring populations in the Far Eastern Seas.

Pacific herring inhabiting the Russian Far East Seas are represented by three ecological morphs: marine, offshore (coastal) and lagoon-lacustrine. Marine herring spend their whole life in higher salinity ocean waters where they undergo long migrations. The feeding area of this morph includes both shelf and bathypelagial waters. Off-shore herring inhabit only the shelf seas, particularly inlets and bays. This morph usually does not migrate long distances. Lagoon-lacustrine herring spend significant parts of their lives in brackish waters and migrate to feed in adjacent marine waters.

Russian waters in the northwest part of the Pacific Ocean are inhabited by 6 marine populations and by 22 off-shore and lagoon-lacustrine populations (Fig. 11). This ecological diversity provides maximum exploitation of forage resources for the species within the area and determines the extensive variability of size and growth parameters for this species.

Current information is based on many years of the author's personal observations of the growth in several herring populations inhabiting the Bering Sea and Pacific Ocean waters adjacent to Kamchatka: Korf-Karaginsky Bay, Eastern Bering Sea, Anadyr Bay, Yuzhnaya Lagoon, Nepichye Lake, Kalygyr Lake and Viluy Lake. The data on the growth of herring in the Sea of Japan and in the Sea of Okhotsk have been taken from literature. Forage base conditions are analyzed from annual standard surveys, each of them consisting of 7 stations sampled within Olyutorsky Bay in June.

The data on the size-at-age of herring taken from 19 areas within the northern part of the Pacific Ocean clearly indicate a significant difference in the growth of fish (Tables 4 and 5). Off-shore and lagoon-lacustrine herring have been classified as moderate or slow growing (Fig. 12). Marine herring are the most divergent in the growth. For example, there are extremely fast-growing (Sakhalin-Hokkaido herring inhabiting the waters adjacent to Hokkaido Island and Peter the Great Bay herring), fast-growing (Sakhalin-Hokkaido herring inhabiting the waters adjacent to Sakhalin Island, Korf-Karaginsky Bay herring, Bristol Bay herring) and moderate-growing (Okhotsk Sea herring, Gijiga-Kamchatkan herring, Anadyr Bay herring, Nunivak Island herring and Norton Bay herring) herrings. In general, the marine morph has a higher growth rate (Fig. 13).

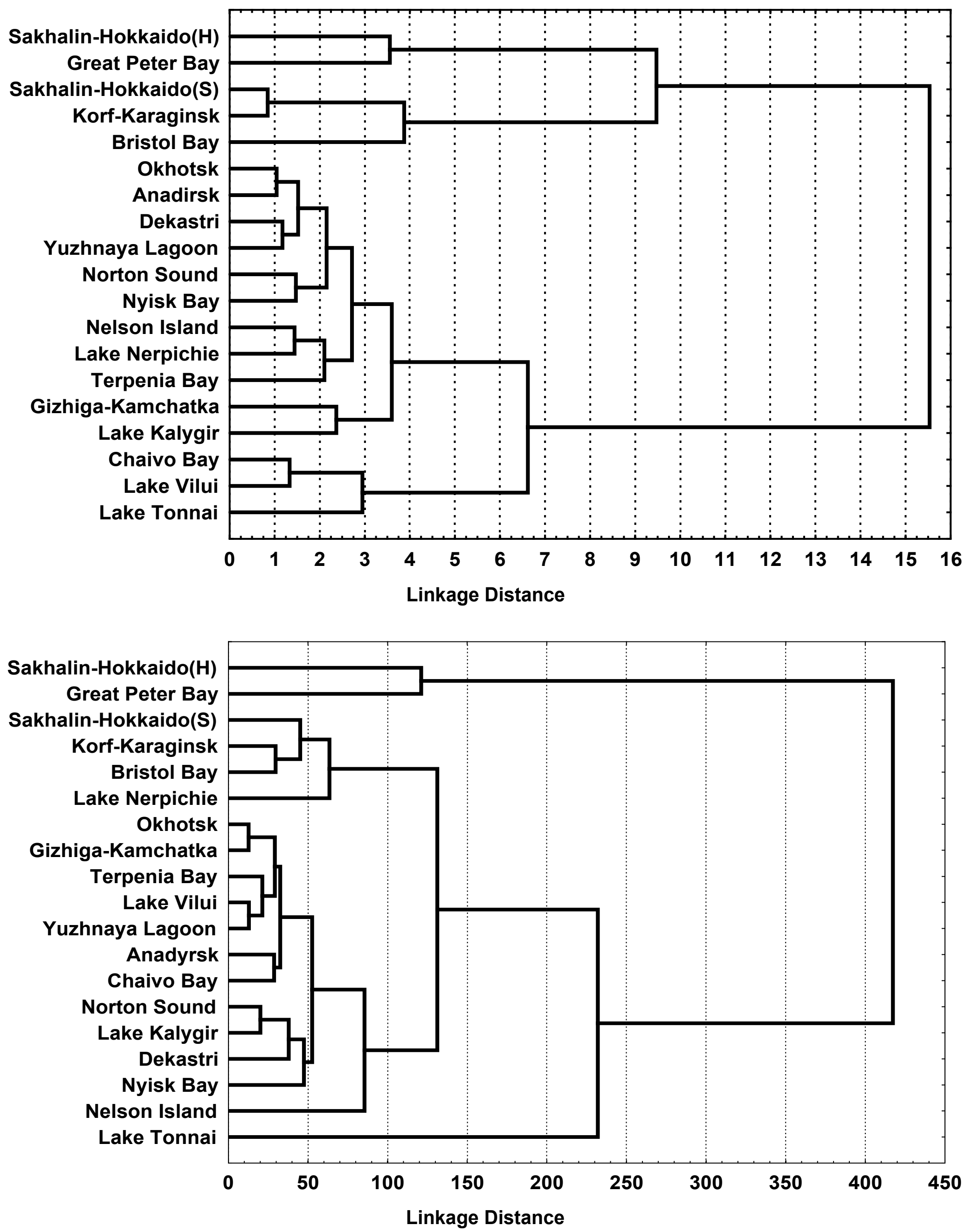

Fig. 12 Cluster analysis of length-at-age (upper panel) and weight-at-age (lower panel) of different Far East herring populations.

Table 4 Fork length-at-age (cm) of herring in different Far Eastern Seas.

Pupulation	Sea	Area	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	Source
Marine herring																
Sakhalin-Hokkaido	Japan Sea	Hokkaido Island	15,0	22,0	26,0	29,0	30,5	32,0	33,0	34,0	34,5	35,0	35,3	35,6		1
Sakhalin-Hokkaido	Japan Sea	Sakhalin Island	12,3	19,4	23,8	26,1	28,3	29,7	31,0	32,0	32,5	33,0	33,3	34,0	34,5	2,3,4,5,6
The Great Piter Bay	Japan Sea	Western part	14,2	22,8	27,8	30,4	32,1	33,2	34,4	35,3	35,4	35,8	35,9	36,9	37,3	7,8,9
Okhotsk	Sea of Okhotsk	North West	7,9	15,0	20,4	23,4	25,5	27,1	28,2	29,1	29,9	30,4	31,1	31,3	31,4	6,10,11,12,13,14,15,16
Gizhiga-Kamchatka	Sea of Okhotsk	North East	7,5	13,5	19,2	22,6	24,8	26,6	27,8	27,9	29,7	29,8	30,1	30,4	31,3	6,17,18
Korf-Karaginsky	Bering Sea	Western part	12,2	19,6	24,1	26,8	28,5	30,0	31,1	32,1	32,9	33,5	34,4	35,1	35,5	19,20,21,22
Anadyrsky	Bering Sea	Gulg of Anadyr	8,2	15,6	20,7	23,3	25,0	26,6	27,9	28,9	29,7	30,8	31,4	31,8	32,2	19
Eeastern Bering Sea	Bering Sea	Norton Sound	9,8	17,2	20,5	23,0	24,7	26,4	27,9	28,8	29,6					19,23
Eeastern Bering Sea	Bering Sea	Nelson Island	9,1	16,2	20,9	23,6	25,9	27,5	28,7							19,23
Eeastern Bering Sea	Bering Sea	Bristol Bay	10,3	19,0	22,3	24,8	27,1	29,0	30,1	31,0	31,9	32,5	32,8			19,23
Coastal herring																
Dekastri	Japan Sea	Northern part	8,3	15,2	19,6	23,2	25,1	26,6	27,5	28,5	30,0	31,3	31,8	32,5		6,24,25,26
Nyisk Bay	Sea of Okhotsk	Sakhalin Island	8,9	15,7	20,2	22,5	24,5	26,6	27,9							7,27,28
Chaivo Bay	Sea of Okhotsk	Sakhalin Island	8,7	15,4	20,0	22,8	24,0	25,1	28,0							7,27
Terpenia Bay	Sea of Okhotsk	Sakhalin Island	9,0	15,6	20,6	22,5	24,4	25,3	27,1							27
Lake-lagoon herring																
Lake Vilui	N-W Pacific	Kamchatka	8,8	15	18,5	20,4	22,9	24	25,2	25,9	26,6	27	27,8	27,9	28,1	19
Lake Kalygir	N-W Pacific	Kamchatka	8,4	14,7	19,5	22,4	24,4	25,4	26,5	27,3	28,1	27,8	28,4	29,1	29,3	19
Lake Nerpichie	N-W Pacific	Kamchatka	9,1	15,4	21,4	24,5	26,3	27,3	28,2	29	29,9	30,5	31,1	31,5	32	19
Lake Tonnai	Sea of Okhotsk	Sakhalin Island	8,6	14,2	17,6	20,2	21,5	22,3	23,5							29
Yuzhnaya Lagoon	Bering Sea	North West	8,5	14,7	19,4	22,4	24,3	25,3	26,5	27,1	28,1	28,8	29,4	30,1	30,6	19,30

Sources: 1. Motoda, Hirano, 1963; 2. Kaganovsky, 1954; 3. Druzhinin, 1957; 4. Pushnikova, 1981; 5. Pushnikova, 1994; 6. Materials of Soviet-Japan Fisheries Commission, 1969-1976; 7. Ambroz, 1931; 8. Gavrilov, Posadova, 1982; 9. Posadova, 1985; 10. Kolesnik, Khmarov, 1970; 11. Labetsky, 1975; 12. Tyurnin, Yolkin, 1975; 13. Tyurnin, Yolkin, 1977; 14. Vyshegorodtsev, 1976; 15. Vyshegorodtsev, 1978; 16. Smirnov, 1994; 17. Piskunov, 1954; 18. Pravotorova, 1965; 19. Our data; 20. Kachina, 1967; 21. Kachina, 1969; 22. Kachina, 1981; 23. Wespestad, 1991; 24. Ambroz, 1930; 25. Kozlov, 1968; 26. Kozlov, Frolov, 1973; 27. Ivankova, Kozlov, 1968; 28. Gritsenko, Shilin, 1979; 29. Probatov, Frolov, 1951; 30. Prokhorov, 1965.

Table 5 Weight-at-age (g) of different populations of herring from Far Eastern Seas.

Pupulation	Sea	Area	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Marine herring																
Sakhalin-Hokkaido	Japan Sea	Sakhalin Island	24	72	140	191	242	279	317	360	375	398	416			
The Great Piter Bay	Japan Sea	Western part	28	135	250	308	371	399	432	465	484	525	547			
Okhotsk	Sea of Okhotsk	North West	8	30	84	119	155	186	213	237	266	285	303	315	364	
Gizhiga-Kamchatka	Sea of Okhotsk	North East	8	29	80	119	151	177	206	234	256	285	295	305	323	337
Korf-Karaginsk	Bering Sea	Western part	12	49	109	178	245	299	341	366	404	424	452	472	510	564
Anadyrsk	Bering Sea	Gulf of Anadyr	7	32	67	104	139	175	223	243	272	312				
Eeastern Bering Sea	Bering Sea	Norton Sound	8	46	79	134	166	210	234	281	313	348	357	373	391	405
Eeastern Bering Sea	Bering Sea	Nelson Island	9	38	84	129	187	227	280	306	337	376	410	429		
Eeastern Bering Sea	Bering Sea	Bristol Bay	12	62	118	174	229	283	331	376	414	445	470	492	508	523
Coastal herring																
Dekastri	Japan Sea	Northern part	8	44	102	125	153	194	215	242	274	304	305	323		
Nyisk Bay	Sea of Okhotsk	Sakhalin Island	8	42	70	100	182	198	224							
Chaivo Bay	Sea of Okhotsk	Sakhalin Island	7	39	83	121	141	160	221							
Terpenia Bay	Sea of Okhotsk	Sakhalin Island	8	40	90	117	148	164	201							
Lake-lagoon herring																
Lake Vilui	N-W Pacific	Kamchatka	8	42	80	107	145	162	184	201	218	228	248	252	255	257
Lake Kalygir	N-W Pacific	Kamchatka	8	39	90	140	179	205	232	258	274	287	295	320	328	359
Lake Nerpichie	N-W Pacific	Kamchatka	8	50	116	180	220	251	287	311	341	354	377	397	406	423
Lake Tonnai	Sea of Okhotsk	Sakhalin Island	7	30	57	85	102	114	132							
Yuzhnaya Lagoon	Bering Sea	North West	7	34	76	115	146	164	188	201	223	240	255	273	286	

Comment: sources as table 1

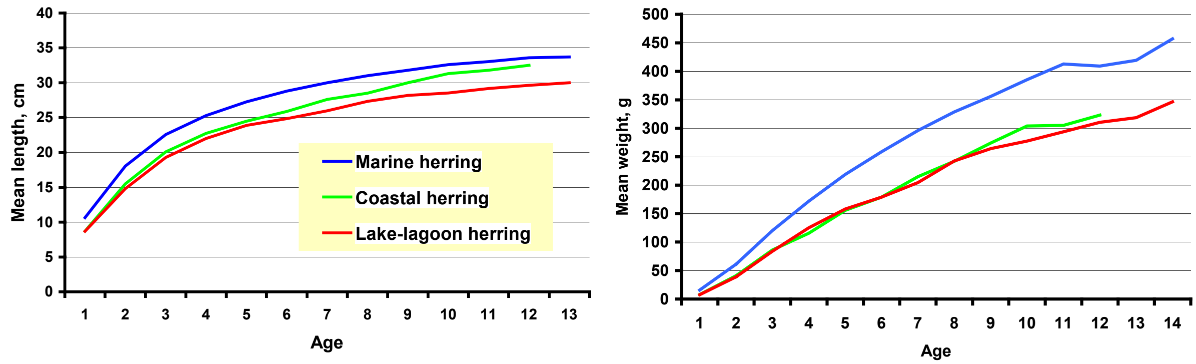

Fig. 13 Length-at-age (left) and weight-at-age (right) of different morphs of Far East herring.

The morphs differ in growth rate. By the character of the length growth the populations studied can be clearly divided into 3 types (Fig. 14A):

I. fast annual growth in the first year of life and rapid decrease of the growth in later years;
II. relatively fast annual growth in two initial years;
III slow growth in the first year of life and comparatively fast annual growth in later years.

Hokkaido Island herring have been classified to be of the first type. Most marine, all off-shore and some lagoon-lacustrine herring populations have been classified to be of second type. Most lacustrine and some marine herring populations are classified to be of the third type.

By the character of the mass growth, Far East herring populations have been divided into three types as well (Fig. 14B):

I. almost similar rich annual mass growth in second and third years of life (Sakhalin-Hokkaido herring inhabiting the waters adjacent to Hokkaido Island and Peter the Great Bay herring);
II. maximum annual mass growth in the third year of life cycle (majority of herring populations in the Sea of Japan and Okhotsk Sea);
III. maximum annual mass growth in the fourth year of life (all marine herring populations of Bering Sea).

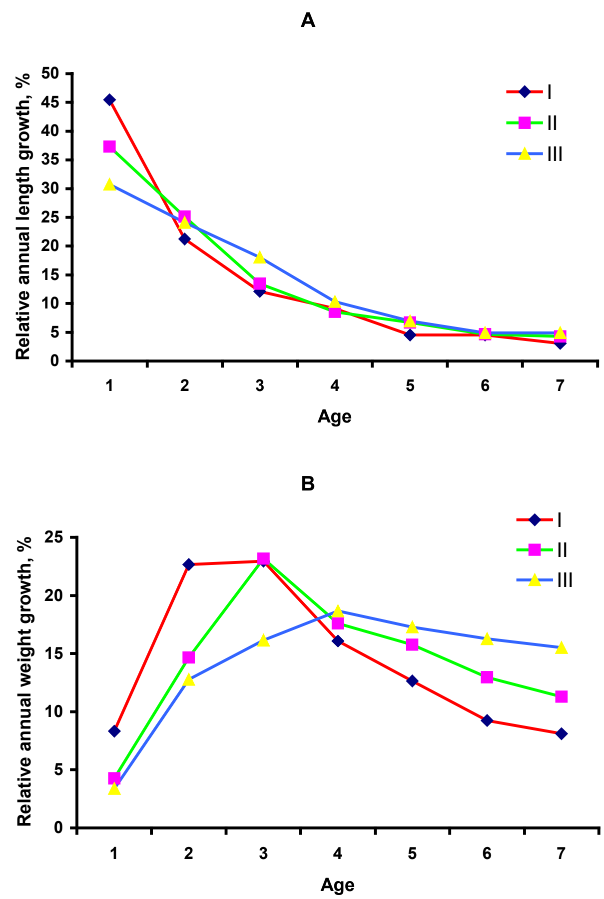

Fig. 14 Relative annual growth in length (A) and weight (B) in Far East herring morphs. See text for descriptions of each morph (I, II and III).

The most obvious trait of this species is significant year-to-year variations in size-at-age. For example, the range in the mean length of Korf-

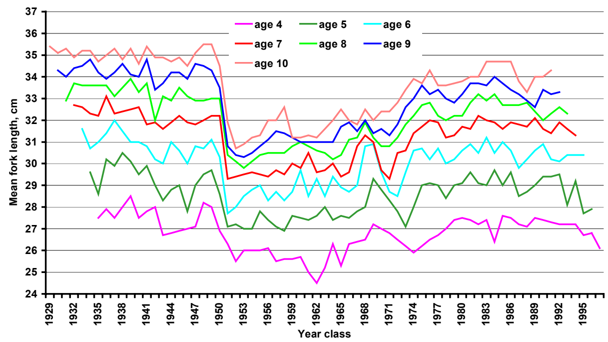

Fig. 15 Mean length-at-age of Korf-Karaginsky herring.

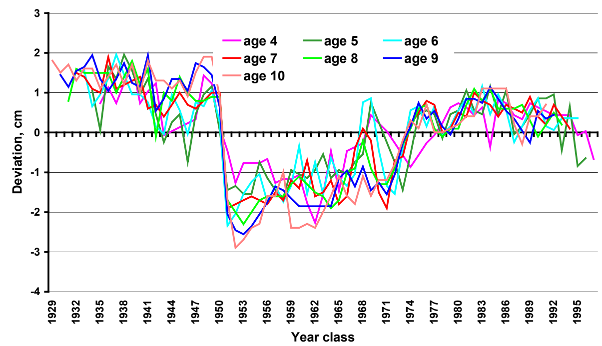

Fig. 16 Deviations from mean length-at-age.

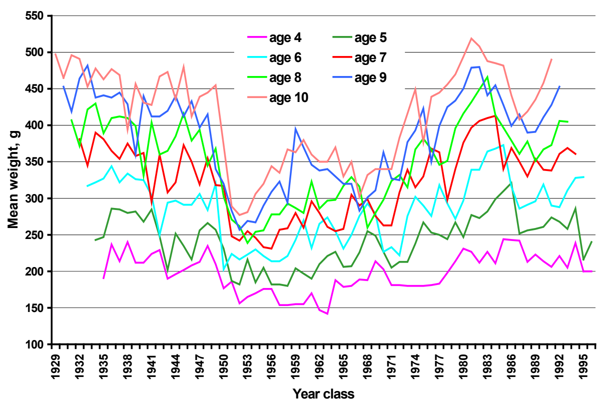

Fig. 17 Mean weight-at-age of Korf-Karaginsky herring.

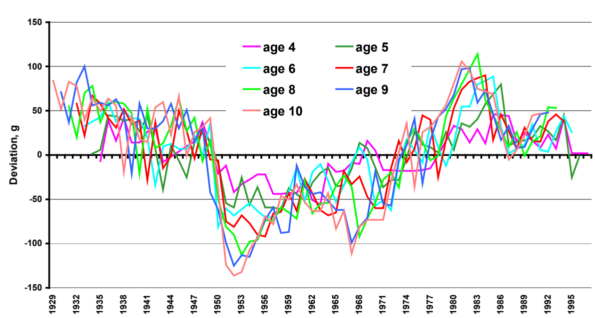

Fig. 18 Deviations in mean weight-at-age.

Karaginsky four-year-old fish is 4 cm (24.5-28.5 cm), of 10-years-old fish - 5.1 cm (30.4-35.5 cm), of 13-years-old fish - 5.9 cm (31.6-37.5 cm). The range in the mean mass of fish varies from 102 g in 4 year old fish to 227-255 g in 8-13 year old fish.

The variation in the biological patterns of Korf-Karaginsky herring demonstrates clear long-term cyclic dynamics (Figs. 15, 16, 17 and 18). The size (length and mass) of mature fish in generations for the 1930-40s was a maximum in all age groups for the whole observation period; the patterns were at a minimum for the 1950-70s and again relatively high for the 1980s. In the 1990s the size-at-age has been decreasing gradually, but being above the mean for many years, as early in the time series (Fig. 19).

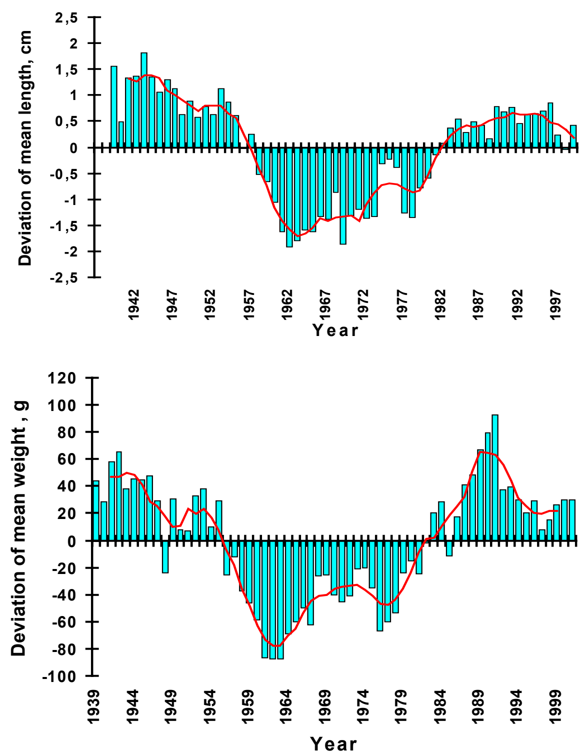

Fig. 19 Deviations of mean length (upper panel) and weight (lower panel) of age 4-10 Korf-Karaginsky herring from multi-year value.

For greater insight into the temporal pattern of the cycles of size variations in herring we used transformed data. We estimated deviations of the annual length and mass growth of 4-10-years-old fish from the mean for many years (Figs. 20 and 21). There are three periods which could be seen clearly in the curve of the dynamics of the mean for 5-year periods of annual growth of mature herring.

The first period, bounded by generations of 1930 and 1951, was generally characterized by accelerated growth; the second period (1950-1970s) was characterized by slower growth, and 1970-1990s characterized by higher growth rates. Within the three twenty-year periods of high or low growth, there are two cycles of about 10 years. Thus, the growth of Korf-Karaginsky herring has cyclic dynamics, with the cycle consisting of 10 or 22-years approximately.

The growth of mature herring in the west part of Bering Sea has been regulated by several circumstances. The length of 5-10-year-old fish depends on the length of recruits *i.e.* maturating 4-year-old fishes (Fig. 22). The more definite length of recruits is, the greater is the length of mature fish in all older ages.

Beyond doubt the growth of herring has been influenced by stock abundance or density factor. Although a reliable correlation between abundance of a certain generation and annual growth has not been observed – very abundant generations demonstrate evidently slower growth as compared to that in other generations. The growth rate is very similar in generations of moderate and low abundance, also in general it is higher compared to that in abundant and highly abundant generations (Table 6). Actually, biological characteristics are influenced much more by population condition. The highest growth rates are observed in the 1940s and the early 1950s when the abundance of mature fish has been moderate (Table 7). After several abundant generations reproduced in 1951-1956 the abundance of mature fish increased quickly. To the late 1950s the abundance of mature fish reaches its' historical maximum. The size (length and mass) of 4-6 year-old fish for this period has been minimum for the whole period of observations. Slow growth has been observed in the fish of old age groups.

From the mid-1960s until mid-1970s the population underwent a depression. Despite the

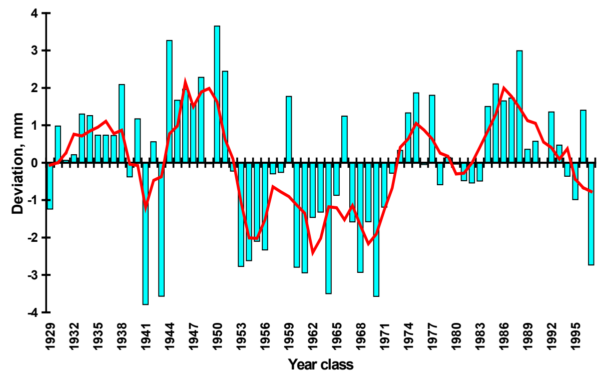

Fig. 20 Deviations of mean annual length growth of 4-10 age Korf-Karaginsky herring from multiyear value.

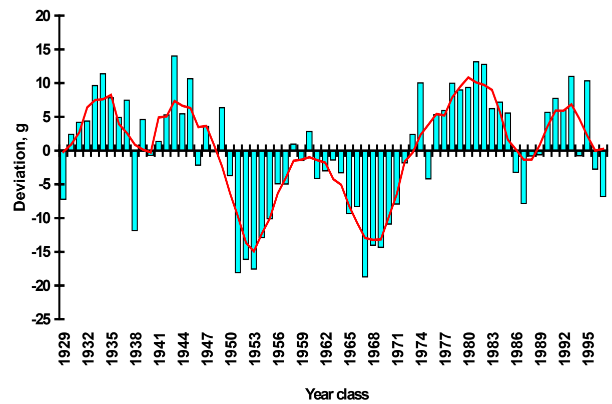

Fig. 21 Deviations of mean annual weight growth of 4-10 age Korf-Karaginsky herring from multiyear value.

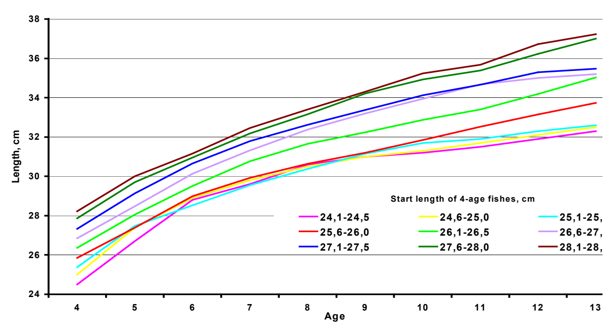

Fig. 22 Growth of Korf-Karaginsky herring in dependence on start length of 4-age fishes.

extremely low abundance of mature fish their growth stayed slow; also the individuals older than 6-years-old demonstrate the minimal growth for the whole historical period of the observations. In the late 1970s and in the 1980s the number of mature fish has increased a little, but remained

Table 6 Growth of Korf-Karaginsk herring in dependence from year-class strength.

Strength of year-class	Length/weight	Age									
		4	5	6	7	8	9	10	11	12	13
Very strong	Length, cm	26.3	27.4	28.6	29.9	30.8	31.2	31.5	31.8	32.0	32.4
	Weight, g	181	202	241	273	283	303	304	328	367	378
Strong	Length, cm	26.8	28.6	30.2	31.0	32.0	32.8	33.2	33.7	33.9	34.1
	Weight, g	192	239	273	313	355	379	401	412	414	416
Average	Length, cm	26.7	28.5	30.1	31.1	31.9	32.6	33.4	34.3	35.0	35.6
	Weight, g	198	245	284	324	348	385	414	444	475	506
Poor	Length, cm	27.0	28.8	30.2	31.6	32.6	33.4	34.2	35.1	36.0	36.2
	Weight, g	203	244	291	333	365	398	430	455	509	534

Table 7 Growth of Korf-Karaginsk herring in relation to stock abundance.

Level of stock-size	Length/weight	Age									
		4	5	6	7	8	9	10	11	12	13
High	Length, cm	25.8	27.3	28.6	30.3	31.3	32.3	33.4	33.9	34.2	-
	Weight, g	165	195	229	270	297	327	374	376	414	-
Average	Length, cm	27.3	29.1	30.7	32.0	33.0	34.0	34.6	35.3	36.1	36.4
	Weight, g	212	257	306	352	388	427	458	476	503	532
Low	Length, cm	26.9	28.8	30.2	31.3	32.1	32.7	33.1	33.7	34.4	34.9
	Weight, g	209	259	300	341	364	388	405	429	473	496
Depression	Length, cm	26.0	27.9	29.3	30.0	30.7	31.3	31.6	32.3	32.6	33.1
	Weight, g	180	220	261	277	300	335	345	352	358	365

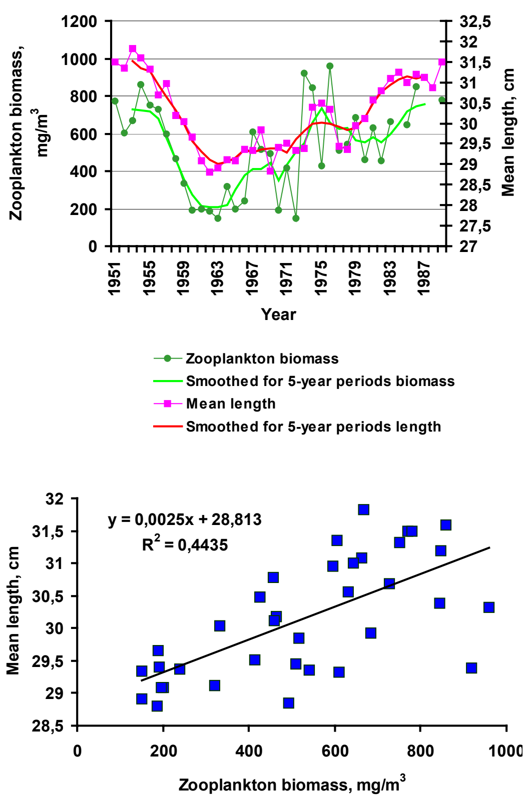

Fig. 23 Relationship between June zooplankton biomass in Olutorsk Bay and mean length of age 4-10 herring.

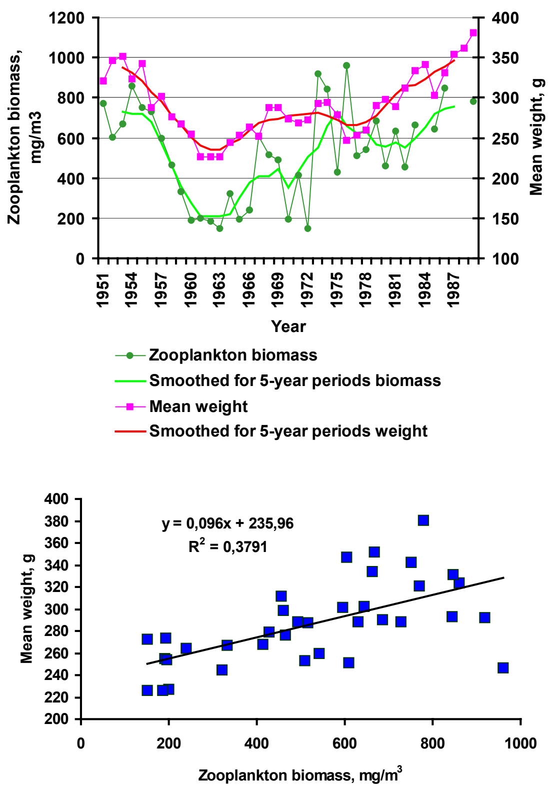

Fig. 24 Relationship between June zooplankton biomass in Olutorsk Bay and mean weight of age 4-10 herring.

low. In the 1990s the numbers have increased moderately. The size-at-age for 25 years (mid 1960s- late 1980s) has been increased gradually. To the early 1990s the size of herring has been similar to that for the 1940s. Thus, the most favorable conditions for growth of Korf-Karaginsky herring usually have been created at a moderate abundance of mature fish in the population. Under the extreme conditions (too high or too low stock abundance) individual growth has been slow.

The most important factor determining individual growth is food supply. In the 1950s - 1980s average zooplankton biomass in Olyutorsky Bay and average dimension (length and mass) of 4-10 years-old fish demonstrate synchronic variations (Fig. 23 and 24). In the periods when the biomass of zooplankton was increasing, the length and the mass of mature herring increased as well, and *vice versa*. A reliable direct correlation has been found between these patterns. The character of the correlation indicates that a zooplankton biomass increase of 100 mg/m^3 corresponds to a length increase of 2.5 mm and to the mass increase of 10 g in average in all age groups. Thus, the size-at-age variations of Korf-Karaginsky herring demonstrate cyclic dynamics. The stock abundance and forage base conditions influence the growth of fish considerably.

Effects of climate on Pacific herring, *Clupea pallasii*, in the northern Gulf of Alaska and Prince William Sound, Alaska

Evelyn D. Brown
University of Alaska Fairbanks, Institute of Marine Science, P.O. Box 757220, Fairbanks, AK 99775-7220, U.S.A. E-mail: ebrown@lms.uaf.edu

Introduction

Links between trends of North Pacific fish populations and climatic variations are well documented. One well-known example is the exceptional salmon production in the North Pacific that occurred during a period associated with an intensified Aleutian Low: high levels of salmon production are strongly correlated with the Pacific Decadal Oscillation (PDO) (Mantua *et al.* 1997), with Alaskan stocks responding positively to the positive phases of the PDO.

Pacific herring (*Clupea pallasii*) also appear to respond to climate. A negative correlation exists between southern British Columbia (BC) herring year-class strength and warm conditions; warm conditions appear to increase piscivory on herring and reduce zooplankton food resources (Ware 1992). The same negative correlation was later reported by Hollowed and Wooster (1995) with higher average recruitment for Vancouver Island herring during cool years associated with a weakened winter Aleutian Low (AL). However, the opposite effect occurred in northern BC and the Gulf of Alaska (GOA), with increased herring production during warm years associated with an intensified winter AL (Hollowed and Wooster 1995). Recruitment of Pacific herring in Southeast Alaska is positively associated with warm, wet climate conditions (Zebdi and Collie 1995). This indicates a north-south bifurcation in climate response by Pacific herring populations similar to that observed in Pacific salmon.

This study shows that the trend in abundance of northern GOA Pacific herring appears to be in phase with decadal-scale climate indices. Population parameters such as growth and spawn timing also appear to be related to climatic signals and may be in opposition to responses by Pacific herring from more southern locations.

Results

An index of GOA herring abundance was developed by combining historic fisheries catches with recent biomass estimate (Fig. 25). Herring abundances were compared to several climate indices and good, positive correlations were found for the Atmospheric Forcing Index (AFI) and Aleutian Low Pressure Index (ALPI) (Beamish