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Abstract

A summer high-seas research cruise to investigate the biology of Pacific salmon was conducted from July 20 to August 9 in the Bering Sea aboard the Japanese research vessel *Hokko maru*. Research cruise activities included the collection of data on oceanography, zooplankton, micronekton, salmonid fishes, and other organisms. A total of 3,694 salmonids were caught by trawls and angling. Chum salmon was the most abundant species (91.4%), followed by sockeye salmon (5.4%), Chinook salmon (3.1%), pink salmon (0.1%), and coho salmon (0.05%). Salmonids were measured with respect to fork length and body and gonad weights, they were sexed, and the scales were removed for age determination. Isotope, genetic, otolith, and radioactive monitoring samples were obtained for future study. There were 70 chum salmon tagged with disk tags and released in the Bering Sea. From among fish released with disk-tags, 28 small and 12 large chum salmon were released carrying DST milli-F and DST magnetic tags, respectively. Age-specific catch per surface trawl (CPUE) and scale mass index of chum salmon from 17 fixed fishing stations from 2007 to 2012 are documented here.

Introduction

Japanese research vessels have monitored the condition of Pacific salmon (*Oncorhynchus* spp.) stock since 1952 (Ishida and Ogura, 1992). The new R/V *Hokko maru* (902 gross tons) was launched in 2004 and the 2012 expedition was her fifth salmon research cruise in the North Pacific (Morita *et al.*, 2007, 2008, 2009, 2011). The main objective for this cruise was to conduct the annual survey of Japanese stocks of chum salmon (*O. keta*) in the Bering Sea. Routine observations on the *Hokko maru* have included the collection of data on physical oceanography, trophic interactions among zooplankton, salmonids, and organisms at higher trophic levels, and analysis of the genetic structure of salmon populations. This document summarizes the research cruise conducted by the R/V *Hokko maru* during summer 2012.

Survey Area

The R/V *Hokko maru* departed from Kushiro, Japan, on July 20, 2012, and returned to Kushiro on August 9, 2012. A total of 17 trawls were conducted at 17 stations during the

cruise (Fig. 1 and Table 1). All fishing stations were located in the Bering Sea.

Temperature and Salinity Sampling

A salinity, temperature, and depth sensor (STD, manufactured by Alec Electronics Co., Ltd., Kobe, Japan) was used at each fishing station before the trawl. The STD recorded data at 1-m intervals from the surface to a maximum of approximately 500 m. Surface water was sampled using a bucket to measure sea surface temperature (SST) and sea surface salinity (SSS) at each fishing station.

Zooplankton and Micronekton Sampling

Macro-zooplankton were sampled with a remodeled NORPAC net (0.45-m ring diameter, 1.93-m net length, 0.33-mm mesh size) at each fishing station. The NORPAC net was towed vertically from a maximum of 150 m to the surface. A calibrated flow meter was attached to the opening of net in a position slightly off-center. The NORPAC net samples were fixed in 10% borax-buffered formalin.

Large macro-zooplankton were collected at eight trawl locations (H22, H24, H16, H18, H20, H08, H10, and H12) using a BONGO net (2 rings, 0.7-m diameter, 4.1-m overall length, 0.335-mm mesh size). An hour after sunset, the net was towed obliquely along the stern of the vessel from 100 m to the surface at a speed of approximately 1.5 knots. Calibrated flow meter was attached to the interior of each ring. Samples were fixed in 10% borax-buffered formalin in seawater.

Fish Collection

A surface trawl was used for experimental fishing operations to collect salmonids and other pelagic fish at each fishing station (Fig. 1, Table 1). The trawl was towed at the speed of 5 knots at the surface layer from the surface to approximately 30 m depth for one hour in daytime. The length of trawl net was 152 m. The cod end of the trawl net was lined with a non-tied net of mesh size 60.0 mm. To monitor depth and temperature of the trawl net, small depth–temperature recorders (SBT-500 manufactured by Murayama Denki Ltd., Tokyo, Japan) were attached to five different points of the trawl net (head rope, ground rope, cod end, right and left otter boards). In addition, hooks and lines were used to collect live fish samples for tagging study.

A total of 3,694 salmonids (2,590 kg) were caught by trawl and angling: 3,582 fishes by trawl and 112 fishes by angling (Table 1). Five species of salmonids were caught during the R/V *Hokko maru* cruise in 2012 summer: sockeye salmon (*Oncorhynchus nerka*), chum salmon, pink salmon (*O. gorbuscha*), coho salmon (*O. kisutch*), and Chinook salmon (*O. tshawytscha*). Chum salmon was the most abundant species (n = 3,375, 91.4%), followed by sockeye salmon (n = 199, 5.4%), Chinook salmon (n = 114, 3.1%), pink salmon (n = 4, 0.1%), and coho salmon (n = 2, 0.05%).

In addition to salmonids, 2,707 teleost fishes (633 kg), 20 squids (0.03+α kg), and many jellyfish (222 kg) were caught in trawls (Table 1). Atka mackerel (*Pleurogrammus monopterygius*; *n* = 2,674), juvenile Atka mackerel (n = 28), prowfish (*Zaprora silenus*; *n* = 2), smooth lumpsucker (*Aptocyclus ventricosus*; n = 3), and unknown small squids were caught.

Fish Measurement

Salmonids were processed soon after removal from the fishing gear. The catch was sorted by species and counted. Biological data were recorded on the deck for each trawl: fork length (mm), body weight (10 g), sex, and gonad weight (0.1 g). Basic biological data were recorded for all individuals. Gonad weight was recorded from a maximum of 240 individuals per species caught in each trawl. Body and gonad weights were measured using the Marine scale (manufactured by POLS, Reykjavik, Iceland). The presence of visceral adhesions was also recorded. One scale (for pink salmon) or two scales (for sockeye, chum, coho, and Chinook salmon) were collected for age determination and back-calculations of growth. When possible, scales were collected from the preferred body area identified by the International North Pacific Fisheries Commission (INPFC) for scale sampling (Davis *et al*., 1990).

Samples of body tissues from each salmon species were collected for stable isotope analyses. The isotope samples were frozen and transported to the Hokkaido National Fisheries Research Institute (HNFRI) for further laboratory examination. Adipose fins of chum, sockeye, Chinook, coho and pink salmon were collected for genetic analyses. Otoliths of chum salmon were collected for detection of thermal marks on the otoliths. Chum salmon fin and otolith samples, fixed in ethanol, were transported to HNFRI. Sockeye and Chinook salmon fin samples, fixed in ethanol, will be sent to Dr. Terry Beacham of the Pacific Biological Station, Canada, and Dr. James E. Seeb of the University of Washington, United Status, respectively, according to the NPAFC sample exchange program.

Radioactive monitoring samples

Samples of body tissues of chum salmon, surface sea water, and zooplanktons were collected for radioactive monitoring. These samples were collected at eight trawl locations (H22, H24, H16, H18, H20, H08, H10, and H12). Body tissues of chum salmon were collected after fish measurement and frozen at -40 °C. 20L surface seawater was sampled from a faucet in the observation room to plastic water bottle canteen, added 50 ml nitric acid immediately, and stored room temperature. Zooplankton were collected using a BONGO net (2 rings, 0.7-m diameter, 4.1-m overall length, 0.6-mm mesh size). After sunset, the net was towed obliquely along the stern of the vessel from 40 m to the surface at a speed of approximately 1.5 knots. Calibrated flow meter was attached to the interior of each ring. Collected zooplankton samples were stored in freezer at -20 °C. All radioactive monitoring samples were sent to Dr. Hideki Kaeriyama of the National Research Institute of Fisheries Science.

Release of Tagged Chum Salmon

Live chum salmon caught in healthy condition were put into a recovery tank. Each fish was tagged with two disk tags, one issued by the Fisheries Agency of Japan (FAJ) and one by the North Pacific Anadromous Fish Commision (NPAFC). Both disk tags were placed on one plastic cinch strap and attached to the fish in an area anterior to the dorsal fin. In additions to two disk tags, small archival tags (model DST milli-F manufactured by Star-Oddi, Gardabaer, Iceland, size, 13 × 38.4 mm; weight in air, 9.2 g; number of records, 340, 000 per sensor) were also used to record seawater temperature and depth of the immature

chum salmon. In addition, large archival tags (model DST magnetic manufactured by Star-Oddi, Gardabaer, Iceland, size, 15 × 46 mm; weight in air, 19 g; number of records, 4,000 per sensor) were used to record seawater temperature, depth, earth's magnetic field strength (in three directions), and tilt (in three directions) of the maturing chum salmon. From the magnetic field strength measurements a relative magnetic field vector is calculated, which can be put into models to find longitude and latitude of the fish. It is also a useful tool for recording compass directions. Archival tags were attached externally with titanium pins to the dorsal musculature of the fish anterior to the dorsal fin (Fig. 2). The fork length was measured and two scales were collected before the fish was released to the sea. A total of 30 disk-tagged chum salmon was released into the Bering Sea (Table 2). A total of 28 chum salmon was released with both disk and small archival tags into the Bering Sea, while a total of 12 chum salmon was released with both disk and large archival tags into the Bering Sea (Table 2).

Preliminary Results

The main objective of this research program is to monitor the stock condition of Japanese chum salmon. Fixed point observations (17 fixed fishing stations) have been conducted since 2007 by the R/V *Hokko maru*. In every years, fork length was distributed bimodally, with chum salmon in the small size group (<400 mm) being mostly 1+ year old, and those in the large size group (>400 mm) being mostly older than 2 years (Fig. 3). Average body size of chum salmon in this year was similar to that of 2009 and 2011, however, smaller compared with 2007 and 2008 fish. In addition, body weight of chum salmon in this year was significantly smaller compared with 2007-2009 years after controlling for fork length (Fig. 4). This trend continues in 2011 fish. On the other hand, copepods, euphausiids, and amphipods were mainly collected by NORPAC and BONGO nets, and these zooplanktons were observed in chum salmon stomach (Fig. 5).

Age-specific catch per surface trawl (CPUE) from 17 fixed fishing stations for each year are documented here (Fig. 6). To calculate age-specific CPUE for 2012, age-length key of 2011 was used as provisional estimation. In addition to CPUE, age-specific stock origin will be routinely estimated using DNA techniques (cf. Sato *et al.*, 2009). The *Hokko-maru* data will be useful for the stock assessment of Japanese chum salmon.

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Table 1. Catches of sockeye salmon (SO), chum salmon (CH), pink salmon (PK), coho salmon (CO), Chinook salmon (CN), Atka mackerel (AM), juvenile Atka mackerel (JM), prowfish (PF), smooth lumpsucker (SL), unknown small squid (US), and jellyfish (JF) along with the sea surface temperature (SST, °C) at each station during the R/V *Hokko maru* cruise in summer 2012. Above line was expressed in number whereas below gray line was expressed in kg for each station. J-gear, surface trawl; O-gear, hook and line; n.a., not available. *Point at which the net was hauled.

St.	Date	Location*			SST	Gear	Salmonid fishes					AM	JM	PF	SL	US	JF
							SO	CH	PK	CO	CN						
H22	2012/7/25	56°00´N	175°09´	E	9.2	J	10	244	0	0	0	0	0	0	0	2	n.a.
							7.96	143.29	0	0	0	0	0	0	0	0.01	7.08
H23	2012/7/26	54°57´N	175°07´	E	9.4	J	6	141	0	0	2	0	0	1	0	13	n.a.
							4.41	87.54	0	0	9.30	0	0	n.a.	0	n.a.	31.64
H24	2012/7/26	54°02´N	175°05´	E	8.8	J	1	151	0	0	0	1	9	0	0	5	n.a.
							0.99	105.50	0	0	0	0.36	0.07	0	0	0.02	43.10
H25	2012/7/27	53°04´N	175°02´	E	9.1	J	0	22	0	0	0	2589	0	0	0	0	n.a.
							0	32.02	0	0	0	608.93	0	0	0	0	1.82
H15	2012/7/28	52°34´N	180°00´		8.4	J	0	65	1	0	0	80	0	0	0	0	n.a.
							0	72.76	1.23	0	0	16.71	0	0	0	0	17.91
H16	2012/7/28	53°31´N	179°54´	W	8.6	J	4	98	1	0	0	3	2	0	0	0	n.a.
							3.47	58.81	1.18	0	0	0.47	0.01	0	0	0	29.14
H17	2012/7/29	54°29´N	179°52´	W	8.6	J	4	87	0	0	5	0	1	0	0	0	n.a.
							4.01	56.26	0	0	8.57	0	0.0063	0	0	0	27.23
H18	2012/7/29	55°34´N	180°00´		8.9	J	2	102	1	0	6	0	0	0	0	0	n.a.
							1.18	79.83	1.19	0	13.27	0	0	0	0	0	6.06
H19	2012/7/30	56°28´N	179°54´	E	9.0	J	3	358	0	0	46	0	0	0	0	0	n.a.
							3.89	195.28	0	0	34.01	0	0	0	0	0	2.63
H20	2012/7/30	57°34´N	179°54´	W	9.8	J	7	147	0	0	6	0	16	0	0	0	n.a.
							6.30	92.18	0	0	4.10	0	0.1	0	0	0	13.71
H21	2012/7/31	58°33´N	179°53´	E	9.2	J	6	158	0	0	6	0	0	0	1	0	n.a.
							4.64	127.53	0	0	5.46	0	0	0	0.17	0	19.61
H07	2012/8/1	58°04´N	175°01´	W	8.6	J	35	425	1	0	3	0	0	1	2	0	n.a.
							28.65	331.86	0.57	0	4.30	0	0	0.28	6.05	0	1.53

Table 1. (continued)

St.	Date	Location			SST	Gear	Salmonid fishes					AM	JM	PF	SL	US	JF
							SO	CH	PK	CO	CN						
H08	2012/8/1	57°03´N	174°53´	W	8.4	J	28	320	0	0	3	0	0	0	0	0	n.a.
							18.39	245.43	0	0	7.75	0	0	0	0	0	1.41
H09	2012/8/2	56°01´N	174°55´	W	8.8	J	61	418	0	0	5	0	0	0	0	0	n.a.
							38.65	254.76	0	0	4.29	0	0	0	0	0	1.90
H10	2012/8/2	55°00´N	174°57´	W	7.8	J	8	142	0	1	3	1	0	0	0	0	n.a.
							5.66	102.75	0	2.33	3.59	0.25	0	0	0	0	1.21
H11	2012/8/3	54°01´N	174°57´	W	7.9	J	8	184	0	0	19	0	0	0	0	0	n.a.
							9.22	113.05	0	0	16.86	0	0	0	0	0	3.95
H12	2012/8/3	53°00´N	174°53´	W	8.7	J	0	223	0	0	5	0	0	0	0	0	n.a.
							0	154.94	0	0	5.73	0	0	0	0	0	12.39
H25-	7/25–8/3	Bering Sea				O	16	90	0	1	5	0	0	0	0	0	0
H10							25.17	39.86	0	2.43	7.71	0	0	0	0	0	0
Total							199	3375	4	2	114	2674	28	2	3	20	0
							162.59	2293.65	4.17	4.76	124.94	626.72	0.1863	0.28	6.22	0.03	222.32

Table 2. Tag releases during the R/V *Hokko maru* cruise in the Bering Sea in 2012 summer. FAJ, Fisheries Agency of Japan; NPAFC, North Pacific Anadromous Fish Commission.

#	St.	Date	Type of archival tag	Archival tag number	Disk tag number		Species	Fork length (mm)	Gear
					NPAFC	FAJ			
1	H15	2012/7/28	Magnetic	625	NA5415	D1728	chum	520	O
2	H15	2012/7/28	Magnetic	621	NA5411	D1729	chum	618	O
3	H16	2012/7/28	Magnetic	587	NA5470	D1730	chum	602	O
4	H16	2012/7/28	Magnetic	607	NA5471	D1725	chum	514	O
5	H16	2012/7/28	Magnetic	623	NA5477	D1724	chum	656	O
6	H16	2012/7/28	Milli-F	705	NA5441	D1761	chum	434	O
7	H16	2012/7/28			NA5430	D1700	chum	332	J
8	H16	2012/7/28			NA5432	D1698	chum	356	J
9	H16	2012/7/28			NA5419	D1695	chum	376	J
10	H16	2012/7/28			NA5417	D1694	chum	398	J
11	H16	2012/7/28			NA5422	D1699	chum	620	J
12	H16	2012/7/28			NA5423	D1692	chum	508	O
13	H16	2012/7/28			NA5424	D1693	chum	500	O
14	H16	2012/7/28	Magnetic	626	NA5479	D1734	chum	578	O
15	H16	2012/7/28	Milli-F	666	NA5437	D1777	chum	448	O
16	H16	2012/7/28	Magnetic	624	NA5475	D1722	chum	570	O
17	H17	2012/7/29	Magnetic	612	NA5473	D1726	chum	576	O
18	H18	2012/7/29	Magnetic	610	NA5426	D1751	chum	505	O
19	H18	2012/7/29	Milli-F	691	NA5472	D1721	chum	342	O
20	H18	2012/7/29			NA5412	D1697	chum	510	O
21	H18	2012/7/29			NA5413	D1696	chum	482	O
22	H19	2012/7/30	Magnetic	608	NA5474	D1755	chum	650	O
23	H19	2012/7/30	Milli-F	687	NA5420	D1759	chum	424	O
24	H19	2012/7/30	Milli-F	689	NA5428	D1757	chum	443	O
25	H19	2012/7/30	Milli-F	677	NA5429	D1760	chum	421	O
26	H19	2012/7/30			NA5465	H1686	chum	432	O
27	H19	2012/7/30			NA5450	H1682	chum	494	O
28	H19	2012/7/30			NA5481	H1690	chum	472	O
29	H20	2012/7/30	Milli-F	680	NA5421	H1683	chum	442	O
30	H20	2012/7/30			NA5487	H1684	chum	444	O
31	H20	2012/7/30	Milli-F	668	NA5416	D1756	chum	418	O
32	H20	2012/7/30	Milli-F	670	NA5488	D1754	chum	396	O
33	H20	2012/7/30			NA5489	H1687	chum	468	O
34	H20	2012/7/30			NA5484	H1685	chum	446	O
35	H20	2012/7/30			NA5486	H1681	chum	402	O
36	H20	2012/7/30			NA5482	H1689	chum	454	O
37	H20	2012/7/30	Magnetic	622	NA5476	D1727	chum	562	O
38	H21	2012/7/31			NA5498	H7678	chum	516	O
39	H21	2012/7/31	Milli-F	692	NA5431	D1753	chum	426	O
40	H21	2012/7/31			NA5427	H1673	chum	464	O

Table 2. (continued)

#	St.	Date	Type of archival tag	Archival tag number	Disk tag number		Species	Fork length (mm)	Gear
					NPAFC	FAJ			
41	H21	2012/7/31	Milli-F	665	NA5436	D1775	chum	444	O
42	H21	2012/7/31			NA5490	H1671	chum	452	O
43	H21	2012/7/31			NA5491	H1677	chum	496	O
44	H21	2012/7/31	Magnetic	611	NA5478	D1723	chum	550	O
45	H07	2012/8/1	Milli-F	702	NA5438	D1772	chum	426	O
46	H07	2012/8/1	Milli-F	707	NA5439	D1771	chum	434	O
47	H09	2012/8/2	Milli-F	683	NA5440	D1769	chum	418	O
48	H09	2012/8/2			NA5492	H1679	chum	468	O
49	H09	2012/8/2	Milli-F	667	NA5497	D1762	chum	466	O
50	H09	2012/8/2	Milli-F	699	NA5435	D1774	chum	438	O
51	H09	2012/8/2			NA5496	D1672	chum	520	O
52	H09	2012/8/2	Milli-F	675	NA5442	D1673	chum	450	O
53	H10	2012/8/2	Milli-F	701	NA5434	D1779	chum	410	O
54	H10	2012/8/2	Milli-F	698	NA5433	D1770	chum	442	O
55	H10	2012/8/2			NA5494	H1674	chum	504	O
56	H10	2012/8/2	Milli-F	664	NA5445	D1763	chum	416	J
57	H10	2012/8/2	Milli-F	681	NA5425	D1780	chum	376	J
58	H10	2012/8/2	Milli-F	688	NA5446	D1764	chum	368	J
59	H10	2012/8/2			NA5495	H1676	chum	468	O
60	H10	2012/8/2			NA5493	H1680	chum	480	O
61	H10	2012/8/2	Milli-F	678	NA5447	D1766	chum	444	O
62	H10	2012/8/2	Milli-F	697	NA5448	D1773	chum	418	O
63	H11	2012/8/3	Milli-F	703	NA5443	D1767	chum	430	O
64	H11	2012/8/3			NA5460	H1688	chum	490	O
65	H11	2012/8/3			NA5414	H1691	chum	542	O
66	H11	2012/8/3			NA5509	H1938	chum	492	O
67	H11	2012/8/3			NA5510	H1933	chum	470	O
68	H11	2012/8/3	Milli-F	693	NA5449	D1776	chum	336	J
69	H11	2012/8/3	Milli-F	674	NA5444	D1768	chum	338	J
70	H11	2012/8/3	Milli-F	696	NA5505	D1765	chum	348	J

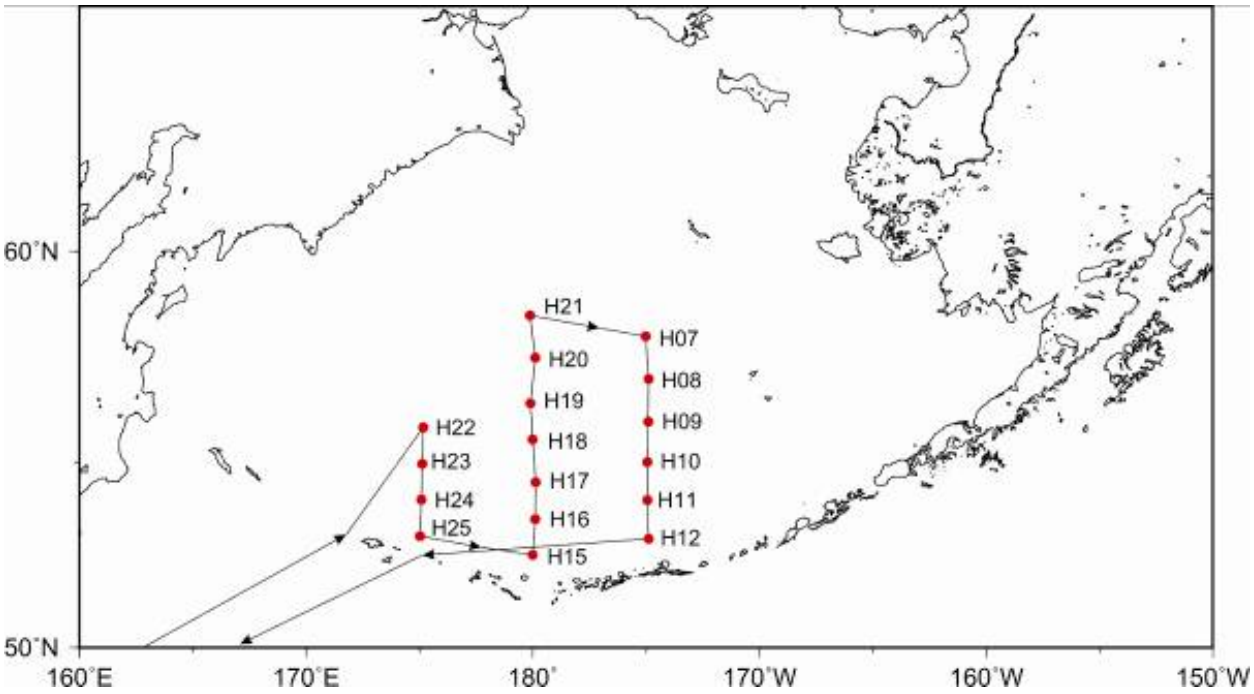

Fig. 1. The path of the R/V *Hokko maru* during the summer 2012 cruise and the location of 17 fishing stations (red circles).

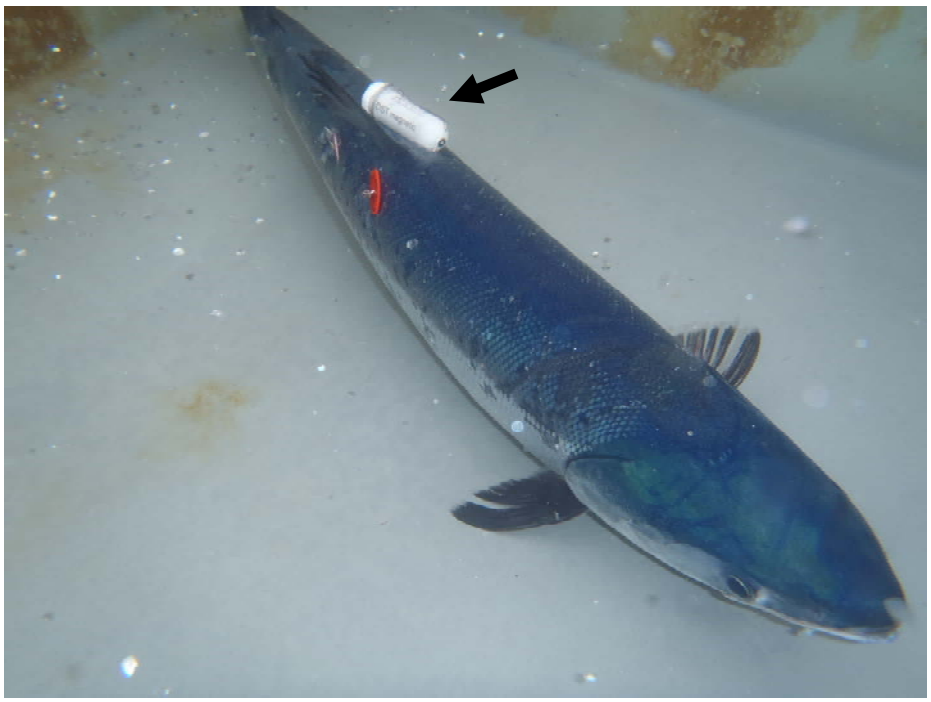

Fig. 2. Chum salmon tagged with an archival tag (arrow, DST magnetic manufactured by Star-Oddi) that measures and records earth's magnetic field strength (in three directions), tilt (in three directions), acceleration, temperature and depth.

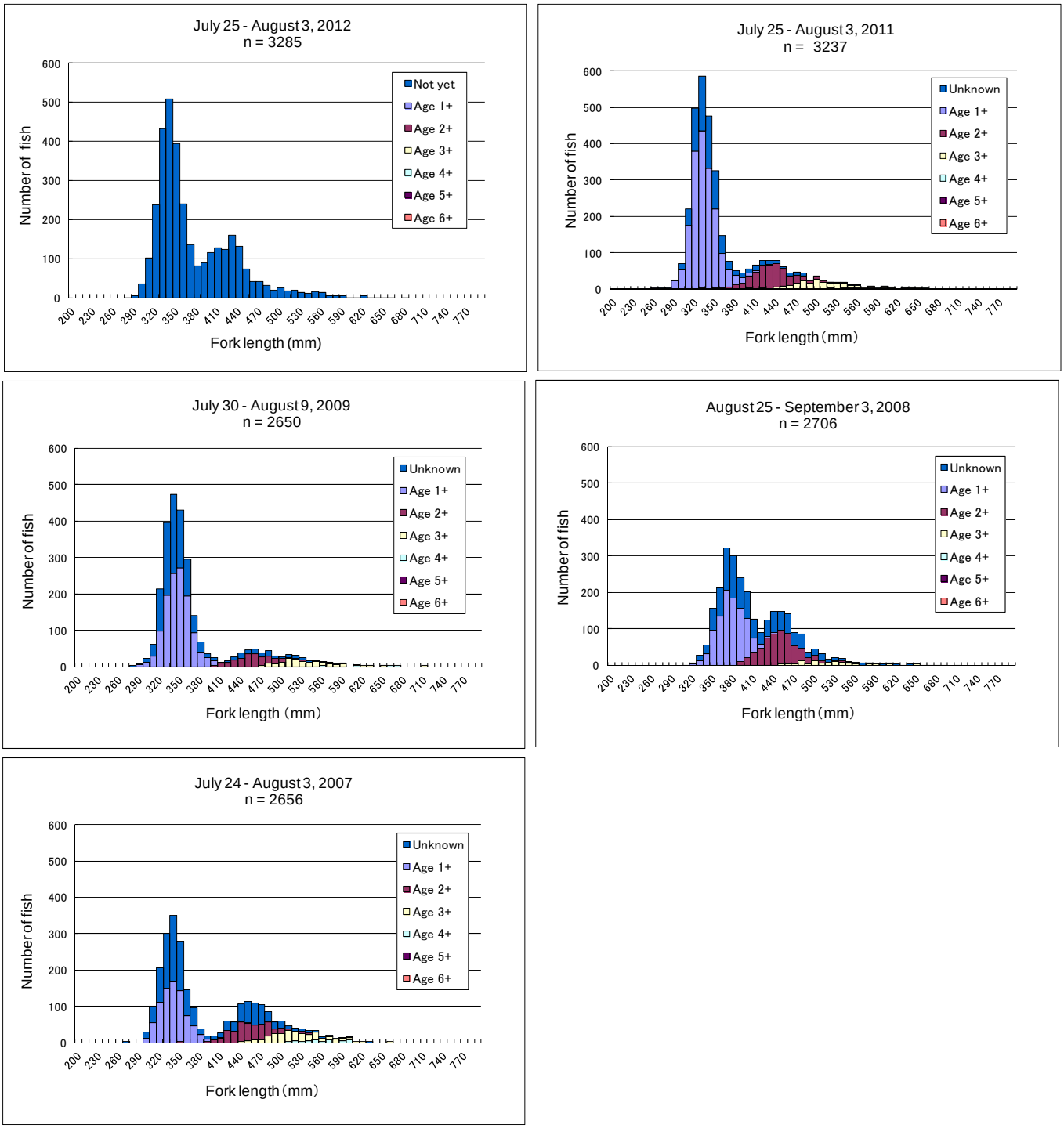

Fig. 3. Yearly fork length distributions of chum salmon in the 17 fixed fishing stations in Bering Sea from 2007 to 2012.

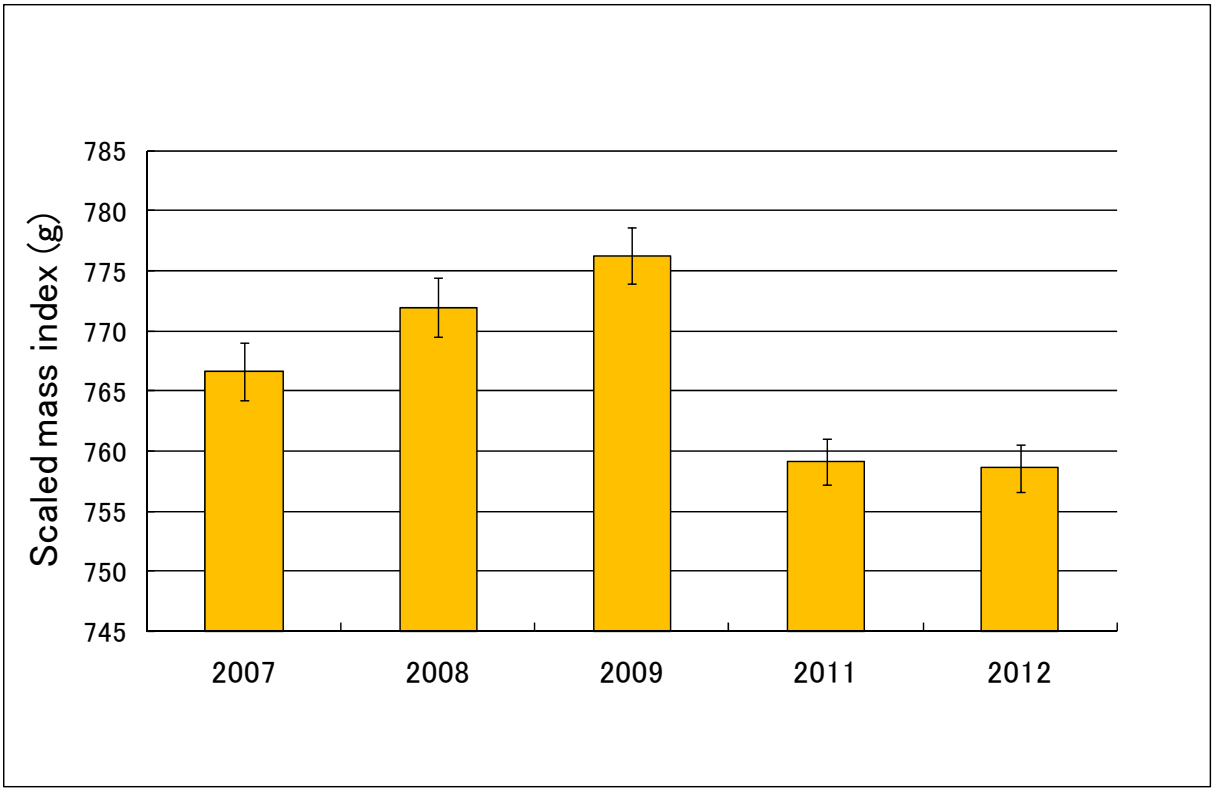

Fig. 4. Scaled mass index (Peig and Green 2009) of chum salmon for each year, obtained from 17 fixed fishing stations, i.e., body weight standardized to 400 mm fork length. Error bars indicate 95% confidence intervals

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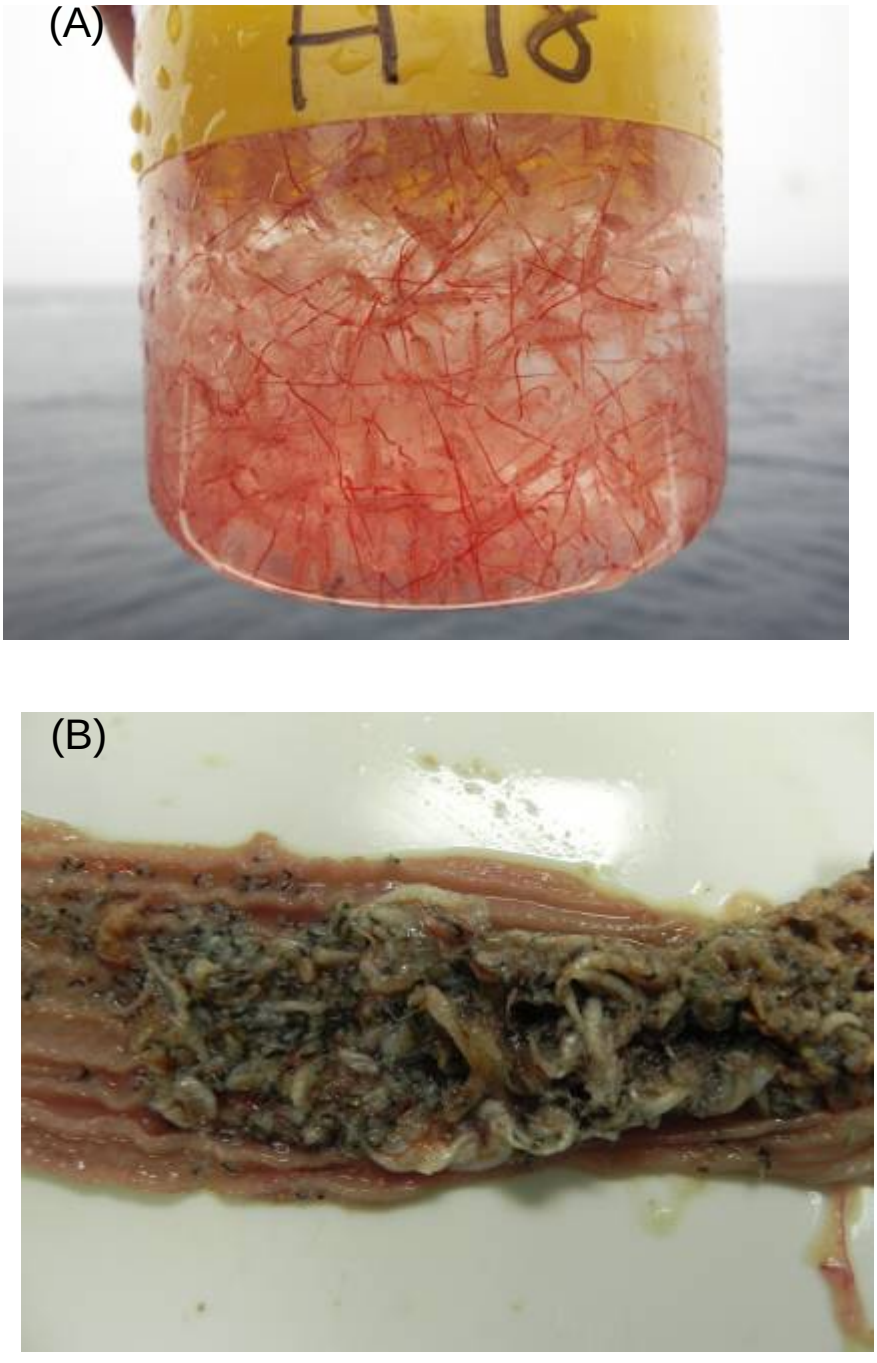

Fig. 5. An example of zooplankton samples collected by NORPAC net (A) and stomach contents (mainly euphausiids, copepods, and amphipods) of chum salmon (B) in the Bering Sea during summer of 2012.

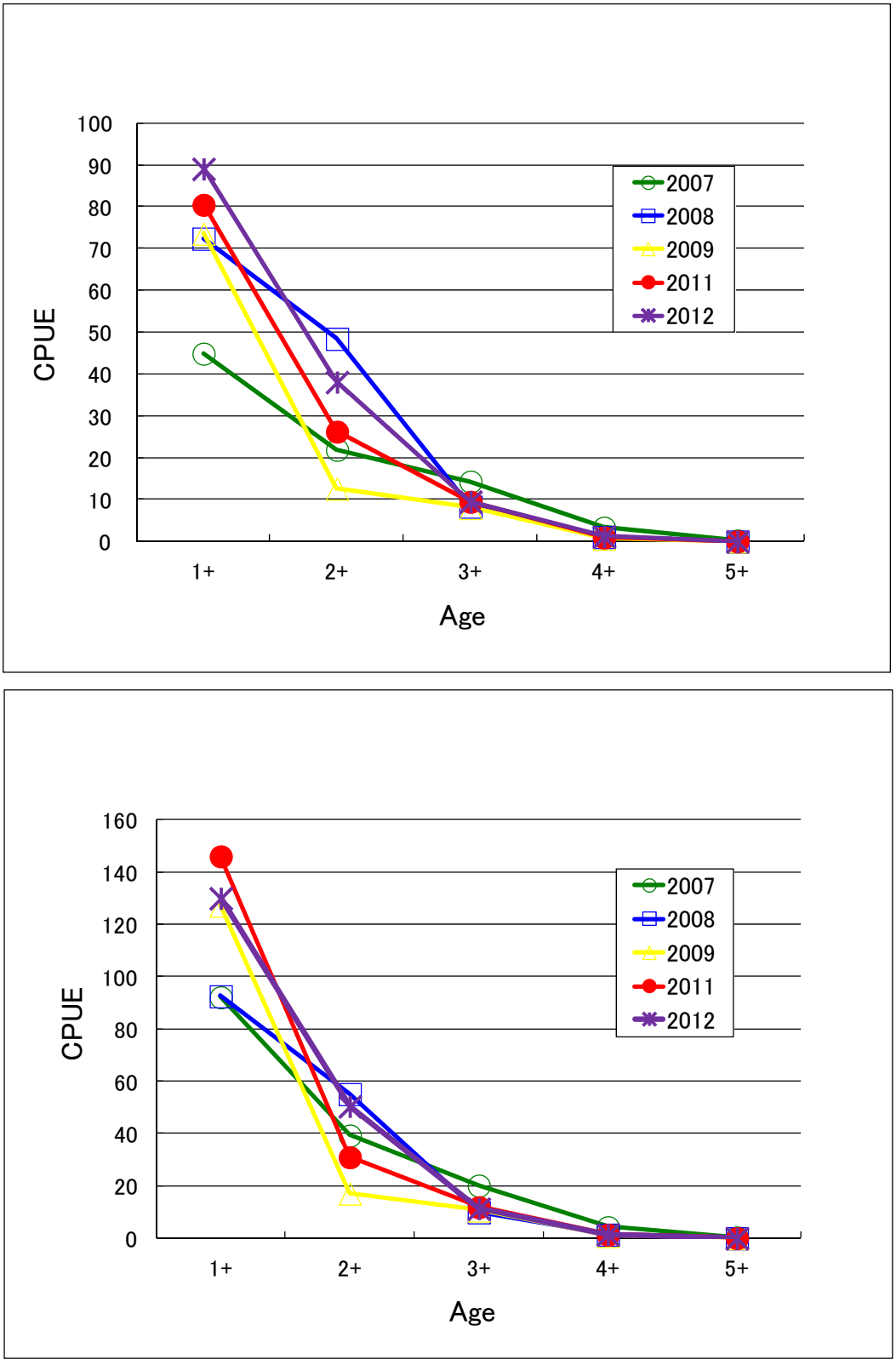

Fig. 6. Age-specific CPUE (number of individuals caught per surface trawl) of chum salmon for each year, obtained from 17 fixed fishing stations. Upper panel: a lognormal distribution of errors was assumed, lower panel: a normal distribution.