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International Salmon Research Aboard the R/V *Kaiyo maru* in the North Pacific Ocean during the Winter of 2006

by

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Abstract

A winter high-seas salmon research cruise was conducted in the western and eastern North Pacific from January 25 to March 6, 2006, onboard the Japanese research vessel, *Kaiyo maru,* to investigate salmon stock condition in winter. Research activities included collection of data on oceanography, zooplankton, micronekton, salmon, and other organisms. Nineteen experimental fishing stations were located in the Transition Domain and the Subarctic Current in the western North Pacific and seven stations were located in the Dilute Domain in the eastern North Pacific. However, trawl fishing operations were completed at 24 stations. A total of 2,336 salmon was caught: 1,696 in the western North Pacific and 640 in the eastern North Pacific. In the western North Pacific, pink salmon was the most abundant species (77.0% of the salmon catch), followed by chum salmon (13.9%), sockeye salmon (8.8%), and chinook salmon (0.3%). In the eastern North Pacific, chum salmon was the most abundant salmon species (83.6%), followed by sockeye salmon (9.5%), pink salmon (3.4%), coho salmon (3.0%), and chinook salmon (0.5%). Twenty-four disk-tagged salmon were released, and 584 salmon stomachs were examined during the survey. A total of 3,827 tissues, round, or gutted samples was collected from 1,321 salmon and sent to laboratories in Japan, U.S., and Korea for further examination. .

Introduction

The main objective of this research cruise was to study the stock condition of salmon (*Oncorhynchus* spp.) and their environment in the winter in the North Pacific Ocean. Three previous winter salmon surveys were conducted in November/December 1992, January 1996, and February/March 1998 by the Japanese research vessel *Kaiyo maru* (Ueno et al. 1997, Ishida et al. 1998). Information from these surveys indicated that salmon were distributed in a narrow range of low water temperatures (3.9-8ºC) (Ueno et al. 1997; Ishida et al. 1998), the low lipid content of pink and chum salmon signified they were starving (Nomura et al. 2000), and the standing stock of prey organisms was smaller in winter than summer (Nagasawa 2000). To investigate the current status of salmon condition, two research cruises of the *Kaiyo maru* were planned for winter and spring of 2006. Specific objectives of these research cruises were to (1) estimate spatial distribution and biomass of salmon by species, stocks or developmental stages, (2) identify characteristics of winter and spring ocean habitats, (3) evaluate salmon winter mortality, trophic condition, and growth rate, and (4) compare physical and biological environments for salmon during winter, spring, and summer seasons. This document summarizes the winter R/V *Kaiyo maru* cruise conducted in the North Pacific from January to March 2006.

Methods

Research Vessel and Survey Areas

The *Kaiyo maru* (2,942 gross tons) departed Kushiro on January 25, 2006, and visited Kodiak on February 11, 2006, after the first cruise leg, and departed Kodiak on February 14, 2006, and returned to Kushiro on March 6, 2006, after the second cruise leg. There were 11 experimental fishing stations during the first cruise leg, and 15 stations during the second leg (Fig. 1; Table 1). Nineteen fishing stations were located in the western North Pacific, and seven fishing stations were located in the eastern North Pacific. However, trawl operations were completed at 24 fishing stations. Oceanographic data were collected at each fishing station and additional oceanographic data were collected between fishing stations. The Electronic Plankton Counting and Sizing System was used to collect data on water temperature, salinity, chlorophyll fluorescence, and zooplankton particle density in surface waters continuously throughout the cruise.

Physical Oceanography

Seawater temperature and salinity data were collected using the conductivity, temperature, and depth sensor (CTD), the memory CTD (MCTD), and the expendable CTD (XCTD). The CTD or MCTD was used at fishing stations (n = 26). The XCTD was used at 1°-longitude intervals on the 45°N line and the return leg between 165°W and 155°E (n = 42). The CTD and XCTD recorded data in 1-m intervals from the surface to deeper than 1500 m.

Zooplankton and Micronekton Collection

Macro-zooplankton were sampled with a remodeled NORPAC net (0.45 m ring diameter, 1.93 m net length, 0.33 mm mesh size) and a Juday net (0.37 m mouth diameter, 1.2 m net length, 0.168 mm mesh size) at 26 fishing stations. The NORPAC net was towed vertically from 150 m to the surface and the Juday net was towed vertically from 200 m to the surface. These nets were towed either before dawn before trawling operations, or in the late afternoon after trawling operations. A calibrated flow-meter was attached to the opening of these nets in a position slightly off-center. The NORPAC net samples were fixed in 5% borax-buffered formalin in seawater and the Juday net samples were examined by A. Volkov while on board the ship.

Large macro-zooplankton were collected at 12 fishing stations using a BONGO net (2 rings, 0.7 m diameter, 4.1 m in overall length, 0.335 mm mesh size). The net was towed obliquely along the side of the vessel from 100 m to the surface at a speed of approximately 2 knots at around 20:00 hrs. Samples were fixed in 10% borax-buffered formalin in seawater.

Micronekton were collected at 9 fishing stations using a Matuda-Oozeki-Hu trawl (MOHT; 2.242×2.242 m rectangular mouth, 12 m net length, 1.59 mm mesh size). The trawl was towed obliquely at the stern of the vessel from 300 m to the surface at a speed of 4 knots after the BONGO net tow. Lantern fishes were sorted from a portion of the sample on board the ship and frozen for further examination in a laboratory. The remaining sample portion was fixed in 10% borax-buffered formalin in seawater. These samples were sent to the Graduate School of Fisheries Science, Hokkaido University.

Fishing Operations

A midwater trawl was used for experimental fishing operations to collect salmonids and other pelagic fish at 24 fishing stations (Fig. 1, Table 1). The trawl was towed at 5 knots in the surface layer from the water's surface to approximately 50 m depth for one hour during the daytime. The height and the width of the mouth of trawl was about 50 m, the length was 222 m, and the liner in the cod end was a 12 mm mesh size.

Tagging and Fish Examination

Live salmon caught in a healthy condition were put into a recovery tank. Fish were tagged with two disk tags issued by the Fisheries Agency of Japan (FAJ) and University of Washington (UW). Both disk tags were placed on one plastic cinch strap and applied to the fish, anterior to the dorsal fin. The fork length was measured and two scales were collected before the fish was released to the sea.

Salmon were processed soon after removal from the trawl. The catch was sorted and counted by species. Biological data were collected from a maximum of 60 sockeye salmon and all individuals of other species. The biological data included fork length (FL, mm), body weight (BW, g), sex, and gonad weight (GW, g). One (pink salmon *O. gorbuscha*) or two scales (sockeye *O. nerka*, chum *O. keta*, coho *O. kisutch*, and chinook salmon *O. tshawytscha*) were collected. Scales were collected from the INPFC (International North Pacific Fisheries Commission) -preferred area on the body for age determination. The presence of external injuries on salmon and visceral adhesions in sockeye salmon and other species were recorded (Nagasawa et al. 1997).

All non-salmonid catches were identified and counted. Body lengths were measured for non-salmonid fish and squid, and a few were frozen or fixed in 10% borax-buffered formalin for taxonomic and ecological studies.

Sample Collections of Salmon

The brain, pituitary, gonad, liver, and blood samples of chum salmon were collected for (1) molecular endocrine analysis of the migration, including the role of salmon gonadotropin-releasing hormone (sGnRH) and (2) analysis of endocrinological changes of the fish during its migration. Blood samples were collected from the caudal vasculature and centrifuged to obtain plasma samples for analyzing levels of steroid hormones. These samples were stored at –20°C. The gonad and liver were dissected out and weighed to calculate the gonadosomatic index (GSI, gonad weight / body weight x 100) and hepatosomatic index (HSI, liver weight / body weight x 100). The brain and pituitary were hemisected and frozen in liquid nitrogen for determination of the level of mRNAs encoding hypothalamic hormones and pituitary hormones. In some fish, the olfactory epithelium, olfactory bulb, telencephalon, optic tectum, hypothalamus, cerebellum, and medulla oblongata were collected to investigate genes related to the homing migration. These tissue samples were stored at –50°C. Additional brain and pituitary samples were fixed in Zamboni solution and stored in 70% ethanol in a refrigerator for later histological analyses. These samples were sent to the Field Science Center for Northern Biosphere, Hokkaido University for further examination in a laboratory.

Round samples from each salmon species were collected for stable isotope analysis. These samples were frozen and sent to the Hokkaido National Fisheries Research Institute (HNFRI) for a further examination in a laboratory.

Scales were collected from a maximum of 10 fish of each salmon species for stable isotope analysis and sagittal otoliths collected from pink salmon caught along the 145°W transect for detection of thermal marks were sent to the Auke Bay Laboratory, Alaska Fisheries Science Center, Juneau, USA, for analysis. Scales collected from a maximum of 60 sockeye and chinook salmon were sent to the Alaska Department of Fish and Game, Anchorage, USA, for stock identification using DNA

A part of the pectoral fin and sagittal otoliths were collected from all young (age 0.1) chum salmon and from a maximum 100 older chum salmon for genetic stock identification and for detection of thermal marks on the otolith. Fin samples were preserved in ethanol and dried otoliths were sent to National Salmon Resources Center (NASREC).

The brain and a portion of the intestine were collected from chum salmon and fixed in 10% formalin for parasitological analysis. In addition, blood, brain, and gonad were collected from chum salmon and frozen for endocrinological analysis. These samples were sent to Korean laboratories for further examination.

Stomach samples were collected from all species of salmon. A maximum 20 stomachs from pink and chum salmon was fixed in 10% borax-buffered formalin and sent to HNFRI for further examination in a laboratory. A maximum of 30 stomachs from each salmon species was examined by A. Volkov while onboard the vessel.

To investigate lipid contents of chum, pink, sockeye, chinook, and coho salmon, gutted fish were collected and sent to NASREC for further examination. A small number of round samples of unusual diseased fish were also collected and sent to NASREC.

Samples of visceral mass, round, or gutted chum salmon were colleted and frozen to investigate the infectious condition of *Anisakis simplex*. A small number of diseased tissues were also collected and fixed in 10% formalin. These samples were sent to NASREC for further examination.

Results

Oceanographic Condition

The position of oceanographic domains was identified along the 165°E and 145°W transects according to the seawater characteristics described by Dodimead et al. (1963) and Favorite et al. (1976). The southern limit of the Transition Domain is the Subarctic Boundary and northern limit is delineated by cold water (< 4°C) below 100 m depth in the western North Pacific. The northern limit of the Transition Domain was located between 44°30'N and 45°N along 165°E transect (Fig. 2, left panels). The Subarctic Current, an eastward-flowing surface current of cool, dilute water can be identified by cold water (near 3.5°C) at approximately 125 m. This current was located at the north of the Transition Domain. Along the 145°W transect, dilute waters (> 33 psu) was located at the surface layer (up to 120 m depth; Fig. 2, right panels). Fishing stations along the 145°W transect were in the Dilute Domain (Favorite et al. 1976).

Surface water was colder in the western North Pacific than in the eastern North Pacific (Fig. 3). Salinity of surface water was low in the eastern North Pacific. Chlorophyll concentration was high between 145°W and 175°E transects. Zooplankton density was consistently low throughout the survey area.

Salmonid Catches

A total of 2,336 salmon was caught in 24 trawl operations: 1,696 fish in the western North Pacific and 640 fish in the eastern North Pacific (Table 2). In the western North Pacific, pink salmon was the most abundant species (77.0% of the salmon catch), followed by chum salmon (13.9%), sockeye salmon (8.8%), and chinook salmon (0.3%). In the eastern North Pacific, chum salmon was the most abundant species (83.6% of the salmon catch), followed by sockeye salmon (9.5%), pink salmon (3.4%), coho salmon (3.0%), and chinook salmon (0.5%). While chum salmon caught in the western North Pacific consisted mainly of young (age 0.1) fish, chum salmon caught in the eastern North Pacific consisted mainly of older age groups.

Non-Salmonid Catches

Japanese anchovy (*Engraulis japonicus*: n = 30,109) and gonate squids (family Gonatidae: n = 3,977) were particularly abundant in the catch (Table 2). In addition, 79 three-spine stickleback (*Gasterosteus aculeatus*) and one spiny dogfish (*Squalus acanthias*) were caught.

Disk Tags

A total of 24 salmon were disk tagged during the survey. In the western North Pacific, eight disk tags were placed on fish, including one sockeye and seven pink salmon. In the eastern North Pacific, a total of 16 disk tags were placed on chum salmon.

Sample Collections

A total of 3,827 tissues, round samples, and gutted fish was collected from 1,321 salmon onboard the ship (Table 3). A total of 584 stomachs were examined onboard the ship. Other samples were sent to laboratories in U.S., Korea, and Japan for further examination.

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Table 1. Research activities conducted at each station during the North Pacific cruise of the *Kaiyo maru*, January-March 2006.

Leg	St. #	Transect	Lat.	Long.	Date	AM/PM	Trawl	CTD	NORPAC	Judday	BONGO	MOHT	Remarks
	01	155E	4100N	15500E	Jan 26	AM	▲	○*	○	○			Insufficient trawl mouth opening;trawl retrieved after 30 minutes; broken kite.
					Jan 28	AM	▲	○*	○	○			Insufficient trawl mouth opening;warp length changed from 250 m to 300 m after trawling for 30 minutes;another kite wire broken.
	02	155E	4200N	15500E	Jan 28	PM	○	○	○	○	○	○	
	03	155E	4300N	15500E	Jan 29	AM	○	○*	○	○			
	04	155E	4400N	15500E	Jan 29	PM	○	●	○	○	×	×	BONGO net and MOHT canceled because of stormy weather.
	11	165E	4200N	16500E	Jan 31	PM	○	●	○	○	○	×	MOHT canceled because of stormy weather.
1st	12	165E	4100N	16500E	Jan 31	AM	○	○*	○	○			
	09	165E	4400N	16500E	Feb 1	PM	○	●	○	○	○	×	MOHT canceled because of stormy weather.
	10	165E	4300N	16500E	Feb 1	AM	○	○*	○	○			
	13	175E	4100N	17500E	Feb 4	PM	○	●	○	○	○	×	Trawl used without net sonar because of stormy weather; broken rope in the trawl mouth;MOHT canceled.
	14	175E	4200N	17500E	Feb 6	AM	○	●	○	○			
	15	175E	4300N	17500E	Feb 6	PM	▲	×	×	×	×	×	Insufficient trawl mouth opening.
					Feb 7	AM	×	●	○	○			Trawl operation canceled because trawl winch not functioning well.
	21	145W	5400N	14500W	Feb 15	PM	○	○	○	○	○	○	
	22	145W	5300N	14500W	Feb 16	AM	○	○*	○	○			
	23	145W	5200N	14500W	Feb 16	PM	○	○	○	○	○	○	
	24	145W	5100N	14500W	Feb 17	AM	○	○*	○	○			
	25	145W	5000N	14500W	Feb 17	PM	○	○	○	○	○	○	
	26	145W	4900N	14500W	Feb 18	AM	○	○*	○	○			
	27	145W	4800N	14500W	Feb 18	PM	○	○	○	○	○	○	
2nd	08	165E	4500N	16500E	Feb 25	PM	○	○	○	○	○	○	
	07	165E	4600N	16500E	Feb 26	AM	○	○*	○	○			CTD, MCTD, and XCTD casts for data comparison.
	06	165E	4700N	16500E	Feb 26	PM	○	●	○	○	○	○	
	05	165E	4800N	16500E	Feb 27	AM	○	●	○	○			
	8.5	165E	4430N	16500E	Feb 28	AM	○	●	○	○			
	9.5	165E	4330N	16500E	Feb 28	PM	○	●	○	○	○	○	
	10.5	165E	4230N	16500E	Mar 1	AM	○	●	○	○			
	11.5	165E	4130N	16500E	Mar 1	PM	○	●	○	○	○	○	

○ : Completed, ▲ : With problems, × : Canceled

● : MCTD cast for oceanographic observation.

* : sea water collection for salinity calibration

Table 2. Trawl catches of salmon, other fishes, and squid by station during the winter research cruise of *Kaiyo maru*, 2006. For jellyfishes, weight is shown in parenthesis. + indicates unmeasured value.

				Sockeye		Chum				Chi-	Gonate	Spiny	Japanese	Three-spine	Jelly-
St.	Date	Lat.	Long.	age x.1	> age x.1	age 0.1	> age 0.1	Pink	Coho	nook	squids	dogfish	anchovy	stickleback	fishes
01b	1/28	4101	15456E	0	0	0	0	0	0	0	1	0	0	0	+(+)
02	1/28	4202	15450E	0	0	1	0	697	0	0	0	0	0	0	0(0)
03	1/29	4305	15459E	0	0	4	0	37	0	0	73	0	0	0	+(0.020)
04	1/29	4406	15453E	0	0	1	0	11	0	0	8	0	0	0	5(1.1)
12	1/31	4107	16500E	0	0	0	0	7	0	0	13	0	0	0	+(0.010)
11	1/31	4203	16455E	0	0	1	0	38	0	0	6	1	0	0	+(0.090)
10	2/1	4254	16458E	0	5	5	0	242	0	1	0	0	0	0	1(0.3)
09	2/1	4402	16449E	0	11	0	0	6	0	0	4	0	0	0	3(1.9)
13	2/4	4059	17447E	0	0	0	0	0	0	0	0	0	0	0	+(+)
14	2/6	4203	17453E	0	0	0	0	0	0	0	0	0	30109	0	0(0)
21	2/15	5356	14446W	0	9	0	15	3	1	0	0	0	0	0	+(23.8)
22	2/16	5301	14500W	0	14	0	34	0	0	0	4	0	0	0	+(5.6)
23	2/16	5209	14458W	0	17	0	66	0	3	1	58	0	0	0	+(0.6)
24	2/17	5052	14452W	1	14	5	128	5	3	2	0	0	0	0	+(0.1)
25	2/17	4952	14453W	0	2	7	131	4	3	0	0	0	0	0	+(0.2)
26	2/18	4853	14449W	0	4	2	32	0	2	0	10	0	0	0	+(0.3)
27	2/18	4754	14449W	0	0	17	98	10	7	0	0	0	0	0	0(0)
08	2/25	4451	16506E	0	0	0	1	0	0	2	712	0	0	0	8(+)
07	2/26	4559	16503E	0	6	0	0	0	0	0	242	0	0	0	+(0.5)
06	2/26	4657	16501E	2	3	0	1	0	0	0	2386	0	0	74	+(0.8)
05	2/27	4800	16503E	0	3	0	2	0	0	0	459	0	0	5	+(14.9)
8.5	2/28	4421	16506E	0	8	22	1	11	0	1	0	0	0	0	0(0)
9.5	2/28	4321	16504E	0	86	131	4	50	0	0	0	0	0	0	0(0)
10.5	3/1	4230	16456E	0	23	58	4	206	0	1	0	0	0	0	0(0)
11.5	3/1	4136	16451E	0	3	0	0	0	0	0	1	0	0	0	0(0)
	Total			3	208	254	517	1327	19	8	3977	1	30109	79	+

Table 3. List of tissue, round, and gutted salmon samples collected by trawl operations during the *Kaiyo maru* winter cruise, 2006.

Sample Type	Sockeye	Chum (age 0.1)	Chum (age > 0.1)	Pink	Coho	Chinook	Total
Onboard measurement	196	239	497	362	19	8	1321
Isotope (Japan)	16	7	10	14	6	6	59
Genetic/Otolith (Japan)	-	239	497	-	-	-	736
Genetic/Isotope (USA)	194	39	128	110	19	8	498
Otolith (USA)	-	-	-	22	-	-	22
Blood/Brain (Japan)	-	9	74	-	-	-	83
Stomach (Japan)	10	73	178	171	-	-	432
Stomach (Russia)	163	71	163	160	19	8	584
Endocrine (Korea)	-	4	30	-	-	-	34
Parasite (Korea)	-	3	36	-	-	-	39
Lipid/Round (Japan)	-	-	-	50	-	-	50
Lipid/Guttted (Japan)	20	53	57	68	7	2	207
Parasite/Gutted (Japan)	-	50	30	-	-	-	80
Skin disease (Japan)	-	-	3	3	-	-	6
Skinny fish (Japan)	-	-	3	-	-	-	3
Diseased organ (Japan-USA)	-	-	-	1	1	-	2

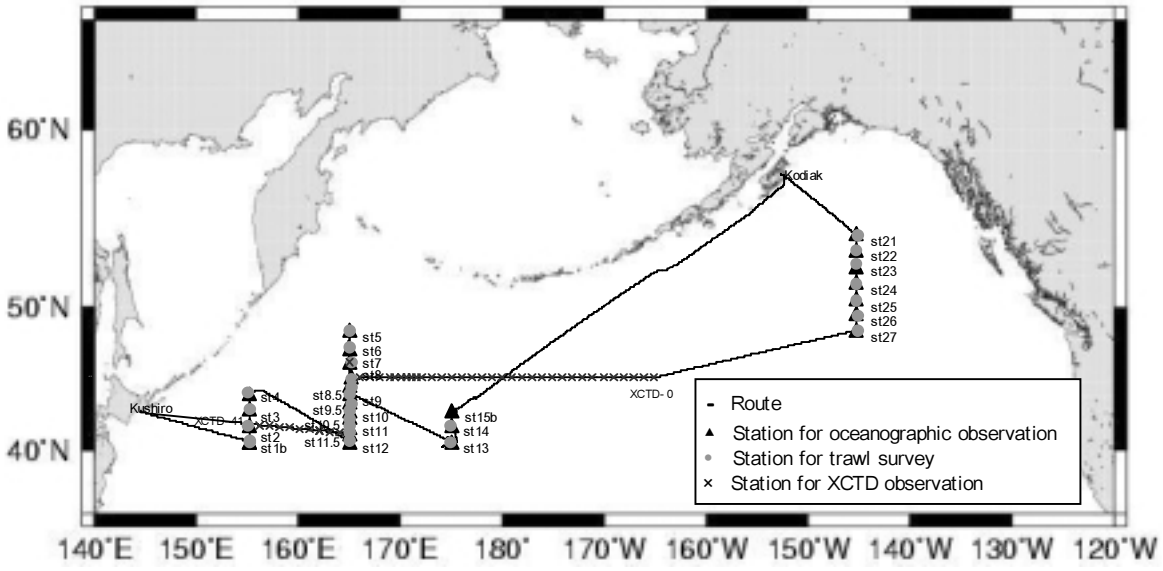

Fig. 1. North Pacific survey area of the R/V *Kaiyo maru* salmon research cruise, January-March 2006.

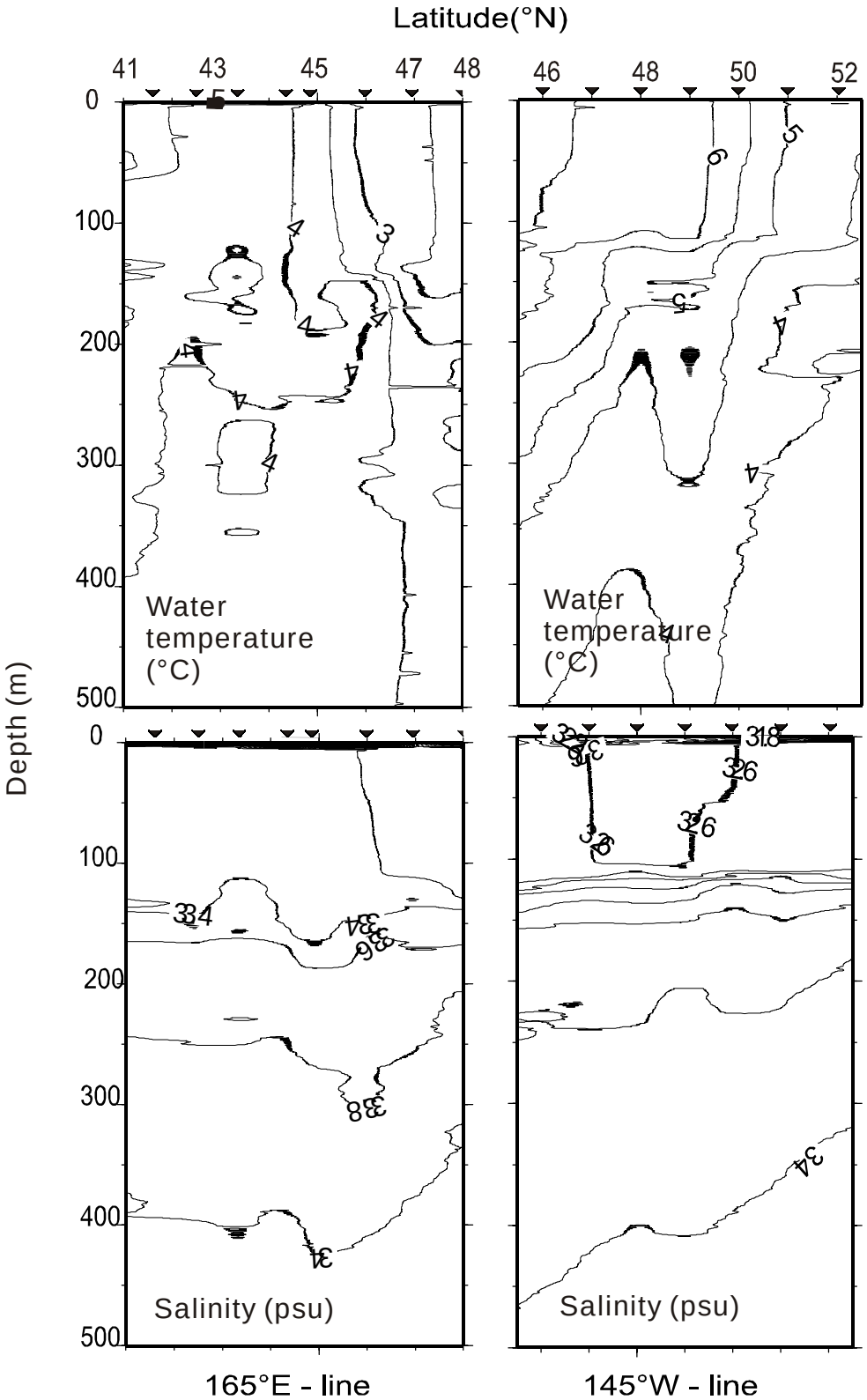

Fig. 2. Vertical sections of water temperature and salinity along the 165°E and 145°W transects of the *Kaiyo maru* winter cruise, 2006.

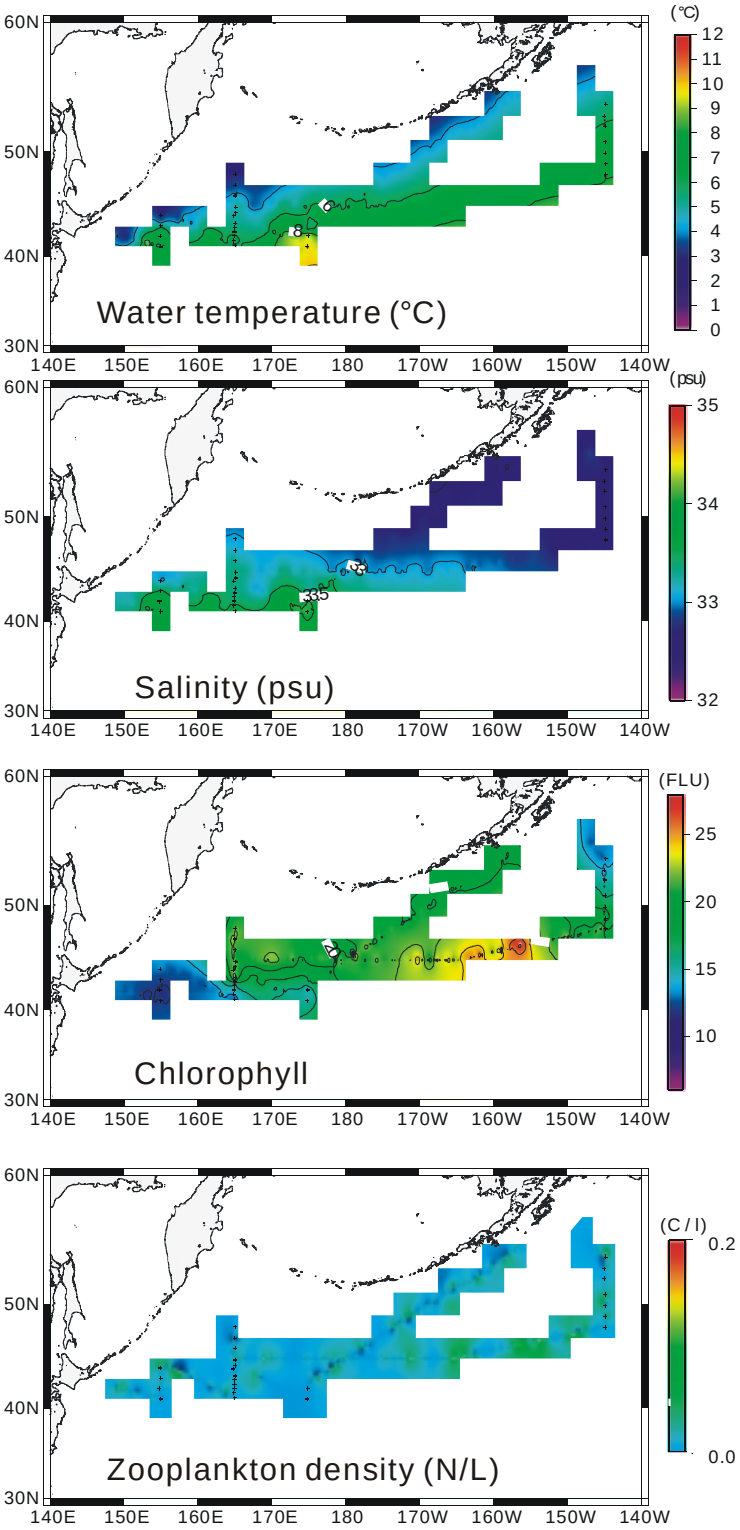

Fig. 3. Spatial distribution of temperature, salinity, chlorophyll concentration, and zooplankton density in the surface water as determined by the Electronic Plankton Counting and Sizing (EPCS) System during th *Kaiyo maru* winter cruise, 2006.