Canadian Data Report of

Fisheries and Aquatic Sciences 1083

2001

SYNOPTIC INVESTIGATION FOR ALGAE IN BALLAST WATER AND SEDIMENTS OF SHIPS USING SELECTED BRITISH COLUMBIA PORTS

by

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Cat. No. Fs 97-13/1083 ISSN 0706-6465

Correct citation for this publication:

Waters, R., N. Haigh, J. N. C. Whyte and C. Levings. 2001. Synoptic investigation for algae in ballast water and sediments of ships using selected British Columbia ports. Can. Data Rep. Fish. Aquat. Sci. 1083: 19p.

ABSTRACT

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Data are presented on the algae identified from ballast water and sediment of eight of fifty-four ships arriving at five British Columbia ports from western North Pacific ports between November 25, 1999 and March 29, 2000. Information on the duration of time the water/sediment was in the ballast tanks, ballast water capacity, quantity on board, and associated characteristics were collected along with temperature and salinity data. Ten of the thirteen incubated ballast water samples grew phytoplankton, most of which were diatoms; the sediment samples were predominated by benthic phytoplankton species. There were very few dinoflagellates noted.

RÉSUMÉ

Waters, R., N. Haigh, J. N. C. Whyte and C. Levings. 2001. Synoptic investigation for algae in ballast water and sediments of ships using selected British Columbia ports. Can. Data Rep. Fish. Aquat. Sci. 1083: 19p.

Il s'agit de données concernant les algues et les sédiments trouvés dans l'eau de ballast de huit des cinquante-quatre navires en provenance de divers ports du Pacifique Nord-Ouest ayant séjourné dans cinq ports de la Colombie-Britannique au cours de la période comprise entre le 25 novembre 1999 et le 29 mars 2000. Données recueillies : information sur la durée de temps passée par cette eau et les sédiments dans les citernes de ballast, capacité des citernes, quantité à bord et autres caractéristiques assimilées, ainsi que données sur la température et la salinité. Dix des treize échantillons d'eau de ballast prélevés contenaient du phytoplancton, principalement des diatomées, alors que les échantillons de sédiments contenaient principalement du phytoplancton benthique. On a observé très peu de dinoflagellés.

INTRODUCTION

This report follows on the initial work conducted in 1995 through 1997 investigating the presence of algae in ship ballast water at south coastal British Columbian ports including Vancouver, Nanaimo, Harmac/Duke Point, Chemainus and Crofton(Piercey et al 2000). Where the initial work focused on macrofauna (zooplankton) filtered from large volume samples of ballast water, this work focused on the algae (phytoplankton) in smaller water samples and sediments in the ballast tanks of vessels sampled between November 1999 and March 2000. During the latter process a few zooplankton samples were also collected which will be the subject of a later report.

Results of the initial work were reported in Levings et al (1998), and a data report (Piercey et al 2000) presents the raw macro-invertebrate data for these earlier investigations conducted between 1995 and 1997.

The following describes the methods used in identifying, contacting and boarding vessels and provides information on the sampling protocols and field observations reporting for the present program.

The data are presented in seven tables detailing ship characteristics, sample details and analytical results.

METHODS

Ships containing ballast water from other countries or from oceanic sources as a result of mid-ocean exchange procedures were identified, and subsequently sampled for ballast water and sediment while they were in the ports of Nanaimo (including Harmac and Duke Point Terminals), Chemainus, Crofton and Vancouver. The mid-ocean exchange procedure is carried out as a measure to reduce the potential introduction of exotic species between international ports. Ship schedules were determined with the aid of local shipping agents, and upon obtaining clearance with the wharf staff or port authority to access the docks, the ships were boarded and the Chief Officer or Captain contacted. The sampling plan was explained with the aid of a standard pre-printed form shown in Piercey et al (2000) and an understanding of the ballast water distribution and control mechanism obtained. The form itemized the vital statistics of the vessel and ballast water sample sources and conditions. At that time inquiries were made on the accessibility and sources of ballast water in the tanks and the appropriate tanks were selected for sampling. It was an essential condition of sampling that ships that arrived were in-ballast and that the ballast water in a tank was confirmed to have come from outside Canadian waters including international port sources and mid-ocean exchange water. Confirmation of the ballast water source was checked in the ballast control records in the ship's pump control room. Because the sample pump could only lift water a few meters the ballast tanks had to be nearly full for a sample to be obtained.

Access to the appropriate sounding tube (standpipe) or manhole to attempt to collect samples was made, usually with the assistance of a member of the crew.

Information on the ships' tonnage and ballast tank capacities were provided by the Nanaimo Port Authority's registered vessel program Fairplay Ships Register (Fairplay, 2000). The sequence of vessel ID numbering applied in Piercey et al (2000) was continued in this program with the vessels sampled on the east coast of Vancouver Island ports covering numbers NAN27 to NAN34, and the Vancouver vessel designated VAN308. Vancouver samples were collected by Entech, and Vancouver Island port samples from Nanaimo (including Harmac/Duke Point Terminals), Chemainus and Crofton were collected by Castor Consultants Ltd.

SAMPLING METHODOLOGY

The sampling protocols are detailed below.

Ballast Water Samples

A 12 volt (DC) pump (Simer Blue Water self-priming Pump) was used to collect ballast water samples from near the bottom of the ballast tank sounding tube (stand pipe) or in those instances when a man-hole was opened, down to the first level in the ballast tank (approximately 3 meters). The intake hose (1.9 cm diameter) was lowered into the sounding tube as far as possible, usually about 7 meters, before pumping was started. The pump and hoses were purged by pumping and discharging approximately 15 litres of ballast water from the subject tank before the samples were collected. The pumping rate was approximately 10 litres per minute. This also purged the sounding tube and drew in additional water from the ballast tank. In one instance, because the ballast tank levels were low, a sample was collected from the pressure gauge lines in the pump room (Table 1). Phytoplankton samples were collected unfiltered and unpreserved in two 1-litre sample bottles from each suitable ballast tank and then held on ice. Observed ballast water temperatures are given in Table 1. In the case of three ballast tanks on one ship one sample was collected from each tank. There were one 1 litre and two 1.5 litre samples as these were the size of the sample bottles at the time.

Zooplankton samples were collected through a 44-um net hung above the deck of the vessel. The retained material was washed off the inside of the net, using the pumped ballast water, and then into a plastic jar using a wash bottle with tap water, and preserved in a 5% formalin solution with Rose Bengal. In the case of the zooplankton samples a 15 ml water sample was also collected for later salinity analysis. Data from these samples will be presented in a later report.

Ballast water sample temperature was measured using a digital pocket field thermometer (+/- 0.1 degree) and observations on odour and sediment entrainment in the water samples were recorded. Samples for salinity measurements were collected and sent to the laboratory for analysis.

Sediment Samples

Where sediment samples could be collected they were obtained by direct access to the ballast tank with the assistance of the crew. Sediments were collected carefully into the sample jar using a pre-cleaned stainless spoon; some ballast water was included in the jar and the sample was submitted for analysis. At each time about 100 to 200 cc of sediment material was collected.

All samples were stored on ice and delivered to the Pacific Biological Station in Nanaimo, B.C. as soon as possible.

LABORATORY METHODOLOGY

Ballast Water Samples

Aliquots of 10 milliliters (mL) of the ballast water samples were placed in 250 mL Erlenmeyer flasks with approximately 125 mL of HESNW media both with and without added silicate (Harrison et al. 1980). Triplicates were done in each case. A series of six flasks were placed in each of one, two, or three incubators with different illumination levels, light:dark regimes, and temperatures (Table 4).

Flasks were incubated for two weeks, and contents were examined weekly. A subsample of 40 mL was taken from each flask, fixed with Lugol's iodine, and examined by light microscopy at 40 to 1000X magnification using phase contrast. Species present were identified to the highest taxonomic level possible, and cell counts were made using a Sedgewick Rafter cell (1 mL volume).

Ballast water salinity measurements were made upon receipt of the samples at the Pacific Biological Station laboratory using a Kernco Salinometer 600L with an operating range of 0-5% (0-50 parts per thousand).

Sediment Samples

After sampling sediments were stored in the dark at 4 C. Subsamples of 50 mL were placed in a beaker and sonicated for 3 minutes in a Branson D-150 sonicating bath, and then the 20 μm to 80 μm fraction was separated by screening through an 80 μm Nitex sieve and collecting onto a 20 μm Nitex sieve. This fraction was backwashed from the 20 μm screen and made up to 50 mL with HESNW media. Aliquots of 0.5 mL of this solution were added to 2 mL aliquots of HESNW with and without added silicate in tissue culture well plates, in six replicate wells for each, and placed in two different incubators (Table 4) for two weeks. Plates were examined weekly using an inverted microscope at 30 to 200X magnification; species present were identified to highest possible taxonomic level (species) and ranked for abundance within each well.

RESULTS

Fifty-four ships and the Public Works and Government Services Canada dry dock in Esquimalt were approached and interviewed between November 25, 1999 and March 29, 2000 in the Port of Vancouver and ports on the east coast of Vancouver Island including Nanaimo, Crofton, Harmac/Duke Point, and Chemainus. The drydock inquiry did not identify any suitable ships. The number of ships contacted in each of the port was 1, 12, 32, 5, and 4, respectively. Among the 54 ships, nine had accessible ballast water from a foreign port, or a mid-Pacific exchange in one or more tanks. As a result thirteen ballast water samples were collected with single samples from four ships, two samples from three ships, and three samples from one ship. Three ballast tank sediment samples were collected one from the Tolten, possibly of Japanese origin, and two, also possibly of Japanese origin, from the Skaugran (Table 2 and 3).

Ballast capacity of the vessels ranged from 1,800 to 44,000 tonnes with an average of about 24,000 tonnes. Of the vessels on which ballast water was sampled the gross tonnage ranged from 15,100 to 36,000 tonnes with an average of about 26,500 tonnes. Vessel ballast capacity data for the 16 for which data was obtained the range was 9,000 to 20,000 tonnes with an average of 14,084 tonnes, and the range of ballast-in-tanks was 1,360 to 13,000 tonnes with an average of 5,400 tonnes. The gross tonnage for the same vessels ranged from 7,388 to 36,008 tonnes with an average of 26,668 tonnes. This indicates that with respect to gross tonnage and ballast tonnage the ships sampled appear to be representative of the vessels boarded.

As shown in Table 1 the length of time that the ballast water was on board ranged from 1 week to 4 months. As indicated in Piercey et al (2000) the last port of call is not necessarily indicative of the source of the ballast water in a ballast tank. Only one of the 12 samples collected actually came from a vessel's last port of call. The source port is included here as it is known that the mid-ocean exchange is less than 100% effective so that it is possible that there is some, though diluted, ballast water from the source port remaining after the exchange.

Ten of the thirteen ballast water samples were of mid-Pacific ocean exchange origin. The remaining three were not of mid-ocean exchange water samples but were of west coast US origin (Los Angeles (LA), San Diego and Sacramento). Among the mid-Pacific ocean exchange samples the source ports or areas included Pusan, Korea (1), a combination of LA, New Zealand and Tasmania (1), Tokyo, Japan (1), Sendai and Fung Chen, China (2), Hiroshima, Japan (2) and Japanese coastal (3) (Table 1). The origin of two of the sediment samples from the Skaugran may be Hiroshima, Japan and the one from the Tolten was from Japanese harbour waters.

Table 2 presents the sample incubation variables for the different test parameters for the respective samples. Replicates are shown for the respective incubators, three for each of the water samples and six for the sediment samples in the media with and without silicate enrichment. In incubators A and B temperatures were 10^0 and 12^0 C

with light:dark exposures of 2:4 and 14:10, and lux of 1700 and 1200 respectively; and in incubator C temperature was 17^0, light:dark was 24:0 and there was 2500 lux.

Table 3 presents the number of species identified in the four basic taxonomic groups in the different media and incubation conditions. The lowest number of species overall within the four of the basic taxonomic groups were found in samples 1 and 2 which were from vessels that had performed mid-Pacific exchange following departure from Asian ports. Ballast water samples 5, 6, and 8 and sediment sample 11, all from mid-Pacific exchange with Asian source port waters, appeared to exhibit the greatest numbers of diatom species. Dinoflagellates appeared to be more associated with the sediment samples than the water samples whereas other flagellates were more widely represented in all samples.

Tables 4 and 5 present the detailed taxonomic identification (species/genera) and relative numbers of individuals identified in the ballast water and sediment samples among the taxonomic groups. This is a qualitative analysis and no quantification was attempted on the samples. Ten of the 13 ballast water samples grew phytoplankton most of which were diatoms. Samples incubated in media with +Si and media without added Si appeared to grow much the same species. This may have occurred because the natural water used for the media is usually high in silicate through the winter, when the work was carried out. It appeared that benthic phytoplankton species predominated the sediment samples and there were very few dinoflagellates. In part this may be due to the action of sonication and screening of the samples.

The ballast water samples were determined to have 32 species or genera, and 6 other general taxa, and the sediment samples exhibited 14 species or genera and 6 other general taxa. The three sediment samples accounted for the larger proportions of individuals in comparison to the water samples. Tables 6 and 7 present the species and associated abundance information. Ballast water samples 5 and 8 and sediment samples 11 and 13 exhibited the greatest number of individual microflora among the samples analyzed.

ACKNOWLEDGEMENTS

This study was funded by Fisheries and Oceans Canada, Environmental Sciences Strategic Research Fund. We are most grateful for the cooperation and assistance of the ships' masters, shipping agents, port authorities and associated industry docks. Dr. Terri Sutherland, West Vancouver Laboratory, kindly reviewed this report.

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Table 1. Overall summary of ships, samples, and ballast water and sediment origins 1999-2000

ship #	sample #	vessel type /load	h2o/ seds	port collected	date coll.	source port	tank	access	depth in tank	time in tank	bh2o TC	bh2o Sal	moe	moe position
Nan27	1	pulp	h2o	Crofton	22/12/99	Fung Chen, CHINA	port side #4	stand pipe	bottom	<3 wks	8.2	34	yes	unknown
Nan27	2	pulp	h2o	Crofton	22/12/99	Pusan, S.KOREA	port side #2	stand pipe	bottom	<3 wks	8.2	35	yes	unknown
Nan28	3	paper	h2o	Crofton	22/12/99	San Diego, CA	upper wing stbd #5	stand pipe	bottom	1-2 wks	10.3	36	no	na
Nan28	4	paper	h2o	Crofton	22/12/99	Long Beach, CA	upper wing stbd #3	stand pipe	bottom	16 wks+	9.2	34	no	na
Nan29	5	forest products	h2o	Chemainus	12/1/00	LA, NZ, AUSTRALIA	pump room	pressure gauge	na	1-4 mths	14.7	32	yes	unknown
Nan30	6	forest products	h2o	Crofton	12/1/00	Sacramento, CA	port side #4	stand pipe	bottom	4 wks	8	3	no	na
Nan31	7	forest products	h2o	Crofton	14/1/00	Tokyo, JAPAN	port #3	hatch	3 m	2 wks	7.6	34	yes	unknown
Nan32	8	general cargo	h2o	Crofton	21/2/00	Sendai, CHINA	port wing #2	stand pipe	bottom	8 wks	6.3	34	yes	54 14 N, 164 05 W
Van308	9	forest products	h2o	Vancouver	26/2/00	Hiroshima, JAPAN	stbd wing #1	unk.	unk.	unk.	unk.	37	yes	26 36 N, 177 45.5 W
Van308	10	forest products	h2o	Vancouver	26/2/00	Hiroshima, JAPAN	port wing #6	unk.	unk.	unk.	unk.	37	yes	27 01.4 N, 173 31.7 E
Van308	11	forest products	seds	Vancouver	26/2/00	Hiroshima, JAPAN	port wing #1	hatch	unk.	unk.	unk.	na	yes	26 36 N, 177 45.5 W
Van308	12	forest products	seds	Vancouver	26/2/00	Hiroshima, JAPAN	port wing #1	hatch	unk.	unk.	unk.	na	yes	26 36 N, 177 45.5 W
Nan33	13	forest products	seds	Nanaimo	23/2/00	JAPAN	stbd wing #1	hatch	3 m	12 wks	unk.	na	no	na
Nan34	14	forest products	h2o	Nanaimo	13/3/00	JAPAN	stbd side #2	stand pipe	bottom	12 wks+	unk.	35	yes	49 11 N, 172 25 W or E
Nan34	15	forest products	h2o	Nanaimo	13/3/00	JAPAN	stbd side #3	stand pipe	bottom	13 wks+	unk.	35	yes	49 11 N, 172 25 W or E
Nan34	16	forest products	h2o	Nanaimo	13/3/00	JAPAN	port side #3	stand pipe	bottom	14 wks+	unk.	35	yes	49 11 N, 172 25 W or E

Notes:

bh2o - ballast water
TC - temperature in degrees Celsius
Sal - salinity in parts per thousand
moe - mid-ocean exchange
depth in tank - approximate depth from which sample was collected.

Table 2. Sample incubation: Ballast water and sediment samples 1999-2000

Incubator		A		B		C	
Temperature (C)		10		12		17	
Light:Dark		1:4		14:10		24:0	
Illumination (lux)		1700		1200		2500	
Media		HESNW+Si	HESNW-Si	HESNW+Si	HESNW-Si	HESNW+Si	HESNW-Si
Sample No.	1	3	3	3	3	3	3
	2	3	3	3	3	3	3
	3					3	3
	4					3	3
	5			3	3	3	3
	6			3	3	3	3
	7	3	3			3	3
	8	3	3			3	3
	9	3	3			3	3
	10	3	3			3	3
	11	6	6			6	6
	12	6	6			6	6
	13	6	6			6	6
	14					3	3
	15					3	3
	16					3	3

A: Algae Incubator, 10 C, 1:2 light:dark
B: Incubator, 12 C, 14:10 light:dark
C: Algae Lab, 17 C, 24h light
HESNW: Harrison's Enriched Natural Seawater

Table 3: Number of species in four basic groups (diatoms, dinoflagellates, other flagellates, and microzooplankton) grown from ballast water and sediment samples collected December 1999 to March 2000 from ships entering Canadian west coast ports.

Sample	Incubator	Media	Diatoms	Dinoflagellates	Other flagellates	Microzooplankton
1	A	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
	B	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
	C	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
2	A	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
	B	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
	C	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
3	C	+Si	4	1	2	0
		-Si	7	0	1	0
		total	7	1	2	0
4	C	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
5	B	+Si	8	0	2	0
		-Si	8	0	3	1
		total	9	0	3	1
	C	+Si	12	0	4	0
		-Si	12	0	3	0
		total	14	0	4	0
6	B	+Si	0	0	3	0
		-Si	0	0	3	0
		total	0	0	3	0
	C	+Si	5	0	0	0
		-Si	7	0	0	0
		total	7	0	0	0
7	A	+Si	0	0	2	0
		-Si	1	0	2	0
		total	1	0	3	0
	C	+Si	6	0	2	1
		-Si	5	0	2	0
		total	8	0	3	1

Table 3 (continued)

Sample	Incubator	Media	Diatoms	Dinoflagellates	Other flagellates	Microzooplankton
8	A	+Si	4	0	2	0
		-Si	4	0	2	1
		total	4	0	2	1
	C	+Si	13	0	1	1
		-Si	11	0	1	1
		total	16	0	1	2
9	A	+Si	1	0	1	0
		-Si	0	0	1	0
		total	1	0	1	0
	C	+Si	1	0	2	2
		-Si	2	0	2	2
		total	2	0	3	3
10	A	+Si	0	0	0	0
		-Si	0	0	0	0
		total	0	0	0	0
	C	+Si	3	0	2	1
		-Si	5	0	3	0
		total	6	0	3	1
11	A	+Si	1	0	2	2
Sed.		-Si	2	0	2	1
		total	3	0	2	2
	C	+Si	12	2	2	4
		-Si	10	1	3	3
		total	16	2	3	6
12	A	+Si	0	0	2	3
Sed.		-Si	1	0	1	5
		total	1	0	2	5
	C	+Si	0	0	2	6
		-Si	0	0	2	7
		total	0	0	2	8
13	A	+Si	0	0	1	2
Sed.		-Si	1	3	2	4
		total	1	3	2	4
	C	+Si	6	0	1	7
		-Si	7	0	1	10
		total	8	0	1	11
14	C	+Si	1	0	3	4
		-Si	1	0	4	4
		total	2	0	4	5
15	C	+Si	0	0	4	4
		-Si	1	1	3	1
		total	1	1	4	4
16	C	+Si	4	0	1	7
		-Si	4	0	2	7
		total	5	0	2	8

Table 4. List of species identified in ballast water samples (numbers refer to estimated number of species in a genus or group)

Sample No.	1	2	3	4	5	6	7	8	9	10	14	15	16
Source Port	Fung Chen	Pusan	San Diego	Long Beach	LA,NZ,Aus	Sacramento	Tokyo	Sendai	Hiroshima	Hiroshima	Japan	Japan	Japan
Salinity	34	35	36	34	32	3	34	34	37	37	35	35	35
DIATOMS													
Achnanthes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Actinoptychus senarius	0	0	0	0	0	0	0	0	1	0	0	0	0
Asterionella japonica	0	0	1	0	0	0	0	1	0	0	0	0	0
Attheya septentrionalis	0	0	0	0	1	0	0	1	0	0	0	0	0
Chaetoceros curvisetus	0	0	0	0	1	0	0	0	0	0	0	0	0
Chaetoceros debilis	0	0	1	0	1	0	1	0	0	0	0	1	1
Chaetoceros decipiens	0	0	0	0	1	0	1	1	0	0	0	0	1
Chaetoceros didymus	0	0	1	0	1	0	0	1	0	0	0	0	1
Chaetoceros cf. *seiracanthus*	0	0	0	0	1	0	0	0	0	0	0	0	0
Chaetoceros socialis	0	0	0	0	0	0	0	1	0	0	0	0	0
Chaetoceros subtilis	0	0	0	0	1	0	0	0	0	0	0	0	0
Chaetoceros tenuissimus	0	0	0	0	1	0	1	0	0	0	0	0	0
Chaetoceros teres	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros wighami	0	0	0	0	0	0	0	0	0	0	1	0	0
Coscinodiscus cf. *marginatus*	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
Cylindrotheca closterium	0	0	1	0	1	0	1	1	0	0	0	0	0
Fragilaria cf. *crotonensis*	0	0	0	0	1	0	0	0	0	1	0	0	0
Fragilariopsis pseudonana	0	0	0	0	0	1	0	0	0	0	0	0	0
Guinardia delicatula	0	0	0	0	0	0	0	1	0	0	0	0	0
Guinardia cf. *delicatula*	0	0	0	0	0	0	0	0	0	1	0	0	0
Leptocylindrus danicus	0	0	1	0	0	0	0	0	1	0	0	0	0
Melosira moniliformis	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula sp.	0	0	0	0	1	2	0	3	0	0	1	0	0

Table 4 (continued)

Sample No.	1	2	3	4	5	6	7	8	9	10	14	15	16
Source Port	Fung Chen	Pusan	San Diego	Long Beach	LA,NZ,Aus	Sacramento	Tokyo	Sendai	Hiroshima	Hiroshima	Japan	Japan	Japan
Salinity	34	35	36	34	32	3	34	34	37	37	35	35	35
Navicula transitrans cf. var *derasa*	0	0	0	0	0	0	0	0	0	1	0	0	0
Nitzschia cf. *bilobata*	0	0	0	0	0	1	0	0	0	0	0	0	0
Paralia sulcata	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudonitzschia sp.	0	0	1	0	1	1	2	1	0	0	0	0	0
Skeletonema costatum	0	0	1	0	1	0	1	1	0	0	0	0	1
Surirella sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
Thalassionema nitzschioides	0	0	0	0	0	0	0	1	0	0	0	0	0
Thalassiosira cf. *aestivalis*	0	0	0	0	0	0	0	1	0	0	0	0	0
Thalassiosira antarctica v. *borealis*	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiosira pseudonana	0	0	1	0	1	0	1	1	1	1	0	0	0
Thalassiosira sp.	0	0	0	0	1	0	0	1	0	2	0	0	1
CHLOROPHYTA													
Oltmannsiellopsis unicellularis	0	0	0	0	0	0	0	0	0	0	0	0	1
DINOFLAGELLATES													
Gymnodinium sanguineum	0	0	1	0	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Katodinium rotundatum	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxyrrhis marina	0	0	0	0	0	0	0	0	0	0	0	1	0
CILIATES													
ciliate, euplotoid	0	0	0	0	0	0	0	1	1	0	1	0	3
ciliate, other	0	0	0	0	0	0	0	0	2	1	2	2	4
ZOOFLAGELLATES													
bodonid	0	0	0	0	0	0	0	0	0	0	0	0	0
choanoflagellate	0	0	0	0	1	0	0	0	0	0	0	0	0
OTHER GROUPS													
amoebae	0	0	0	0	0	0	1	1	0	0	2	2	1

Table 4 (continued)

Sample No.	1	2	3	4	5	6	7	8	9	10	14	15	16
Source Port	Fung Chen	Pusan	San Diego	Long Beach	LA,NZ,Aus	Sacramento	Tokyo	Sendai	Hiroshima	Hiroshima	Japan	Japan	Japan
Salinity	34	35	36	34	32	3	34	34	37	37	35	35	35
nanoflagellates	0	0	2	0	4	3	4	2	3	3	4	4	1
coccoid cells	0	0	0	0	0	0	0	0	1	1	0	0	0

Table 5. List of species identified in ballast sediment samples (numbers refer to estimated number of species in a genus or group)

Sample No.	11	12	13
Source Port	Hiroshima	Hiroshima	Japan
DIATOMS			
Achnanthes sp.	0	0	1
Actinoptychus senarius	1	0	0
Asterionella japonica	0	0	0
Attheya septentrionalis	0	0	0
Chaetoceros curvisetus	0	0	0
Chaetoceros debilis	0	0	0
Chaetoceros decipiens	0	0	0
Chaetoceros didymus	0	0	0
Chaetoceros cf. *seiracanthus*	0	0	0
Chaetoceros socialis	0	0	0
Chaetoceros subtilis	0	0	0
Chaetoceros tenuissimus	0	0	0
Chaetoceros teres	0	0	1
Chaetoceros wighami	0	0	0
Coscinodiscus cf. *marginatus*	1	0	0
Coscinodiscus sp.	2	0	0
Cylindrotheca closterium	0	0	0
Fragilaria cf. *crotonensis*	0	0	0
Fragilariopsis pseudonana	0	0	0
Guinardia delicatula	0	0	0
Guinardia cf. *delicatula*	0	0	0
Leptocylindrus danicus	0	0	0
Melosira moniliformis	0	0	1
Navicula sp.	5	0	5
Navicula transitrans cf. var *derasa*	0	0	0
Nitzschia cf. *bilobata*	0	0	0
Paralia sulcata	1	0	0
Pseudonitzschia sp.	0	0	0
Skeletonema costatum	1	0	0
Surirella sp.	0	0	0
Thalassionema nitzschioides	0	0	0
Thalassiosira cf. *aestivalis*	0	0	0
Thalassiosira antarctica v. *borealis*	1	0	0
Thalassiosira pseudonana	1	1	0
Thalassiosira sp.	2	0	1
CHLOROPHYTA			
Oltmannsiellopsis unicellularis	0	0	0
DINOFLAGELLATES			
Gymnodinium sanguineum	0	0	0
Gymnodinium sp.	1	0	3
Katodinium rotundatum	1	0	0
Oxyrrhis marina	0	0	0
CILIATES			
ciliate, euplotoid	2	2	3
ciliate, other	1	3	6
ZOOFLAGELLATES			
bodonid	2	2	1

Table 5 (continued)

Sample No.	11	12	13
Source Port	Hiroshima	Hiroshima	Japan
choanoflagellate	0	0	0
OTHER GROUPS			
amoebae	1	4	2
nanoflagellates	2	2	2
coccoid cells	1	1	0

Table 6. List of species and relative abundance identified in ballast water samples (no. •2 L^{-1}; except samples 14, 15 are in no.•1.5 L^{-1}, and sample 16 no.•1L^{-1}).

Sample No.	1	2	3	4	5	6	7	8	9	10	14	15	16
Source Port	Fung Chen	Pusan	San Diego	Long Beach	LA,NZ,Aus	Sacramento	Tokyo	Sendai	Hiroshima	Hiroshima	Japan	Japan	Japan
Salinity	34	35	36	34	32	3	34	34	37	37	35	35	35
DIATOMS													
Achnanthes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Actinoptychus senarius	0	0	0	0	0	0	0	0	8	0	0	0	0
Asterionella japonica	0	0	7	0	0	0	0	3	0	0	0	0	0
Attheya septentrionalis	0	0	0	0	15	0	0	18	0	0	0	0	0
Chaetoceros curvisetus	0	0	0	0	18	0	0	0	0	0	0	0	0
Chaetoceros debilis	0	0	2	0	6	0	7	0	0	0	0	7	1
Chaetoceros decipiens	0	0	0	0	2	0	11	8	0	0	0	0	2
Chaetoceros didymus	0	0	5	0	16	0	0	9	0	0	0	0	5
Chaetoceros cf. *seiracanthus*	0	0	0	0	12	0	0	0	0	0	0	0	0
Chaetoceros socialis	0	0	0	0	0	0	0	6	0	0	0	0	0
Chaetoceros subtilis	0	0	0	0	19	0	0	0	0	0	0	0	0
Chaetoceros tenuissimus	0	0	0	0	8	0	6	0	0	0	0	0	0
Chaetoceros teres	0	0	0	0	0	0	0	0	0	0	0	0	0
Chaetoceros wighami	0	0	0	0	0	0	0	0	0	0	6	0	0
Coscinodiscus cf. *marginatus*	0	0	0	0	0	0	0	0	0	0	0	0	0
Coscinodiscus sp.	0	0	0	0	0	7	0	0	0	0	0	0	0
Cylindrotheca closterium	0	0	3	0	4	0	8	10	0	0	0	0	0
Fragilaria cf. *crotonensis*	0	0	0	0	17	0	0	0	0	3	0	0	0
Fragilariopsis pseudonana	0	0	0	0	0	1	0	0	0	0	0	0	0
Guinardia delicatula	0	0	0	0	0	0	0	4	0	0	0	0	0
Guinardia cf. *delicatula*	0	0	0	0	0	0	0	0	0	9	0	0	0
Leptocylindrus danicus	0	0	11	0	0	0	0	0	4	0	0	0	0
Melosira moniliformis	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula sp.	0	0	0	0	11	8,9	0	11,15,17	0	0	9	0	0

Table 6 (continued)

Sample No.	1	2	3	4	5	6	7	8	9	10	14	15	16
Source Port	Fung Chen	Pusan	San Diego	Long Beach	LA,NZ,Aus	Sacramento	Tokyo	Sendai	Hiroshima	Hiroshima	Japan	Japan	Japan
Salinity	34	35	36	34	32	3	34	34	37	37	35	35	35
Navicula transitrans cf. var *derasa*	0	0	0	0	0	0	0	0	0	2	0	0	0
Nitzschia cf. *bilobata*	0	0	0	0	0	4	0	0	0	0	0	0	0
Paralia sulcata	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudonitzschia sp.	0	0	4	0	7	10	9,12	13	0	0	0	0	0
Skeletonema costatum	0	0	10	0	3	0	3	1	0	0	0	0	8
Surirella sp.	0	0	0	0	0	6	0	0	0	0	0	0	0
Thalassionema nitzschioides	0	0	0	0	0	0	0	20	0	0	0	0	0
Thalassiosira cf. *aestivalis*	0	0	0	0	0	0	0	16	0	0	0	0	0
Thalassiosira antarctica v. *borealis*	0	0	0	0	0	0	0	0	0	0	0	0	0
Thalassiosira pseudonana	0	0	1	0	9	0	1	12	5	4	0	0	0
Thalassiosira sp.	0	0	0	0	10	0	0	5	0	5,6	0	0	11
CHLOROPHYTA													
Oltmannsiellopsis unicellularis	0	0	0	0	0	0	0	0	0	0	0	0	14
DINOFLAGELLATES													
Gymnodinium sanguineum	0	0	9	0	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Katodinium rotundatum	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxyrrhis marina	0	0	0	0	0	0	0	0	0	0	0	6	0
CILIATES													
ciliate, euplotoid	0	0	0	0	0	0	0	8	3	0	11	0	6,10,15
ciliate, other	0	0	0	0	0	0	0	0	9,10	10	5,10	4,10	4,7,9,13
ZOOFLAGELLATES													
bodonid	0	0	0	0	0	0	0	0	0	0	0	0	0
choanoflagellate	0	0	0	0	14	0	0	0	0	0	0	0	0
OTHER GROUPS													
amoebae	0	0	0	0	0	0	10	19	0	0	4,8	5,8	12
nanoflagellates	0	0	6,8	0	1,5,13,20	2,3,5	2,4,5,13	2,7	1,2,6	1,7,8	1,2,3,7	1,2,3,9	3
coccoid cells	0	0	0	0	0	0	0	0	7	11	0	0	0

Table 7. List of species and abundance identified in ballast sediment samples (counts are in no.•2 L^{-1})

Sample No.	11	12	13
Source Port	Hiroshima	Hiroshima	Japan
DIATOMS			
Achnanthes sp.	0	0	16
Actinoptychus senarius	8	0	0
Asterionella japonica	0	0	0
Attheya septentrionalis	0	0	0
Chaetoceros curvisetus	0	0	0
Chaetoceros debilis	0	0	0
Chaetoceros decipiens	0	0	0
Chaetoceros didymus	0	0	0
Chaetoceros cf. *seiracanthus*	0	0	0
Chaetoceros socialis	0	0	0
Chaetoceros subtilis	0	0	0
Chaetoceros tenuissimus	0	0	0
Chaetoceros teres	0	0	22
Chaetoceros wighami	0	0	0
Coscinodiscus cf. *marginatus*	24	0	0
Coscinodiscus sp.	5,6	0	0
Cylindrotheca closterium	0	0	0
Fragilaria cf. *crotonensis*	0	0	0
Fragilariopsis pseudonana	0	0	0
Guinardia delicatula	0	0	0
Guinardia cf. *delicatula*	0	0	0
Leptocylindrus danicus	0	0	0
Melosira moniliformis	0	0	13
Navicula sp.	9,10,12,17,18,19	0	5,7,14,20,23
Navicula transitrans cf. var *derasa*	0	0	0
Nitzschia cf. *bilobata*	0	0	0
Paralia sulcata	27	0	0
Pseudonitzschia sp.	0	0	0
Skeletonema costatum	25	0	0
Surirella sp.	0	0	0
Thalassionema nitzschioides	0	0	0
Thalassiosira cf. *aestivalis*	0	0	0
Thalassiosira antarctica v. *borealis*	11	0	0
Thalassiosira pseudonana	7	9	0
Thalassiosira sp.	13,16	0	4
CHLOROPHYTA			
Oltmannsiellopsis unicellularis	0	0	0
DINOFLAGELLATES			
Gymnodinium sanguineum	0	0	0
Gymnodinium sp.	14	0	15,17,19
Katodinium rotundatum	20	0	0
Oxyrrhis marina	0	0	0
CILIATES			
ciliate, euplotoid	4,22	4,6	6,18,25

Table 7 (continued)

Sample No.	11	12	13
Source Port	Hiroshima	Hiroshima	Japan
ciliate, other	26	5,8,10	3,9,10,11,21,24
ZOOFLAGELLATES			
bodonid	2,15	3,12	8
choanoflagellate	0	0	0
OTHER GROUPS			
amoebae	23	2	2
nanoflagellates	1,3	1,11	1,12
coccoid cells	21	7	0