Favorable Sediment Environments for Juveniles of the Brackish-Water Bivalve *Corbicula japonica* in Lake Abashiri

Katsuhisa Baba ^{1)*}, Kazuhiro Takahashi ^{1)†}, Toshifumi Kawajiri ²⁾, and
Yasuhiro Kuwahara ¹⁾

¹⁾Hokkaido Abashiri Fisheries Experimental Station, 31 Masuura,
Abashiri, Hokkaido 099-3119, Japan

²⁾Nishiabashiri Fisheries Cooperative Association, 330 Yobito,
Abashiri, Hokkaido 099-2421, Japan

Abstract: To determine the favorable sediment environments for juveniles of the brackish-water bivalve *Corbicula japonica*, the relationship between the presence of juveniles and limiting factors of the sediment environment that are negatively correlated with juvenile density was investigated in Lake Abashiri, one of the northernmost areas of this bivalve's distribution in Japan. Correlations between juvenile density and sediment factors were estimated by Spearman's rank correlation coefficient. Logit models were made between the presence or absence of juveniles, as the dependent variable, and limiting sediment factors, as independent variables. The models were compared by the Akaike Information Criterion (AIC). The values at probability 50% of the logit models (V50s) and the standard errors of the univariate logit models were calculated for each sediment factor. We defined favorable sites as those where any of these values are less than the V50s, which seem to provide good criteria to distinguish between favorable and unfavorable sediment conditions for juveniles. The V50s for limiting factors were: organic carbon 1.10 %, organic nitrogen 0.15%, organic carbon / nitrogen ratio 7.43, ignition loss 4.45%, water content 40.97%, and silt-clay (particle diameter <0.063 mm) plus very fine sand (0.063 - 0.125 mm) 36.88%. A significant logit model could not be made for total sulfide. These criteria may provide important information for the management of *C. japonica* resources.

Key words: *Corbicula japonica*, juvenile, limiting factor, logit model, sediment environment

INTRODUCTION

The brackish-water bivalve *Corbicula japonica* is distributed in brackish lakes and tidal flats

of rivers in Japan and Sakhalin (Kafanov 1991). Lake Abashiri is one of the northernmost areas of its distribution in Japan. *Corbicula* spp. are commercially harvested in Japan. The annual catches ranged from 24,000 to 37,000 tons during 1990-1994 (Ministry of Agriculture, Forestry and Fisheries 1990-1994), among which *C. japonica* was the dominant species.

The influence of environmental factors on the physiology of *C. japonica* has been studied, including temperature tolerance (Nakamura,

Received May 7, 1997; Accepted April 30, 1998

* Correspondence author.

† Present address: Hokkaido Hakodate Fisheries Experimental Station, 1-2-66 Yunokawa, Hakodate, Hokkaido 042-0932, Japan

Shinagawa and Nakao 1996), salinity tolerance in adults (Tanaka 1984a; Nakamura, Yasugi, Takahashi, Shinagawa and Nakao 1996), salinity tolerance in juveniles (Tanaka 1984b), sulfide tolerance (Nakamura et al. 1997a), tolerance to anoxic conditions (Nakamura et al. 1997b), metabolic changes due to lack of oxygen (Ida & Hamada 1978), salinity effect on larval development (Asahina 1941), and free amino acid uptake (Matsushita & Yamada 1992). However most of these were laboratory analyses.

In the fisheries management of brackish-water clams, it would be convenient to be able to assess whether the environmental conditions of a given site are suitable for the clams. In our preliminary analysis, we could not gain sufficient results with commonly used, and ordinary statistical methods such as multiple-regression analysis, principal component analysis, and their combinations, because they showed only non-significant differences and sometimes did not fulfil the assumptions inherent in a regression analysis, e.g. unbiasedness or homoscedasticity. Transformations were not sufficient to ensure such preconditions were met.

Yamamuro et al. (1990) reported the lethal factors of *C. japonica* in Lake Shinji, western Japan, based on field data. They suggested that the function expressing the limiting effect of each environmental factor ought to be S-shaped, take a positive value between 0 and 1, and be characterized by three ranges: lethal, limiting, and non-limiting. However, in fisheries management we would rather know simply whether the sediment environment is favorable or unfavorable for the clam, because fishermen could then avoid the areas with lethal environments. Therefore, we adopted logit models in the present study; they are similar to the function proposed by Yamamuro et al., but can be treated more easily.

In this study, we employed logit models to analyze the relationships between juvenile presence and sediment variables and to clarify which sediment conditions are favorable for *C. japonica*. Understanding the favorable conditions is very important for the management of fisheries grounds and it also facilitates judgements about which sites are appropriate

for the release of seed clams. Our report is probably the first one demonstrating criteria for judging whether sediment conditions are favorable for juvenile *C. japonica*.

MATERIALS AND METHODS

The field investigation was carried out on October 13, 1995, in Lake Abashiri, Japan. The lake is connected to the Sea of Okhotsk by the 7.2 km long Abashiri River. Since sea water flows back into the lake depending on the tide, the lake has a well-oxygenated, oligohaline upper layer and an anoxic, polyhaline lower layer, with a boundary at a depth of around 5 m (Mikami et al. 1993); *C. japonica* is restricted to the area above this boundary.

Sediment samples were collected from 32 sites laid out along seven lines (L1 to L7) at depths of 1, 2, 3, 4, and 5 m, except L5 which was sampled only at depths of 1, 2, and 3 m (Fig. 1). No sample was collected at a depth of 1 m along L3 because the sediment was rocky.

A Smith-McIntyre grab was used to collect 0.05 m² sediment samples twice at each site. The sediment in the first grab was washed on a 1 mm sieve, and *C. japonica* was sorted from the

Fig. 1. Locations of sampling sites in Lake Abashiri.

residue. The sediment in the second grab was weighed, and about 1 / 10 of it was washed on a series of four sieves from 0.125 to 1 mm to sort the juveniles. Sorting was completed with a binocular microscope.

Here we define juveniles as individuals that passed through the 1 mm sieve. Juvenile density was calculated according to the ratio of sorted sediment weight to total weight of the sediment sample obtained in the second grab. The minimum shell length of the juveniles was 0.48 mm. The juveniles were at least at age 1⁺ because *C. japonica* did not spawn that summer due to the low salinity and low temperature of Lake Abashiri (Baba & Takahashi 1997). The spawning season is normally from July to September in Lake Abashiri (Maru 1981). The size of 1⁺ individuals was much smaller than that previously reported by Utoh (1981). Some problems remain concerning the initial growth of *C. japonica* in Lake Abashiri (not discussed in this paper).

The other 90% of the sediment from the second grab was used for laboratory analysis of the sediment factors described below. Sediment particle size composition was analyzed by a series of sieves: 2.00, 1.00, 0.50, 0.25, 0.125, and 0.063 mm mesh. Organic carbon and organic nitrogen were measured with a C-N analyzer (Yanagimoto, C-N corder, MT-600) after treatment with 1N HCl for 24h to remove the CaCO₃. Water content and ignition loss were calculated by weight loss at 80°C for 24h from wet sediment and at 600°C for 1h from dry sediment, respectively. Total sulfide was measured with a detector tube (Gastec No 102L and No 102H, Kitazawa Sangyo Inc.).

Spearman's rank correlation coefficient was used to estimate correlations between the densities of *C. japonica* and sediment factors, and among sediment factors. Pearson's correlation coefficient can describe only the linear component of the relations (Sokal & Rolf 1995), however, no such relation was observed in some of our data sets. With Kendall's coefficient of rank correlation, it is difficult to calculate probability if the data contain tied ranks (Sokal & Rolf 1995), and since our data sets contained some tied ranks, we used Spearman's rank correlation coefficient.

Empirical logit models were made by the

maximum-likelihood method using juvenile presence or absence as the dependent variable and each sediment factor and depth or their combinations as independent variables. Sites where juveniles were present were assigned a value of 1 as a dependent variable and sites where they were absent were assigned a value of 0.

The depth is further raised to the *r*-th power (*r*: real number; see results for the reason). We treated the *r*-th power as a parameter *a_r* (not as a transformation). The parameter *a_r* was also optimized by the maximum-likelihood method.

The proportion of silt-clay (particle diameter less than 0.063 mm) plus very fine sand (0.063 - 0.125 mm) fraction in the sediments was used as an independent variable, because a significantly better model, in terms of AIC, was obtained by this variable than either silt-clay or very fine sand alone in our preliminary analysis.

An empirical logit model is useful for analyzing binary data when the sample size is small (Sokal & Rolf 1995). The equations of the logit models used here are as follows:

$$f_1(x_1) = \frac{e^{(a_0 + a_1 x_1)}}{1 + e^{(a_0 + a_1 x_1)}},$$

$$f_2(x_1, x_2) = \frac{e^{(a_0 + a_1 x_1 + a_2 x_2)}}{1 + e^{(a_0 + a_1 x_1 + a_2 x_2)}},$$

$$f_3(x_1, x_2) = \frac{e^{(a_0 + a_1 x_1 + a_2 x_2^{a_3})}}{1 + e^{(a_0 + a_1 x_1 + a_2 x_2^{a_3})}},$$

where *x_i* (*i* = 1, 2) are independent variables (*x₁*: each sediment variable, *x₂*: depth), and *a_i* (*i* = 0, 1, 2, and 3) are regression coefficients.

The Akaike Information Criterion (AIC) was calculated to compare the models. This criterion is useful to compare models that use the same dependent variables. In the AIC, one or more difference is regarded as a statistically significant difference (Sakamoto et al. 1983).

The values at probability 50% (V50s) and their standard errors in the univariate logit models were calculated for each sediment factor. In the case of the dose-response relationship of a poison, this value indicates the dose at which half of the examined animals probably

die (lethal dose 50). In fact, the value can also be used for any condition which separates the results, i.e., death or survival (Yajima et al. 1992). In our study, we thought this value could be used as an indicator segregating sediment conditions into favorable or unfavorable ones. An advantage of this model is that it does not depend on the density. The density is not determined by the sediment conditions only, because larval supply, which varies depending on both biotic and abiotic environment factors, is also important (Sekiguchi 1992, 1996; Tsutsumi et al. 1996; Hall 1994; Olafsson et al. 1994).

RESULTS

Corbicula japonica densities and sediment factors

As shown in Table 1, the average density of juveniles was much higher than the density of non-juveniles; however, there were more sites where juveniles were absent than sites where non-juveniles were absent. The absent sites are located along only three lines (L2, L4, and L5).

As shown in Table 2, seven limiting sediment factors were significantly negatively correlated with juvenile density. Juvenile density and non-

Table 1. *Corbicula japonica* densities and sediment factors in Lake Abashiri.

No. of line	Depth (m)	Juvenile (n/0.05m ²)	Non-juvenile (n/0.05m ²)	C (%)	N (%)	C/N (%)	IL (%)	WC (%)	TS (%)	Silt-clay (%)	VFS (%)
1	1	70	123	0.221	0.035	6.309	1.314	20.866	0.528	1.644	2.143
	2	842	70	0.056	0.012	4.496	1.358	23.730	0.000	1.316	1.017
	3	2065	57	0.052	0.011	4.901	1.215	22.526	0.003	0.782	0.544
	4	846	54	0.466	0.081	5.742	4.479	38.877	0.149	2.978	1.723
	5	1312	116	0.788	0.159	4.974	3.941	34.677	1.282	24.044	8.023
2	1	0	36	0.113	0.021	5.277	1.961	34.097	0.062	2.070	12.054
	2	0	45	1.554	0.191	8.145	4.637	50.138	0.296	29.870	17.687
	3	0	24	1.786	0.219	8.161	5.593	49.634	0.355	28.782	33.592
	4	0	11	2.756	0.310	8.894	8.003	60.800	0.318	53.277	30.412
	5	0	1	2.741	0.303	9.045	8.383	63.859	1.082	61.635	19.491
3	2	260	127	0.082	0.014	5.979	0.914	22.127	0.003	1.956	1.883
	3	395	107	0.166	0.029	5.687	1.470	25.954	0.030	2.501	0.991
	4	954	63	0.309	0.058	5.308	3.267	28.383	0.139	11.362	3.675
	5	2105	88	0.879	0.185	4.750	3.679	41.943	0.003	9.248	8.020
4	1	0	335	0.084	0.016	5.089	1.040	22.584	0.017	1.687	0.773
	2	0	158	0.116	0.020	5.685	1.167	23.996	0.023	2.950	0.832
	3	0	351	1.260	0.177	7.105	4.717	44.200	0.561	21.727	4.307
	4	0	73	1.158	0.148	7.823	4.247	40.805	2.401	24.880	14.125
	5	41	32	1.885	0.221	8.543	6.127	54.272	1.609	61.464	12.952
5	1	8	39	0.131	0.016	8.119	1.555	25.952	0.007	2.820	4.163
	2	0	0	2.522	0.229	10.992	9.658	62.642	0.070	96.710	2.381
	3	0	7	2.944	0.282	10.445	8.718	59.134	0.505	97.897	1.612
6	1	1267	110	0.158	0.024	6.560	1.043	21.420	0.029	1.845	3.523
	2	143	403	0.105	0.018	5.875	0.916	23.115	0.014	1.812	2.374
	3	2321	89	0.103	0.018	5.591	1.198	23.299	0.003	2.164	3.937
	4	195	87	0.089	0.016	5.606	0.935	25.713	0.000	2.384	4.199
	5	1079	48	0.097	0.017	5.828	1.213	26.115	0.010	1.503	6.012
7	1	243	126	0.091	0.015	6.193	0.772	22.351	0.016	1.211	2.750
	2	80	54	0.322	0.049	6.574	2.179	26.638	0.014	2.702	4.871
	3	261	18	0.107	0.018	5.818	1.806	25.234	0.009	1.604	7.421
	4	2679	108	0.217	0.036	6.013	3.122	31.671	0.002	1.973	2.911
	5	906	798	0.104	0.021	4.899	1.595	14.253	0.000	0.810	0.582
Average		565	117	0.733	0.093	6.576	3.194	34.093	0.298	17.488	6.906
Standard deviation		785	158	0.935	0.100	1.676	2.608	14.303	0.555	27.388	8.262

C: Organic carbon, N: Organic nitrogen, C/N: Organic carbon/nitrogen ratio, IL: Ignition loss, WC: Water content, TS: Total sulfide, VFS: Very fine sand, Silt-clay: $\phi \geq 4$, Very fine sand: $4 > \phi \geq 3$.

Table 2. Spearman's rank correlation coefficients between densities of *Corbicula japonica* and sediment factors and among sediment factors in Lake Abashiri.

	Juvenile <i>C.japonica</i>	Non-juvenile <i>C.japonica</i>	Depth	Organic carbon	Organic nitrogen	Organic carbon/ nitrogen ratio	Ignition loss	Water content	Total sulfide
Non-juvenile <i>C.japonica</i>	0.31								
Depth	0.31	-0.18							
Organic carbon	-0.45**	-0.51**	0.32						
Organic nitrogen	-0.39*	-0.47**	0.41*	0.98**					
Organic carbon/nitrogen ratio	-0.61**	-0.50**	-0.09	0.69**	0.59**				
Ignition loss	-0.38*	-0.65**	0.44*	0.90**	0.90**	0.53**			
Water content	-0.45*	-0.69**	0.43*	0.85**	0.84**	0.55**	0.90**		
Total sulfide	-0.56**	-0.29	0.11	0.76**	0.73**	0.57**	0.62**	0.60**	
Silt - clay+very fine sand	-0.45*	-0.68**	0.33	0.84**	0.81**	0.66**	0.80**	0.88**	0.62**

* Significant at $P < 0.05$ ** Significant at $P < 0.01$ **Fig. 2.** Logit models made with limiting sediment factors for the presence of juveniles and densities of *Corbicula japonica* juveniles. Closed circles indicate sites where juveniles were present. Open circles indicate sites where juveniles were absent. The S-shaped curve represents the logit model. The vertical line indicates the V50 (the value at probability 50%) of the logit model.

Table 3. Empirical logit models and their statistics. The logit models were made between the presence or absence of juveniles, as the dependent variable, and limiting sediment factors, as independent variables.

Independent variable (x_1, x_2)	Regression coefficient				Log-likelihood	AIC ^{*1}	P ^{*2}	Value at probability 50% (V50) and SE ^{*3} or equation for isopleth of probability 50%	
	a_0	a_1	a_2	a_3				V50	SE ^{*3}
Organic carbon	2.098	-1.914			-13.538	31.1	0.0002**	1.10	0.30
Organic nitrogen	2.162	-14.699			-14.661	33.3	0.0006**	0.15	0.03
Organic carbon/nitrogen ratio	6.701	-0.902			-15.004	34.0	0.0008**	7.43	0.57
Ignition loss	2.673	-0.601			-14.687	33.4	0.0006**	4.45	0.88
Water content	4.914	-0.120			-13.560	31.1	0.0002**	40.97	4.46
Silt-clay + very fine sand	1.987	-0.054			-14.083	32.2	0.0003**	36.88	10.73
<hr/>									
Organic carbon, depth	-0.581	-3.738	1.440		-9.702	25.4	1.86E-05**	-0.581-3.738 x_1 +1.44 x_2 =0	
Organic nitrogen, depth	-0.652	-35.361	1.730		-9.636	25.3	1.75E-05**	-0.652-35.361 x_1 +1.73 x_2 =0	
Ignition loss, depth	0.521	-1.544	1.816		-9.661	25.3	1.79E-05**	0.521-1.544 x_1 +1.816 x_2 =0	
Water content, depth	4.780	-0.255	1.717		-8.872	23.7	8.13E-06**	4.780-0.255 x_1 +1.717 x_2 =0	
Silt-clay + very fine sand, depth	-0.341	-0.093	1.184		-10.898	27.8	6.16E-05**	-0.341-0.093 x_1 +1.184 x_2 =0	
<hr/>									
Organic carbon, (depth) ^{a3}	1.964	-7.423	0.012	4.416	-8.044	24.1	1.47E-05**	1.964-7.423 x_1 +0.012 x_2 +4.416 x_3 =0	
Organic nitrogen, (depth) ^{a3}	2.237	-62.810	0.033	3.757	-8.065	24.1	1.50E-05**	2.237-62.81 x_1 +0.033 x_2 +3.757 x_3 =0	
Water content, (depth) ^{a3}	13.331	-0.517	0.048	3.643	-6.953	21.9	5.15E-06**	13.331-0.517 x_1 +0.048 x_2 +3.643 x_3 =0	
Silt-clay + very fine sand, (depth) ^{a3}	2.911	-0.358	0.013	4.690	-7.216	22.4	6.64E-06**	2.911-0.358 x_1 +0.013 x_2 +4.690 x_3 =0	

^{*1} Akaike Information Criterion

^{*2} Calculated by likelihood ratio test in which the log-likelihood of intercept only was -20.592 and degrees of freedom was number of regression coefficient minus 1.

^{*3} Standard error

** Significant at $P < 0.01$

Fig. 3. Plots of *Corbicula japonica* juvenile density scores and an isopleth of V50 of the logit model made with depth and the other sediment factors. Open circles indicate sites where juveniles were present, and their size indicates the density of the juveniles. Closed circles indicate sites where juveniles were absent.

juvenile density had similar correlations with the sediment factors; however, there were some exceptions. Juvenile density was significantly negatively correlated with total sulfide but non-juvenile density was not. Depth was not significantly correlated with either juvenile density or non-juvenile density. Juvenile density was not significantly correlated with non-juvenile density. All of the sediment factors were correlated with each other.

Logit models

The values at probability 50% (V50s) and their standard errors are shown in Table 3. The

significant logit models of limiting factors, the V50s, and the densities of juveniles are shown in Fig. 2. These figures show that sites with juveniles present predominated on the left side of the V50s. A significant logit model could not be made with total sulfide. The V50s for the limiting factors were: organic carbon 1.10%, organic nitrogen 0.15%, organic carbon/nitrogen ratio 7.43, ignition loss 4.45%, water content 40.97%, and silt-clay plus very fine sand 36.88%.

In a bivariate logit model, all combinations of sediment factors were tested as independent variables, but none of them was significantly better than the univariate logit models in terms of AIC except the combination with depth.

The logit models were significantly improved, in terms of AIC, when depth was added as the independent variable. But upon seeing the plots of Fig. 3, we thought a curved surface would be more appropriate than a plane surface for the bivariate logit model. In the logit model analysis, an interaction term (e.g., silt-clay $\times$ depth) is usually added to the independent variables to describe the curved surface. However, in our preliminary analysis, the bivariate logit models were not improved in terms of AIC by adding such an interaction term. Therefore, we instead raised the depth to the α_3 -th power, which significantly improved the logit model in terms of AIC. The juvenile density scores and V50 isopleths of four of these bivariate logit models are shown in Fig. 3.

DISCUSSION

We could not construct a significant logit model for total sulfide. In Lake Abashiri the sulfide probably has two origins, one related to sediment particle size and organic matter, and the other to water of the anoxic polyhaline lower layer, in which a lot of sulfide is accumulated. The latter is caused by temporary climate conditions, i.e., a strong wind in the *C. japonica* habitat (shallower than 5 m) in Lake Abashiri. This kind of temporary exposure to sulfide should not affect the survival of *C. japonica* because both juveniles and adults of *C. japonica* have a high tolerance for hydrogen sulfide. Half of the examined *C. japonica* survived for 23 days under a condition of 50 mg / l hydrogen sulfide at 18°C (Nakamura et al. 1997a). Therefore, the total sulfide may not be an important factor in determining the most favorable sediment conditions for *C. japonica* in Lake Abashiri.

In this paper, we treated the density data as binary, i.e., present or absent. One may question whether the sites of purported absence are really so. To completely prove absence is very difficult because there remains the possibility of finding some individuals if the sample size is expanded greatly. But we consider our judgments of absence to have been adequate, because there is at least assuredly a much lower density (undetectable) than at the present sites.

Tsutsumi & Sekiguchi (1996) proposed three possible processes leading to the absence of benthic bivalves, i.e., avoidance of settling until the larvae encounter preferable sediment, high mortality at the unfavorable sites, and subsequent transportation after settlement. In our analysis, we could not elucidate which processes have led to the absence of *C. japonica* juveniles at some sites in Lake Abashiri. Juveniles of *C. fluminea* have been reported to prefer fine and coarse sand but not mud for settlement (Sickel & Burbank 1974; McMahon 1983). Thus, it is likely that the first process, avoidance of settlement, also applies to *C. japonica* in Lake Abashiri.

As shown in Fig. 3, the V50s increased with depth. The reason for this is unknown, but there might be some survival-promoting or dispersion-restricting (i.e., retention-promoting) factors such as higher salinity in the deeper sites. *Corbicula japonica* requires a salinity of at least 3.1 psu (psu: practical salinity unit) for the development of its planktonic larva (Asahina 1941). The favorable salinity for juveniles (shell length about 0.2 mm) is more than 1.7 psu (Tanaka 1984b). On the other hand, the salinity of the oligohaline upper layer in Lake Abashiri varied from 1 to 1.5 psu during June to November in 1995 (Baba & Takahashi 1997). Salinity did not vary within the oligohaline upper layer (variation was between 0.1 and 0.5 psu), but it increased to around 15 psu near its lower boundary (Torisawa 1997). On windy days the polyhaline lower layer rises to shallower depths than its usual upper boundary in Lake Abashiri (Mikami et al. 1993). The anoxic conditions and hydrogen sulfide, which temporarily coincidentally increase along with a rise in salinity, may not affect the survival of *C. japonica*, because *C. japonica* has a high tolerance for them (Ida & Hamada 1978; Nakamura et al. 1997a, 1997b).

Yamamuro et al. (1990) found that high mud content is the most limiting factor for the distribution of *C. japonica* among several environmental factors: dissolved oxygen saturation, chlorinity, pH of bottom water, ignition loss and mud content of sediment. They found the lethal mud level was 91.5%. In this study, the highest silt-clay content at sites where non-juveniles were found was 97.9%, whereas the

highest silt-clay content at sites where the juveniles were present was 61.5%, and the V50 of silt-clay plus very fine sand was 36.9% (if silt-clay or very fine sand was separately used as the independent variable of the logit model, the V50s were 27.2% and 10.7% respectively). These findings suggest that large individuals have a higher tolerance for different sediment conditions.

As shown in Fig. 2, the V50s seem to be good criteria for judging whether a site is favorable for juveniles because the juvenile presence sites were predominately on the left side of the V50 among the limiting factors. Failure of *C. japonica* recruitment, maybe due to poor sediment conditions, has been reported in several places in Hokkaido, Japan (Rumoi Hokubu Fisheries Technology District Training Center, unpublished data; Nemuro Hokubu Fisheries Technology District Training Center, unpublished data); therefore, these criteria should be useful in plans to enhance *C. japonica* resources.

Here, we have clarified the favorable sediment conditions for juveniles of *C. japonica*. On the other hand, there remain some unresolved problems concerning the distribution of *C. japonica*, i.e., the relationship to the larval supply or mortality not related to sediments. We need further investigations to clarify these problems.

Acknowledgements. We express our thanks to Mr. H. Shimazaki and the staff of the Abashiri Toubu Fisheries Technology District Training Center for their cooperation in field sampling. We are also grateful to Dr. M. L. Klein, Professor of California State Polytechnic University, Pomona, for his comments and correction of the English in this manuscript.

REFERENCES

- Asahina, E. 1941 An ecological study of *Corbicula japonica* group, the brackish water bivalve, with special reference to the environmental factors of its habitat in Hokkaido. *Bulletin of the Japanese Society of Scientific Fisheries*, 10: 143-152 (in Japanese).
- Baba, K. and Y. Takahashi 1997 Experiment of seed collection of *Corbicula japonica* in Lake Abashiri. *Annual Report of 1995 Fiscal Year*. Hokkaido Abashiri Fisheries Experimental Station, Hokkaido, pp. 227-229 (in Japanese).
- Hall, S. J. 1994 Physical disturbance and marine benthic communities: life in unconsolidated sediments. *Annual Review of Oceanography and Marine Biology*, 32: 179-239.
- Ida, T. and A. Hamada 1978 Metabolic change of *Corbicula japonica* in anoxic condition. *The Aquiculture*, 23: 111-114 (in Japanese).
- Kafanov, A. I. 1991 *Bivalves on Continental Shelf and Continental Slope of Northern Pacific*. Redaktsionno-izdatelskii otdel DVO AN SSSR, Vladivostok, 197 pp. (in Russian).
- Maru, K. 1981 Reproductive cycle of the brackish-water bivalve, *Corbicula japonica*, in Lake Abashiri. *Scientific Reports of Hokkaido Fisheries Experimental Station*, 23: 83-95 (in Japanese).
- Matsushita, O. and A. Yamada 1992 Uptake of L- and D-alanine by a brackish-water bivalve, *Corbicula japonica*, with special reference to their transport pathways and the salinity effect. *The Journal of Experimental Zoology*, 263: 8-17.
- McMahon, R. F. 1983 *The Mollusca (Ecology)*. Russell-Hunter, W. D. (ed.), Academic Press, Orlando, Florida, 6: 517 pp.
- Mikami, H., S. Hino and J. Arisue 1993 Chemical and biological environment change in Lake Abashiri after an uprise of anoxic polyhaline bottom water. *Report of Hokkaido Institute of Environmental Sciences*, 20: 55-59 (in Japanese).
- Ministry of Agriculture, Forestry and Fisheries 1990-1994 Statistics on fisheries and water culture production (in Japanese).
- Nakamura, M., A. Shinagawa and S. Nakao 1996 Temperature tolerance of the brackish water bivalve, *Corbicula japonica* Prime. *Suisanzoshoku*, 44: 267-271 (in Japanese).
- Nakamura, M., S. Yasugi, F. Takahashi, A. Shinagawa and S. Nakao 1996 Salinity tolerance of the brackish water bivalve, *Corbicula japonica* Prime. *Suisanzoshoku*, 44: 31-35 (in Japanese).
- Nakamura, M., A. Shinagawa, K. Toda and S. Nakao 1997a Sulfide tolerance of the brackish water bivalve, *Corbicula japonica* Prime. *Suisanzoshoku*, 45: 17-24 (in Japanese).

- Nakamura, M., A. Shinagawa, K. Toda and S. Nakao 1997b Tolerance to low concentrations of dissolved oxygen of *Corbicula japonica*. *Suisanzoshoku*, 45: 9-15 (in Japanese).
- Olafsson, E. B., C. B. Peterson and G. Ambrose 1994 Does recruitment limitation structure populations and communities of macro-invertebrates in marine soft sediments: the relative significance of pre- and post-settlement process. *Annual Review of Oceanography and Marine Biology*, 32: 65-109.
- Sakamoto, Y., M. Ishiguro and G. Kitagawa 1983 *Statistics of Information (Jouhouryou Toukei Gaku)*. Kyouritu Shuppan, Tokyo, 236 pp. (in Japanese).
- Sekiguchi, H. 1992 Retention mechanisms of planktonic larvae of marine benthic invertebrates in coastal and estuarine regions. *Monthly Kaiyo Kagaku (Marine Sciences)*, 24: 485-491 (in Japanese).
- Sekiguchi, H. 1996 Larval recruitment process of *Corbicula japonica* in the Kiso River. *Monthly Kaiyo Kagaku (Marine Sciences)*, 28: 157-165 (in Japanese).
- Sickel, J. B. and W. D. Burbanck 1974 Bottom substratum preference of *Corbicula manilensis* (Pelecypoda) in the Alatamaha River, Georgia. *Association of Southeast Biology Bulletin*, 21: 84.
- Sokal, R. R. and F. J. Rohlf 1995 *Biometry* (3rd edition). W. H. Freeman and Company, New York, 887 pp.
- Tanaka, Y. 1984a Salinity tolerance of brackish water clam, *Corbicula japonica* Prime. *Bulletin of National Research Institute of Aquaculture*, 6: 29-32 (in Japanese).
- Tanaka, Y. 1984b Morphological and physiological characteristics of the post larval stage in *Corbicula japonica* Prime, reared in the laboratory. *Bulletin of National Research Institute of Aquaculture*, 6: 23-27 (in Japanese).
- Torisawa, M. 1997 Investigation on fisheries resources (Japanese pond smelt). *Annual Report of 1995 Fiscal Year*. Hokkaido Abashiri Fisheries Experimental Station, Hokkaido, pp. 20-31 (in Japanese).
- Tsutsumi, Y. and H. Sekiguchi 1996 Spatial distributions of larval, newly-settled, and benthic stages of bivalves in subtidal areas adjacent to tidal flats. *Benthos Research*, 50: 29-37.
- Utoh, H. 1981 Growth of the brackish-water bivalve, *Corbicula japonica* Prime, in Lake Abashiri. *Scientific Reports of Hokkaido Fisheries Experimental Station*, 23: 65-81.
- Yajima, Y., C. Hirotsu, Y. Fujino, A. Takemura, K. Takeuchi, K. Nawada, N. Matsubara and M. Fushimi 1992 *Analysis of Scientific Data (Basic Statistics 3)*. University of Tokyo Press, Tokyo, 366 pp. (in Japanese).
- Yamamuro, M., M. Nakamura and M. Nishimura 1990 A method for detecting and identifying the lethal environmental factor on a dominant macrobenthos and its application to Lake Shinji, Japan. *Marine Biology*, 107: 479-483.