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Estimation of Pink and Chum salmon Digestion Coefficients Based on Data Collected from Ship-board Experiments

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ABSTRACT

Digestion experiments for pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon were conducted in the North Pacific Ocean in summer from 1991 to 1993. Data were analyzed using the exponential model and five fitting methods to estimate the digestion coefficient. Estimates of the digestion coefficient were different among fitting methods and the year in which the experiment was conducted. Based on the 1992 experiments, in which the largest number of chum salmon were examined, digestion coefficients for chum salmon are estimated to be 0.12-0.14 per hour. Digestion coefficients for pink salmon are estimated to be 0.11-0.17, although the number of fish examined were not sufficient.

INTRODUCTION

Digestion experiments for salmonids were conducted in the central North Pacific Ocean and Bering Sea in the summer, 1991-1993 (Ishida et al. 1991; Ishida et al. 1992; Nagasawa et al. 1994). Stomach digestion rate was estimated by measuring the decrease in the index of stomach content weight over time. Preliminary analysis indicates that the estimates of digestion rate were from 0.15 to 0.20 (Ishida et al. 1991; Nagasawa et al. 1994). In this paper, we analyze those data using the exponential model and five fitting methods.

MATERIALS AND METHODS

Data

Longline operations at sunset were conducted in the central North Pacific Ocean and Bering Sea in the summer of 1991, 1992, and 1993 on board the research vessel *Wakatake maru*. The longline was composed of 30 hachi. Each hachi was 133.5m long and had 49 hooks baited with salted Japanese anchovy (*Engraulis japonicus*). The longline was set 30 min before sunset and was hauled after 60 min. A maximum of 20 fish stomachs was routinely collected from chum and pink salmon at each station. Routine stomach content examination consisted of removing the stomach, weighing it to the nearest gram, removing the contents, and weighing the stomach again. These examinations were usually performed at approximately 2100 hrs.

In addition to the routine examination of salmonid stomach contents, digestion experiments were conducted. When chum or pink salmon were abundant in the catch, approximately 20-50 live fish put in a tank. Approximately 5-10 fish were removed from the tank and sacrificed for stomach examination at the following predetermined times: 2300, 0200, 0500, 1000, and 1500 hours LMT. The stomachs were removed from the fish and the contents examined using the routine procedure described above. The index of stomach content weight (SCI) were calculated by multipling stomach content weight × 100/body weight.

Models

Although several models were proposed to estimate salmonid digestion rate (Suzuki 1993), we assumed the following exponential model in this analysis:

$$S(t) = \alpha \exp(-\beta t) \tag{1}$$

where *S(t)* and α are the index of stomach content weight at time *t* and time 0, respectively, and β is the digestion coefficient. We used the digestion coefficient instead of the digestion rate *d* which was used in previous analyses (Ishida et al. 1992: Nagasawa et al. 1994) as follows:

$$S(t) = \alpha(1-d)^t . \tag{2}$$

The relation between β and *d* is as follows:

$$\beta = -\ln(1-d) . \tag{3}$$

We used several fitting methods to estimate the digestion coefficient β.

(1) Linear regression using log-transformation of the mean index of stomach content weight at time t

The model is written as:

$$\bar{S}(t) = \alpha \exp(-\beta t) \exp(\varepsilon) \quad (4)$$

where $\bar{S}(t)$ is the mean index at time t and ε is the random error. The objective function for this model is

$$\sum_t \left(\ln\{\bar{S}(t)\} - \ln \alpha + \beta t \right)^2 . \quad (5)$$

We obtained the estimates of β by ordinary linear regression.

(2) Weighted nonlinear least squares using the mean index of stomach content weight and the variance of the mean at time t

This model is written as:

$$\bar{S}(t) = \alpha \exp(-\beta t) + \varepsilon(t) \quad (6)$$

where $\varepsilon(t) \sim N(0, \sigma_t^2 / n_t)$, σ_t^2 is the variance of the index at time *t*, and n_t is the number of fish examined at time *t*. The objective function is

$$\sum_t \left(\frac{n_t}{\sigma_t^2} \right) \left(\bar{S}(t) - \alpha \exp(-\beta t) \right)^2 . \quad (7)$$

(3) Linear regression using log-transformation of the mean index of stomach content weight adjusted by data at time 2300

This model is developed in order to reduce the variation of environmental factors among the stations and defined as:

$$\bar{S}(\tau) / \bar{S}(0) = \exp(-\beta \tau) \exp(\varepsilon) \quad (8)$$

where τ is the elapsed time from 2300 and $\bar{S}(0)$ is the index at 2300. The objective function is

$$\sum_\tau \left(\ln\{\bar{S}(\tau) / \bar{S}(0)\} - \beta \tau \right)^2 . \quad (9)$$

(4) Nonlinear least squares using individual data adjusted by hauling time

The model is written as:

$$S(t_i) = \alpha \exp(-\beta t_i) + \varepsilon \quad (10)$$

where i=1,2,...,n is for n individuals. The objective function is

$$\sum_i \left(S(t_i) - \alpha \exp(-\beta t_i) \right)^2 . \quad (11)$$

(5) Weighted nonlinear least squares using individual data adjusted by hauling time and variance at time t

The model is written as:

$$S(t_i) = \alpha \exp(-\beta t_i) + \varepsilon(t_i) \tag{12}$$

where t_i is the elapsed time from hauling, $\varepsilon(t_i) \sim N(0, \sigma_{t_i}^2)$, and $\sigma_{t_i}^2$ is the variance of the index at time t_i (we use σ_t^2 as $\sigma_{t_i}^2$ in this analysis). The objective function is

$$\sum_i \left(\frac{1}{\sigma_{t_i}^2}\right)\left(S(t_i) - \alpha \exp(-\beta t_i)\right)^2 . \tag{13}$$

In the linear regression model, we did not use the log-transformation of individual data because there were several empty salmon stomachs in the data set.

RESULTS

The number of fish examined in the digestion experiments at each station are shown in Table 1. The number of fish in the column of 2100 are the number of fish examined just after fish caught by longline as part of the routine examination. The time sacrificed for routine examination is not clear, but it is between 2000 and 2200. Table 1 also shows the starting time of setting and hauling for each station. Table 2 shows the summary of digestion experiments for each year. Figure 1 shows the histogram of the index of stomach content weight at each time. The estimates of digestion coefficients from various models with and without data at 2100 are shown in Table 3. Previous estimates are shown in the row of eye fitting. Fitted curve for 1992 chum salmon using linear regression with log-transformation of the mean index is shown in Figure 2.

DISCUSSION

Table 3 shows that there are differences in estimates of digestion coefficient among the fitting methods and the years of experiments. The causes of differences among fitting methods are the stochastic variation due to the small sample size and the departure from the assumption of models. Estimates from 1992 data are stable, reflecting large sample size and balanced sampling (Table 1c). Based on the 1992 data, the digestion coefficient for chum salmon is estimated to be 0.12 to 0.14 per hour. It is premature, however, to draw a general conclusion that the digestion coefficient for chum salmon is around 0.13, because the digestion coefficient depends on several factors, such as temperature, and size and composition of the item to be digested. These dependencies may cause differences in estimates among the years.

Table 3 also shows that the estimates of digestion coefficient with 2100 data are equal to or lower than those without 2100 data. This indicates that the definition of time of routine examination might be inappropriate.

Ishida et al. (1992) indicated that the digestion rate of chum salmon was slightly faster than that of pink salmon. The results of this analysis do not confirm this hypothesis because almost all stations examined pink salmon differ from that for chum salmon (Tables 1a and 1b) and there is no clear difference between the estimates of digestion coefficient for pink salmon and that for chum salmon in 1992 and 1993 (Table 3).

Suggestions for future digestion experiments

- The experimental design which enable us to estimate the elapsed time from the end of feeding is desirable.
- If we would like to pool several individual experiments (stations) for analysis, balanced sampling design among the experiments (stations) is needed.
- More data are needed for each experiment if we would like to analyze the individual experiment (without pooling).

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Table 1a. Longline set and haul time and the number of pink salmon examined by time interval and station, 1991.

			Time					
Station	Set	Haul	2100	2300	0200	0500	1000	1500
12	1921	2020	20	10*	5	5	4	0
13	1936	2026	20	5	5	5	5	0
18	1945	2044	20	5	5	5	5	4
27	1958	2058	20	4	4	4	6	0
28	2010	2105	20	3	3	3	6	0
Total			100	27	22	22	26	4

*five of them are at 2230

Table 1b. Longline set and haul time and the number of chum salmon examined by time interval and station, 1991.

			Time					
Station	Set	Haul	2100	2300	0200	0500	1000	1500
15	1921	2026	20	5	5	3	5	0
18	1945	2044	20	10	5	5	5	5
19	1952	2051	19	5	5	5	5	7
26	2000	2055	20	4	3	5	7*	0
29	2014	2032	19	4	4	4	4	0
Total			98	28	22	22	26	12

*at 0900

Table 1c. Longline set and haul time and the number of chum salmon examined by time interval and station, 1992.

			Time					
Station	Set	Haul	2100	2300	0200	0500	1000	1500
8	1911	2004	3	3	3	3	1	0
11	1924	2020	3*	3	3	2	1	0
12	1929	2025	4	2	2	2	1	0
14	1939	2033	8	2	2	2	1	0
15	1944	2039	20	7	6	6	6	10
16	1949	2043	13	6	6	6	6	5
17	1956	2052	20	10	10	10	10	10
18	2001	2056	10	6	6	6	6	5
21	2022	2117	10	9	9	9	9	7
22	2009	2103	12	10	10	10	9	0
23	2005	2100	11	3	3	3	3	5
24	1957	2052	10	4	4	4	4	8
25	1958	2052	19	10	10	10	10	10
26	2005	2100	10	6	6	6	6	7
27	2009	2104	14	7	7	7	7	5
Total			167	88	87	86	80	72

*clearly indicate "at 2100" in field note

Table 1d. Longline set and haul time and the number of chum salmon examined by time interval and station, 1993.

Station	Set	Haul	Time 2100	2300	0200	0500	1000	1500
11	1932	2031	20	6	0	0	0	0
14	1947	2050	20	0	5	0	0	0
18	2011	2110	20	5	5	5	5	4
19	2017	2116	20	5	5	6	6	7
20	2023	2122	20	5	5	5	0	0
21	2032	2131	20	5*	6	6	5	5
22	2018	2117	20	7	6	7	0	0
24	2004	2102	20	7	7	7	6	7
25	2007	2105	20	5	6	5	0	0
26	2011	2109	20	7	7	7	7	6
27	2016	2117	20	6	7	7	7	7
28	2020	2121	20	5	5	5	5	5
Total			240	63	64	60	41	41

* at 0000

Table 2a. Index of stomach content weight and number of pink salmon observed in digestion experiments, 1991.

Time	N. of station	N. of fish	Mean of index	Standard deviation
2100	5	100	1.94(0.14)	1.42
2300	5	27*	1.73(0.24)	1.26
0200	5	22	1.08(0.17)	0.80
0500	5	22	0.49(0.11)	0.52
1000	5	26	0.47(0.19)	0.97
1500	1	4	0.24(0.24)	0.48

Parentheses indicate standard error of mean

*including five data at 2230

Table 2b. Index of stomach content weight and number of chum salmon observed in digestion experiments, 1991.

Time	N. of station	N. of fish	Mean of index	Standard deviation
2100	5	98	1.72(0.08)	0.81
2300	5	28	1.38(0.17)	0.90
0200	5	22	0.74(0.16)	0.77
0500	5	22	0.26(0.06)	0.28
1000	5	26	0.10(0.05)	0.26
1500	2	12	0.06(0.04)	0.14

Parentheses indicate standard error of mean

Table 2c. Index of stomach content weight and number of chum salmon observed in digestion experiments, 1992.

Time	N. of station	N. of fish	Mean of index	Standard deviation
2100	15	167	1.31(0.07)	0.92
2300	15	88	0.97(0.07)	0.64
0200	15	87	0.90(0.09)	0.81
0500	15	86	0.47(0.05)	0.51
1000	15	80	0.20(0.05)	0.41
1500	10	72	0.14(0.05)	0.46

Parentheses indicate standard error of mean

Table 2d. Index of stomach content weight and number of chum salmon observed in digestion experiments, 1993.

Time	N. of station	N. of fish	Mean of index	Standard deviation
2100	12	240	1.34(0.05)	0.80
2300	11	63*	1.17(0.10)	0.81
0200	11	64	0.80(0.09)	0.69
0500	10	60	0.40(0.07)	0.51
1000	7	41	0.21(0.06)	0.39
1500	7	41	0.10(0.04)	0.28

Parentheses indicate standard error of mean

*including five data at 0000

Table 3. Estimates of the chum and pink salmon digestion coefficient ads caluculated using several models and data sets.

Models	91Pink	91Chum	92Chum	93Chum
Eye fitting	0.16*	0.22*		0.17**
Fitting mean				
Linear(log-transform)	0.12(0.02)***	0.21(0.02)***	0.13(0.01)***	0.15(0.01)***
	0.12(0.02)	0.21(0.02)	0.14(0.02)	0.16(0.01)
Weighted non-linear	0.15(0.02)***	0.21(0.02)***	0.13(0.01)***	0.14(0.01)***
	0.17(0.03)	0.25(0.02)	0.13(0.02)	0.16(0.01)
Linear(adjusted)	0.11(0.02)	0.21(0.02)	0.13(0.02)	0.17(0.01)
Fitting individual data				
Non-linear	0.12(0.02)***	0.17(0.02)***	0.12(0.01)***	0.13(0.01)***
	0.15(0.04)	0.24(0.04)	0.12(0.01)	0.16(0.02)
Weighted non-linear	0.14(0.02)***	0.21(0.02)***	0.13(0.01)***	0.13(0.01)***
	0.17(0.04)	0.26(0.03)	0.13(0.01)	0.17(0.02)

Parentheses indicate standard error

*from Ishida et al. 1991. **from Nagasawa et al. 1994. ***including 2100 data

Fig.1a

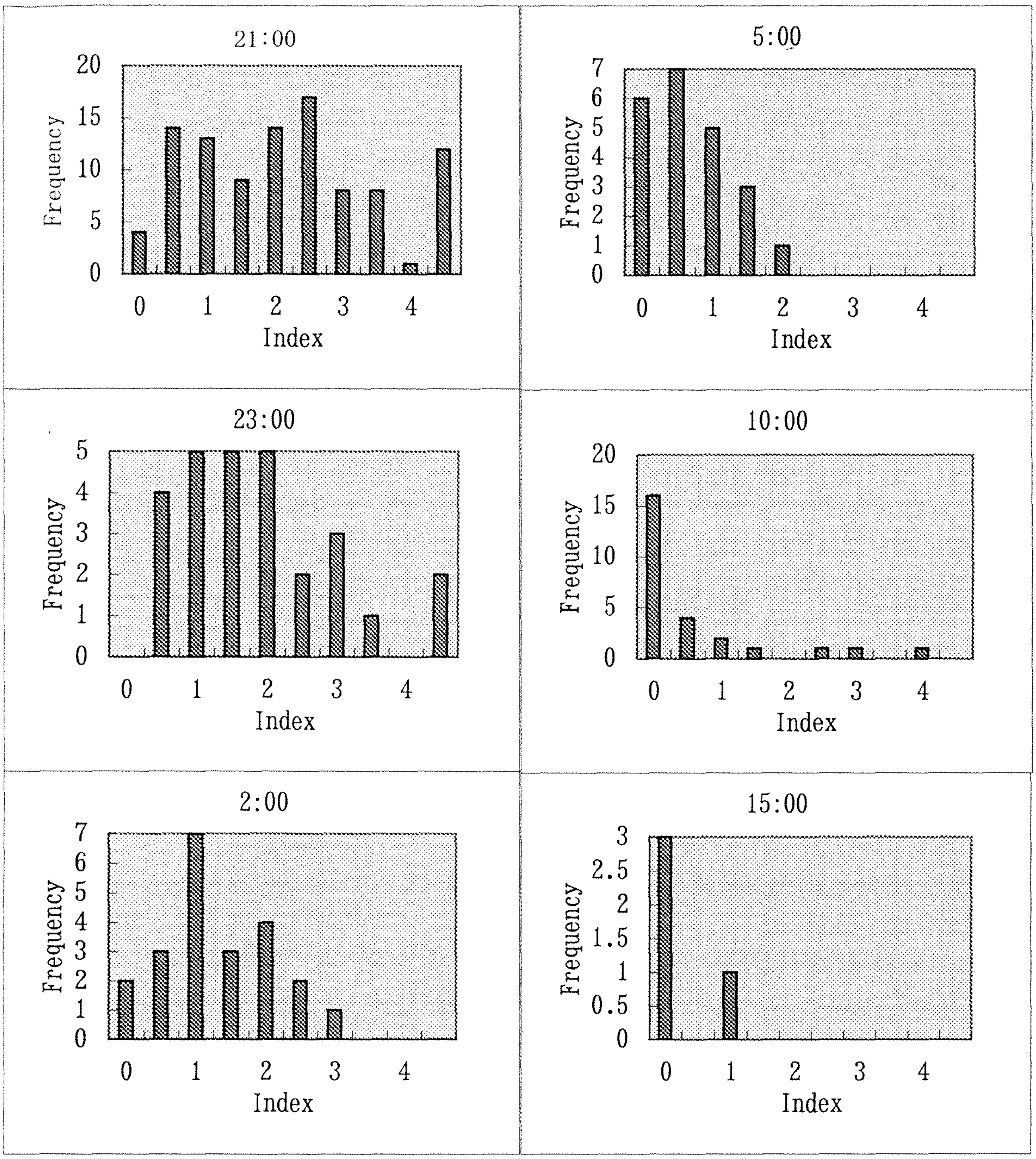

Figure 1a. Histogram of the index of stomach content weight. Pink salmon in 1991.
0 means the empty stomach.

Fig.1b

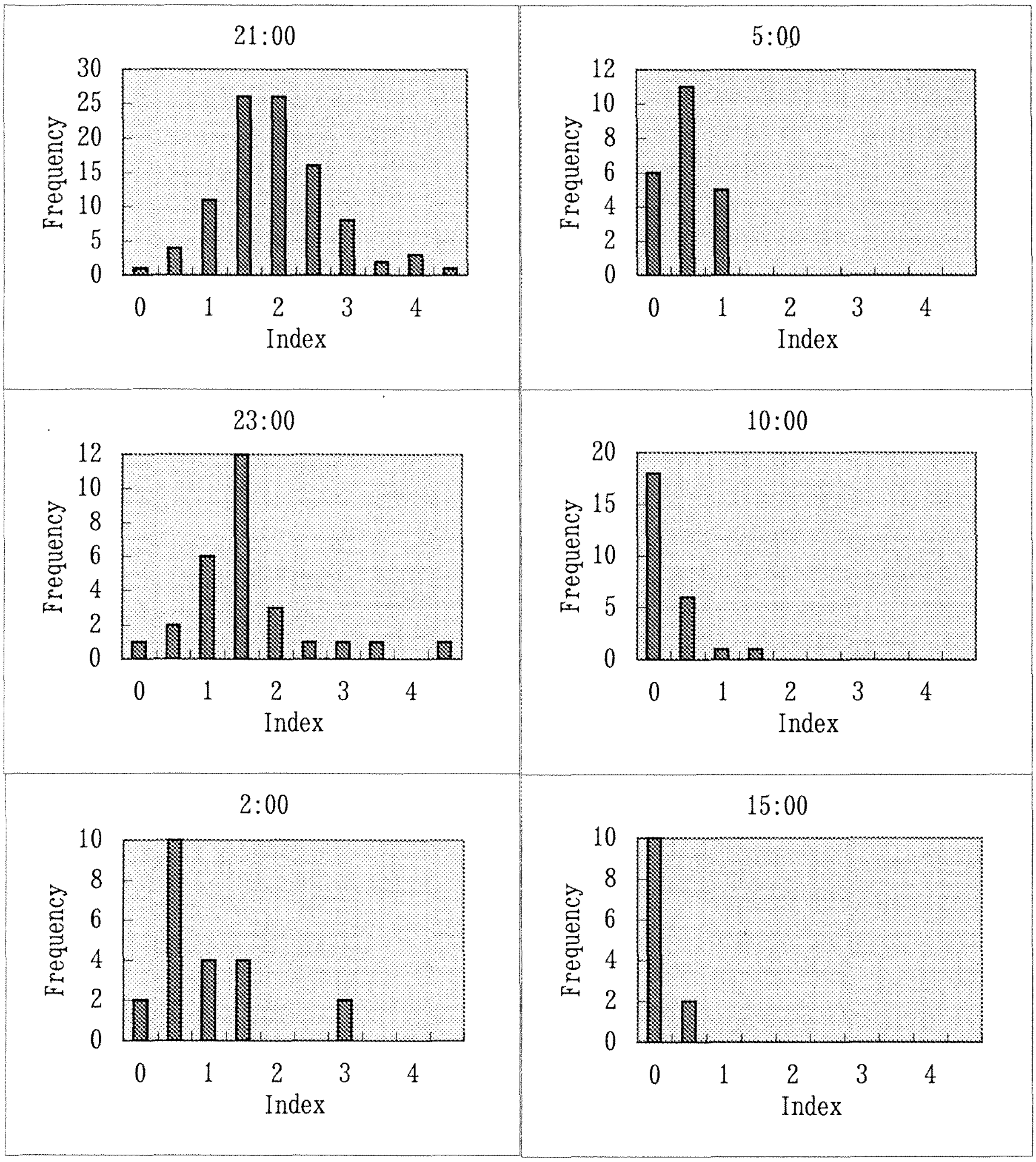

Figure 1b. Histogram of the index of stomach content weight. Chum salmon in 1991.
0 means the empty stomach.

Fig.1c

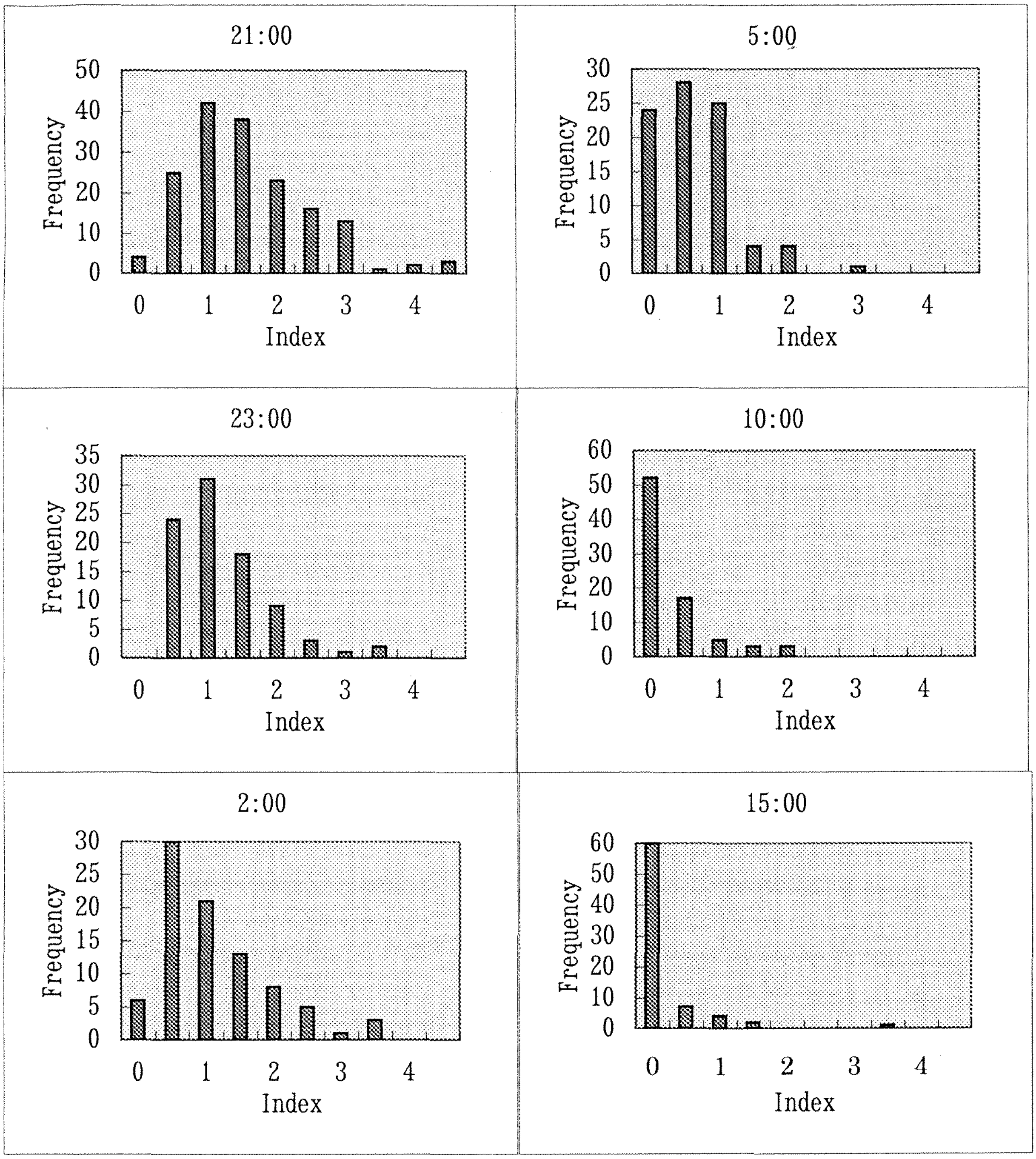

Figure 1c. Histogram of the index of stomach content weight. Chum salmon in 1992.
0 means the empty stomach.

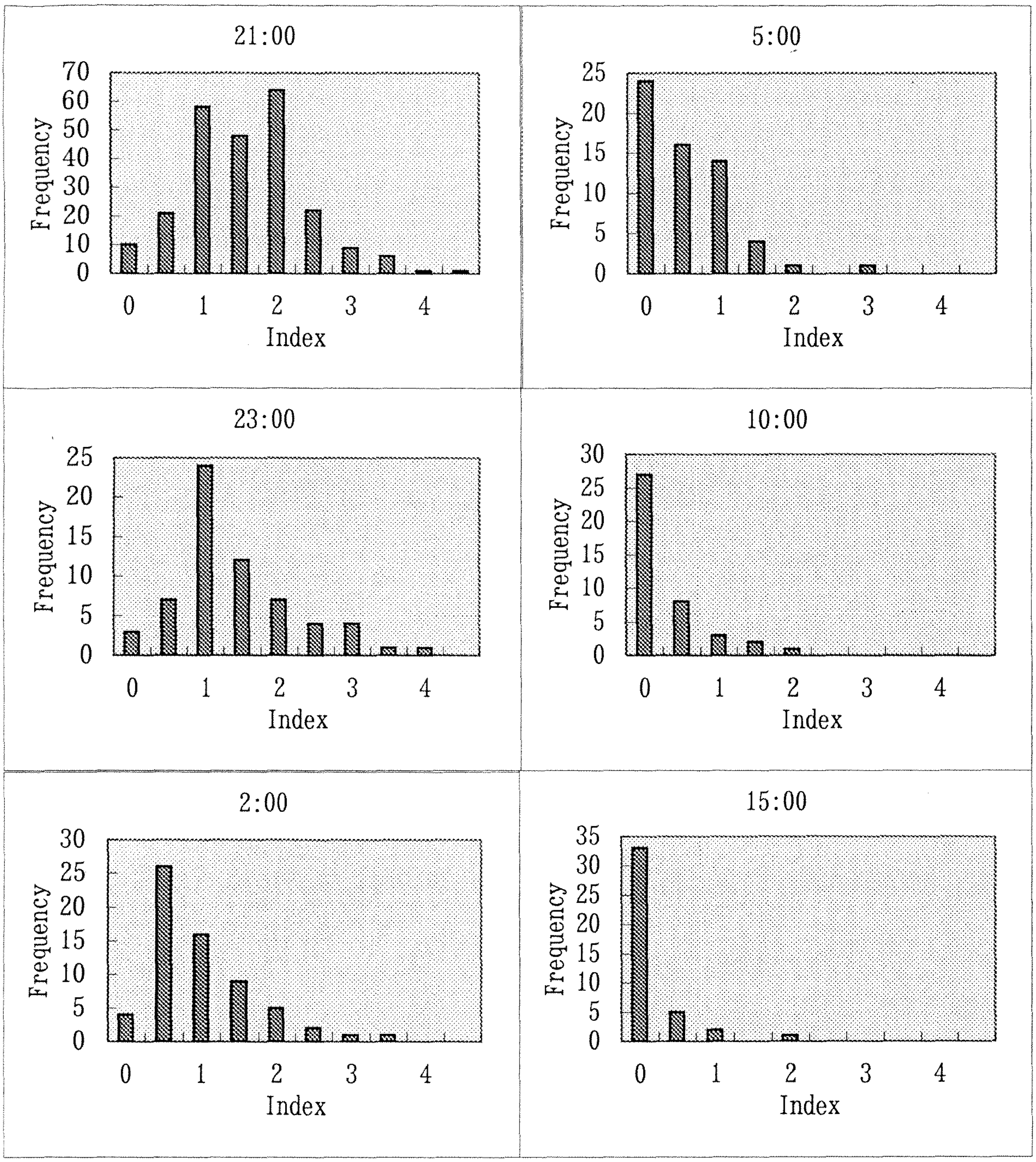

Figure 1d. Histogram of the index of stomach content weight. Chum salmon in 1993.
0 means the empty stomach.

Fig.2

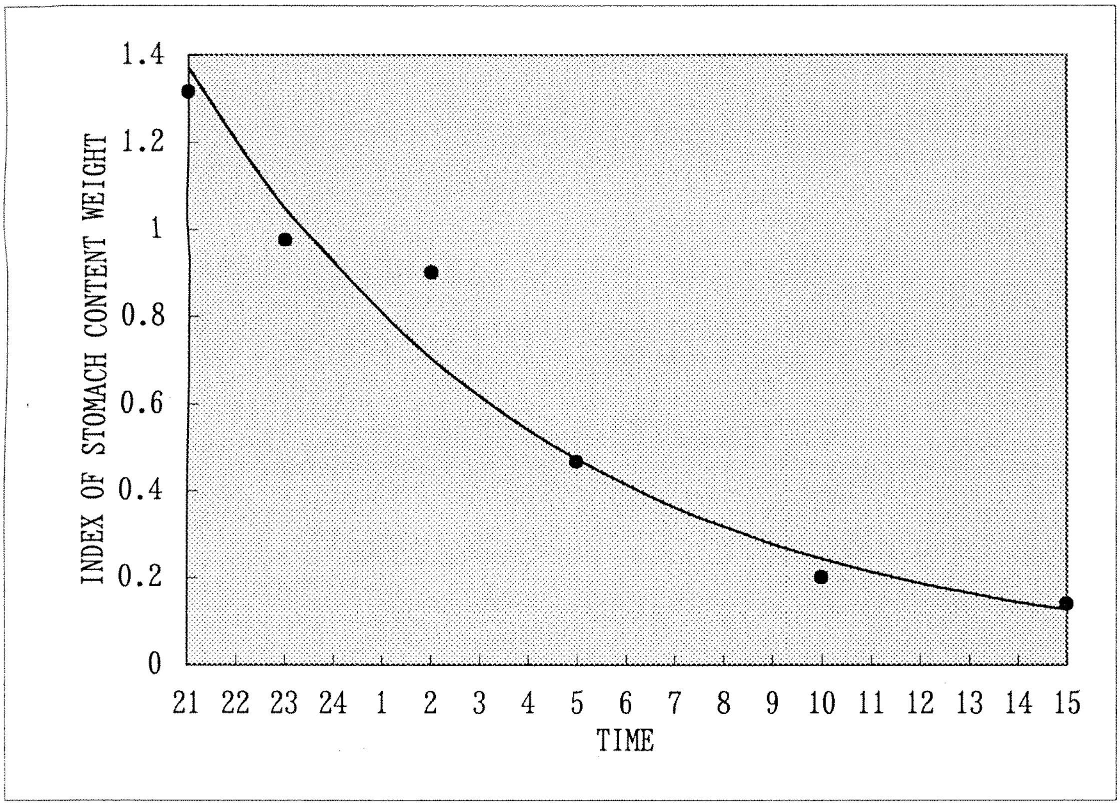

Figure 2. Plot of the reduction in 1992 chum salmon index of stomach content weight over time. The points represent mean value from experiments. The curve is the estimated index using linear regression model.