Prediction of the Path Type and Offshore Distance of the Kuroshio Current Using Neural Network

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We built a forecasting system for the path types of the Kuroshio current and the distance between the Kuroshio axis and Cape Iroh-zaki. A layered type of the artificial neural network was used in the system. Input data sets included six months' precedent data of distances between the Kuroshio axis and major capes, occurrence rates of Kuroshio path types and deviations of sea surface temperature. The predicted values of the hydrographic conditions in the months of March and April were well matched to the observed values. The investigation of the interconnection weight values suggests that the deviations of sea surface temperature and occurrence order of the Kuroshio path types significantly affected the predictions in the neural network. As the catch of sardine larvae in Sagami Bay during March and April is affected by the path types of the Kuroshio current and the distance between the Kuroshio axis and Cape Iroh-zaki, the predicted results will be used to forecast the catch.

Key words: Kuroshio, neural network, artificial intelligence, sardine larvae, forecast, hydrographic conditions

In the Sagami Bay area of Japan, the whitebait fish (*shirasu*) is one of the most important materials of the fisheries industry. Three major species of the whitebait fish during the post-larval stage of Clupeoid fishes are: Japanese sardine *Sardinops melanostictus*, Japanese anchovy *Engraulis japonicus* and round herring *Etrumeus teres*. Quantitatively, larvae of sardine and anchovy are the dominant catch. It has been the desire to be able to forecast the catch of these species for stable fisheries management and stable supply of fisheries products in Sagami Bay.

According to a study by Mitani¹⁾ on sardine larvae caught in Sagami Bay during 1978–87, the Kuroshio path types and the distance between the Kuroshio axis and Cape Iroh-zaki during March and April significantly influence the catch of sardine larvae in Sagami Bay. Thus, we started to develop a forecasting method for the catch of sardine larvae. In this attempt, we initially developed the forecasting method for the Kuroshio path types and the distance between the Kuroshio axis and Cape Iroh-zaki.

In forecasting the Kuroshio path, the linear regression models are generally applied.^{*3} However, until now, such forecasting models for the hydrographic conditions have not been fully realized. To develop more satisfactory methodology, we attempted to apply the Artificial Intelligence (AI) technique in this paper, which has already been applied for forecasting in various other fields. However, the AI technique has not yet been applied broadly in the hydrography or fishery fields. There were only several studies on the catch of sardine juveniles in the east coast of Japan by Aoki and Komatsu²⁾ and the catch of Japanese anchovy in Sagami Bay.^{3,4)} The former study, using a neural

network and a non-linear model, obtained the satisfactory predictions of the catch.

In forecasting the catch of sardine larvae in waters like Sagami Bay, we needed to forecast the hydrographic conditions very accurately because the catches were significantly affected by the hydrographic conditions such as the Kuroshio path.¹⁾ The Forecast Committee under the Fisheries Agency of Japan, for the long-term fishing and hydrographic conditions in the central block of Japan, has been working on forecasting problems. At four months intervals, they attempted to forecast the Kuroshio path types in the south of Honshu in the next four months by comparing the previous particular periods showing similar processes in the hydrographic conditions. This approach may be considered a kind of pattern recognition and it can be conducted on a computer by the neural network technique, a type of artificial intelligence. Therefore, by applying the neural network, we started to develop a forecasting method for the hydrographic conditions. The path types of the Kuroshio and the distance between the Kuroshio axis and Cape Iroh-zaki in the fishing season of sardine larvae in Sagami Bay were investigated. The results will be used for forecasting the catch of *shirasu* in Sagami Bay between March and April by our next report.

Source of Information and Analytical Method

Neural Network

The engineering model of the neural network has the following functions: (a) when one neuron receives signals (stimuli) from others, the signals are weighted, and these interconnection weights differ between input neurons and (b) each neuron will accumulate the weighted signals, and

*³ S. Ohnishi, T. Watanabe, M. Ishiguro, K. Okuda, and Y. Matsumiya: Prediction of position of Kuroshio axis by the multiple auto-regression. Abstracts of the presentations in the annual meeting of Japanese Society of Fisheries Oceanography 1992, pp. 36–37 (in Japanese).

when the summed signals exceed threshold values, output signals will be transmitted to other neurons. Neural networks with such functions are classified into two types depending upon the structure of the network: (a) feed-forward (layered) neural network structures where the signals are transmitted in only one direction and (b) mutual bond neural network structures where the signals are exchanged in any direction among neurons. The former type is suitable to develop a pattern recognition technique, while the latter type is suitable to solve problems of association, combination and optimization.⁵⁾ In this study, we applied the former type of neural network since the pattern recognition problem was involved in the study.

The layered type of neural network has an input layer, an output layer and several intermediate layers inbetween. The input signals go through units in the input layer, are transmitted into the units in the intermediate layer, and finally become output signals. The layered type of neural network generally uses the back propagation technique. This technique has a function to adjust the weight and threshold values in the units (neurons) in order to minimize errors between output signal values and the correct signal values (or the "teacher's" signal values). This process is called "supervised learning". Computer software that can realize such a process is called a neural network simulator.

It has been understood that greater weight values of units in the neural network, given after completing the "learning" process, affect the output values greatly, while smaller values affect it less. Based on this relationship, it is possible to find out which input data greatly contribute to output values by checking the size of the weight values in a neural network that completes the "learning" process. In this paper, we used a commercially available neural network simulator, the RHINE (CRC Inc.).

Forecasting System for the Hydrographic Conditions

We designed the forecasting system for the occurrence rates of the Kuroshio path types and the distance between the Kuroshio axis and Cape Iroh-zaki. The procedures done for the forecasting system for the path types of the Kuroshio (Fig. 1) were as follows: (a) prepare input data for the preceding six months before the months to be forecasted, *i.e.*, sea surface temperatures, distances between the Kuroshio axis and major capes, and the Kuroshio path types, (b) prepare the Kuroshio path types as the desired outputs, and (c) have a neural network learn a mapping function from the set of learning data composed of pairs of input and output vectors by adjusting the weights and threshold. The distance between the Kuroshio axis and Cape Iroh-zaki was forecasted based on the same data sets used in the forecasting of the occurrence rate for the Kuroshio path types.

We selected 'occurrence rates of the Kuroshio path types', 'distances between the Kuroshio axis and the major capes' and 'sea surface temperature' as the input data because (a) there is a certain duration period in the Kuroshio path types, (b) the Kuroshio meander moves to the east because of the characteristics of the wave motions and (c) the sea surface temperatures vary according to the changes of the meander patterns. 'Six months' was selected as the time period of the input data for two reasons:

(a) it is an appropriate time period to learn the leading phenomena regarding changes of the Kuroshio path and (b) this time period is within the computer's capacity in terms of speed and storage.

The types of the Kuroshio path were defined by Kawai⁶⁾ based on studies by Yoshida⁷⁾ and Nitani,⁸⁾ that is, they are classified into A, B, C, D, and N types.

For the information of the Kuroshio path types, we used the relevant information on the Kuroshio axis available in the maps of the Quick Bulletin of Ocean Conditions published semimonthly by the Hydrography Department of Maritime Safety Agency of Japan. We assigned 0.5 points for path types A, B, C, D, or N when their types occurred exclusively. We assigned 0.25 points for path types B and D when both types appeared concurrently. Then, we calculated the occurrence rates of each type of Kuroshio path by summing these scores twice each month since the bulletin is published semi-monthly. Thus, the total point of the Kuroshio path types was always 1.0 in each month.

From the bulletin, we obtained monthly average distances between the Kuroshio axis and the major capes of the following places: Cape Toi-misaki, Cape Ashizuri-misaki, Cape Muroto-misaki, Cape Shiono-misaki, Cape Daio-zaki, Cape Omae-zaki, Cape Iroh-zaki, and Cape Nojima-zaki (Fig. 2).

We used deviations of the sea surface temperatures processed as follows: (a) calculation of monthly mean surface temperature in each location mentioned below, (b) calculation of the mean surface temperature for each month in each location by averaging the monthly mean temperature of the same month in each year between 1978 and 1990, (c) calculation

Fig. 1. Forecasting system for the hydrographic conditions to predict the occurrence rates of the Kuroshio path types and the distances between the Kuroshio axis and the Iroh-zaki Cape after one or two months.

Fig. 2. The distances between the Kuroshio axis and the following Capes: Toi-misaki, Ashizuri-misaki, Muroto-misaki, Shiono-misaki, Daio-zaki, Omae-zaki, Iroh-zaki, and Nojima-zaki.

The thick curve and the thin lines represent the Kuroshio axis and the distances between the axis and the capes, respectively.

of deviations by subtracting (b) from (a). Locations: Hyuga-nada Sea, Tosa Bay, Southern Kumano-nada Sea, Northern Kumano-nada Sea, Enshu-nada Sea, Sagami Bay, Sotobo Sea, and Ohshima Island (Fig. 3). In these locations, the sea surface temperatures were collected through the routine transect observations every month from 1978 by the research vessels of the prefectures along the Pacific coast of Japan.

We used the data from 1978 to 1985 for the learning procedure and used the data from 1986 to 1990 for the test of the trained neural network by comparing between forecasted (calculated) and observed values. The number of units in the input layers was 126 in forecasting the Kuroshio path types and distance between the Kuroshio axis and Cape Iroh-zaki. For the former, five units were used in the output layer to represent the five types of the Kuroshio paths (A, B, C, D, and N), while 35 units were assigned to the intermediate layer. For the latter, one unit was used in the output layer to represent the distance, while 30 units were assigned to the intermediate layer. The number of learning cycles was 3000.

Results

Forecast of the Kuroshio Path Types

In the forecast for the occurrence rates of the Kuroshio path types after one month, the forecasted and observed values corresponded well both in the learning and the non-learning period. Especially, the patterns of A, C, and N types could be successfully forecasted. Although the forecasts after two months were less successful, the trends of the patterns roughly corresponded (Fig. 4, 5).

Forecast of the Distance between the Kuroshio Axis and Cape Iroh-zaki

The forecast for the distance between the Kuroshio axis

Fig. 3. Small dots showing the observation points used to evaluate the monthly deviations of the sea surface temperature in the following locations: Hyuga-nada Sea, Tosa Bay, Southern Kumano-nada Sea, Northern Kumano-nada Sea, Enshu-nada Sea, Sagami Bay, Sotobo Sea, and Ohshima Island (based on the report of the monthly routine observations by Prefectural Fishery Experimental Stations).

Fig. 4. Comparisons of the predicted values (broken lines) and observed values (solid lines) on the occurrence rates of the Kuroshio path types after one month.

The hatched length represents the learning period.

Fig. 5. Comparisons of the predicted values (broken lines) and observed values (solid lines) for the occurrence rates of the Kuroshio path types after two months.

The hatched length represents the learning period.

Fig. 6. Comparisons of the predicted values (broken line) and observed values (solid line) of the distance between the Kuroshio axis and Cape Iroh-zaki after one month.

The hatched length represents the learning period.

and Cape Iroh-zaki corresponded to the leaving or approaching tendencies of the Kuroshio current from the cape (Fig. 6, 7). In this case, we could also forecast better after one month than two months.

Forecast in March and April

We made a comparison between the predicted and observed values of the occurrence rates of the Kuroshio path types and the distance between the Kuroshio axis and Cape Iroh-zaki in March and April, *shirasu* fishing season (Table 1). Table 1 shows that the predicted and observed values during 1979–85 (the learning period) corresponded well. It also shows that the predicted values of the occurrence rates of the Kuroshio path types in March and April during 1986–90 (non-learning period) were close to the real values.

The predicted values of distance between the Kuroshio axis and Cape Iroh-zaki in the months of March and April corresponded with the Kuroshio's tendency to leave and reapproach Cape Iroh-zaki. The prediction is evaluated by the difference between the predicted and the observed values. The range of the differences including the signs was 69.2 nautical miles. The mean and standard deviation of the differences including signs were 6.7 (12.6) and 21.8 (23.2) nautical miles, respectively. The numbers in parentheses represent those of cases during the non-learning period. The difference was below 20 nautical miles in 14 (5) cases and from 20 to 40 nautical miles in 7 (3) cases. It was above 40 nautical miles in 3 (3) cases. When we give the 1, 0.5 and zero points to the classes listed above, respectively, the score is 17.5 (6.5). The percentage of the score on full

Table 1. Comparisons between the observed values (upper figures) and the predicted values (lower figures) of (a) the occurrence rates of the Kuroshio path types and (b) the distances between the Kuroshio axis and Cape Iroh-zaki for March–April from 1979–90

Year	Month	Kuroshio path types by neural net						By Committee		By neural net	
		A	B	C	D	N	Result	Pred.	Result	Dist.	Dif.
79	March	1.00	0.00	0.00	0.00	0.00				30.0	
		0.98	0.08	0.00	0.00	0.01	V.G.	A	V.G.	36.9	6.9
	April	1.00	0.00	0.00	0.00	0.00				42.5	
		0.99	0.04	0.00	0.03	0.03	V.G.	A	V.G.	36.0	6.5
80	March	1.00	0.00	0.00	0.00	0.00				47.7	
		0.96	0.07	0.04	0.00	0.00	V.G.	A	V.G.	74.5	26.8
	April	0.00	1.00	0.00	0.00	0.00				160.0	
		0.55	0.65	0.03	0.03	0.07	V.B.	A	V.B.	134.3	25.7
81	March	0.00	0.00	0.00	0.00	1.00				65.0	
		0.02	0.22	0.07	0.04	0.86	V.G.	B or C	V.B.	67.9	2.9
	April	0.00	0.00	0.00	0.00	1.00				60.0	
		0.12	0.11	0.02	0.07	0.92	V.G.	N	V.G.	55.8	4.2
82	March	0.50	0.00	0.50	0.00	0.00				125.0	
		0.85	0.04	0.28	0.01	0.00	G.	B or C	G.	108.5	16.5
	April	1.00	0.00	0.00	0.00	0.00				45.0	
		0.91	0.07	0.11	0.02	0.02	V.G.	N	V.B.	82.4	37.4
83	March	0.50	0.00	0.50	0.00	0.00				175.0	
		0.12	0.04	0.88	0.08	0.01	B.	B or C	G.	166.1	8.9
	April	1.00	0.00	0.00	0.00	0.00				100.0	
		0.84	0.04	0.19	0.04	0.05	V.G.	B or C	V.B.	117.8	17.8
84	March	0.00	0.00	1.00	0.00	0.00				165.0	
		0.05	0.13	0.89	0.07	0.05	V.G.	B or C	G.	146.9	18.1
	April	0.00	0.00	1.00	0.00	0.00				165.0	
		0.10	0.11	0.86	0.03	0.03	V.G.	B or C	G.	142.8	22.2
85	March	0.50	0.00	0.50	0.00	0.00				107.5	
		0.53	0.07	0.79	0.04	0.00	V.G.	B or C	G.	120.7	13.2
	April	0.00	0.00	1.00	0.00	0.00				170.0	
		0.11	0.04	0.96	0.09	0.02	V.G.	C	V.G.	201.7	31.7
86	March	0.00	0.25	0.75	0.00	0.00				102.5	
		0.01	0.26	0.84	0.09	0.04	V.G.	N	V.B.	107.4	4.9
	April	0.00	0.00	1.00	0.00	0.00				175.0	
		0.03	0.30	0.86	0.06	0.03	G.	B	V.B.	148.4	26.6
87	March	1.00	0.00	0.00	0.00	0.00				40.0	
		0.98	0.04	0.00	0.01	0.07	V.G.	A	V.G.	47.5	7.5
	April	1.00	0.00	0.00	0.00	0.00				60.0	
		0.99	0.03	0.01	0.01	0.09	V.G.	A	V.G.	64.9	4.9
88	March	1.00	0.00	0.00	0.00	0.00				65.0	
		0.98	0.03	0.00	0.01	0.09	V.G.	C	V.B.	50.8	14.2
	April	1.00	0.00	0.00	0.00	0.00				30.0	
		0.99	0.03	0.02	0.02	0.02	V.G.	C	V.B.	70.4	40.4
89	March	0.00	0.00	1.00	0.00	0.00				95.0	
		0.01	0.22	0.91	0.11	0.06	V.G.	C	V.G.	137.0	42.0
	April	0.00	0.00	0.50	0.00	0.50				85.0	
		0.01	0.21	0.58	0.06	0.41	V.G.	N, B or C	V.G.	127.6	42.6
90	March	1.00	0.00	0.00	0.00	0.00				42.5	
		0.77	0.02	0.01	0.03	0.51	B.	A	V.G.	39.8	2.7
	April	1.00	0.00	0.00	0.00	0.00				32.5	
		0.92	0.01	0.02	0.03	0.51	B.	A	V.G.	59.5	27.0

The predicted Kuroshio path types by the Forecast Committee of long-term fishing and hydrography conditions are also listed. The classification of the predicted values and types are as follows. V.G., G., B., V.B. means very good prediction, good prediction, bad prediction, and very bad prediction, respectively.

points is 72.9% (65%). We named this the percentage of predicted success.

Next, we compared the predictions of occurrence rates of Kuroshio path types by the neural network and the Kuroshio path types by the Forecast Committee for long-term fishing and hydrographic conditions in March and April from 1979 to 1990. We ranked the predicted values of occurrence rates for the Kuroshio path into very good, good, bad and very bad predictions when the predicted

occurrence rate was above 75%, 50–75%, 25–50%, and below 25% of the actual rate, respectively. When the prediction of the occurrence rate disperses into two or three types, a penalty is imposed on a rank of the prediction as follows. When the predicted values for 0.0 of the real occurrence rate are 0.25–0.5, 0.5–0.75, and 0.75–1.0, we reduce the rank i.e., one, two, and three ranks down, respectively. The points of very good prediction, good prediction, and others are 1, 0.5, and 0, respectively. On

Fig. 7. Comparisons of the predicted values (broken line) and observed values (solid line) of the distance between the Kuroshio axis and Cape Iroh-zaki after two months.
The hatched length represents the learning period.

the other hand, the predictions by the Committee were judged as very good or very bad in the case of accordance or discordance with the types which really appeared. When the predictions by the Committee were two types, they were ranked into very good, good, and very bad predictions when both types appeared, one type appeared, or both types did not appear, respectively. The very good prediction, the good prediction, and the bad prediction are given 1, 0.5, and 0 points, respectively. Finally, we summed the points of predictions by the different methods and calculated the percentage of predicted success.

The cases of the prediction by the Committee were as follows: Very good prediction-11, good prediction-5, and very bad prediction-8. The score of predicted success was 13.5. The percentage of predicted success was 56.3% in 24 cases. On the other hand, the cases of prediction by the neural network were as follows: Very good prediction-18, good prediction-2, bad prediction-3, and very bad-1. Total points of predicted success was 19. Their percentage was 79.2% and 75% from 1979 to 1990 (whole period) and from 1986 to 1990 (non-learning period), respectively.

Discussion

Forecast of the Kuroshio Path Types

The predicted values of the occurrence rates of the Kuroshio path types after one month corresponded well to the observed values both in the learning and the non-learning period. Although the predictions after two months became worse, the trends of the fluctuations of the predicted and the observed values were roughly matched. Among the Kuroshio path types, the occurrence rates of types A, C, and N corresponded better to the observed values than other types (B and D). Reasons of unsuccessful predictions for other types, B and D were due to the short duration of their appearances and difficulty in discriminating these two types from the others. However, the most significant reason was that there were not enough cases of types B and D, thus the system could not learn enough about the character-

Table 2. A list of important input variables effecting the occurrence rates of the Kuroshio path type, 'type A' after one month

Input layer units	
Positive sign	Negative sign
<i>Kuroshio path types</i>	
Type A in zero mon.	Type N in zero mon.
<i>Distance between the Kuroshio axis and the following shore</i>	
Shiono-misaki four mon. before	Toi-misaki five mon. before
Daio-zaki in zero mon.	
<i>Deviation of sea surface temperature in the following sea</i>	
Enshu-nada five mon. before	Sagami Bay in zero mon.
Ohshima Island two mon. before	Sotobo Sea four mon. before

istics of these two types of the Kuroshio path. On the other hand, the predictions for types A and C were much easier since the system could learn well about these two patterns due to many cases and clear characteristics to discriminate.

Under such situations, we focused our discussions on the weight of the units in the trained neural network that could forecast types A, C, and N after one month, which are the cases that forecast successfully.

We first selected the intermediate units whose absolute weight values of the connection to the output unit were more than 1.0. If there were not enough numbers of such intermediate units, those with absolute weight values more than 0.8 were selected. Then, we selected the input layer units that satisfied the following two conditions: (i) the absolute value of the weight of the connection from the input layer unit to the above-selected intermediate units was two times greater than the threshold values of the latter units and (ii) the weight value kept a consistent sign (plus or minus) in the connections to the majority of the selected intermediate layer units.

Tables 2, 3, and 4 list the input units that satisfy the above mentioned two conditions.

According to Fujimoto and Tomosada,⁹⁾ type A of the

Table 3. A list of important input variables effecting the occurrence rates of the Kuroshio path type, 'type C' after one month *

Input layer units	
Positive sign	Negative sign
<i>Kuroshio path types</i>	
Type A three mon. before	
Type B in zero mon.	
Type C two mon. before	
<i>Distance between the Kuroshio axis and the following shore</i>	
Iroh-zaki four mon. before	Daio-zaki four mon. before
Iroh-zaki two mon. before	
Iroh-zaki in zero mon.	
<i>Deviation of sea surface temperature in the following sea</i>	
	Ohshima Island two mon. before

Table 4. A list of important input variables effecting the occurrence rates of the Kuroshio path type, 'type N' after one month

Input layer units	
Positive sign	Negative sign
<i>Kuroshio path types</i>	
Type B three mon. before	Type B in zero mon.
Type D in zero mon.	
<i>Distance between the Kuroshio axis and the following shore</i>	
Toi-misaki in zero mon.	Omae-zaki in zero mon.
	Iroh-zaki two mon. before
<i>Deviation of sea surface temperature in the following sea</i>	
North. Kumano. five mon. before	
Sagami Bay five mon. before	
Sotobo Sea in zero mon.	

Kuroshio path, the path type of large meander period of the Kuroshio, has the following two tendencies: (a) a longer period of appearance and (b) higher sea surface temperatures maintained than in the non-large meander period (Kuroshio path types except type A) in the waters from the Kumano-nada Sea to the Enshu-nada Sea, and lower temperatures in the waters of the Sotobo Sea. These situations partially corresponded to the results of analysis of the weight values in the neural network (Table 2). The Kuroshio's tendency to leave Cape Daio-zaki and Cape Shiono-misaki are characteristics of type A. These characteristics appeared in the weights of the distances between the Kuroshio axis and the capes.

According to Nitani,⁸⁾ the Kuroshio path tends to change periodically in the order of N→B→C→D→N when the Kuroshio path is in the non-large meander period. Then, he described the sustained duration of types N and C as about two months, while the duration of types B and D were about 0.9 and 0.8 months, respectively. Nitani's report matches well to the result of the great weight value for type B in zero month (Table 3). Matsumoto¹⁰⁾ pointed out that the Kuroshio path had a tendency to repeat types B and C at a period of about 2.4 months. The average durations of types B and C were about 1 and 1.3 months, respectively. When type C occurs two months before, it reappears after one month according to his report. If the neural network

Table 5. A list of important input variables effecting the distance between the Kuroshio axis and Cape Iroh-zaki after one month

Input layer units	
Positive sign	Negative sign
<i>Kuroshio path types</i>	
	Type D in zero mon.
<i>Distance between the Kuroshio axis and the following shore</i>	
Omae-zaki two mon. before	Shiono-misaki two mon. before
Omae-zaki one mon. before	Daio-zaki five mon. before
Iroh-zaki four mon. before	Daio-zaki in zero mon.
Iroh-zaki three mon. before	
Nojima-zaki three mon. before	
<i>Deviation of sea surface temperature in the following sea</i>	
	Enshu-nada three mon. before
	Enshu-nada two mon. before
	Sotobo Sea one mon. before

learns this feature, the weight value for type C two months before becomes great. It is true as shown in Table 2. Furthermore, type C path shows the tendency to periodically leave Cape Iroh-zaki. This tendency appeared in weight values of distance between the Kuroshio axis and Cape Iroh-zaki.

The input units with great weight values for the type N prediction show that types B and D of the Kuroshio path tended to change to type N at different intervals (Table 4). The great weight values of type D in zero month and type B three months before correspond to the changing tendency of the Kuroshio path reported by Nitani.⁸⁾ The Kuroshio's tendency to approach Cape Omae-zaki is a typical characteristic of type N. The Kuroshio's tendency to leave Cape Toi-misaki in zero months is caused by type N with cold water eddies off the cape pointed out by Sun *et al.*¹¹⁾ Fujimoto and Tomosada⁹⁾ clarified that deviations of the sea surface temperature in the Sotobo Sea were higher in the non-large meander period than in the large meander period (type A). This also corresponds to the results of the weight values.

Forecast of the Distance between Kuroshio Axis and Cape Iroh-zaki

The Kuroshio's tendency to leave or reapproach the shore could be clearly predicted. The forecast after one month was more accurate than the forecast after two months. This was the same result as the previous forecast for the occurrence rates of the Kuroshio path types.

Table 5 shows the input units that satisfy two conditions, (i) and (ii) as explained previously. When the sea surface temperatures were lower in the Enshu-nada Sea (meaning that the Kuroshio axis showed the tendency to leave Cape Omae-zaki), the distances between the Kuroshio axis and Cape Iroh-zaki and Cape Omae-zaki would become longer. The distances between the axis and Cape Iroh-zaki become longer when the Kuroshio path was type C and became shorter when the paths were types A, B, and N. The typical characteristics of type C of the Kuroshio path are represented by the Kuroshio's tendency to approach Cape Shiono-misaki and Cape Daio-zaki and also by the Kuroshio's tendency to leave Cape Omae-zaki and Cape Iroh-zaki. This feature is seen in the weight values of the dis-

tances between the Kuroshio axis and the capes. Moreover, the weight values of the distances suggest the tendency of periodic changes for the occurrence of the type C pattern, which is also pointed out by Nitani.⁸⁾

Predicted Values in March and April

We could obtain exact or very accurate predicted values compared to the observed values of the occurrence rates for the Kuroshio path types in March and April. The percentage of predicted success was 79.2 and 75% from 1979 to 1990 (whole period) and from 1986 and 1990 (non-learning period). In addition, even five non-learning cases from 1986 to 1990 could predict the occurrence rates in very realistic values. On the other hand, the percentage of predicted success by the Forecast Committee was 61.3 and 60% from 1979 to 1990 and from 1986 to 1990, respectively. Thus, it seems that the prediction of the Kuroshio path types by the neural network is better than that by the Committee.

The distance between Cape Iroh-zaki and the Kuroshio axis was estimated sufficiently. The distances were classified by the difference between the predicted and the observed distances. The percentage of predicted success was 72.9 and 65% from 1989 to 1990 and 1986 to 1990, respectively. These results permit the estimation of the Kuroshio's tendency to leave or reapproach Cape Iroh-zaki for the distance between the axis and Cape Iroh-zaki.

A prediction for the Kuroshio path types and the distance between its axis and Cape Iroh-zaki was also attempted. It was found that the predictions were more reliable when the Kuroshio paths were types A, C, or N. Factors significantly affecting the prediction can be checked by investigating the weight values in the trained neural network. The significant factors were well matched to those pointed out in the past studies, *i.e.*, occurrence order of the Kuroshio path types, locations of the axis, and deviations of the sea surface temperatures. The predicted values in March and April were well matched to the observed values in the non-learning period from 1986–90. Thus, it is possible to use the predictions by the neural network for the Kuroshio path types and the distances between the Kuroshio axis and Cape Iroh-zaki in March and April to forecast the catch of the *shirasu* fisheries in Sagami Bay.

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