DISTRIBUTION AND ABUNDANCE OF DALL'S PORPOISES OFF JAPAN*

TOMIO MIYASHITA** AND TOSHIO KASUYA**

ABSTRACT

Results of nine whale sighting cruises in the Japanese coastal waters in 1983 through 1986 and some additional cruises provided following conclusion. Dall's porpoises inhabit waters below 24°C, but the upper temperature limit is lower in winter. *Dalli*-type individuals occur throughout the range of the species, but the majority of them winter in the Sea of Japan, and summer in the Okhotsk Sea and Pacific coast of Japan. *Truei*-type individuals inhabit only waters off the Pacific coast of northern Japan and southern Kuril Islands. They winter off the Pacific coast of Japan, and summer mainly in the waters between 40° and 45°N and west of 155°E. A minimum estimate of the number of *dalli*-type that winter in the eastern Sea of Japan is about 46,000 individuals, of these about 15,000 migrate through the Tsugaru Strait to the Pacific coast of Japan with the major portion of the stock summering in the Okhotsk Sea and northern Sea of Japan. The number of *truei*-types in the nearshore surveyed area is estimated at about 26,000, and the extraporation of the density to the offshore range of the type provides an estimation of total *truei*-type population of about 58,000 individuals. The continuation of current Japanese harpoon fishery will further deplete the stock(s) of Dall's porpoises.

INTRODUCTION

The Dall's porpoise, *Phocoenoides dalli* (True, 1885), includes two major color morphs designated as *dalli*-type and *truei*-type (Houck, 1976; Kasuya, 1978), the former being mainly distributed in the cold waters of the North Pacific and the latter in a limited area of the northwestern North Pacific (Nishiwaki, 1972; Ohsumi, 1975; Kasuya, 1978, 1982). Considering distribution of these color types and their seasonal movement, Kasuya (1978) suggested the presence of at least three local stocks of the Dall's porpoise in the northwestern North Pacific and the adjacent seas, i.e. 1) off the Pacific coast of northern Japan and southern Kuril Islands, 2) offshore northwestern North Pacific and the Bering Sea, and 3) in the Sea of Japan and the Okhotsk Sea. He considered

---

* *An earlier version of this manuscript was submitted to the Scientific Committee of the International Whaling Commission, Bournemouth, June 1987 (Document no. SC/39/SM11).*

** *Far Seas Fisheries Research Laboratory, 5-7-1, Orido, Shimizu-shi, Shizuoka-ken, 424 Japan*

Sci. Rep. Whales Res. Inst.,
No. 39, 1988, 121–150

that all the *dalli*-type individuals in the *truei*-type range off the Pacific coast of Japan would not be the members of Japanese east coast stock, but that at least some of them, especially those in the schools containing no *truei*-types, would be migrants from the offshore stock in the northwestern North Pacific and the Bering Sea or from the Sea of Japan-Okhotsk Sea stock. A similar view was presented by Miyazaki and Fujise (1985).

Recent data on the distribution of mother-calf pairs, parasite load, electrophoretic analysis of isoenzymes and pollutant levels in Dall's porpoise suggest that the hypothetical stock of Kasuya (1978) in the northwestern North Pacific and the Bering Sea probably includes two or more stocks, each breeding in the Bering Sea, south of the western Aleutian Islands, and perhaps off the east coast of northern Kuril Islands, respectively (Kasuya and Ogi, 1987; Subramanian, Tanabe, Fujise and Tatsukawa, 1986; Walker, 1987; Winans and Jones, in press). Additionally, Yoshioka, Ogura and Shikano (1987) presented data suggesting another apparently isolated breeding ground in the Gulf of Alaska.

Subramanian, Tanabe, Fujise and Tatsukawa (1986) found that the PCB/DDE ratio in the *dalli*-types taken in summer off the Pacific coast of Hokkaido was closer to those in the Sea of Japan than the *truei*-types in the same region, and considered that the *dalli*-types in the two locations could have shared a common feeding area. This suggests that the *dalli*-types migrate seasonally between the Sea of Japan and the Pacific coast of northern Japan.

The number of Dall's porpoises in the principal area of *truei*-type distribution has been estimated, using sightings data pooled for the months April to August since 1980, as about 64,000 (Kato, 1986) or about 125,000 individuals (Kato, 1987).

The present study analyzes the distribution and segregation of two types of Dall's porpoises in the Japanese waters using data obtained through nine whale sighting cruises in the western North Pacific, Sea of Japan and the Okhotsk Sea. The population of the two types of Dall's porpoises in the area is estimated using line transect methodology.

MATERIALS AND METHODS

The main body of data was obtained from the nine whale sighting cruises conducted using two whale catcherboats (*Toshimaru No. 15*, 647.3 gross tons, 3,480 HP; *Toshimaru No. 25*, 739.9 gross tons, 3,600HP) chartered by the Japan Fisheries Agency in 1983 through 1986 (Table 1). Other sighting cruises in which no Dall's porpoises were observed were excluded. The seasons covered were nine months of the year, excluding April, November and December.

In these cruises, survey was conducted along predetermined track line placed systematically perpendicular to the coast line. Two mast-top observers and three to six upper wheel-deck observers conducted sightings during

TABLE 1. WHALES SIGHTING CRUISES USED IN THE PRESENT STUDY

Cruise no.	Period*	Year	Name of vessel	Biologists on board	Number of schools sighted			
					D	T	M	U
1	12 Jan. – 24 Mar.	1983	Toshimaru No. 15	S. Shiraga	0	0	0	3
2	11 Jan. – 10 Mar.	1984	Toshimaru No. 15	S. Nishiwaki	24	0	0	3
3	10 Jan. – 10 Mar.	1985	Toshimaru No. 15	H. Shimada	1	0	0	0
4	2 May – 30 June	1986	Toshimaru No. 25	–	85	71	1	0
5	9 June – 4 Sep.	1984	Toshimaru No. 25	T. Kasuya (7 July–6 Aug.)	9	47	2	5
6	10 June – 5 Aug.	1983	Toshimaru No. 25	–	9	38	0	0
7	8 June – 5 Sep.	1985	Toshimaru No. 25	Y. Fujise (88 June–8 July), F. Kasamatsu (6–20 Aug.), H. Kishino (6–20 Aug.)	47	24	1	9
8	1 Sep. – 30 Oct.	1985	Toshimaru No. 15	T. Miyashita (1–30 Sep.)	24	5	0	0
9	1 Sep. – 30 Oct.	1986	Toshimaru No. 15	H. Shimada, M. Ichihara (2 Sep.–8 Oct.)	34	16	4	6

D: *dalli*-type Dall's porpoise. T: *truei*-type Dall's porpoise. M: mixed school of the two color types. U: school of unknown color type. *: Total period of the cruise including the period that cruised out side the ranges of Figs 2 to 7 and had no Dall's porpoise sightings.

daytime from 15 minutes after sunrise to 15 minutes before sunset except during poor weather condition (Kasuya, 1986). The method of sighting was basically the same with that used for the Southern Hemisphere minke whale assessment cruises and described by Best and Butterworth (1980).

Sighting effort has usually been discontinued when visibility is less than 1.0 nautical mile (n. m.) or the sea state is Beaufort 5 or over. The vessel remained at the termination position until the weather changed, as far as time permitted. Only sighting effort during searching mode under good weather conditions and with mast-top observers was used as the primary sighting effort, and sightings made under these condition are designated as primary sightings. We used only primary sightings and accompanying effort data for the estimation of abundance. Any sightings other than primary sightings were dealt as secondary sightings and used only for the analyses of distributional ranges.

All the marine mammals sighted were attempted to approach for identification of species, color types of Dall's porpoise and school composition. The following data were collected by the biologist and the captain for each sighting; sighting time, sighting cue, angle from the bow of the vessel to the school, radial distance, position and swimming direction of the school when first seen, and estimated size composition. Surface water temperature at the position of school was recorded, except for the 1983 and part of the 1984 cruises of *Toshimaru No. 25*. Radial distance between the vessel and Dall's porpoise school was estimated usually when school was within about 0.5 n. m., but when school was apart for over the distance it was estimated from the vessel speed (15 knot for closure) and the time required for closure to a certain

TABLE 2. NUMBER OF DALL'S PORPOISE SIGHTINGS IN THE JAPANESE COASTAL WATERS BY AREA, MONTH AND COLOR TYPE MADE DURING THE NINE CRUISES IN TABLE 1

Area & Month	*dalli*-type		*truei*-type		mixed		U	Total*	
	no.	%	no.	%	no.	%	no.	no.	%
Pacific									
March	–	–	–	–	–	–	3	–	–
May	4	5.3	70	93.3	1	1.3	–	75	100
July	18	15.3	98	83.1	2	1.7	5	118	100
August	21	63.3	11	33.3	1	3.0	1	33	100
September	18	64.3	6	21.4	4	14.3	2	28	100
October	35	77.7	10	22.2	–	–	4	45	100
Sea of Japan									
March	25	100.0	–	–	–	–	3	25	100
May	22	100.0	–	–	–	–	–	22	100
June	56	100.0	–	–	–	–	–	56	100
July	8	100.0	–	–	–	–	2	8	100
October	2	100.0	–	–	–	–	–	2	100
Okhotsk Sea									
May	3	75.0	1	25.0	–	–	–	4	100
July	18	100.0	–	–	–	–	6	18	100
October	3	37.5	5	62.5	–	–	–	8	100
Total	233		201		8		26	442	

U: school of unidentified color type. mixed: school of the two color types.
*: excluding school of unidentified color type.

position from the school where the rest of distance could be estimated visually. However, the majority of the Dall's porpoise sightings occurred within the former range.

School size was estimated by the two mast-top observers. Calves were identified by their small size and close association with a larger individual (presumably the mother). Color type of the porpoise was identified by the biologist on board or by the captain. When color type was not recorded for all the members of a Dall's porpoise school, we considered that all individuals in the school were of the same color type. This could have underestimated the proportion of mixed schools composed of both color types. Since 1983 summer cruise, an attempt was made to photograph all the marine mammal sightings for later confirmation of the species identificaiton.

The surface isotherm was drawn based on surface water temperature hourly recorded. Although this does not reflect the actual isotherm at any particular moment, it is useful to indicate the relationship between the distribution of Dall's porpoise and surface water temperature.

Additional data recorded by the officers of research vessels include position of the vessel and hourly meteorological records from 4 a.m. to 8 p.m.

TABLE 3. OCCURRENCE OF DALL'S PORPOISE SCHOOLS OFF THE PACIFIC COAST OF JAPAN IN RELATION TO THE SURFACE WATER TEMPERATURE AT THE POSITION OF SIGHTING. NOON POSITIONS INCLUDE ALL RECORDS FOR DAYS WITH ORDINARY SIGHTING EFFORT DURING THE CRUISES IN TABLE 1*

Surface water temperature (°C)	May			July			August			September			October		
	N	D	T	N	D	T	N	D	T	N	D	T	N	D	T
3.0– 3.9	1	2	3												
4.0– 4.9	1		1												
5.0– 5.9	2		10												
6.0– 6.9	2	1	8												
7.0– 7.9	5	1	12												
8.0– 8.9	2	1	9	1											
9.0– 9.9	1		7		1										
10.0–10.9			7	2	1									3	
11.0–11.9	1		2			10								2	
12.0–12.9			5			2		2		1	1		3		1
13.0–13.9			5					1			9		4	11	1
14.0–14.9	1					7	1	3		1	2	4	8	13	1
15.0–15.9	1		1	2		1		5		1	1	1	7	2	2
16.0–16.9	1					1		2		2	3	2	7		
17.0–17.9						1		1		2	2	1	10	2	3
18.0–18.9	3		1			1		1		7	3	1	10	2	1
19.0–19.9				3	1	1		1		7		1	4		
20.0–20.9	1			3		1	1	2		11	1				
21.0–21.9						1	5	1		6					
22.0–22.9				3			5		1	6			1		
23.0–23.9				3		1	3	1	1	1					
24.0–24.9				4	1	4	3			3					
25.0–25.9				3			3			4					
26.0–26.9				9			2						1		
27.0–27.9				3			6			2					
Total	22	5	71	36	4	31	29	20	2	54	22	10	55	35	9

N: number of noon positions, D: number of *dalli*-type schools, T: number of *truei*-type schools.
*: mixed schools are included into schools of each color type.

in local time during steaming, and when the activity of the vessel changed.

The northeastern range of *truei*-type porpoise was determined using information recorded by biologists on board several Dall's porpoise research vessels operated by the Japan Fisheries Agency during transits to the northwestern North Pacific and Bering Sea. These cruises and the references where details of the cruise including track lines and sightings are available are as follows;

May to June, 1984: Miyazaki, Fujise, Komuro and Taketomi (1984)

June to August, 1978: Miyazaki, Jones and Beach (1984), Kasuya and Ogi (1987)

TABLE 4. OCCURRENCE OF DALL'S PORPOISE SCHOOLS IN THE SEA OF JAPAN IN RELATION TO THE SURFACE WATER TEMPERATURE AT THE POSITION OF SIGHTING. NOON POSITIONS INCLUDE ALL RECORDS FOR DAYS WITH ORDINARY SIGHTING EFFORT DURING THE CRUISES IN TABLE 1

Surface water temperature (°C)	March		May		June		July		October	
	N	D	N	D	N	D	N	D	N	D
2.0– 2.9			1							
3.0– 3.9										
4.0– 4.9										
5.0– 5.9										
6.0– 6.9				1						
7.0– 7.9						1				
8.0– 8.9		2	2	15	3	6				
9.0– 9.9		7	1	7		12				
10.0–10.9	3	14			1	10				
11.0–11.9	1	1			1	18			1	
12.0–12.9	3	1			1	7	1			
13.0–13.9	2				1	2		2		1
14.0–14.9					1		1	3	1	
15.0–15.9					1		2	3	5	
16.0–16.9					4		1		2	
17.0–17.9					2					
18.0–18.9					4				1	
19.0–19.9					6					1
20.0–20.9					4				3	
21.0–21.9									1	
22.0–22.9									3	
23.0–23.9									4	
24.0–24.9									1	
Total	9	25	4	23	29	56	5	8	22	2

N: number of noon positions, D: number of *dalli*-type schools.

August to September, 1982: Kasuya and Jones (1984), Kasuya and Ogi (1987)

August to September, 1983: Ogi and Fujise (1984), Kasuya and Ogi (1987)

August to September, 1985: Ogi, Tanaka, Kuramochi and Yamamoto (1986), Kasuya and Ogi (1987).

SURFACE WATER TEMPERATURE

Sea of Japan-Okhotsk Sea dalli-*types*

Only *dalli*-type individuals were sighted in the Sea of Japan. Although *truei*-types were sighted in summer months near the southeastern border of

TABLE 5. OCCURRENCE OF DALL'S PORPOISE SCHOOLS IN THE OKHOTSK SEA IN RELATION TO THE SURFACE WATER TEMPERATURE AT THE POSITION OF SIGHTING. NOON POSITIONS INCLUDE ALL DAYS WITH ORDINARY SIGHTING EFFORT DURING THE CRUISES IN TABLE 1*

Surface water temperature (°C)	May			July			October		
	N	D	T	N	D	T	N	D	T
2.0– 2.9	2								
3.0– 3.9									
4.0– 4.9	1								
5.0– 5.9									
6.0– 6.9		3							
7.0– 7.9	2		1						
8.0– 8.9				1	1			3	
9.0– 9.9							1		1
10.0–10.9							1		
11.0–11.9					1				1
12.0–12.9				2	11		1		3
13.0–13.9					5				
Total	5	3	1	3	18		3	3	5

N: number of noon positions, D: number of *dalli*-type schools, T: number of *truei*-type schools.
*: mixed school of the two color types are included into schools of each color type.

the Okhotsk Sea (Figs 2 and 6), the primary color morphs of the Dall's porpoise inhabiting the sea was considered to be *dalli*-type. In these two waters, the survey was conducted in surface water temperature between 2° (May) and 25°C (October), and the Dall's porpoise occurred in the temperature range of 6° (May) to 20°C (October) (Tables 4 and 5).

Sighting effort below 6°C was about 6 hours (one day) in the Sea of Japan and 18 hours (three days) in the Okhotsk Sea resulting in a survey distance of about 290 n. m. The absence of Dall's porpoise during the period suggests that *dalli*-type Dall's porpoises in the Sea of Japan and Okhotsk Sea may be uncommon in the waters below 6°C. Further definition of the lower temperature bound of the species is not possible due to the limited survey effort near the northern limits of the species.

The comparison between distribution of surface water temperature at the noon position (indication of effort distribution) and the temperature at the position of the Dall's porpoise sightings suggests that *dalli*-type Dall's porpoises are rare in waters over 16°C in the Sea of Japan and in the Okhotsk Sea (Tables 4 and 5). If one exceptional October record between 19° and 19.9°C is excluded, the upper bound of surface water temperature for the distribuion of the species in the Sea of Japan varied from about 13°C in March, 14°C in June, and to 16°C in July and October (Table 4 and 5, and Fig. 1). This change will be more enhanced if an exceptional record in October

is taken into consideration. Thus we consider that Dall's porpoises do not change the geographical distribution seasonally so much as expected from the change in the surface water temperature, but they tend to live in higher water temperature in the summer season than in the winter.

The number of *dalli*-type sightings relative to the quantity of survey effort in certain water temperature range (represented by the number of noon position at certain surface temperature) was high in the temperature ranges of 7°–11°C in March, 8°–13°C in June, and 12°–16°C in July, indicating a temperature increase of 3°–5°C during the three months. Although data were scanty in May and October, the feature was probably close to March and July, respectively.

Pacific coast truei-*types*

Although six schools of *truei*-types were sighted in May and October in the southern Okhotsk Sea (Figs 2 and 6, and Table 5), they were very close to the boundary to the Pacific Ocean. Therefore we consider they have not altered our general concept that the southern Okhotsk Sea is primarily inhabited by *dalli*-types (Kasuya, 1978).

Off the Pacific coast survey was conducted within the surface water temperature of 3° to 28°C (May to October), and *truei*-type individuals were sighted at temperature below 25°C (Tables 3 and 5). The lower bound of distribution was not detected, because the surveyed area was limited well to the south of the northern range of distribution of *truei*-types indicated in Fig. 8.

The upper bound of the temperature range in May (19°C) increased to 25°C in July, and this was followed by a gradual decline to 24°C in August, 20°C in September, and to 19°C in October (Table 3). Three schools of Dall's porpoise of unknown color type were sighted in March at about 35°N off the Pacific coast of Japan (Fig. 1). Surface water temperatures for these sightings were between 12° and 13°C. Thus it is suggested that seasonal migration of *truei*-type Dall's porpoises is less than the magnitude of seasonal change of surface water temperature, and that they inhabit waters of relatively high temperature in summer season. A similar trend was indicated on *dalli*-types in the Sea of Japan-Okhotsk Sea (see above), but the absolute temperature ranges were several degrees higher in the Pacific *truei*-types.

The water temperature range of high sighting frequency was between 5° and 14°C in May and did not seem to fluctuate seasonally, which appeared to be different from feature in the Sea of Japan-Okhotsk Sea stock.

Pacific coast dalli-*types*

Although, upper bounds of the temperature range of Pacific *dalli*-type sightings in July through October did not significantly differ from that of *truei*-types in the same area, it was considerably lower in May and the range of the most preferred temperature seemed to be lower than that of *truei*-type

in August through October (Table 3).

This will reflect the distribution of *dalli*-types in the northern part of the surveyed area. The factors controlling this geographical segregation were unclear.

GEOGRAPHICAL RANGE

Sea of Japan-Okhotsk Sea dalli-*types*

Data are available for February/March (Fig. 1), May (Fig. 2), June (Figs 2 and 5), July (Fig. 5), and October (Fig. 6) to indicate seasonal change of Dall's porpoise distribution in the Sea of Japan and Okhotsk Sea.

The currently confirmed southern limit of the distribution in the Sea of Japan has been between 35° and 36°N. A small number of individuals was recorded in winter from northern Kyushu at latitude of about 34°N during the extensive sighting survey of dolphins in the Iki Island area between southern Sea of Japan and the East China Sea (Kirishima, 1986). Thus, we consider that the southern limit of Dall's porpoise in the Sea of Japan is in the Tsushima Strait between Korea and Kyushu in western Japan, and that they do not migrate to the East China Sea. Dall's porpoises have not been recorded from China (Zhou, 1986).

The southern limit moved with the progress of season from the Tsushima Strait to 40°N in early June (Fig. 2), and to 43°N in early July (Fig. 5). In October some sporadic sightings of the *dalli*-type were recorded in the northeastern part of the Sea of Japan between 41° and 43°N (Fig. 6). Noguchi (1946) reported past records of dolphin fishery off Tajima (35°30'N) in the southern Sea of Japan. The records indicated that the season of Dall's porpoise hunting ended while the Pacific white-sided dolphin started in early May. No data are available to indicate southward movement in the autumn/winter season.

Although the majority of Dall's porpoise in the Sea of Japan leave there in summer months and enter the Okhotsk Sea (Kasuya, 1978; 1982), some individuals may summer in the Tatarskii Strait region where the surface water temperature remains below 17°C.

Pacific coast truei-*types*

Data on the seasonal change of Dall's porpoise distribution off the Pacific coast of Japan were available in March (Fig. 1), May (Fig. 2), July (Figs 3, 4 and 5), August (Figs 3, 4 and 5), September (Figs 6 and 7), and October (Fig. 7).

Truei-types were not observed in the Sea of Japan (Table 2), and the western limit observed in the present study was about 30 n. m. northeast of the eastern entrance of the Tsugaru Strait (Fig. 3). Kawamura, Nakano, Tanaka, Sato, Fujise and Nishida (1983) reported the occurrence of *truei*-types in the Tsugaru Strait area at 41°30'N, 141°00'E in June and December. This

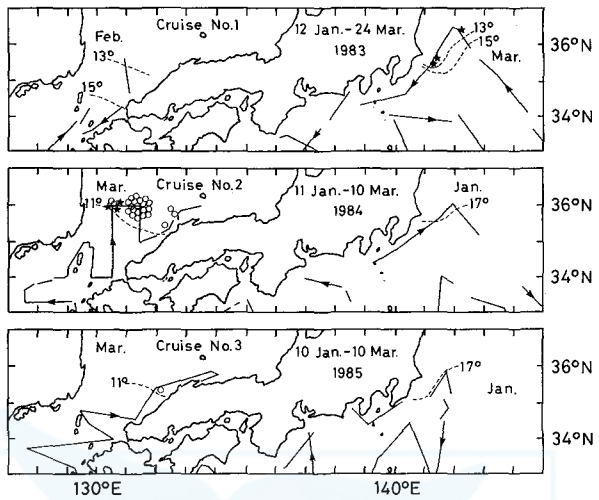

Fig. 1. Southern limits of Dall's porpoises in winter season observed during three whale sighting cruises of the *Toshimaru No. 15* (January, February and March in 1983, 1984 and 1985). Solid line indicates track line cruised with ordinary sighting effort, dotted line the surface water isotherm in centigrade, open circle sighting of *dalli*-types, and star that of type unidentified Dall's porpoises. Dall's porpoise schools of secondary sighting included.

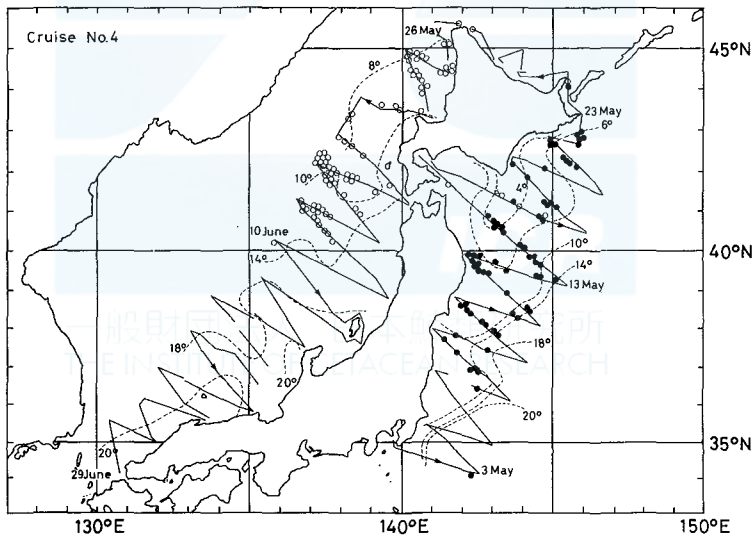

Fig. 2. Dall's porpoise sightings, surface water isotherms (dotted lines, in centigrade), and the track lines of the *Toshimaru No. 25* cruised with ordinary sighting effort in May through June, 1986 (solid line and arrow head). Open circle indicates school of *dalli*-types, closed circle that of *truei*-types, open triangle that containing two color types, and star that of unidentified color types. Secondary sightings of Dall's porpoise schools included.

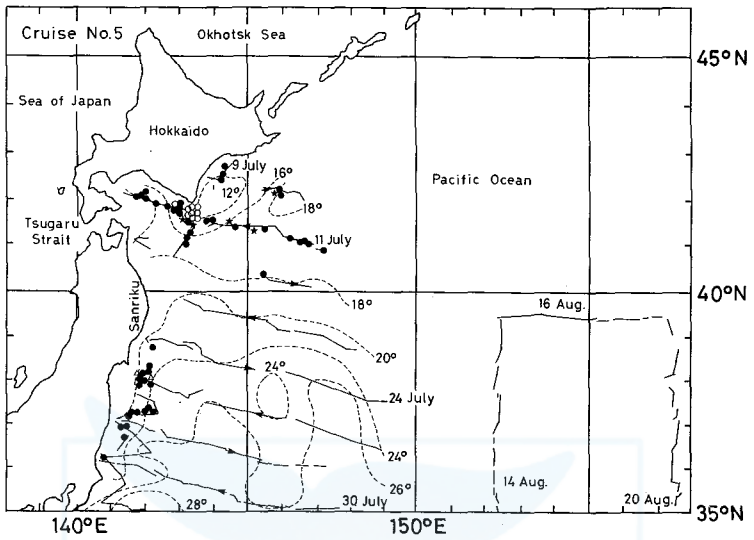

Fig. 3. Dall's porpoise sightings, surface water isotherms (dotted lines in centigrade), and the track lines of the *Toshimaru No. 25* cruised with ordinary sighting effort in July through August, 1984 (solid line and arrow head). Open circle indicates school of *dalli*-types, closed circle that of *truei*-types, open triangle that containing two color types, and star that of unidentified color types. Secondary sightings of Dall's porpoise schools included.

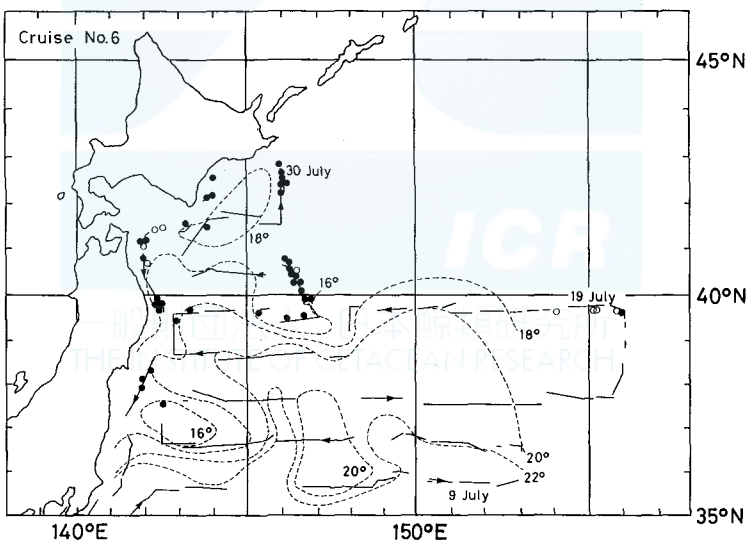

Fig. 4. Dall's porpoise sightings, surface water isotherms (dotted lines in centigrade), and the track lines of the *Toshimaru No. 25* cruised with ordinary sighting effort in July through August, 1983 (solid line and arrow head). Open circle indicates school of *dalli*-types, closed circle that of *truei*-types, open triangle that containing two color types, and star that of unidentified color types. Secondary sightings of Dall's porpoise schools included.

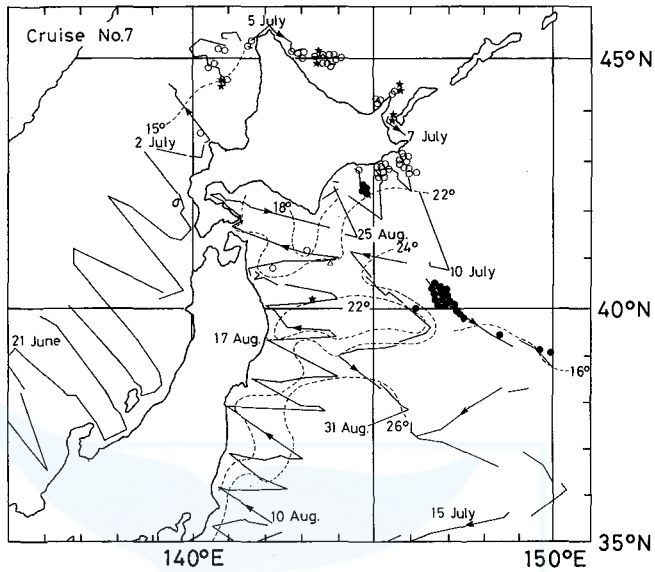

Fig. 5. Dall's porpoise sightings, surface water isotherms (dotted lines in centigrade), and the track lines of the *Toshimaru No. 25* cruised with ordinary sighting effort in July through August, 1985 (solid line and arrow head). Open circle indicates school of *dalli*-types, closed circle that of *truei*-types, open triangle that containing two color types, and star that of unidentified color types. Secondary sightings of Dall's porpoise schools included.

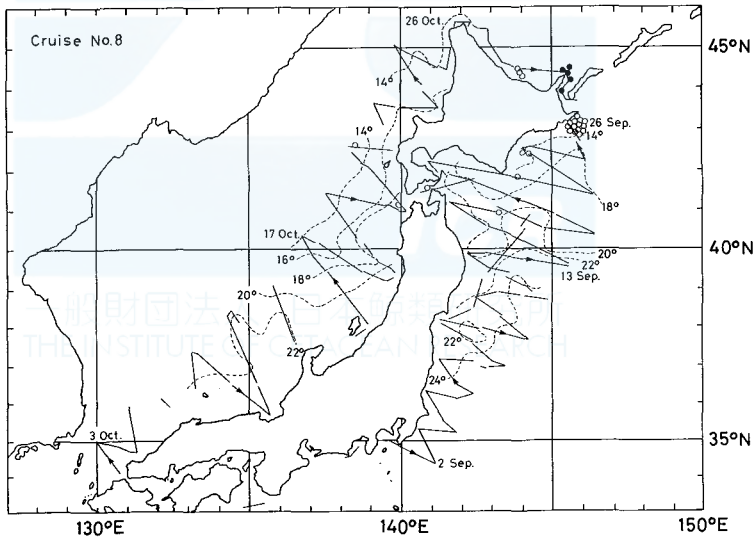

Fig. 6. Dall's porpoise sightings, surface water isotherms (dotted lines, in centigrade), and the track lines of the *Toshimaru No. 15* cruised with ordinary sighting effort in September through October, 1985 (solid line and arrow head). Open circle indicates school of *dalli*-types, closed circle that of *truei*-types, open triangle that containing two color types, and star that of unidentified color types. Secondary sightings of Dall's porpoise schools included.

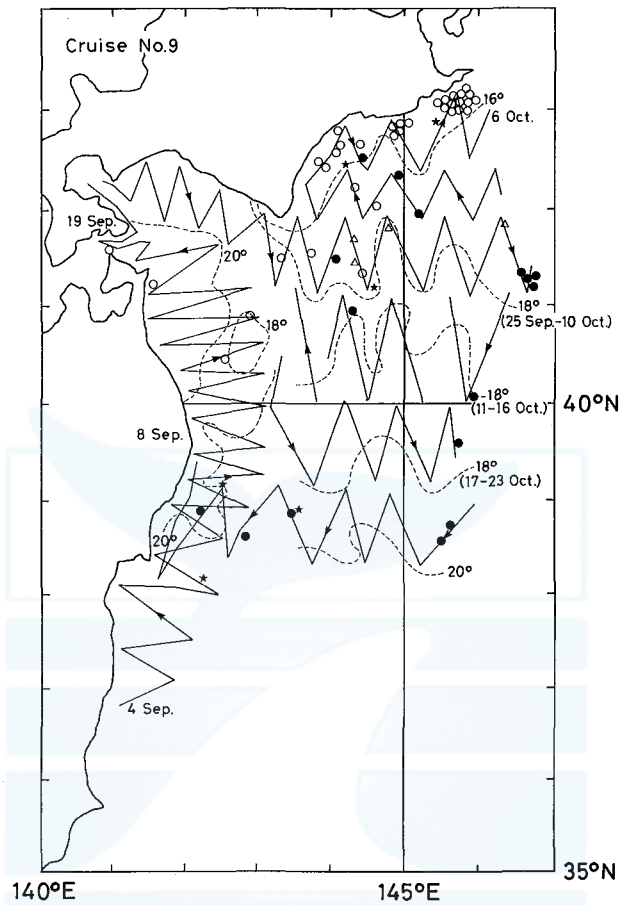

Fig. 7. Dall's porpoise sightings, surface water isotherm (dotted lines in centigrade), and the track lines of the *Toshimaru No. 15* cruised with ordinary sighting effort in September through October, 1986 (solid line and arrow head). Open circle indicates school of *dalli*-types, closed circle that of *truei*-types, open triangle that containing two color types, and star that of unidentified color types. Secondary sightings of Dall's porpoise schools included.

is the confirmed western limit of the color type in the Tsugaru Strait area.

The southernmost sighting of *truei*-types was recorded in May at about 34°N and at the water temperature of about 24°C (Fig. 2 and Table 3). This was an isolated southern record for the season and we do not consider it to represent the ordinary range of the color type in the season (Fig. 2). The next southern records (three schools of unknown color type) were obtained in March in between 35° and 36°N (Fig. 1) and this agreed with the previously reported range of the species off the Pacific coast of Japan (Kasuya, 1978).

The sourthern range of *truei*-types in the Japanese coastal Pacific waters moved from around 35°N in March to around 36°N in early May and early

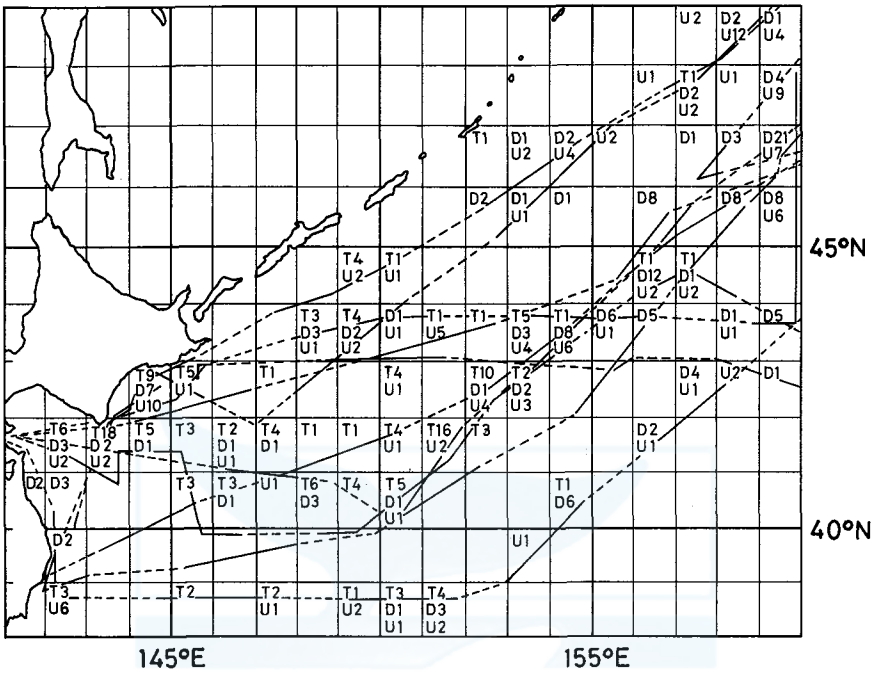

Fig. 8. Number of Dall's porpoise sightings off the Pacific coast of northern Japan and southern Kuril Islands in May through September appeared in the published records of the Dall's porpoise research cruises (Kasuya and Jones, 1984; Miyazaki *et al.* 1984a; Miyazaki *et al.*, 1984b; Ogi and Fujise, 1984; Ogi *et al.*, 1986). Secondary sightings included. Color type code: T, *truei*-type school; D, *dalli*-type school; U, school of unidentified type. Mixed schools of two color types are included into each type.

July (Figs 2 and 4), to 40°N in early August (Fig. 4). The southern limit of *dalli*-type in the coastal waters tended to be to the south of their range in the offshore waters (Figs 5 and 7). This reflects the presence of cold water in the coastal area.

Kasuya (1978) indicated that although the proportion of *dalli*-type catch increased with month the majority (about 96%) of Dall's porpoise catches off Sanriku Region between 37°30′N and 40°00′N were *truei*-types in January to March. The feature is similar in principle to our sighting data during May through July (Figs 2 to 4), but the predominance probably changes in August as seen in Figs 4 and 5.

In August, *truei*-types were absent in the coastal Pacific waters during the cruise no. 7 in 1985 (Fig. 5), but present during the cruise no. 6 in 1983 (Fig. 4) suggesting some annual fluctuation in the timing of seasonal movements and predominance change. *Truei*-types were almost totally absent from Japanese coastal waters in September of 1985 (cruise no. 8) and 1986 (cruise no. 9) (Figs 6 and 7). However, a survey in September and October 1986

(cruise no. 9) suggested that the porpoise had probably moved in summer to the offshore waters between 144° and 147°E and returned to coastal waters in October (Fig. 7). Some *truei*-types were sighted in late October in the boundary area between the southern Okhotsk Sea and Pacific Ocean at latitudes around 44°N (Fig. 6). We conclude therefore that *truei*-types predominates over *dalli*-types in the coastal waters along the Pacific coast of northern Japan during winter and spring seasons (probably, from November to July) but the predominance alters during a short summer/autumn period (September to early October) with possible annual fluctuation.

Information on the northern range of *truei*-types has been reported by biologists on board of five Dall's porpoise research cruises in the northwestern North Pacific and the Bering Sea (Fig. 8). Although Dall's porpoises were sighted almost continuously during the cruises in the area, the dominant color type altered rather sharply. The approximate positions of the change in the predominant color types of the Dall's porpoise are as follows (*truei*-type predominating on the southwestern side of the designated points);

1. May 38°30′N, 152°00′E (Miyazaki, Fujise, Komuro, Taketomi, 1984).
2. June 42°30′N, 153°00′E (Miyazaki, Fujise, Komuro, Taketomi, 1984).
3. June 45°00′N, 150°00′E (Miyazaki, Jones and Beach, 1984).
4. August 42°00′N, 143°30′E (Ogi, Tanaka, Kuramochi and Yamamoto, 1986).
5. August 43°00′N, 154°00′E (Miyazaki, *et al.*, 1984).
6. August 43°30′N, 152°00′E (Ogi and Fujise, 1984).
7. August 44°00′N, 157°00′E (Kasuya and Jones, 1984).
8. September 43°00′N, 145°00′E (Kasuya and Jones, 1984).
9. September 43°00′N, 151°00′E (Ogi and Fujise, 1984).
10. September 43°00′N, 153°30′E (Ogi *et al.*, 1986).

Two coastal points (nos 4 and 8 in the above list) reflect the local concentration of *dalli*-types mentioned below and may not be a good indicator of the eastern limit of the range of *truei*-types. The point no. 1 will possibly represent the eastern range of *truei*-types in May.

In other months (June to September), the observed northern boundary of distribution of *truei*-types was located between 42° and 45°N, and showed no north/south movement. This is in good contrast with the disappearance of most of *truei*-types from the Japanese coastal waters in September and October (see above).

The above analysis indicates that *truei*-type Dall's porpoise has seasonal northeast to southwest movement within their range between 35° and 45°N, and in late summer they almost disappear from a narrow Japanese coastal waters south of 43°N to concentrate in the northern and presumably slightly offshore waters. Northern limit of *truei*-types in the winter season is still to be examined.

Pacific coast dalli-*types*

Data on the distribution of *dalli*-type Dall's porpoise off the Pacific coast of northern Japan were obtained during cruises in March (no color type identification available, Fig. 1), May (Fig. 2), July (Figs 3, 4 and 5), August (Figs 4 and 5), September (Figs 6 and 7), and in October (Fig. 7).

About 4% of the catch of the winter operation of harpoon fishery off Sanriku were *dalli*-types (Kasuya, 1978), and there was no difference detected in the temperature preference between the two color types off the Pacific coast of Japan (see above). Therefore, we consider that the southern limit of the normal distribution of *dalli*-types would be at about 35°N as in the case for the *truei*-types.

Our data recorded small local concentrations of *dalli*-types to the east of the Tsugaru Strait as already indicated by Kasuya (1978) and Miyazaki and Fujise (1985). This concentration occurred in May along the southern coast of Hokkaido from the east of the Tsugaru Strait to 41°N, 145°E (Fig. 2). The feature was similar in July 1984, when we observed a concentration in 42°N, 143°30'E close to the southern coast of Hokkaido (Fig. 3). Such concentration possibly existed in August 1983 in the southeastern area of the Tsugaru Strait (Fig. 4).

The abundance and distribution of *dalli*-type individuals off the Pacific coast of Japan was high during the months when *truei*-types were becoming scarce in August (Fig. 5), almost absent (September, Figs 6 and 7), or probably just starting to reappear (October, Fig. 7). Among Dall's porpoise sightings in Fig. 5, all the 24 *truei*-type sightings occurred in July, 2 *dalli*-type sightings in the Pacific area in July, and 19 *dalli*-type sightings in August.

Our data confirmed that the distribution of *dalli*-types in the Pacific waters was continuous through the Tsugaru Strait to the Sea of Japan at least in May (Fig. 2), September (Fig. 7) and October (Fig. 6). However the density in the strait area appeared to be low. Similar observations have been made by Kawamura *et al.* (1983) in the Tsugaru Strait area. They recorded more *dalli*-types in the strait area in April through July than *truei*-types, but they considered that the frequency was low compared with that of other dolphin species.

We consider therefore that the distribution of *dalli*-type Dall's porpoises is continuous between the Sea of Japan and Pacific waters during spring and autumn season, and that most of the *dalli*-types in the latter area are probably migrants from the former waters. Thus, we presume that a portion of the putative Sea of Japan-Okhotsk Sea stock of Kasuya (1978) passes the Tsugaru Strait in spring to migrate to the Pacific coast of Japan and summer there while the majority of *truei*-types summer further offshore in the northern area. *Dalli*-types will return to the Sea of Japan in autumn preceding the arrival of *truei*-types. The bases for the above conclusion are summerized as follows;

(1) A small local concentration of *dalli*-types occurred in the waters east

of the Tsugaru Strait in May when the distribution of *dalli*-types was continuous through the strait between the Sea of Japan and Pacific coast of Japan (Fig. 2).

(2) The *dalli*-type range extended east/south before summer when the distribution of the species became discontinuous between the two seas (Fig. 5).

(3) The distribution of *dalli*-types was continuous through the Tsugaru Strait in September and October, when the migration of *dalli*-types in the southern Okhotsk Sea did not apparently reach to the west coast of Hokkaido (Fig. 6).

This migration pattern of the Dall's porpoise is similar to schematic drawing by Noguchi (1946), which has not received the attention of biologists, presumably due to the lack of presentation of basic data for the hypothesis.

Data are not available to determine whether *dalli*-types summering off the Pacific coast of northern Japan and in the southern Okhotsk Sea (they are considered to belong to Sea of Japan/Okhotsk Sea stock) intermingle in the waters adjacent to the southern Kuril Islands and eastern Hokkaido.

ABUNDANCE

Mathematical methodology

Population size (N) was estimated for the two color types and sub-areas defined below using following equation,

$$N = \frac{n \cdot f(0)}{2 \cdot L} \cdot A \cdot s$$

where n represents number of primary sightings, A size of surveyed area (n. m.^{2}), L length of transect line (n. m.), $f(0)$ probability density function of the perpendicular distances evaluated at the origin, and s mean school size. The coefficient of variation (c.v.) for n, s and $f(0)$ were estimated by the equations of Anon. (1985a), then that of N by following equation,

$$\text{c.v.}(N)^2 = \text{c.v.}(n)^2 + \text{c.v.}(f(0))^2 + \text{c.v.}(s)^2$$

assuming each factor was independent statistics.

In this study we firstly fitted both Fourier series (FS) and negative exponential models (NE) to estimate $f(0)$ value, then chose the model with better fit for each data using the Chi-square goodness of fit test (Table 7). The probability of seeing a Dall's porpoise school on the track line was assumed as one. No smearing was done to eliminate the rounding error of sighting angle and radial distance estimate.

Sub-area definition

We used only data obtained through six spring/summer cruises (cruise nos 2, 4, 6, 8 and 9) which had relatively good coverage of the Dall's porpoise range of distribution and had a large number of sightings. Five sub-areas (two

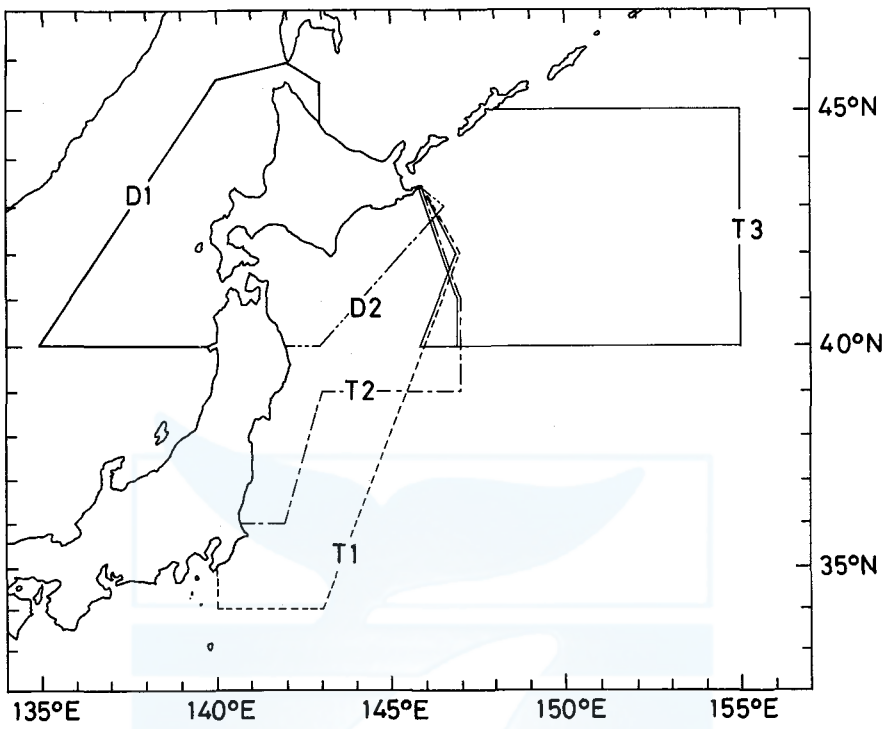

Fig. 9. Sub-areas defined to estimate the population of Dall's porpoises off Japan. D1, observed range of *dalli*-types in the Sea of Japan; D2, observed range of *dalli*-types off the Pacific coast of Japan; T1 and T2, observed ranges of *truei*-types off the Pacific coast of Japan; T3, known range of *truei*-type predominance but unsurveyed in the present study.

for *dalli*-type range and three for *truei*-type range) (Fig. 9 and Table 6) were defined to cover the whole range of Dall's porpoise sighting. Of these five sub-areas, four (D1, D2, T1 and T2) are areas covered by our sightings effort, but the remaining one (T3) is the unsurveyed area known to be inhabited by *truei*-types (see above). A minor modification is done for T3 to meet the boundary difference of T1 and T2. We have extrapolated the *truei*-type densities in the two surveyed sub-areas (T1 and T2) into the unsurveyed sub-area (T3) in order to obtain a rough estimate of the total population of *truei*-types. The methodological problem that surrounds this procedure will be discussed later.

School size

We used primary sightings of 143 *dalli*-type schools and 136 *truei*-type schools for the population estimate, but school size estimate was not available for one *dalli*-type school. There were three mixed schools of the two color types, and we regarded them as separate school for each color type.

TABLE 6. PARAMETERS FOR THE ESTIMATION OF DALL'S PORPOISE POPULATION IN THE SURVEYED AREA

Cruise number*	Sub-area	Period of data	Area (n. mile)^2	Transect length (n. mile)	no. of sightings**	Mean school size (c.v.)	Sighting rate*** (c.v.)
dalli-type							
4	D1	26 May – 11 June 1986	48,802	1,296	75	6.7 (0.07)	3.75 (0.19)
7	D2	7 July – 26 Aug. 1985	25,365	1,003	14	13.3 (0.19)	1.40 (0.40)
8	D2	16 Sep. – 30 Oct. 1985	25,365	1,398	17	9.6 (0.19)	1.36 (0.65)
9	D2	11 Sep. – 30 Oct. 1986	25,365	1,756	32	7.5 (0.16)	1.65 (0.33)
8+9	D2	11 Sep. – 30 Oct.	25,365	3,154	49	8.4 (0.13)	1.48 (0.30)
truei-type							
4	T1	2 May – 23 May 1986	93,718	2,296	68	6.4 (0.08)	2.92 (0.22)
5	T2	8 July – 3 Aug. 1984	74,311	1,124	35	3.5 (0.10)	2.94 (0.32)
6	T2	14 July – 3 Aug. 1983	74,311	836	33	9.7 (0.15)	3.95 (0.34)
5+6	T2	8 July – 3 Aug.	74,311	1,960	68	6.5 (0.13)	3.42 (0.24)

*: see Table 1. **: number of primary sightings; ***: number of primary sightings per 100 n. miles.

The size of 142 *dalli*-type schools ranged from one to 34 individuals, with the modal school size at four to six individuals in the three sub-area/cruises (Fig. 10). Mode was unclear in the Pacific sightings in sub-area D2. Mean school sizes of *dalli*-type were from 7.5 to 13.3 individuals in the Pacific sub-area D2 and 6.7 in the Sea of Japan sub-area D1. The first and last figures were significantly smaller than the largest figure for the Pacific sub-area (Mann-Whitney U-test, $p<0.04$), but other means were not significantly different each other ($p>0.19$).

The 136 primary sightings of *truei*-types ranged from one to 70 individuals (the second largest school was composed of 34 individuals). We excluded from the following analysis this largest school of 70 individuals recorded during the cruise no. 6 in sub-area T2, because we were uncertain if it was a real large school or included some nearby schools that should have been classified as secondary sightings. This exclusion decreased the mean school size from 11.5 (with the largest school) to 9.7 (used here). It could have also caused small degree of underbias in the population estimate (Tables 7 and 8) through the under representation of school density. However, we do not consider this effect very important, because the population estimate thus calculated still had extraordinarily large coefficient of variation (see below).

The modal figures of the *truei*-type school sizes varied between three to 10 individuals in the three sub-area/cruises (Fig. 10), and the mean values between 3.5 and 9.7 individuals (Table 6). Only the smallest mean school size (3.5 individuals) for cruise no. 5 in sub-area T2 was significantly smaller than any other values (Mann-Whitney U-test, $p<0.01$).

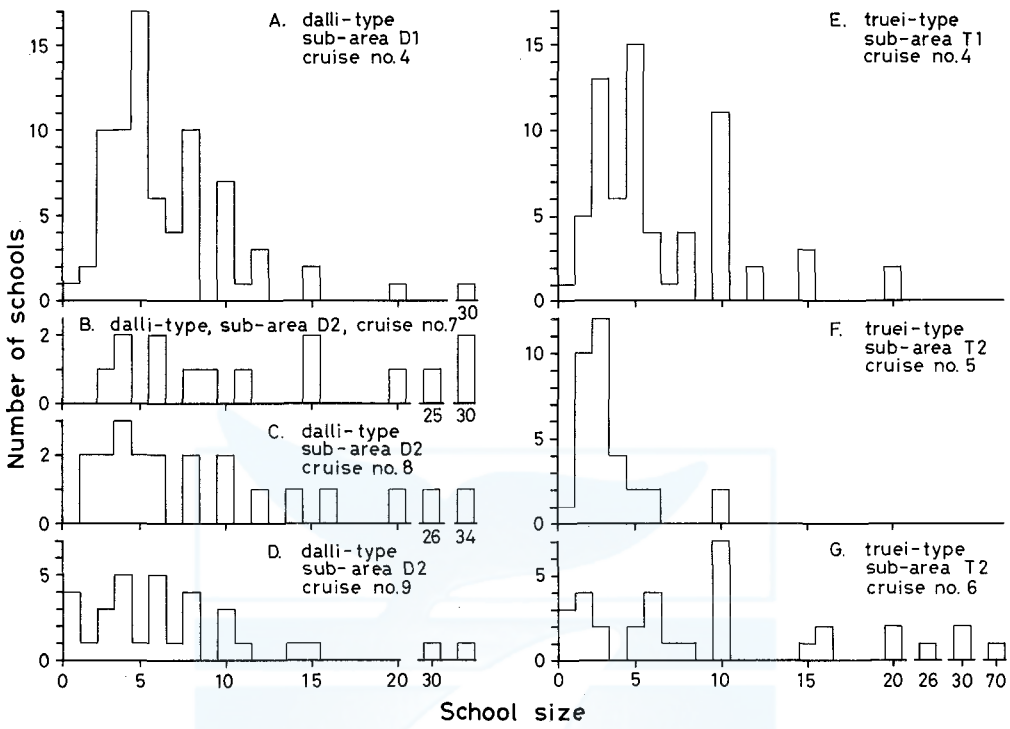

Fig. 10. School size composition of primary sightings of Dall's porpoises.

Sighting rate

The sighting rate (number of primary sightings per 100 n. m. of transect line) of the *dalli*-type schools was between 1.36 and 1.65 in the Pacific sub-area D2 (cruise nos 7, 8 and 9) and 3.75 in the Sea of Japan sub-area D1 (cruise no. 4) (Table 6). The figure for the Sea of Japan sub-area was significantly larger than any of the three corresponding figures of the *dalli*-type in the Pacific (Mann-Whitney U-test, $p<0.01$).

The three sighting rates for *truei*-type in the Pacific sub-area T1 and T2 ranged from 2.92 to 3.95 (Table 6), and the difference was not statistically significant (Mann-Whitney U-test, $p>0.14$).

Perpendicular distance

The distribution of perpendicular distances of *dalli*-type (Sea of Japan) and *truei*-type (Pacific) sightings during the cruise no. 4 (*Toshimaru No. 25*) had clear shoulder at 0.2 to 0.3 n. m. (Fig. 11 A and E), but different cruises by one vessel often had different distribution pattern as seen in the contrast between A or E and F or G in Fig. 11 (*Toshimaru No. 25* cruise). This suggests that the distribution pattern of the perpendicular distances is not dependent on the vessel but varies between cruises (presumably affected by observer or weather).

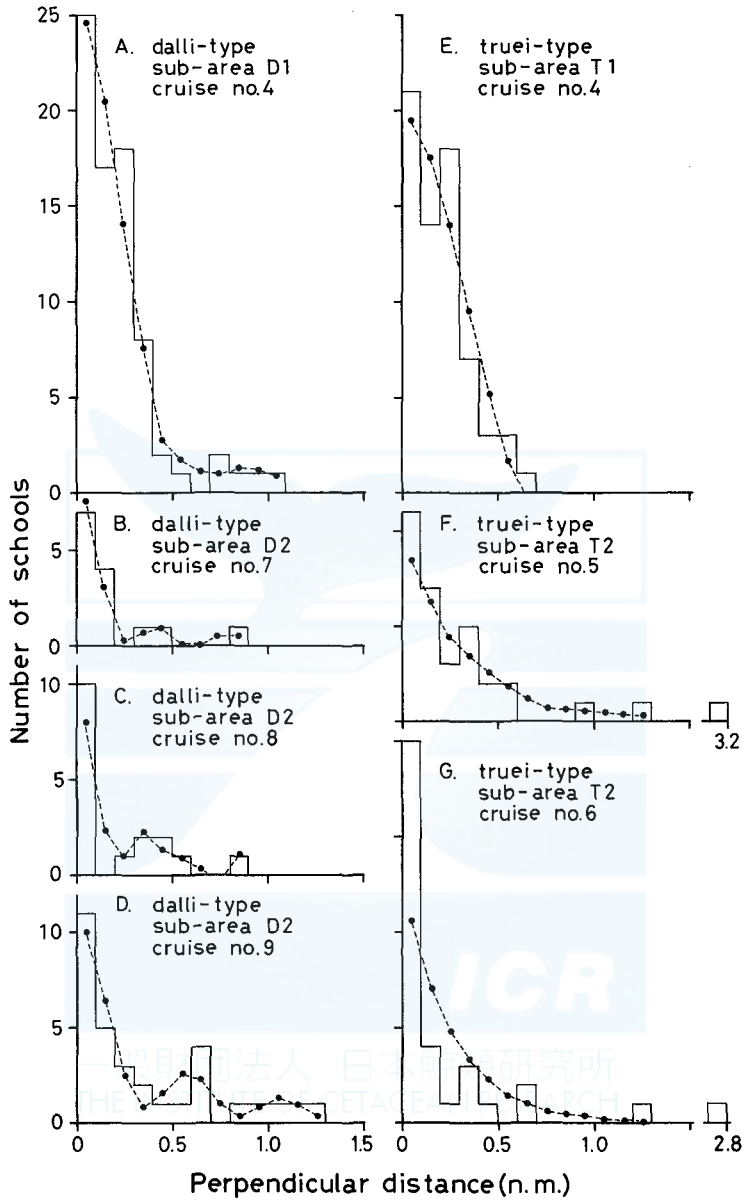

Fig. 11. Perpendicular distances of primary sightings of Dall's porpoises (white squares) and Fourier or negative exponential model fitted to them (closed circles and dotted line). For models used see Table 7.

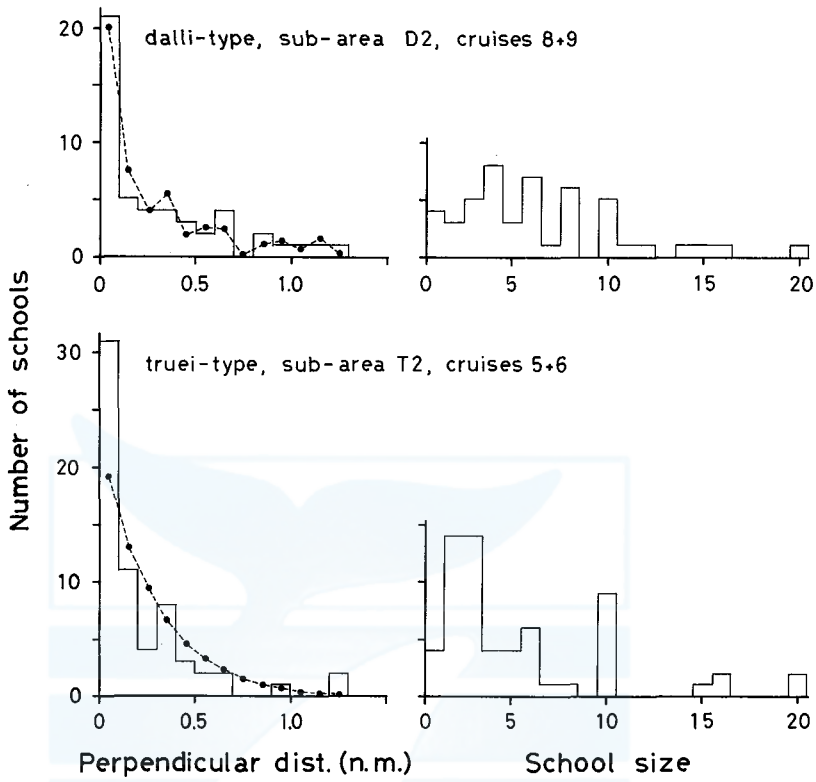

Fig. 12. Distribution of school size and perpendicular distance for *dalli*-types (sum of the cruise nos 8 and 9) and *truei*-types (sum of the cruise nos 5 and 6) off the Pacific coast of Japan. For marks see Fig. 11 and Table 7.

Population estimate

Either Fourier series or negative exponential model was selected for individual data set based on Chi-square goodness of fit test (Table 7). The Fourier series model showed better fit for *dalli*-type sightings in all sub-area/cruises and one *truei*-type data set (cruise no. 4, sub-area T1). Another *truei*-type data set (cruise no. 5, sub-area T2) showed better fit to the negative exponential model. And only negative exponential model could be successfully fitted to a *truei*-type data set in the Pacific sub-area T2 (cruise no. 6). The Fourier series model could not be fitted to this data set, because the terms of the Fourier series fit exceeded the number to satisfy the 'stopping rule' of Burnham, Anderson and Laake (1980).

Population of *dalli*-types in the Sea of Japan (for sub-area D1) was estimated at 31,789 individuals (with 95% confidence interval of 17,770 to 45,808) using data in May to June, 1986 (cruise no. 4) (Table 7). This value represents only a portion of the Sea of Japan-Okhotsk Sea stock of the Dall's porpoise (*dalli*-type), because it does not include individuals in the whole

TABLE 7. POPULATION ESTIMATE OF DALL'S PORPOISES IN THE SURVEYED AREA. f(0) WAS CHOSEN BY THE CHI-SQUARE FITNESS TEST

Cruise no. in Table 1	Sub-area	Period of data	f(0) (c.v. and model used)*	Chi-squ. goodness of fit**	Population size (c.v.)
dalli-type					
4	D1	May – June 1986	3.36 (0.09, FS)	0.816	31,789 (0.23)
7	D2	July – Aug. 1985	6.19 (0.24, FS)	0.600	14,579 (0.50)
8	D2	Sep. – Oct. 1985	5.69 (0.25, FS)	0.082	8,424 (0.72)
9	D2	Sep. – Oct. 1986	3.31 (0.21, FS)	0.430	5,737 (0.42)
8+9	D2	Sep. – Oct.	4.91 (0.19, FS)	0.247	8,126 (0.38)
truei-type					
4	T1	May 1968	2.94 (0.06, FS)	0.452	26,113 (0.25)
5	T2	July – Aug. 1984	2.88 (0.24, NE)	0.522	11,662 (0.41)
6	T2	July – Aug. 1983	3.87 (0.25, NE)	0.004	55,057 (0.45)***
5+6	T2	July – Aug.	3.36 (0.17, NE)	0.018	27,844 (0.32)***

*: FS, Fourier series model. NE, Negative exponential model.
**: probability of obtaining a deviation as great or greater than calculated Chi-square value.
***: low reliability due to poor model fit.

range of the stock considered to extend during the survey period to the Okhotsk Sea (Kasuya, 1978) and western part of the Sea of Japan (see Fig. 2) or to the Pacific coast of northern Japan (see above). At the time of the cruise (early June) the southern limit of distribution has already moved to 40°N from the southernmost limit at 35°N in winter season. The cruise (no. 4) proceeded from north to south against the seasonal movement of the Dall's porpoise (Fig. 2). This also could have caused some degree of underbias in the estimate of population size.

Three population estimates of *dalli*-types in the Pacific sub-area (D2) ranged from 5,737 to 14,579 individuals (Table 7), but none of these figures were statistically different ($p>0.33$). Since none of the parameters of *dalli*-type sightings during the two cruises of no. 8 and no. 9 in the Pacific sub-area D2 and in September and October, we combined the data to increase sample size and to decrease the confidence interval. The procedure gave *dalli*-type population of 8,126 with 95% confidence interval of 2,105 to 14,146 (Tables 6 and 7). This was not significantly different still from 14,579 estimated for July–August data of the same area. However, the September/October figure was only half of the July/August figure, and it is suggested that the difference may reflect in some degree the migration of the *dalli*-type individuals to the Sea of Japan in autumn (see above). Therefore, we considered that about 15,000 individuals of *dalli*-types in the Sea of Japan migrate through the Tsugaru Strait and spend summer off the Pacific coast of Japan. The rest of individuals in the stock will summer in the northern Sea of Japan or in the Okhotsk Sea (Kasuya, 1978).

The above population estimates of *dalli*-types in the Sea of Japan (D1)

and Pacific (D2) area were made using data obtained in slightly different seasons of the year (late May to early June in the Sea of Japan, and early July to late August in the Pacific). Although there is some possibility that individuals counted in the Sea of Japan were again included in the population estimate for the Pacific area, we consider that the effect may not be very large compared with the individuals distributed in the western Sea of Japan or in the Okhotsk Sea far from the Hokkaido (Japanese) coast and excluded from the calculation. We note that the southern boundary of the Dall's porpoise in the Sea of Japan has almost passed the latitude of the Tsugaru Strait at the survey time in early June (Fig. 2). We have excluded some *dalli*-types found in the offshore unsurveyed *truei*-type area (T3), which belonging is still uncertain to us. Thus we consider that the currently available best figure of the minimum estimate of Sea of Japan-Okhotsk Sea stock of Dall's porpoises is about 46,000 (=31,789+14,579) individuals with 95% confidence interval of 26,290 to 66,445.

We obtained primarily three population estimates for *truei*-types in the surveyed area, one for May and two for July/August. Although their range was wide (11,662 to 55,057 individuals, Table 7), none of them were statistically different from others ($p>0.14$). Although the mean school sizes were different between the two cruises (nos 5 and 6) conducted in the same season (July/August) and in the some sub-area T2, we combined these data as in the *dalli*-type case (cruise nos 8 and 9) to improve the estimate of *truei*-type population size. This procedure provided an estimate of 27,844 individuals with 95% confidence interval of 10,380 to 45,308 (Tables 6 and 7). This figure (July/August, sub-area T2) is not significantly different from 26,113 (with 95% confidence interval of 13,522 to 38,704) estimated using May data in the sub-area T1.

Above estimates of *truei*-type population do not include individuals known to be distributed in their summering ground outside the present survey area. Extrapolation of the density data corresponding to the above three estimates to the unsurveyed area almost doubles the estimation of *truei*-type population (Table 8). This procedure assumes equal Dall's porpoise density in any particular moment for both surveyed and unsurveyed part of the sea. Table 9 compares, using data listed in Fig. 12, Dall's porpoise density between offshore and inshore Pacific areas off the northern Japan, which roughly correspond to T3 and T1 or T2 of this study, respectively. The ratios of *truei*-types: *dalli*-types in each of the area are 190:59 (northern offshore area), 186:51 (northern inshore) and 52:11 (southern inshore), and the *truei*-type proportion ranged from 76 to 82% showing no significant difference between the three areas. The density of Dall's porpoises were almost same between two northern areas while that in the southern area was lower than the two.

These suggest that the Dall's porpoise density in the present surveyed areas (T1 and T2) is almost same with that in unsurveyed area (T3) if averaged

TABLE 8. *TRUEI*-TYPE POPULATION ESTIMATES EXTRAPORATED TO UNSURVEYED AREA OF THE NORTHEASTERN PORTION OF THE RANGE (T3*)

Cruise no.	Month	Population in surveyed area	Unsurveyed area of distribution (n. mile^2)	Population in unsurveyed area	Total population
4	May	26,113	113,834	31,718	57,831
5	July – Aug.	11,662	112,852	17,710	29,372
6	July – Aug.	55,057	112,852	83,612**	138,669**
5+6	July – Aug.	27,844	112,852	42,235**	69,779**

*: see Fig. 9 for range.

**: low reliability due to poor model fit.

over months (May through September) and years (5 seasons). However, this does not necessarily imply that the densities of *truei*-types in the northern inshore and offshore areas are same in any particular month or year. Rather, we consider that the number of *truei*-types in the inshore area and that in the offshore area are negatively correlated, and that the densities are also dependent each other. Therefore, the estimates of *truei*-type population in the unsurveyed area thus extrapolated can be biased to the same direction as that in the surveyed area, and the bias can be amplified in the total population estimate. We feel that two extreme estimates of the total *truei*-type population in Table 8 (29,372 for cruise no. 5 and 138,669 for cruise no. 6) have higher probability of being far from the true figure than other figures. Additionally two figures in Table 8 using the cruise no. 6, i.e. 138,669 and 69,779, have lower reliability due to the poor goodness of fit of the model (Table 7). Only remaining estimate is 57,831 based on the cruise no. 4 in May 1986. As the conclusion, we consider that the population of the *truei*-type will be about 58,000 individuals. The confidence interval can not be estimated, but the c.v. has to be over 0.25 the figure calculated for surveyed area.

DISCUSSION

We made two assumptions in the present population estimate. They are (1) all the Dall's porpoises on the trackline are counted, and (2) Dall's porpoise schools do not respond to vessels. If Dall's porpoise schools respond to an approaching research vessel by moving toward or away from the vessel before the schools are detected by researchers the population estimate of the present study will be seriously under or over biased, respectively (Hammond, 1986). The response of the species to the vessel was investigated using helicopters (Bouchet, Braham and Tsunoda, 1983), and there was an attempt to calculate the correction factor (0.22–0.41) for the attraction of porpoises to the vessel (Turnock, 1987). However, the species could be either attracted to the vessel, neutral, or avoid the vessel depending on the area, season, growth stage, sex,

TABLE 9. GEOGRAPHICAL COMPARISON OF THE DALL'S PORPOISE DENSITY BASED ON DATA IN FIG. 8

Area	School density			Porpoise density		
	no. school sighted	transect length in n.m.	density /100 n.m.	no. indivi-duals	transect length in n.m.	density /100 n.m.
Northern offshore*	30	815	3.7	116	755	15.4
Northern inshore**	84	1,111	7.6	364	976	36.9
Southern inshore***	135	1,777	7.6	389	1,435	27.1

*: 40°–45°N, 147°–155°E. **: Pacific area north of 40°N and west of 147°E. ***: Pacific area between 38° and 40°N, and west of 155°E.

and reproductive status (Kasuya and Jones, 1984). Therefore we felt it risky to use the above correction factor without further observation of the porpoise behavior. If we missed some individuals on the trackline, which we believe very possible especially for individuals that avoid vessels, it could have caused an underestimate. Additionally, present estimate of the Dall's porpoise population will also include possible underbias due to rounding of the sighting angle and radial distance (Buckland and Anganuzzi, 1987), which have not been considered in the present study.

Using sighting data obtained from the salmon research vessels cruising from Hokkaido to northern North Pacific in April to August (mainly June and July), Kato (1986) estimated the Dall's porpoise population of both color types in his *truei*-type area (40°–44°N, east of 155°E, which is slightly smaller than corresponding area of the present study), as about 64,000 individuals. Although Kato (1987) added 1986 data to the previous data set, expanded the southern range to 38°N (where some sighting efforts existed as well as the distribution of Dall's porpoises), and obtained the estimate of 125,000, this will be an overestimate due to the extrapolation of northern high density to southern low desnity area (Table 9). Our estimate of the Dall's porpoise in the similar area, 72,410 individuals (57,831 *truei*-types plus 14,579 *dalli*-types) is close to Kato (1986).

Our sighting survey confirmed results of previous studies on the general pattern of distribution of two color types of Dall's porpoises in the Japanese coastal waters, i.e. Sea of Japan and southern Okhotsk Sea inhabited by *dalli*-types, and the Pacific coast of northern Japan and southern Kuril Islands by both *dalli*- and *truei*-types.

Although the previous studies (Kasuya, 1978, 1982) have assumed without firm data that the majority of Dall's porpoises that summer off the Pacific coast of northern Japan would be *truei*-types, the present study showed that the assumption was not always correct. Dall's porpoises which winter off

the Pacific coast of northern Japan south of 40°N are composed mainly of *truei*-types (Kasuya, 1978, and also see below). They migrate in late summer and autumn to waters between 40° and 45°N and east of 145°E, and almost disappear from the Japanese coastal waters for some short period in September/October. We cosidered that their southbound migration probably start in October.

The Pacific coastal waters off Sanriku (38°–41°N) and southern Hokkaido (41°–43°N) are occupied mostly by *dalli*-types while *truei*-types are summering in an offshore northern area. This agrees with the fact that the Dall's porpoise catches of hand harpoon fishery which was landed in October and November at Otsuchi (39°20′N) and Yamada (39°30′N) Fish Markets on the Sanriku coast and reportedly caught off the Pacific coast of Hokkaido were mainly (87%) *dalli*-types (Anon., 1985b; N. Miyazaki, per. commn in 1986), but those taken off the Sanriku coast in January to March and landed at the same fish markets were mostly (96%) *truei*-types (Anon., 1985b; Kasuya, 1978). Such high *dalli*-type proportion was also confirmed in early November 1986 by one of the authors (T.M.) on the Kamaishi Fish Market (39°15′N) on the Sanriku coast.

Hand harpoon fishery for the Dall's porpoise had been operated only in winter season and off the Sanriku coast (Kasuya, 1978; 1982), and the annual catch during the 1960s and 1970s fluctuated between 5,000 and 9,000 individuals with the annual mean of 6,000 individuals (Kasuya, 1982). Kasuya (1978) considered on the *truei*-type stock that the population of 125 to 400 thousands will be required to sustain the mean annual take. The corresponding net annual recruitment rates were 0.048 to 0.015. The maximum net recruitment rate (R_{max}) of the offshore stock of *dalli*-type Dall's porpoise has been estimated to be 0.09 (Hester, 1986), 0.08 (Ohsumi, 1986), or 0.06 (Jones, Breiwick, Bouchet and Turnock, 1986). Although these estimates will need further improvement with improved biological parameters or refined model, it will be too optimistic to consider that the *truei*-type stock can sustain the annual take of over 10% of the population. If the present population of 60,000 individuals is not large enough to sustain the past level of the annual catch, then it means that the population has declined by the past catch. Although our data are unable to prove the past decline of the stock, we believe that such change could have occurred in the population.

Some fishermen from Iwate Prefecture (part of the Sanriku area) started in recent years the operation during other seasons and in other areas such as Sea of Japan off Akita Prefecture (41°N), off the Pacific coast of Southern Hokkaido, and in the southern Okhotsk Sea (Anon., 1985b; Kawamura *et al.*, 1983; Kasuya, unpublished), while operating the fishery off the Sanriku coast in winter as before. This expasion of fishery was due to the increased demand of porpoise meat. The total annual catch increased to around between 10,000 and 13,000 individuals, and there has been expressed a great concern on the effect of the catch on the Dall's porpoise populatin (IWC, 1984).

The results of the present study indicate that the recent hand harpoon fishery in northern Japan for the Dall's porpoise hunts *truei*-type population off the Pacific coast of Japan during winter and *dalli*-types in the Sea of Japan-Okhotsk Sea stock in summer operation. Available statistics of the fishery do not give the catch by color type or by month. With the absence of catch statistics by stock or any other alternative way to estimate it, we find it impossible to assess the effect of the current fishery on the Dall's porpoise stocks. However, it should be stressed that the current catch of Dall's porpoises by the Japanese harpoon fishery is still over 10% of the total number of Dall's porpoises known to migrate annually to the fishing grounds, i.e. 104,199 individuals (46,368 *dalli*-types plus 57,831 *truei*-types), and that there is a great risk of further depletion of one or more stocks of the species by the fishery.

ACKNOWLEDGEMENTS

We wish to express our thanks to Dr L. L. Jones, National Morine Fisheries Service (USA), for her reviewing the manuscript and correcting English. We also owe to Dr N. Miyazaki, National Science Museum (Japan), for his critical review on the earlier version of the draft, and to two anonymous reviewers who made valuable comments on the manuscript. Mrs Y. Yamamoto and Mrs M. Ikeya helped us in data analysis and drawings.

REFERENCES

ANON., 1985a. C.V. estimates for sighting assessments. Appendix 7.2 of the Report of the Sub-Committee on Southern Hemisphere Minke Whale. *Rep. int. Whal. Commn*, 34: 92.

ANON., 1985b (ms). [Report of investigation on the dolphin stocks exploited by dolphin fishery]. Whales Research Institute, Tokyo. 128pp. (in Japanese).

BEST, P.B. and D.C. BUTTERWORTH, 1980. Report of the southern hemisphere minke whale assessment cruise, 1978/79. *Rep. int. Whal. Commn*, 30: 257–283.

BOUCHET, G.C., H.W. BRAHAM and L.M. TSUNODA, 1983. Investigation of Dall's porpoise (*Phocoenoides dalli*) responses to a survey vessel: Preliminary assessment. IWC/SC/35/SM13. 15pp.

BUCKLAND, S.T. and A.A. ANGANUZZI, 1987. Comparison of smearing methods in the analysis of minke sightings data from IWC/IDCR Antarctic cruises. IWC/SC/39/Mi2. 26pp.

BURNHAM, K.P., D.R. ANDERSON and J.L. LAAKE, 1980. Estimation of density from line transect sampling of biological populations. *Wild. Monogr.*, 72: 1–202.

HAMMOND, P.S., 1986. Line transect sampling of dolphin populations. pp.251–279. *In*: M.M. Bryden and R. Harrison (eds), *Research on Dolphins*. Clarendon Press, Oxford. 478pp.

HESTER, F.J., 1986. Estimates of reproductive rates of Dall's porpoise in the North Pacific. Statement for the Public Hearings. MMPAH-1986-01, 27pp.

HOUCK, W.J., 1976. The taxonomic status of the porpoise genus *Phocoenoides*. ACMRR/MM/SC/114 (Document presented to the FAO Scientific Consultation on Marine Mammals, Bergen). 12pp.

JONES, L.L., J.M. BREIWICK, G.C. BOUCHET and B.J. TURNOCK, 1986. Report of the incidental take, biology and status of Dall's porpoise. National Marine Fisheries Service, NOAA. 92pp.

IWC, 1984. Report of the sub-committee on small cetaceans. *Rep. int. Whal. Commn*, 34: 144–159.

KASUYA, T., 1978. The life history of Dall's porpoise with special reference to the stock off the Pacific coast of Japan. *Sci. Rep. Whales Res. Inst.*, 30: 1–63.

KASUYA, T., 1982. Preliminary report of the biology, catch and populations of *Phocoenoides* in the western North Pacific. pp.3–19. *In*: J.G. Clark, J. Goodman and G.A. Soave (eds) *Mammals in the Seas*. FAO Fisheries Series No. 5, Vo. IV, FAO, Rome. 534pp.

KASUYA, T., 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. *Rep. Whales Res. Inst.*, 37: 61–83.

KASUYA, T. and L.L. JONES, 1984. Behavior and segregation of the Dall's porpoise in the northwestern North Pacific Ocean. *Sci. Rep. Whales Res. Inst.*, 35: 107–128.

KASUYA, T. and H. OGI, 1987. Distribution of mother-calf Dall's porpoise pairs as indication of calving grounds and stock identity. *Rep. Whales Res. Inst.*, 38: 125–140.

KATO, M., 1986. Outline of sighting survey for marine mammals Japanese salmon research vessels in 1985 and estimation of Dall's porpoise abundance in the Pacific Ocean. Document submitted to the International North Pacific Fisheries Commission. 7pp.

KATO, M., 1987. Outline of sighting survey for marine mammals by Japanese salmon research vessels in 1986 and estimation of Dall's porpoise abundance in the North Pacific Ocean. Document submitted to the International North Pacific Fisheries Commission. 8 pp.

KAWAMURA, A., H. NAKANO, H. TANAKA, N. SATO, Y. FUJISE and K. NISHIDA, 1983. [Sighting results of dolphins from the Aomori-Hakodate ferry boat in the Tsugaru Strait]. *Geiken Tsusin* 351 and 352: 29–51. (in Japanese).

KIRISHIMA, K. 1986. [Analysis of sighting results]. pp.55–77. *In*: T. Tamura, S. Ohsumi and S. Arai (eds) *Report of the Investigation in Search of Solution of Dolphin-fishery Conflict in Iki Island Area.* Japan Fisheries Agency. 285pp. (in Japanese with English summary.)

MIYAZAKI, N., L.L. JONES and R. BEACH, 1984. Some observations on the schools of *dalli*- and *truei*-type Dall's porpoises in the northwestern Pacific. *Sci. Rep. Whales Res. Inst.*, 35: 93–105.

MIYAZAKI, N., Y. FUJISE, T. KOMUTO and H. TAKETOMI, 1984. [Outline of Dall's porpoise research cruise by the *Hoyomaru No. 53* in 1984]. Published by Far Seas Fisheries Research Laboratory. 47pp. (in Japanese).

MIYAZAKI, N. and Y. FUJISE, 1985. Report of the survey by the dedicated vessel, *Hoyomaru No.53*, in 1984. Document submitted to the meeting of the Scientific Subcommittee. Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, Tokyo, March 11–15, 1985. 25pp.

NISHIWAKI, M., 1972. *General biology*. pp. 3–204. *In*: S.H. Ridgway (ed.) *Mammals of the Sea*. Charles C. Thomas Publisher, Illinois. 812pp.

NOGUCHI, E., 1946. [Dolphin and its utilization]. *In:* E. Noguchi and A. Nakamura, *Utilization of Dolphins and Scomber Fishery.* Kasumigaseki Shobo, Tokyo. 36pp. (in Japanese).

OGI, H. and Y. FUJISE, 1984. Outline of the research on marine mammals by the *Hoyomaru No. 12* in 1983 (August 10 to September 11). Document submitted to the meetng of the Scientific Subcommittee, Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, Tokyo, March 5–9, 1984. 14pp.

OGI, H., H. TANAKA, T. KUROMACHI and Y. YAMAMOTO, 1986. Outline of the research on the Dall's porpoise by the *Hoyomaru No. 12* in 1985. Document submitted to the meeting of the Scientific Subcommittee, Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, Tokyo, March 10–14, 1986. 20pp.

OHSUMI, S., 1975. Incidental catch of cetaceans with salmon gillnet. *J. Fish. Res. Board. Can*, 32(7): 1229–1235.

OHSUMI, S., 1986. Estimation of biological parameters of Dall's porpoise related to reproduction. Statement for the Public Hearings. MMPAH-1986-01, 23pp.

SUBRAMANIAN, A., S. TANABE, Y. FUJISE and R. TATSUKAWA; 1986. Organochlorine residues in Dall's porpoises collected from northeastern Pacific and adjacent waters. *Mem. Natl Inst. Polar Res.*, Spec. Issue, 44: 167–73.

TURNOCK, B.J., 1987. Analysis of experiments to assess movement of Dall's porpoise in relation to survey vessels and population estimates corrected for movement and visibility bias for the North Pacific Ocean. Document submitted to the Scientific Subcommittee, Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, March 10–14, 1987, Tokyo. 33pp.

WALKER, W.A., 1987. Geographical variation of the parasites *Crassicauda* (nemotoda) and *Phyllobothrium* (cestoda) in *Phocoenoides dalli* in the northern North Pacific and Bering Sea. Document submitted to the meeting of the Scientific Committee of the Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, Tokyo, March 10–14, 1987. 17pp.

WINANS, G.A. and L.L. JONES, (in press). Electrophoretic variability in the Dall's porpoise, *Phocoenoides dalli*, in the North Pacific Ocean and Bering Sea. *J. Mamm.*

YOSHIOKA, M., M. OGURA and C. SHIKANO, 1987. Results of the transpacific Dall's porpoise research cruises by the *Hoyomaru No. 12* in 1986. Document submitted to the Scientific Committee, Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, Tokyo, Japan, March 10–14, 1987, 25pp.

ZHOU, K., 1986. An outline of marine mammalogical researches in China. *Acta Theriol. Sinica*, 6(3): 219–32. (in Chinese with English summary).