



Partial abundances of three fishery-targeted species of Delphinidae cetaceans (false killer whale, striped dolphin, and Pacific white-sided dolphin) off the Pacific coast of Japan, estimated by the conventional line-transect approach

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Abstract

False killer whales, striped dolphins, and Pacific white-sided dolphins have been targeted by dolphin fisheries in the coastal waters off Japan. Annual catch quotas are allocated on the basis of past abundance estimates, but those estimates were unpublished or more than 30 years old. Here, we reanalyzed the line-transect data collected from the sighting survey on the Pacific coast of Japan from 1985 to 2021 and estimated the past and latest abundances of those three species using a standard distance sampling approach. The surveys were conducted as part of the JAFRACSS-SC (Japan Fisheries and Education Agency Cetacean Sighting Survey-Small Cetacean Survey Program). This program mainly targets other fishery-targeted cetacean species and, thus, covers only a part of the above three species' distribution ranges. As a result, we obtained the latest abundance estimates of 4105 false killer whales, 84,657 striped dolphins, and 28,052 white-sided dolphins. Considering the current estimates represent only a part of the entire population size and that annual catch records did not largely exceed potential biological removals calculated based on these abundances, the current harvest level will not lead to a severe depletion or extinction for these three species.

Keywords Dolphin fisheries · Shipboard sighting survey · Stock assessment · Whaling · Management and conservation

Introduction

Dolphin fishery is one of the most controversial fisheries in the world in terms of its sustainability of fisheries and resources (Kasuya 2007). Nine species of Delphinidae cetaceans are targeted by dolphin fisheries (drive fisheries, hand-harpoon fisheries, and land-based whaling) in the coastal waters off Japan. Compared with other fishery-targeted animals, marine mammals have a long life history and low reproductive rates (Kasuya 2011), so the dolphin population is likely to be vulnerable to several sources of mortality. Therefore, close monitoring of these species' abundances is particularly needed to prevent severe depletion from

anthropogenic activities and unpredictable environmental disturbances in those populations.

From this standpoint, a long-term sighting survey program was established in the 1980s to estimate the abundance of several cetaceans (Miyashita 1993). Japan Fisheries Research and Education Agency Cetacean Sighting Survey (JAFRACSS) originally targeted multiple species (please note that the survey names might differ in some literature due to the past reorganization of Japan Fisheries Research and Education Agency and its predecessors). Thus, the survey designs were inconsistent yearly, such as the arrangement of survey blocks and track lines. Since the 2000s, JAFRACSS has become a more systematic survey design. Survey blocks have been set for particular target species (or species groups). For example, the Small Cetacean Survey Program (JAFRACSS-SC) was planned to estimate the abundance mainly of bottlenose dolphins (*Tursiops truncatus*) and the southern form (Magondo in Japanese) of short-finned pilot whales *Globicephala*

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macrorhynchus, and five blocks were set to cover the main habitats of these species and populations (Kanaji et al. 2018). Thus far, phases I–III of JAFRACSS-SC have been completed, and the abundances were estimated for these two species and other four species (Risso's dolphins, *Grampus griseus*, rough-toothed dolphins, *Steno bredanensis*, pantropical spotted dolphins, *Stenella attenuata*, and melon-headed whales, *Peponocephala electra*), which shared the main habitat within the survey blocks (Kanaji et al. 2018, 2023). Those estimates have also been used to determine population status relative to management thresholds (Kanaji et al. 2021) and calculate acceptable catch limits (Kanaji et al. 2023).

Despite such substantial efforts to monitor the abundance of fishery-targeted species in recent years, the other three species, namely false killer whale (*Pseudorca crassidens*), striped dolphin (*Stenella coeruleoalba*), and Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), have lacked a systematic framework to monitor their abundance. The latest abundance estimates of the former two species were obtained from surveys performed in 1983–1991 (Miyashita 1993). Abundance estimates of white-sided dolphins are only from the conference abstract, which was based on the surveys in 1992–1996 (Miyashita et al. 2007). As a result, annual catch quotas for these three species have not been updated for many years. All these species have wide distribution ranges from coastal to offshore areas of the North Pacific, and their abundance estimates range from 74,101 false killer whales to 418,090 white-sided dolphins and 1,766,025 striped dolphins (Kanaji et al. 2017). In contrast, the annual catch records by dolphin fisheries in the last 5 years (2017–2021) were 0–2 false killer whales, 265–436 striped dolphins, and 13–21 white-sided dolphins (Minamikawa and Yoshida 2023). These harvested numbers are much smaller than those in early 1980s (e.g., 16,344 striped dolphins in 1980, Kasuya 2017), but we cannot evaluate whether current catch numbers are acceptable without latest abundance information. Unlike the species mainly targeted by fishers, such as bottlenose dolphins and pilot whales, these three species have not been prioritized in managing and conserving the cetacean populations off Japan.

Since the amendment to Japan's Fisheries Act in 2020, quantitative assessment has become a mandate for all fishery-targeted species. Thus, information of absolute abundances is urgently needed for the above three species. JAFRACSS-SC has covered only small portions of their wide distribution ranges. Simultaneously, even partial abundance estimates would provide more quantitative information for assessing population status and evaluating the sustainability of dolphin fisheries. Here, we reanalyze the data from JAFRACSS-SC phases I–III and estimated

time-series abundances of three fishery-targeted Delphinidae species.

Materials and methods

JAFRACSS-SC data

JAFRACSS-SC was first established in 2006–2007; a total of five blocks were designed to cover the main habitats of bottlenose dolphins and pilot whales. In the phase I program (2006–2007), these blocks were further divided into several sub-blocks, while only five blocks were surveyed in phases II (2014–2015) and III (2019–2021) (Fig. 1). Survey months were slightly different between phase I and phases II/III; the cruise periods were set from late July to early September in phase I, while it was set from mid May to early July in phases II/III. In the standard protocol of JAFRACSS, the research vessels ran on the zig-zag designed track lines at around 11.5 knots (≈ 21.3 km/h). Two experienced observers searched for cetacean schools using scaled binoculars (7×50) from an observation barrel mounted on the top of the mast whenever weather conditions permit (Beaufort scales of 4.0 or lower) during the day. All cetacean sightings within three nautical miles (nmi) (≈ 5.6 km) of the track line for both the right and left sides were recorded. Two types of vessels were engaged in the surveys of JAFRACSS-SC: whaling-type vessel (often called as catcher boat) and research-type vessel. The former type was used for commercial whaling before and, thus, have specialized equipment for observing cetacean schools, such as a higher observation barrel (about 20 m from the waterline), higher approaching speed, good performance in turning circles, and experienced crews. In comparison, the latter type was a multipurpose research vessel for which the height of the observation barrel was 11–18 m and the equipment was not specialized for the cetacean survey. All surveys were conducted in “closing mode” (Hammond et al. 2021). In this mode, when a cetacean school was detected, the vessel diverted from the track line and directly approached the detected school to confirm the species identification and estimate the group size. Further details of the data collection methods are provided by Kanaji et al. (2018).

JAFRACSS legacy data

Before 2006, JAFRACSS mainly targeted large cetaceans (e.g., Minke whale *Balaenoptera acutorostrata* and Bryde's whale *Balaenoptera brydei*) and were not dedicated to small cetaceans (JAFRACSS-Legacy data), while surveys in 1985 and 1992 covered almost all the survey areas of JAFRACSS-SC. Poststratification may cause underestimation in variance if stratification is made

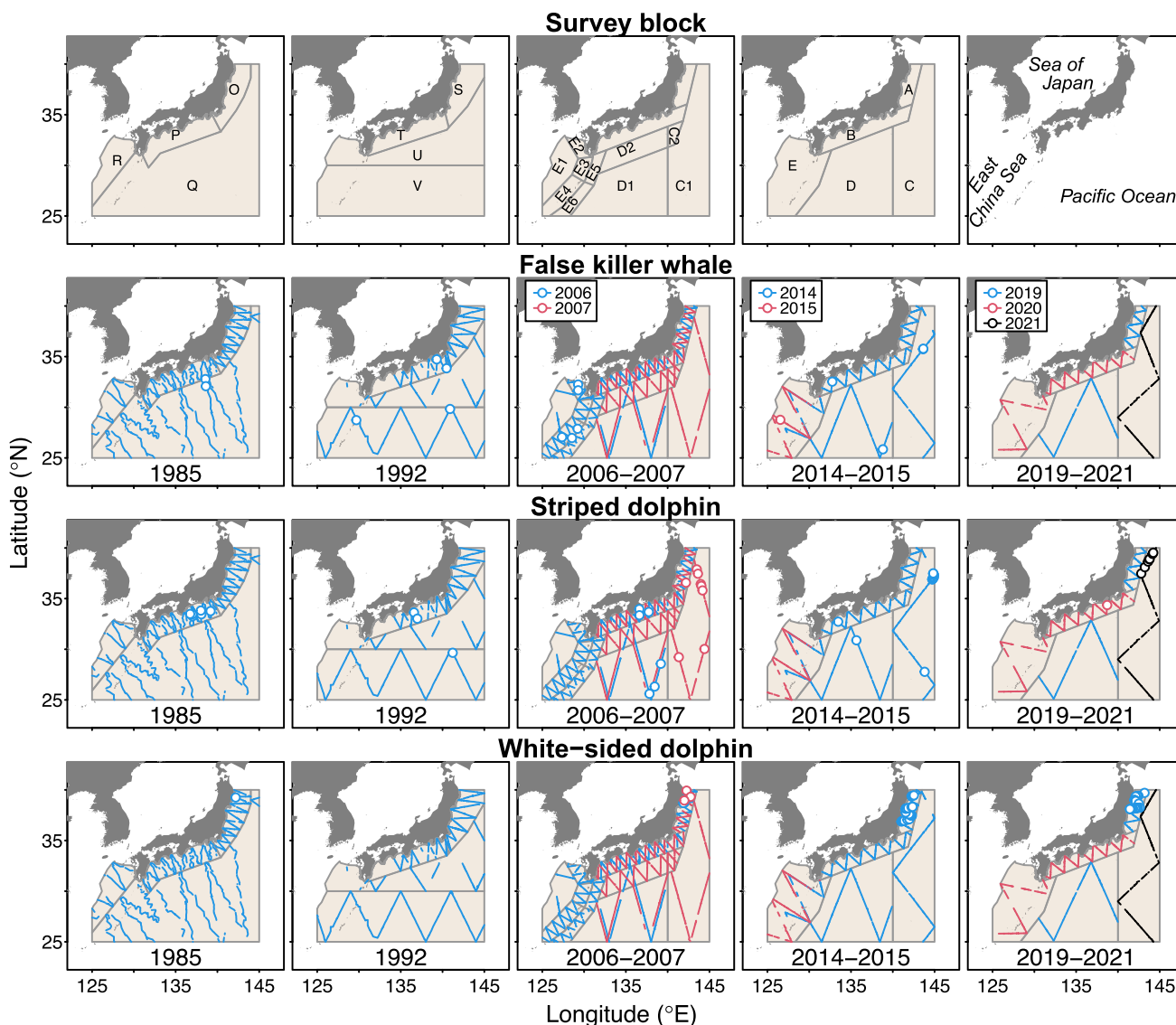


Fig. 1 Survey blocks, track lines, and sighting positions of false killer whale, striped dolphins, and Pacific white-sided dolphins, recorded in Japan Fisheries Research and Education Agency Cetacean Sighting

Survey in 1985 and 1992 (JAFRSCSS-Legacy data) and Small Cetacean Survey Programme (JAFRSCSS-SC) in 2006–2021

according to animal density (Buckland et al. 2001). Here, we simply trimmed the previous data to fit all the JAFRACSS-SC areas, regardless of such density information. The abundances were estimated together with the data recently obtained. These previous surveys also followed standard JAFRACSS protocol, in which the two observers searched for cetacean schools from the barrel in the closing mode. Two whaling-type vessels were engaged in the surveys in 1985, while two whaling-type and two research-type vessels were engaged in 1992. Those two research-type vessels were not equipped with an observation barrel, and thus, observation was made from a compass deck (at a height of about 10 m from the waterline).

Abundance estimation

The abundance of false killer whales, striped dolphins, and white-sided dolphins was estimated based on the standard line-transect analyses using the sighting survey data from 1985 to 2021. In theory, detection probability decreases as a function of the distance from the track line to the cetacean school. Here, we considered two detection functions to estimate detection probability,

$$\text{Half normal : } g(x) = \exp \left[\frac{-x^2}{2\sigma(z)^2} \right] \tag{1}$$

$$\text{Hazard rate : } g(x) = 1 - \exp \left[- \left(\frac{x}{\sigma(z)} \right)^{-\beta} \right] \quad (2)$$

, where x is a perpendicular distance, and σ and β are parameters to be estimated. Other factors (covariates, z), such as wind force (Beaufort scale), vessel type, and observed school size, potentially affect detection probability. These covariates were included as linear combinations into a scale parameter α under a multivariate distance sampling approach (Marques and Buckland 2003). The Beaufort scale covariate was divided into two categories: strong (0–2) and moderate (≥ 3). Whaling-type and research-type vessels were also considered as potential covariates. School size was treated as a continuous covariate as recorded. Combinations of detection functions and covariates were compared on the basis of Akaike's information criterion, but up to one covariate was included in each model because of insufficient samples size for testing multiple covariates.

The abundance in the j -th block was calculated as:

$$N_j = \frac{A_j \bar{s}}{2L_j} \sum_{i=1}^{n_j} \frac{1}{w_{ij}} \quad (3)$$

where A_j (square nautical miles, nmi²) is surface area and L_j (nautical miles, nmi) is total on-effort track line length in the j -th block. The \bar{s} is the school size averaged by year. The w_{ij} is effective strip half-width (ESW) in the i -th sighting in the block j obtained by definite integration of $g(x)$ between 0 and 3 nmi. The variance of abundance estimates was calculated using the delta method (see Kanaji et al. 2018).

Temperature maps

To investigate the effect of temperature distribution on the differences in sighting positions by species and years, spatial temperature maps were created on each year's start, middle, and end dates of each survey. Sea surface temperature data were obtained from MOVE, the Meteorological Research Institute multivariate ocean variational estimation system (Usui et al. 2006), but this service ceased at the end of 2021. We used the data from MOVE for 1985–2015 (periods of Legacy data and JAFRACSS-SC phase I and II), while obtaining sea surface temperature data from FRA-ROMS II, the Japan Fisheries Research and Education Agency Regional Ocean Modeling System II for 2019–2021. FRA-ROMS II is an ongoing project that provides oceanographic data since 1993 (Kuroda et al. 2017).

Results

Observation records of three species

A total of 285 track lines of 33,014 nmi ($\approx 61,143$ km) were surveyed in JAFRACSS-Legacy and JAFRACSS-SC from 1985 to 2021 (Table 1). During these surveys, 16, 43, and 70 school sightings of false killer whales, striped dolphins, and white-sided dolphins, respectively, were recorded. Both false killer whale and striped dolphin schools were sighted in relatively wide ranges within the survey area. Simultaneously, the former was more frequently sighted in the East China Sea (block E and the corresponding area in block V in 1992), whereas the latter was more frequent in the eastern side of the survey area (particularly in block C) (Fig. 1). White-sided dolphin schools were sighted only within block A and the northern part of block O (Fig. 1).

The sighting surveys were conducted 1–2 months earlier in the surveys FRACSS-SC phase II (2014 and 2015) and III (2019–2021) than before. Therefore, temperature tended to be warmer in the survey areas in Legacy data (1985 and 1992) and phase I (2006 and 2007) (Fig. 2).

Abundance estimates

As a result of the Akaike's information criterion-based model comparison, a half-normal model with vessel type covariate was selected for false killer whale. In contrast, models with school size and Beaufort scale covariates were selected for striped and white-sided dolphins, respectively (Table 2). Those detection functions well described the tendency that detection probability decreases as the perpendicular distances increase (Fig. 3). The curve of detection functions tended to be steep (narrower ESW) for research-type vessels (false killer whale), smaller school size (striped dolphin), and larger Beaufort scale (white-sided dolphins) (Fig. 3). The estimated ESW (w) ranged from 0.36 to 0.83 for false killer whales, from 0.64 to 3.00 for striped dolphins, and from 0.46 to 0.78 nmi for white-sided dolphins (Table 3). False killer whales were sighted in relatively small schools whose yearly means ranged from 23 to 47.6. On the other hand, mean school sizes were 72.7–164.7 for striped dolphins and 4–167.5 for white-sided dolphins (Table 3). As it is often the case for small cetaceans, school size tends to be highly variable (Table 3). As a result, large coefficient variations (CVs) of estimated abundances were mainly caused by CVs of mean school sizes (Table 3).

Table 1 Summary of JAFRACSS data from 1985 to 2022

Phase	Year	Block	Area (square nmi)	Vessel type	No. of track lines	Effort (nmi)
Legacy data	1985	O	37,229	WV	16	1385
	1985	P	52,000	WV	17	1728
	1985	Q	441,419	WV	13	4017
	1985	R	49,675	WV	7	676
Legacy data	1992	S	43,704	RV	12	1412
	1992	T	45,302	RV	11	859
	1992	U	176,114	WV/RV	9	943
	1992	V	315,203	WV	8	2273
Phase I	2006	A	18,891	RV	9	501
	2006	B	44,095	RV	17	1170
	2006	D	213,731	WV	4	1236
	2006	E*1	120,949	WV/RV	41	2376
Phase I	2007	A	18,891	RV	8	493
	2007	B	44,095	WV	20	1477
	2007	C*2	182,656	WV/RV	8	1357
	2007	D*3	213,731	WV/RV	20	2528
Phase II	2014	A	18,891	RV	7	424
	2014	B	44,095	RV	13	936
	2014	C	182,656	WV/RV	4	865
	2014	D	213,731	WV	4	1231
	2014	E	120,949	RV	5	664
Phase II	2015	E	120,949	RV	6	931
Phase III	2019	A	18,891	RV	7	415
	2019	D	213,731	RV	3	982
Phase III	2020	B	44,095	RV	13	973
	2020	E	120,949	RV	4	681
Phase III	2021	C	182,656	RV	4	862

*(1) The block E was further divided into six sub-blocks (E1–6, Kanaji et al. 2018)

*(2) The block C was further divided into two sub-blocks (C1 and C2, Kanaji et al. 2018)

*(3) The block D was further divided into two sub-blocks (D1 and D2, Kanaji et al. 2018)

False killer whales were sighted in nine blocks (including two sub-blocks) in 1985, 1992, 2006, 2014, and 2015. Abundances in these blocks were estimated to be 1489 (coefficient of variation of 1.28) in block B in 2014 to 6418 (1.48) in block E4 in 2006 (Table 3). Striped dolphins were sighted in every year, except in 2015 and 2019. Abundance estimates in 12 blocks ranged from 731 (1.41) in block B in 2020 to 102,124 (1.46) in block C in 2014 for striped dolphins. The abundance of white-sided dolphins was estimated to be 117 in block O. Coefficient of variation was inestimable for the estimated abundance because only one school was sighted in 1985. White-sided dolphins were sighted in block A in 2006, 2007, 2014, and 2019 (Table 3). Abundance in the blocks ranged from 12,198 (1.98) in 2006 to 65,277 (2.83) in 2014 (Table 3). Abundances in all the other blocks were estimated at zero because of no sightings.

Discussion

Possible bias and error in line transect analyses

Field survey often faces difficulties in strictly following the fundamental assumptions of line-transect sampling: (1) objects on the line are detected with certainty, (2) objects do not move, and (3) measurements are exact (Buckland et al. 2001, 2015; Thomas et al. 2010). First assumption is known as the detection probability directly on the track line, $g(0) = 1$. If target animals are missed by their diving (availability bias) or by observer error (perception bias), this assumption is violated. In general, small cetacean school is conspicuous, and their diving is short less than 10 min (Black 1994; Minamikawa et al. 2013); thus, this assumption was considered not violated largely. Second assumption is violated if animals respond to vessel before they are detected. Such bias can be modified by modeling swim direction of

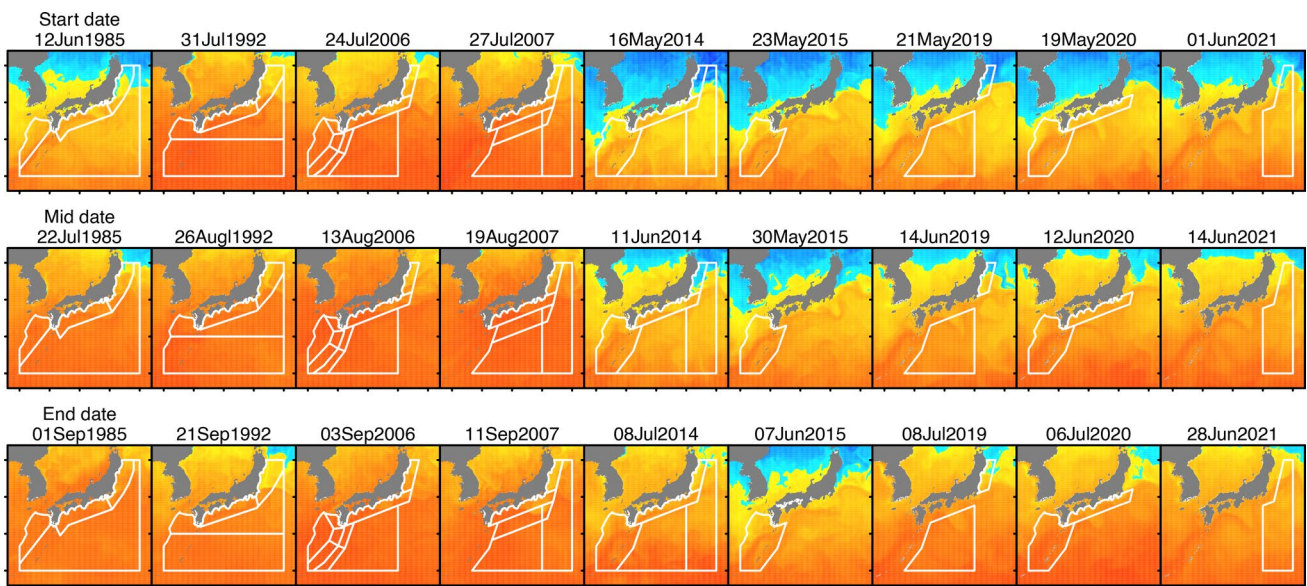


Fig. 2 Sea surface temperature distributions in the start, middle, and end dates of sighting surveys conducted in 1985, 1992, 2006, 2007, 2014, 2015, 2019, 2020, and 2021

Table 2 Model comparison based on Akaike’s information criterion (AIC) and its difference from the lowest AIC value (ΔAIC)

Function	Covariates	False killer whale		Striped dolphin		White-sided dolphin	
		AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC
Half-normal	null	2.4	3.2	74.2	22.9	4.3	7.4
Half-normal	Beaufort	4.4	5.2	76	24.7	-3.1	0
Half-normal	School size	4.3	5.1	51.3	0	0.4	3.5
Half-normal	Vessel type	-0.8	0	71.6	20.3	1.9	5
Hazard-rate	null	4.5	5.3	66.8	15.5	8.5	11.6
Hazard-rate	Beaufort	6.1	6.9	64.8	13.5	3.2	6.3
Hazard-rate	School size	4.6	5.4	57	5.7	3.3	6.4
Hazard-rate	Vessel type	2.7	3.5	68.8	17.5	5.5	8.6

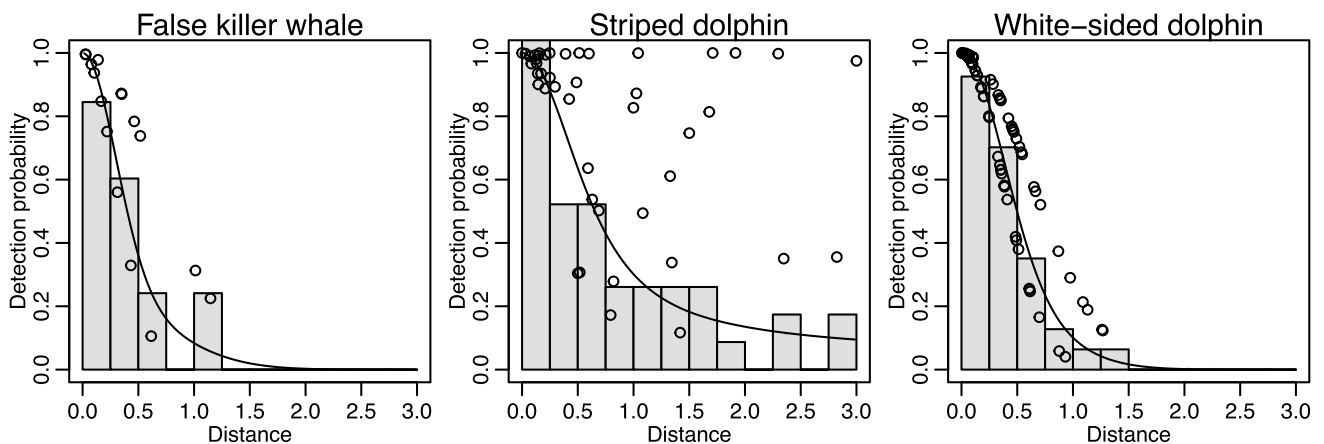


Fig. 3 Histograms of perpendicular distances of false killer whales, striped dolphins, and Pacific white-sided dolphin schools. Solid curves are averaged detection functions and plots represent fitted values with different covariates (two categories for Beaufort scale and vessel type while continuous values for school size)

Table 3 Abundance estimates of false killer whale, striped dolphin, and Pacific white-sided dolphin

Year	Block	Area (square nmi)	Effort (nmi)	No. of track lines	No. of sightings (CV)	Mean school size (CV)	ESW (CV)	Abundance (CV)
(a) False killer whale								
1985	Q	441,419	4017.3	13	2 (0.58)	28.5 (0.57)	0.83 (0.35)	3763 (0.89)
1992	T	45,302	859.5	11	2 (0.6)	29 (1.25)	0.36 (0.24)	4200 (1.41)
1992	V	315,203	2272.8	8	2 (0.58)	29 (1.25)	0.83 (0.35)	4832 (1.42)
2006	E2	9649	282.9	6	2 (0.61)	47.6 (1.36)	0.36 (0.24)	4461 (1.51)
2006	E4	26,153	799.5	10	3 (0.52)	47.6 (1.36)	0.36 (0.24)	6418 (1.48)
2014	B	44,095	936	13	1 (1)	23 (0.76)	0.36 (0.24)	1489 (1.28)
2014	C	182,656	864.5	4	2 (0.72)	23 (0.76)	0.83 (0.35)	5839 (1.11)
2014	D	213,731	1230.7	4	1 (1.27)	23 (0.76)	0.83 (0.35)	2400 (1.53)
2015	E	120,949	931	6	1 (0.71)	23 (0.76)	0.36 (0.24)	4105 (1.07)
(b) Striped dolphin								
1985	P	52,000	1727.7	17	6 (0.54)	164.7 (0.76)	2.2 (0.12)	11,026 (0.94)
1992	T	45,302	859.5	11	2 (0.94)	98.3 (1.43)	1.7 (0.13)	7369 (1.71)
1992	V	315,203	2272.8	8	1 (0.93)	98.3 (1.43)	0.64 (0.17)	10,599 (1.71)
2006	B	44,095	1169.5	17	3 (0.62)	96.2 (1.54)	0.99 (0.18)	5899 (1.67)
2006	D	213,731	1236.1	4	3 (0.69)	96.2 (1.54)	0.82 (0.18)	33,619 (1.7)
2007	A	18,891	492.9	8	1 (0.94)	96.2 (1.54)	1.9 (0.23)	970 (1.82)
2007	C1	174,425	975.6	3	7 (0.71)	96.2 (1.54)	1.61 (0.18)	57,419 (1.7)
2014	B	44,095	936	13	1 (0.96)	72.7 (0.91)	2.84 (0.07)	604 (1.32)
2014	C	182,656	864.5	4	11 (1.13)	72.7 (0.91)	1.12 (0.17)	102,124 (1.46)
2014	D	213,731	1230.7	4	1 (0.79)	72.7 (0.91)	2.15 (0.22)	2937 (1.22)
2020	B	44,095	973.3	13	1 (1.08)	96.8 (0.9)	3 (0)	731 (1.41)
2021	C	182,656	861.8	4	7 (1.3)	96.8 (0.9)	1.48 (0.16)	83,926 (1.59)
(c) Pacific white-sided dolphin								
1985	O	37,229	1385.2	16	1 (1.22)	4 (NA)	0.46 (0.11)	117 (0)
2006	A	18,891	501	9	3 (0.67)	167.5 (1.86)	0.78 (0.15)	12,198 (1.98)
2007	A	18,891	492.9	8	3 (0.51)	167.5 (1.86)	0.46 (0.11)	20,873 (1.93)
2014	A	18,891	424.3	7	27 (0.35)	76.6 (2.81)	0.73 (0.14)	65,277 (2.83)
2019	A	18,891	415.4	7	36 (0.6)	16.6 (0.89)	0.5 (0.11)	28,052 (1.08)

animals (Black 1994; Minamikawa et al. 2013). Those data were recorded for some detected schools in JAFRACSS-SC and can be used to account for animal response in future. To reduce bias and error caused by violating third assumption, we conducted training and testing of angle and distance measurements using a buoy with radar reflector during each survey cruise. In fact, overall mean of bias factor was less than 10% (Kanaji et al. 2018).

Spatiotemporal variations in distribution and abundance

A total of 16, 43, and 70 schools of false killer whales, striped dolphins, and white-sided dolphins, respectively, were sighted during JAFRACSS in 1985–2021. Nevertheless, no false killer whale schools were recorded in 2019–2021 (phase III). In these years, the surveys were conducted from late May to early July, 1–2 months earlier

than those providing the Legacy data (1985 and 1992) and phase I survey (2006–2007). Sea surface temperature was, therefore, cooler in early-season surveys in 2019–2021, which might have caused a lower encounter rate in these surveys. However, relatively large numbers of schools (five schools) were detected in the phase II surveys (2014–2015), which were made in the same months as phase III surveys (2019–2021). False killer whales are one of the warm-water delphinid species mainly inhabiting tropical and subtropical waters (Kanaji et al. 2016, 2017). Unlike cold water species, false killer whales are considered not to exhibit prominent seasonal migration patterns. In fact, large differences were not detected in the total abundance between early-season surveys (2014 and later) and late-season surveys (2007 and before). Total abundance estimates in 2014 were 9728 (blocks B + C + D, Table 3a), 9032 (T + V, Table 3a) in 1992, and 10,879 (E2 + E4, Table 3a) in 2006. Thus, seasonal

temperature and species distribution shifts would not be the primary cause for no sightings in phase III surveys. Conversely, 7 of 16 sightings were made in the East China Sea (block E and corresponding area in block V in 1992), and five sightings were in the coastal waters along warm Kuroshio current (Fig. 1). For logistical reasons, survey efforts were substantially reduced in block E in the phase III program. In addition, the Kuroshio current showed prominent southward meandering off mainland Japan in 2019–2021. Such Kuroshio path pattern might cause offshore habitat shift, but survey efforts were also reduced in offshore block C (Fig. 1). Increasing the survey effort to these blocks would enable the test of this hypothesis and improve the accuracy of abundance estimation in a future survey.

Striped and white-sided dolphins mainly inhabit colder waters, namely the Transition Zone north of the Kuroshio extension and the Transitional Zone north of the Subarctic boundary, respectively (Kanaji et al. 2016). Spatial differences in sighting positions were not clear between early-season survey (2014 and later) and later-season survey (2007 and before) (Fig. 1). However, total abundance estimates of striped dolphins were 105,665 (B + C + D, Table 3b) in 2014 (phase II) and 84,657 (B + C, Table 3b) in 2020 and 2021 (phase III), being larger than the estimates from late-season survey: 11,026 (P) in 1985, 17,968 (T + V) in 1992, 39,518 (B + D) in 2006, and 58,389 (A + C1) in 2007 (Table 3b). Similarly, abundance estimates of white-sided dolphins tended to be larger in phase II and III surveys conducted in early seasons (65,277 in 2014 and 28,052 in 2019) than in phase I surveys conducted in late seasons (12,198 in 2006 and 20,873 in 2007) (Table 3c). These results suggest that striped and white-sided dolphins migrate north- or eastward from early summer (May–July) to mid and late summer (July–September), and certain numbers of dolphins move outside the study areas because of migration. Although these two species are not the main targets of JAFRACSS-SC, the results also suggest that surveying the study areas in early summer more efficiently covers many fishery-targeted species for monitoring their abundances.

White-sided dolphin sightings were recorded only in the northern part of the study areas (Fig. 1), representing the southern margin of the species distribution ranges and the small portions of entire population sizes in the study seasons. Striped dolphins were more widely distributed, while sightings were highly concentrated in block A in 2021 (Fig. 1). These distributional patterns were possibly because of Kuroshio meanders, which brought relatively warm waters into offshore blocks C and D (Fig. 2). Tendency to avoid warm temperature suggests that only a small part of the striped dolphin population was sighted in the present study.

Management implications

This study estimated the abundances of three fishery-targeted delphinid species, false killer whales, striped dolphins, and white-sided dolphins, based on a secondary use of sighting survey data from JAFRACSS programs. Therefore, these surveys covered only small portions of their entire habitats, and a relatively small number of sightings were recorded. The estimated abundances were much smaller than those of previous estimates of the entire population size, and coefficients of variation tended to be larger for these estimates (Table 3). Despite such limited information, current estimates are crucial to improve management measures for these species because the abundance estimates have not been updated for many years, and animals have continued to be harvested without quantitative assessments of population status.

Except for the period of JAFRACSS-SC phase III (2019–2021), abundance of false killer whales was estimated to be several thousands. Similarly, abundances of striped and white-sided dolphins were estimated to be at least several ten thousand. An annual catch limit is allocated for coastal fishers based on Potential Biological Removal (PBR) (Wade 1998). PBR is a simple product of the 20th percentile of the latest abundance estimates, half of intrinsic growth rate (generally assumed to be 4% for small odontocetes), and recovery factor (default value is 0.5). PBR is expected to provide conservative catch limitation even if estimated abundance has high uncertainty, because those baseline abundance is of the 20th percentile instead of median (or mean) of the abundance estimates. If this algorithm is applied to the latest abundance estimates for false killer whales, PBRs are 6, 28, 10, and 20 in blocks B, C, and D in 2014 and E in 2015, respectively. PBRs for striped dolphins are 3, 415, 13 in blocks B, C, and D, respectively in 2014 and those are 3 and 326 in B in 2020 and C in 2021, respectively. PBRs for white-sided dolphins were 187 and 134 in block A in 2014 and 2019, respectively. Recent catch records by dolphin fisheries (2017–2021) were 0–2 false killer whales, 265–436 striped dolphins, and 13–21 white-sided dolphins (Minamikawa and Yoshida 2023). Care must be taken for PBRs of false killer whales, because those values were not obtained from the latest surveys but from phase II program in 2014–2015. In addition, false killer whale females have long post-reproductive lifespans (Photopoulou et al. 2017), and thus, the population growth rate could be smaller than other delphinid species. Despite such caveats, current fishing pressure on false killer whales and white-sided dolphins would not be strong regarding these PBR values. Harvest levels on striped dolphins could exceed PBR values depending on the year, but the entire abundance across the species distribution range is much larger than current

partial estimates. These results suggest that the current harvest level is not leading to a severe depletion or extinction for these three species.

However, if several local populations constitute large distribution ranges, more careful assessments will be required to manage these populations safely. In the western North Pacific, there are three high-density areas of striped dolphins (Kasuya 1999). Kasuya (2011) speculated that these three distributions in northern offshore, inshore, and southern offshore corresponded to geographically distinct stocks; although, there is no genetic evidence for this hypothesis. If this hypothesis is tentatively applied, the current abundance estimates mainly cover nearshore stock during the summer months. Alternatively, sighting rates reported by fishing boats of dolphin drive fishery in Taiji showed clear seasonality, those rapidly increased from December to January (Hashida et al. 2023). This fact suggests that fishers target the stock migrating from outside of nearshore areas, possibly from the northern offshore. Similarly, sighting rates of white-sided dolphins increased from December to February (Hashida et al. 2023), suggesting that the stock targeted by fishers migrated from outside of fishing grounds. For white-sided dolphins, genetically distinct nearshore and offshore populations have been recognized (Hayano et al. 2004), but seasonal changes in their distributional patterns are not known. Current abundance estimates are probably from nearshore populations, while it is unclear which populations fishers target. Information on stock structures is limited also for false killer whales around Japan (Martien et al. 2014). In addition to the abundance information, identifying population structures and seasonal migration patterns is required to assess current population status and sustainability of fisheries. This study is a first step to improving the management measures for false killer whales, white-sided dolphins, and striped dolphins around Japan and a step toward reacknowledging the importance of accumulating and updating our data on these delphinid species.

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Declarations

Conflict of interest The authors declare no conflicts of interest.

References

- Black NA (1994) Behavior and ecology of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in Monterey Bay, California. M.S. thesis, San Francisco State University, San Francisco, CA
- Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L (2001) Introduction to distance sampling. Oxford University Press, Oxford
- Buckland ST, Rexstad EA, Marques TA, Oedekoven CS (2015) Distance sampling: methods and applications. Springer, New York
- Hammond PS, Francis TB, Heinemann D, Long KJ, Moore JE, Punt AE, Reeves RR, Sepúlveda M, Sigurðsson GM, Siple MC, Víkingsson G, Wade PR, Williams R, Zerbini AN (2021) Estimating the abundance of marine mammal populations. *Front Mar Sci*. <https://doi.org/10.3389/fmars.2021.735770>
- Hashida K, Funasaka N, Maeda H, Kai Y, Yoshioka M (2023) Cetacean fauna and occurrence pattern in the southern Kumanonada, Pacific coast of western Japan during fall and winter from sighting records obtained by dolphin drive fishery. *Nippon Suisan Gakkaishi* 89:102–114. <https://doi.org/10.2331/suisan.22-00016>
- Hayano A, Yoshioka M, Tanaka M, Amano M (2004) Population differentiation in the Pacific white-sided dolphin *Lagenorhynchus obliquidens* inferred from mitochondrial DNA and microsatellite analyses. *Zoolog Sci* 21:989–999
- Kanaji Y, Okazaki M, Watanabe H, Miyashita T (2016) Biogeography of small odontocetes in relation to wide-scale oceanographic structure in the North Pacific Ocean. *Fish Oceanogr* 25:119–132. <https://doi.org/10.1111/fog.12140>
- Kanaji Y, Okazaki M, Miyashita T (2017) Spatial patterns of distribution, abundance, and species diversity of small odontocetes estimated using density surface modeling with line transect sampling. *Deep Res Part II Top Stud Oceanogr* 140:151–162. <https://doi.org/10.1016/j.dsr2.2016.05.014>
- Kanaji Y, Miyashita T, Minamikawa S, Yoshida H (2018) Abundance estimates of six species of Delphinidae cetaceans off the Pacific coast of Japan between 1985 and 2015. *Mar Mammal Sci* 34:1034–1058. <https://doi.org/10.1111/mms.12502>
- Kanaji Y, Maeda H, Okamura H, Punt AE, Branch T (2021) Multiple-model stock assessment frameworks for precautionary management and conservation on fishery-targeted coastal dolphin populations off Japan. *J Appl Ecol* 58:2479–2492. <https://doi.org/10.1111/1365-2664.13982>
- Kanaji Y, Sasaki H, Hakamada T, Okamura H (2023) Hierarchical modelling approach to estimate the abundance of data-limited cetacean species and its application to fishery-targeted and rarely seen delphinid species off Japan. *ICES J Mar Sci* 80:1643–1657. <https://doi.org/10.1093/icesjms/fsad091>
- Kasuya T (1999) Review of the biology and exploitation of striped dolphins in Japan. *J Cetacean Res Manag* 1:81–100
- Kasuya T (2007) Japanese whaling and other cetacean fisheries. *Environ Sci Pollut Res* 14:39–48. <https://doi.org/10.1065/espr2006.09.346>
- Kasuya T (2011) Conservation biology of small Cetaceans around Japan. University of Tokyo Press, Tokyo
- Kasuya T (2017) Small cetaceans of Japan, exploitation and biology. CRC Press, Boca Raton
- Kuroda H, Setou T, Kakehi S, Ito S, Taneda T, Azumaya T, Inagake D, Hiroe Y, Morinaga K, Okazaki M, Yokota T, Okunishi T, Aoki K, Shimizu Y, Hasegawa D, Watanabe T (2017) Recent advances in Japanese fisheries science in the Kuroshio-Oyashio region through development of the FRA-ROMS ocean forecast system: overview of the reproducibility of reanalysis products. *Open J Mar Sci* 07:62–90. <https://doi.org/10.4236/ojms.2017.71006>

- Marques FFC, Buckland ST (2003) Incorporating covariates into standard line transect analyses. *Biometrics* 59:924–935. <https://doi.org/10.1111/j.0006-341X.2003.00107.x>
- Martien KK, Chivers SJ, Baird RW, Archer FI, Gorgone AM, Hancock-Hanser BL, Mattila D, McSweeney DJ, Oleson EM, Palmer C, Pease VL, Robertson KM, Schorr GS, Schultz MB, Webster DL, Taylor BL (2014) Nuclear and mitochondrial patterns of population structure in North Pacific false killer whales (*Pseudorca crassidens*). *J Hered* 105:611–626. <https://doi.org/10.1093/jhered/esu029>
- Minamikawa S, Watanabe H, Iwasaki T (2013) Diving behavior of a false killer whale, *Pseudorca crassidens*, in the Kuroshio-Oyashio transition region and the Kuroshio front region of the western North Pacific. *Mar Mammal Sci* 29:177–185. <https://doi.org/10.1111/j.1748-7692.2011.00532.x>
- Minamikawa S, Yoshida H (2023) Fisheries and surveys of small cetaceans (Review). In: *The Current status of international fishery stocks*. https://kokushi.fra.go.jp/R04/R04_48_whalesS-R.pdf
- Miyashita T (1993) Abundance of dolphin stocks in the western North Pacific taken by the Japanese drive fishery. *Rep Int Whal Comm* 43:417–437
- Miyashita T, Iwasaki T, Moronuki H (2007) Abundance estimation of Pacific white-sided dolphins in the waters around Japan using the sighting survey data in 1992–1996. In: *Program and Abstracts of the Meeting of the Mammal Society of Japan*. p 129
- Photopoulou T, Ferreira IM, Best PB, Kasuya T, Marsh H (2017) Evidence for a postreproductive phase in female false killer whales *Pseudorca crassidens*. *Front Zool* 14:1–14. <https://doi.org/10.1186/s12983-017-0208-y>
- Thomas L, Buckland ST, Rexstad EA, Laake JL, Strindberg S, Hedley SL, Bishop JRB, Marques TA, Burnham KP (2010) Distance software: design and analysis of distance sampling surveys for estimating population size. *J Appl Ecol* 47:5–14. <https://doi.org/10.1111/j.1365-2664.2009.01737.x>
- Usui N, Ishizaki S, Fujii Y, Tsujino H, Yasuda T, Kamachi M (2006) Meteorological Research Institute multivariate ocean variational estimation (MOVE) system: some early results. *Adv Sp Res* 37:806–822
- Wade PR (1998) Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Mar Mammal Sci* 14:1–37
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