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ARTICLE

Group definition for underwater observation of wild Indo-Pacific bottlenose dolphins

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Abstract
The group definition for an animal population is important for building associations among individuals (i.e., social network). Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) have a society with high fission–fusion dynamics that changes their group memberships over time, making it difficult to define groups clearly. In addition, current group definitions of small delphinid species are mainly related to boat-based or land-based surveys, and few definitions exist for underwater surveys. We propose a group definition for underwater observations after comparing 234 group transitions from 44 surveys of simultaneous boat-based and underwater observations targeting the resident Indo-Pacific bottlenose dolphins around Mikura Island, Japan. Our results highly matched group transitions between boat-based and underwater observations when all video-recorded dolphins during one encounter (from entering to exiting the water) were defined as a group, and groups with at least one shared individual during one survey were treated as the same group. This definition successfully produced highly similar association indices to boat observation. This is useful for underwater surveys of highly maneuverable delphinids, especially for commercial-tour-based studies in which researchers do not have the full decision-making authority for the observations.

Keywords Indo-Pacific bottlenose dolphin · *Tursiops aduncus* · Group definition · Social network analysis · Underwater observation

Introduction

The structure of social associations and interactions between individuals is a fundamental feature of animal populations that affects many key ecological and evolutionary processes (Kurvers et al. 2014). To understand this structure, social network analysis has been used (Webber and Vander Wal 2019). The definition of a group is an important aspect to be considered for social network analysis because the association between individuals is usually measured as a probability of observing both individuals together in the same group ('gambit of the group') (Franks et al. 2010; Whitehead 2008, Whitehead and Dufault 1999). This 'gambit of the group' is a convenient way of sampling to study a society with high fission–fusion dynamics (Aureli et al. 2008), in which group memberships change over time (Franks et al. 2010). A recent study demonstrated that the social network using the gambit of the group can be an acceptable substitute for the network of direct (tactile) interactions in a small delphinid, which has a society with high fission–fusion dynamics (Danaher-Garcia et al. 2022).

As other delphinid species, the Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) have a society with high fission–fusion dynamics (Connor et al. 2000) in which group definitions highly vary among the studied populations (see Syme et al. 2022 for the variation and recommendation of group definitions in delphinid). In Shark Bay, Australia, the longest field study for *T. aduncus*, the 10 m chain rule was applied to define groups (Smolker et al. 1992). In contrast, all dolphins coordinating their activities within a 100 m radius were grouped in southeastern Australia populations (Möller et al. 2002). Near Amakusa-Shimoshima Island, Japan, all individuals sighted during the survey were defined as associated (Nishita et al. 2015). At our research site (around Mikura Island, Japan), we defined a group as individuals in spatial proximity to one another, moving in a similar direction, and usually engaged in similar activities

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(Kogi 2001, modified Shane 1990). The definitions for this species are mainly related to boat-based and land-based observations.

The target population is the resident population of Indo-Pacific bottlenose dolphins; it has two unique characteristics, a small habitat area (20 km^2) and a closed population (93% yearly resight rate from 1994 to 2011) with at most 160 individuals around the small, rounded Mikura Island (Tsuji et al. 2017). An underwater video-identification study (ID study) using natural marks on the body has been conducted annually since 1994, from spring to early autumn. No photo-identification studies from boats have been conducted for this population. During the ID study, one to several videographers and other underwater observers entered the water without leaving any observers on the boat. Thus, the group movements during underwater observations are unknown. Considering their high fission–fusion dynamics and high population density (Connor et al. 2019), a group may split and fuse during the underwater observation period. Moreover, dolphins encountered our survey boat more than once during the same survey because the habitat is round in shape, especially when dolphins move in an opposite direction to the survey. Therefore, it is difficult to define a group for this population.

Two trials were conducted to define the groups of this population for underwater observations to conduct a social network analysis. Nagata (2006) defined a group as all video-recorded dolphins during an encounter (from when the videographer entered the water to when they returned to the boat). However, since we normally observe the same group again to record as many individuals in a group as possible, this definition may split an actual group into many small groups. In contrast, Sakai et al. (2016) used observation sequences to define the group. All dolphins with a "best time" (defined as the time for identification when the dolphin was sufficiently close to the video camera) within 16.3 min of the best time of any other dolphin were considered to be in the same group. This definition was determined by the broken-stick linear regression analysis, which revealed that the breakpoint of the time differences between successive best times sampled from this population from 2007 to 2012 was 16.3 min. This definition was made using actual data from this population, which would likely be accurate for this population when the available information is only from underwater observations. However, we cannot determine whether this definition tends to split or merge actual dolphin groups.

For underwater observations of other dolphin species, researchers, apart from those in the Bahamas, defined a group based only on data from boats before and after entering the water. Elliser and Herzing (2012) applied a combination of two methods for the Atlantic spotted dolphins *Stenella frontalis*: first, they defined dolphin groups from the boat using Shane's (1990) definition as all dolphins in sight, moving in the same direction, and typically involved in the same activity; second, the encounter was defined as a group of dolphins that can be observed underwater for more than 2–3 min. If the group's composition changed by more than 50%, it was considered a different group. This definition requires simultaneous individual identification during underwater observations and a high identification rate within a group. For the dolphins around Mikura Island, we were able to identify individuals within one group at an average of 29% (Kasanuki 2013); therefore, this definition does not apply to our population.

This study focuses on finding a group definition for underwater observations that better approximates observations from boats. We compared the group transitions of successive encounters (different groups or the same group) observed from the boat and the estimated group transitions from simultaneously conducted underwater observations using five group definitions. We also conducted downstream analysis to compare the effects of group definitions on social network properties. After determining the group definition, we investigated the effects of the group event, group transition, and year on the results of the proposed definition to understand the characteristics of the proposed definition.

Materials and methods

Study area and periods

The study was conducted around Mikura Island, Tokyo, Japan (33°52′ N, 139°36′ E; approximately 16 km of coastline; Fig. 1) during two periods: from August 10 to

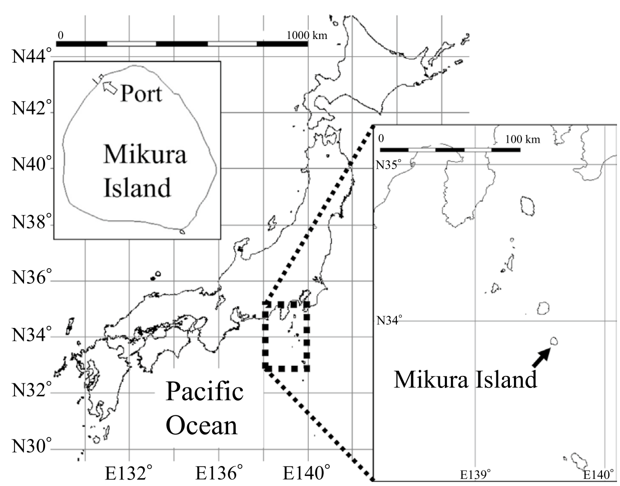


Fig. 1 Location of Mikura Island, Japan and the location of the Port of Mikura Island. The base map was created by "MapMap Ver 6.0" [Kamada T., http://www5b.biglobe.ne.jp/t-kamada/CBuilder/mapmap.htm]

September 10, 2000 and from June 26 to October 24, 2018. To validate the results, we separately analyzed the data from each period. The majority of the observations were conducted in a 300 m offshore area at depths of approximately 2–45 m, with water clarity ranging from 1 to 30 m (15 m on average) depending on the season, sea conditions, and other factors (Kogi et al. 2004).

Field observations

Simultaneous underwater and boat-based observations of the target dolphin groups were conducted with the ID study group, mainly organized by the Mikurashima Tourism Association using either commercial swim-with-dolphin boats from Mikura Island or a research boat. The boat searched for dolphins in the area described above. The captain guided the boat northward or southward from the port (located northwest of the island; Fig. 1), depending on the sea conditions and weather. When dolphins were found, the observer on the boat (hereafter, boat observer) began observations and recorded the beginning and end times of the boat and underwater observations, behavioral states of the dolphins, number of individuals in a group, and group fission/fusion if applicable until the boat left the group. Group fission/fusion was recorded when the observer detected the targeted group for underwater observation split into two groups (fission), and the targeted group merged with another group (fusion) (see the section "Comparison between the group transition observed from the boat and that estimated by underwater observation for each group definition"). The group definition for boat observations was that individuals in spatial proximity move in a similar direction and usually engage in similar activities (Kogi 2001, modified Shane 1990). The boat observer kept tracking the group movements of the target group and other groups if present for underwater observation, without any individual identification trials from the boat.

During boat observation, more than one member of the individual identification study entered the water using skin diving, and dolphins were recorded for individual identification with various video cameras (e.g., SONY HDR-CX430V, HDR-SR12, and HDR-XR550V, Tokyo, Japan) with underwater housings. The underwater observers counted the number of individuals and recorded the behavioral states for each encounter. Once the animals departed, the underwater observers returned to the boat. The encounter number, start time for the encounter, end time for the encounter, sea states, wave height, location, behavioral states, possible number of individuals for the encounter, specific behavior, and identified individuals were recorded by the underwater observers before and after returning to the boat. From this information, we used only the encounter number, start and end times of the encounter, and the number of individuals counted underwater. The numbers of individuals within a group observed by boat and underwater were averaged if the numbers were very dissimilar; otherwise, the number of individuals within a group viewed from the boat was used. The encounter numbers and start/end times for the encounters enabled us to identify the encounter number in the video. The boat captain allowed us to enter the water with the same group or search for other dolphins by considering sea conditions, water clarity, dolphin group movement, behavioral states, number of swim-with-dolphin boats, and other factors, resulting in 1–15 encounters within a survey. One survey was conducted per trip, and up to two surveys were conducted between sunrise and sunset depending on boat capacity and availability.

Individual identification

The ID study group (including the second author [T.F.]) conducted individual identification of the dolphins in the underwater video using individual identification catalogs (best videos and sketches of all identified dolphins) stored by the Mikurashima Tourism Association. The individual was identified if at least three natural marks (e.g., cookie-cutter shark (*Isistius sp.*) bites and notches on fins) of the dolphin matched. The ID study group recorded the video number; the individuals observed, including the time the individuals were framed in and out; the best times for viewing the individual in the video; and other information, such as conspicuous behaviors and events. The best time was defined as the time required for identification when the dolphin was sufficiently close to the video camera. The ID rate per encounter is calculated as follows:

$$\text{ID rate for the encounter} = \frac{\text{Number of identified dolphins from underwater observation in the encounter}}{\text{Estimated number of dolphins in the encounter from boat observation}}$$

		Encounter #1	Encounter #2	Encounter #3

	IDs	#A, #B, #C, #D, #E	#F, #G, #H, #I	#A, #J
definition	E-No	Group #1	Group #2	Group #3
	E+ID	Group #1	Group #2	Group #1
	E+ID_th	Group #1	Group #1	Group #1

Fig. 2 Three candidates of group definition for underwater observation using encounter information (E-No, E + ID, and E + ID_th). IDs indicate the individuals that were identified during the encounter

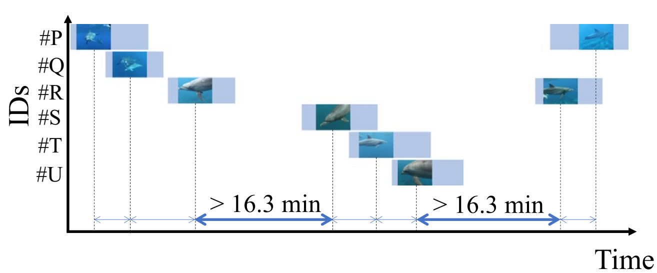
Candidates of group definition for underwater observation

The information from underwater observations, recorded by the ID study group, was limited to the encounter number, individuals in a video with the related time when the individuals were framed, and the best time for viewing the individuals. We listed five potential group definitions for underwater observation, using and combining the above information with previous studies conducted on this population.

1) E-No: All video-recorded dolphins during one encounter (from the time underwater observers entered the water to when they returned to the boat) were defined as a group (Nagata 2006) (Fig. 2).
2) E + ID: The same definition as E-No, except that the groups with at least one shared individual during one survey were treated as the same group. This definition was expected to overcome the weakness of the E-No definition, which tends to split the group into smaller groups (Fig. 2).
3) E + ID_th: The same definition as E-No, except that the groups with at least one shared individual during one survey and any group between these two groups were treated as the same group. This definition was expected to overcome the weakness of E-No more effectively than E + ID, particularly when the ID rate was low and there was a high possibility of missed detection of at least one shared individual in the same group among the encounters in a survey (Fig. 2).
4) TD: All dolphins with the best time (defined as the time for identification when the dolphin was sufficiently close to the video camera) within 16.3 min of the best time of any other dolphins were considered to be in the same group (Sakai et al. 2016) (Fig. 3).
5) TD + ID: The same definition as TD, except that the groups with at least one shared individual during one survey were treated as the same group. This definition was expected to merge groups (Fig. 3).

Comparison between the group transition observed from the boat and that estimated by underwater observation for each group definition

To compare how the group definitions for underwater observation approximate the group transition observed from the boat, we analyzed the transitions of the groups between two successive encounters (hereafter, group transitions that included Different and Same). To investigate the effects of group fission and fusion events observed from the boat during the former encounter or between successive encounters



	IDs	#P, #Q, #R	#S, #T, #U	#P, #R
definition	TD	Group #4	Group #5	Group #6
	TD+ID	Group #4	Group #5	Group #4

Fig. 3 Two candidates of group definition for underwater observation using time differences. Blue bar-like squares with the dolphin picture indicate the segment of a video where the dolphin appeared in the frame until the dolphin left the frame. The dotted lines from the center of the picture indicate the best time of the dolphin from the video. Two out of seven differences between nearest best times were more than 16.3 min, suggesting the encounters changed during the time differences. There appeared to be three encounters: the first was with #P, #Q, and #R; the second with #S, #T, and #U; and the last was between #P and #R

Table 1 Schematic diagram and the actual number of the group event and group transition for boat observation

Group event	The former encounter	→	The latter encounter	Group transition	2000	2018
No event	A	→	B	Different	79	50
	C	→	C	Same	58	33
Fission	D → E, F	→	G	Different	0	0
	H → I, J	→	I or J	Same	7	3
Fusion	K, L → K+L	→	M	Different	0	1
	N, O → N+O	→	N+O	Same	0	3

Capital letters (A–O) denote different groups

Table 2 The confusion matrix for comparisons between the boat and underwater observations

Group transition	Underwater observation	
	Different	Same
Boat observation		
Different	True positive (TP)	False negative (FN)
Same	False positive (FP)	True negative (TN)

on the results, we separately analyzed these group events as No event, Fission, and Fusion (Table 1). If the former encounter was group A with No event and the successive encounter was group B, we considered the group transition as Different. If the former encounter was group C with No event, and the successive encounter was also group C group, we considered the group transition as Same. We considered group transition as Different when group D group split into groups E and F during the former encounter or between the successive encounters and the successive encounter was group G (Fission), and when the L group joined the K group during the former encounter or between the successive encounters and the successive encounter was the different group M (Fusion). We considered group transition as Same when group H group split into groups I and J during the former encounter or between successive encounters and the successive encounter was the I or J group (Fission), and when the O group joined the N group during the former encounter or between successive encounters and the successive encounter was the N plus O group (Fusion).

For underwater observations, group transitions (Different/Same) were also analyzed between two successive encounters for each group definition. We then compared these group transitions between boat and underwater observations for each successive encounter and classified them into four classes that are used for binary classification of machine learning, as shown in Table 2.

1) True positive (TP): Both observations detected group transition as Different.
2) False negative (FN): The boat observation detected the group transition as Different, but the underwater observation detected it as Same.
3) True negative (TN): Both observations detected group transition as Same.
4) False positive (FP): The boat observation detected group transition as Same, but the underwater observation detected it as Different.

We counted these four classes separately for 2000 and 2018. To evaluate which underwater group definition produced similar group transitions by boat observation, we calculated the accuracy, precision, recall, and weighted F-measure using the four classes as follows:

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FN} + \text{FP}}$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

$$\text{Weighted F} - \text{measure} = \frac{(1+\beta^2)\times \text{Precision} \times \text{Recall}}{(\beta^2 \times \text{Precision}) + \text{Recall}}$$

Accuracy measures the number of identical group transitions included in all pairs of group transitions between the boat and underwater observations. Precision measures how many Different group transitions for boat observations are included in all Different group transitions estimated by the underwater group definition. Recall measures how many Different group transitions estimated by the underwater group definition are included in all Different group transitions for boat observations. Precision and recall are inversely proportional to each other. The weighted F-measure is the weighted harmonic mean of the precision and recall. F1-measure is a special case when $\beta = 1$ (harmonic mean). The weighted F-measure with $0 < \beta < 1$ (often $\beta = 0.5$) gives preference for precision, and that with $\beta > 1$ (often $\beta = 2$) gives preference for recall. We changed the β value from 0.5 to 2 and plotted the relationship between the β value and the weighted F-measure. We determined that the underwater group definition with the highest weighted F-measure with approximately $\beta = 1$ approximates the group transition observed from the boat. Since this research was mainly focused on creating group definitions for social network analysis, FN should have a lower rate because it would produce more relationships among individuals compared to those by boat observation. A β value slightly larger than 1 is preferred because a lower FN gives a higher recall to avoid false network relationships.

Effects of the group definitions on the social network properties

To evaluate which underwater group definition produced a similar social network using boat observations, we conducted downstream analysis using SOCPROG ver. 2.9 (Whitehead 2009) to compare social network properties (association index and non-zero element) between boat and underwater observations with the five group definitions. Associations were calculated using half-weight association indices (HWI) because our identification rate was around 30% (Kasanuki 2013), which is a better condition when using the half-weight index than the simple ratio index (Whitehead 2008). After calculating the association indices of all pairs, the means, standard deviations, and CVs of the association indices of the five group definitions with boat observations were calculated. In addition, the proportion, mean, standard deviation, and CVs of the non-zero elements of the association indices were calculated. Sociograms of boat observations and the five group definitions in each year for all associations with HWI ≥ 0.3 were constructed to visualize the differences in edge density between boat observation and the five group definitions. Mantel tests with 9999 permutations using Spearman's rank correlation were performed between the matrix of association indices of boat observation and those of five group definitions using the package 'vegan' (Oksanen et al. 2020) in R ver 4.1.1 (R Core Team 2020).

Effects of group events, transitions, and year on the results of the proposed definition

The relationships of group conditions (group event and group transitions) and year on the results of the proposed definition were investigated after determining the definition to understand how the definition includes the effects of group conditions and year using logistic regression analysis. Due to the definition of group transition, Different group transitions had only two classes (TP and FN), and the Same had two other classes (TN and FP). We combined TP and TN as TRUE, FN and FP as FALSE, and ran statistics using TRUE and FALSE to investigate these effects.

Statistical analyses

All statistical analyses, except network analyses, were performed using JMP 11.2.1, a statistical software (SAS Institute Inc. Cary, NC). We used the Wilcoxon rank-sum test to test the ID rate difference between observation years (2000 and 2018). We used contingency analysis with the chi-square value to test the difference between the rates of group transitions (Different/Same) in 2000 and 2018. Logistic regression analyses were used to investigate the effects of group events (No event/Fission/Fusion), year (2000/2018), and the interaction between the two, and the effects of group transition (Different/Same), year (2000/2018), and the interaction between the two on the comparison results (TRUE/FALSE). We used Excel solver to find the intersection points of the lines of the five group definitions on the graph for the relationship between the β value and the weighted F-measure.

Results

Study efforts and differences between observation years

We conducted 23 surveys in 2000 and 21 in 2018. The number of encounters with at least one identified individual was 163 out of 181 (90%) in 2000 and 103 out of 121 (85%) in

Table 3 Comparison results of boat and underwater observations of group transitions using the five group definitions in each year

Year	Indices	Group definition				
		E-No	E + ID	E + ID_th	TD	TD + ID
2000	TP	76	60	42	40	28
	TN	1	43	47	62	63
	FN	3	19	37	39	51
	FP	64	22	18	3	2
	Accuracy	0.53	0.72	0.62	0.71	0.63
	Precision	0.54	0.73	0.70	0.93	0.93
	Recall	0.96	0.76	0.53	0.51	0.35
	F1-measure	0.69	0.75	0.60	0.66	0.51
2018	TP	43	40	30	19	16
	TN	0	22	28	36	38
	FN	8	11	21	32	35
	FP	39	17	11	3	1
	Accuracy	0.48	0.69	0.64	0.61	0.60
	Precision	0.52	0.70	0.73	0.86	0.94
	Recall	0.84	0.78	0.59	0.37	0.31
	F1-measure	0.65	0.74	0.65	0.52	0.47

For TP, TN, FN, and FP, the number of group transitions in a year is shown

TP: True positive, TN: True negative, FN: False negative, FP: False positive

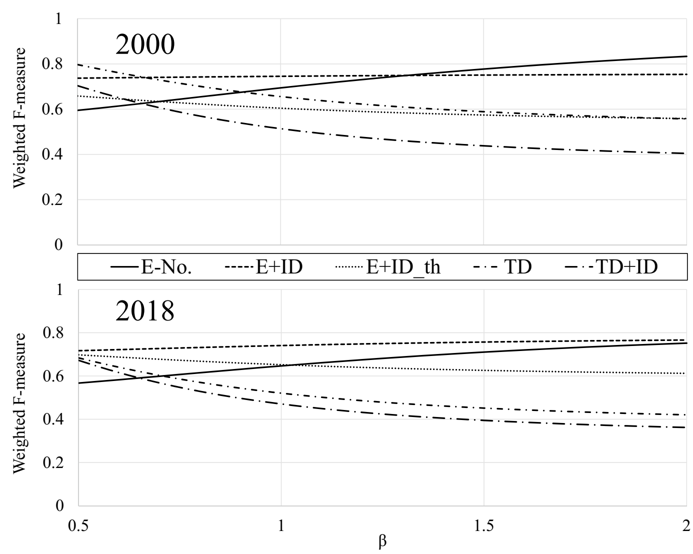


Fig. 4 The relationships between β value and weighted F-measure of each group definition in 2000 and 2018

2018. The number of group transitions analyzed was 144 in 2000 and 90 in 2018. The ID rate for 2000 was significantly higher (0.57) than that for 2018 (0.33) (Wilcoxon rank-sum test, $Z = -6.00$, $p < 0.0001$). Among the three group events, No event was the most frequent (137/144 in 2000, 83/90 in 2018), followed by Fission (7/144 in 2000, 3/90 in 2018). We detected Fusion in 2018 (4/90) but not in 2000 (Table. 1). The proportion of group transitions did not significantly differ between years (Different: 79/144 in 2000, 51/90 in 2018; Same: 65/144 in 2000, 39/90 in 2018; contingency analysis, $\chi^2 = 0.07$, $p = 0.79$).

Comparison between the group transition observed from the boat and that estimated by underwater observation for each group definition

Table 3 shows the comparison results of the group transitions between the boat and underwater observations with the five group definitions. E + ID had the highest accuracy and F1-measure of all candidates of the group definitions for each year (0.72 and 0.75 in 2000, 0.69 and 0.74 in 2018). Figure 4 shows the relationships between the β value and weighted

F-measure of each group definition in 2000 and 2018. In 2000, the weighted F-measure was the highest of the five group definitions when the β value was $0.67 < \beta < 1.31$, and in 2018 when β value was $0.44 < \beta < 2.33$.

Network analysis

Table 4 shows the social network properties (association index and non-zero element) of boat observations and the five group definitions. The association index of boat

Table 4 The social network properties (association index and non-zero elements) of boat observation and five group definitions

	Year 2000 ($n = 128$)						Year 2018 ($n = 102$)					
	Boat	E-No	E + ID	E + ID_th	TD	TD + ID	Boat	E-No	E + ID	E + ID_th	TD	TD + ID
Association index												
Mean	0.09	0.06	**0.08**	0.11	0.12	0.14	0.05	0.05	**0.05**	0.06	0.07	0.08
s.d	0.15	0.12	0.14	0.15	0.17	0.18	0.14	0.14	0.15	0.15	0.17	0.18
CV	1.67	2.11	1.80	1.40	1.35	1.23	2.87	2.97	2.83	2.62	2.31	2.19
Non-zero elements												
Proportion	0.33	0.23	**0.29**	0.41	0.43	0.47	0.15	0.12	0.13	**0.15**	0.18	0.20
Mean	0.27	0.25	0.26	**0.27**	0.29	0.30	0.40	0.39	0.41	**0.40**	0.41	0.41
s.d	0.13	0.13	0.13	0.12	0.13	0.13	0.16	0.16	0.17	0.16	0.16	0.16
CV	0.48	0.50	0.49	0.46	0.46	0.44	0.40	0.41	0.41	0.40	0.40	0.40
Mantel test												
ρ (rho)	–	0.80	**0.88**	0.73	0.83	0.77	–	0.82	**0.86**	0.79	0.78	0.76
p	–	0.00	0.00	0.00	0.00	0.00	–	0.00	0.00	0.00	0.00	0.00

The closest values of the proportion and mean for the group definition to the boat are shown in bold. The rho (ρ) and p values of Mantel tests between boat observation and the five group definitions are also shown. The highest rho (ρ) value is shown in bold

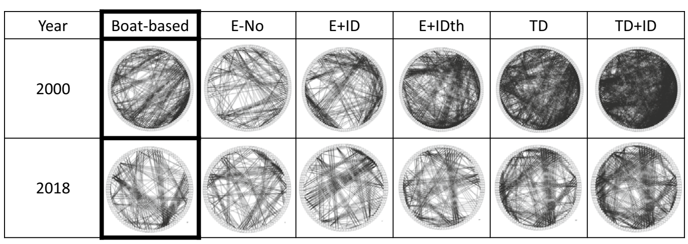


Fig. 5 Sociograms of association indices from 2000 to 2018 data calculated using five definitions. Individuals are circularly arranged but the location of the individuals are not set among each sociograms. The thickness of links between pairs of individuals corresponds to the relative value of association indices from 0.3 to 1.0

Table 5 The comparison results between boat observation and underwater observation with the E + ID definition for group events, group transitions, and years

Group event	Group transition	Year 2000					Year 2018				
		TRUE		FALSE		All	TRUE		FALSE		All
		TP	TN	FN	FP		TP	TN	FN	FP	
No event	Different	60	–	19	–	79	40	–	10	–	50
	Same	–	38	–	20	58	–	19	–	14	33
Fission	Different	0	–	0	–	0	0	–	0	–	0
	Same	–	5	–	2	7	–	1	–	2	3
Fusion	Different	0	–	0	–	0	0	–	1	–	1
	Same	–	0	–	0	0	–	2	–	1	3

TP: True positive, TN: True negative, FN: False negative, FP: False positive observation was the closest to E + ID in both years. Mantel tests between boat observations and the five group definitions predicted strong correlations of all pairs, but E + ID had the highest r values in both years (0.88 in 2000, 0.86 in 2018), indicating the strongest correlation. The proportion of non-zero elements of boat observations was the closest to E + ID in 2000, but E + ID_th in 2018, and the mean of the non-zero elements of boat observations was the closest to E + ID_th in both years. Figure 5 shows the sociograms using boat observations and the five definitions to visually show the similarity of the edge density of the five definitions to that of boat observation.

Effects of group event, group transition, and year on the results of the E + ID definition

The comparison results between the boat and underwater observations with the E + ID definition for group events, group transitions, and years are shown in Table 5. There was no significant effect of group event, year, and the interaction between the two on the results (TRUE [TP and TN] vs. FALSE [FN and FP]) (logistic regression analysis, $\chi^2 = 1.16$, $p = 0.56$ for group event; $\chi^2 = 1.26$, $p = 0.26$ for year; and $\chi^2 = 1.17$, $p = 0.28$ for the interaction). There was a significant effect of group transition on the results (logistic regression analysis, $\chi^2 = 6.51$, $p < 0.05$), but no effect of year or interaction between group transition and year (logistic regression analysis, $\chi^2 = 0.20$, $p = 0.65$ for year; and $\chi^2 = 0.86$, $p = 0.35$ for the interaction). This indicated that the group transitions considered as Same had significantly more FALSE cases (FN and FP) than those considered as Different in the comparison results between the observations.

Discussion

Our results indicated that the E + ID group definition for underwater observation (all video-recorded dolphins during one encounter were defined as a group, except that the groups with at least one individual during one survey were treated as the same group) most approximated the boat observation. Despite the ID rate difference between 2000 and 2018, E + ID was the most similar to boat observations in both years, which indicated that this group definition was robust against such differences in ID rates. This definition had well-balanced precision and recall values, and the weighted F-measure was the highest at $0.7 < \beta < 1.3$, suggesting a robust definition for the researchers to minimize FN (Boat observation: Different group transition/Underwater: Same group transition) and avoid extra relationships among individuals and to minimize FP (Boat observation: Same group transition/Underwater: Different group transition) for other purposes such as population estimates in an area. Network analysis also showed that E + ID produced the most similar association indices to boat observations. Thus, we determined that E + ID is the appropriate underwater group definition to analyze the association among individuals for this population.

The TD group definition, which was used by Sakai et al. (2016), had high accuracy and precision with lower recall, which means that TD could be used but tended to merge different groups. TD is an alternative definition when the encounter number is unavailable, such as constant video recording using a stationary buoy system. This definition is similar to the association definition of ID studies from boats by Johnston et al. (2017) for common bottlenose dolphin (*Tursiops truncatus*) ID studies and by Tavares et al. (2017) for killer whales (*Orcinus orca*), where the pairs photographed within a very short time were considered associated. TD + ID group definition greatly merged the different groups since TD alone had this tendency. In future, new definitions using TD should be considered to overcome the weaknesses of this method of merging different groups into one. E-No group definition, which Nagata (2006) used, had the lowest accuracy, lowest precision, and highest recall. This definition tends to split a group into many smaller groups. E + ID overcomes the disadvantages of E-No. The E + ID_th method merged the different groups, resulting in lower accuracy and F-measure than E + ID. Thus, E + ID is the best definition using the encounter and ID data.

The E + ID had a 12.8% (30/234) FN. This means that boat observations were reported as different groups between the two encounters, but E + ID found the shared individuals between the two groups. These cases occurred when the boat observer missed individual movements between groups. It is likely that boat observations were sometimes inaccurate. An accuracy of 83% and an F1-measure of 87% for the E + ID definition could be achieved if the boat observer did not miss the group movements. In the Same group transition, the FP rate was 16.7% (39/234), which was determined by our inability to identify the same individual between two encounters of the same group due to the lower ID rate (0.57 for 2000, and 0.33 for 2018). However, our definition is still weak for this type of error. Thus, the E + ID definition tends to split one group into several groups compared to boat observations. This tendency resulted in differences in the proportion and mean of non-zero edges between boat observations and E + ID. FP is more acceptable than FN for network analysis because it creates extra-networks among individuals. Researchers should combine boat observations and underwater observations to increase the accuracy and F1-measure; for example, the underwater definition could be utilized for different group transitions, along with boat observations in the same group transition if this data is available.

Here, we demonstrate that we can define a "group" for network analysis using only the encounter number and individual identification information from underwater observations. However, future studies should be cautious when applying this approach to other populations of Indo-Pacific bottlenose dolphins as well as other small delphinid species given the influence of different ecological (e.g., water turbidity) and social (e.g., cohesion/dispersion patterns, strength of fission–fusion dynamics, and ID rate) factors on group definition. For researchers who already have many years of underwater observations and want to choose a definition that matches boat observations, we recommend a single season of simultaneous boat and underwater observations that will allow them to replicate our analyses and choose the right definition for the population/animal. For researchers who cannot conduct simultaneous boat and underwater observations and want to apply this method to other dolphin populations and/or species, the E + ID definition may be applied by default. The E + ID definition is straightforward; therefore, researchers studying not only aquatic mammals but also highly maneuverable terrestrial mammals with high fission–fusion dynamics could utilize this method, particularly for commercial-tour-based studies where researchers do not have complete control of the observation parameters. In addition, the E + ID and TD definitions can be applied when researchers need to define a group from constant video recordings using stationary recording systems, such as buoys, trail cameras, or animal tracking remotely operated vehicles (ROVs).

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Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was conducted in accordance with voluntary regulatory rules for sustainable dolphin swimming programs developed by program operators on Mikura Island. Mikurashima Village granted permission to enter the protected sea area around Mikura Island. The Mikurashima Tourism Association approved all the research protocols for underwater observations. To minimize disturbance, we followed a noninvasive approach for observation in accordance with the Guidelines to Study Wild Animals of the Wildlife Research Center of Kyoto University. In most cases, the dolphins did not exhibit unusual behavior during our observations. We did not use scuba tanks, never attempted to touch the dolphins, and never fed them.

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