

SOCIAL ORGANIZATION OF BELUGAS *DELPHINAPTERUS LEUCAS* SUMMERING OFF THE SOLOVETSKY ISLANDS (WHITE SEA, RUSSIA) BASED ON PHOTO-IDENTIFICATION DATA: IDENTIFYING SOCIAL CLUSTERS

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Received March 27, 2024

Revised June 18, 2024

Accepted October 03, 2024

Abstract. Belugas are gregarious and form different types of social groups, which may include both related and unrelated individuals. Apart from mother–calf dyads, there is almost no information about individual associations in beluga groups. Using photo-identification data, we investigated the social organization of belugas summering off the Solovetsky Islands in the White Sea, Russia, based on sightings of 122 individuals in a reproductive gathering off Cape Beluzhy, Solovetsky Island, in July – August 2022. Data analysis was carried out using the program SOCPROG 2.9. We have not found any social clusters with stable individual composition within the gathering. Nevertheless, some pairs of individuals, which usually included a female, had high association indices. In general, association indices in pairs decreased during the study period. These results could be influenced not only by the nature of social relationships among belugas, but also by the individual variance of visiting patterns to the area of the gathering. These factors cannot be differentiated within the framework of the current study. Associations of individuals outside the study area, as well as beyond the study period, remain unknown.

Keywords: cetaceans, beluga whale *Delphinapterus leucas*, social structure, social organization, association index, White Sea, Solovetsky Islands

DOI: 10.31857/S00301574250111e3

INTRODUCTION

Many species of toothed whales are gregarious. The social organization of their communities can either be similar to that of terrestrial mammals or have its own unique features [19, 21, 24]. For example, social groups of sperm whales *Physeter macrocephalus* and African elephants *Loxodonta africana* are stable and include related females and their offspring [41]. The community structure of bottlenose dolphins *Tursiops sp.* is fluid and represented by groups with different sizes and compositions, which often form, disintegrate, and reform, and shares common features with the social organization of some primates [21, 22, 24]. As in terrestrial mammals, the social organization of toothed whales is influenced by various factors, of which the main ones are the availability and distribution of resources, predator pressure, and the need to care for offspring [19, 20, 37], and can vary even at the intraspecific level [17, 20, 23, 29].

Arctic cetaceans, beluga whales *Delphinapterus leucas* are gregarious and can form herds of up to several hundred or even thousands of individuals [6, 13, 39]. Many beluga populations migrate seasonally between wintering and summering habitats to which they return from year to year, and may sexually segregate by habitat use [8, 28, 33, 36, 39].

Many aspects of the social organization of beluga communities in the natural environment are poorly studied. The primary family group of belugas consists of a female with her calf and sometimes include another older calf [5, 7, 9, 11, 35, 39]. Other types of social groups include associations of females with calves, groups of adult males, groups of immature individuals, as well as mixed herds with different ages and sexes [1, 10, 14, 34, 35, 39]. Except for stable mother–calf pairs which can persist for three years [11, 14], the data on individual associations in belugas are limited. They are mainly based on the field observations of visually identified whales [1, 14, 15] or on the movements of individuals from the same group tagged

with satellite transmitters [16, 39, 40]. In general, the social structure of belugas is considered fluid [33, 34]. Membership in social groups is variable [1, 11, 35]; they can unite both related and unrelated individuals [18, 35], forming a multilevel and dynamic community [35]. In this study, we used photo-identification data to investigate the social organization of belugas summering off the Solovetsky Islands in the White Sea and forming a coastal gathering near Beluzhy Cape of Solovetsky Island.

MATERIALS AND METHODS

Solovetsky Gathering of Beluga Whales

The beluga is the only resident cetacean species in the White Sea. Current studies consider White Sea belugas as a separate population [38]. The Solovetsky Islands area is the permanent summer habitat of White Sea belugas. Regular gatherings of belugas can be observed near Beluzhy Cape, Solovetsky Island (65° 04.47' N, 35° 30.75' E). Here coastal waters can be divided into four sites preferred by belugas (Fig. 1, sites A, B, C, and A'), where up to several dozen individuals gather daily, except for stormy days [5, 10]. The time when whales visit the gathering area depends primarily on the tidal conditions. Belugas usually appear on a mid-ebb tide; their greatest number is observed during low tide—beginning of flood tide (low water); from the middle of flood tide, belugas begin to leave waters near Beluzhy Cape [10]. The Solovetsky gathering has a mixed composition and is represented by individuals with different sexes and ages, mainly by females with calves of different ages and immature individuals and by a smaller number of sexually mature males which usually become more numerous in July [10]. The gathering forms annually in the second half of May and exists until the end of August, serving as a place for mating, giving birth and raising of calves, socialization, and development of hierarchical relationships between animals. Basic activity forms of belugas include different types of social interactions (parental, sexual, hierarchical, and play); feeding is not observed in the Solovetsky gathering [2, 9, 11].

Photo-Identification

The photo-identification studies accompanying annual (June–August from 1995 to date) shore-based visual observations of belugas near Beluzhy Cape, Solovetsky Island, have been conducted since 2007 [14, 15]. Belugas are photographed from an observation point directly in front of the central (“A”) site (Fig. 1) during low tide, when the number of animals is at its

maximum in the research area. The semi-diurnal tidal cycle in the White Sea, resulting in two peaks of beluga occurrence near Beluzhy Cape, as well as the long polar day, make it possible to carry out up to two photographic sessions per day. Nikon digital cameras (D80, D90, and D850) with Nikkor 80–400 mm and Sigma 150–500 mm telephoto lenses were used for shooting in different years. Photo images were processed visually using Adobe Photoshop, ACDSee or FastStone Image Viewer in search of belugas with natural markers, that makes it possible to identify the whales in the future. Identification considers both sides of the body or (more often) one side. The age category is determined from the combination of animal's body size and color: “ad/subad” (white and light gray individuals aged five years and older), “juv” (from two to five years), and “calf” (one-year-old calves and newborns). If possible, the sex of the identified individuals is determined.

Based on the photo identification study of the Solovetsky gathering, a regularly updated electronic database with (by 2022) >500 individually identified belugas has been created. It contains the following information: identification number of an individual to which an identified side (or both sides) belongs; photo image and description of individual marker(s); the side on which a marker is located (left or right); sex (if determined); age category; presence of calves (for females); and recording dates. The database mainly contains individuals of the ad/subad age category, because they have more stable markers.

Social Structure Analysis

The 2022 photo-identification data, including 28 photographic sessions conducted for 25 days (from July 11 to August 6, 2022), were used to analyze a social structure of the Solovetsky belugas. The data included 564 identifications (from 1 to 42 identifications, with an average of 20 ± 12 , per session) of 122 belugas with the following age categories: 114 ad/subad, 6 juv, and 2 calves. The sex was determined for 35 individuals: 27 females and 8 males (or presumed males). Due to a variable marker preservation degree [12], the identification of individuals within a single field season is the most reliable. Even though some individuals were found repeatedly in different years [14], the current analysis was limited to a single field season.

The data processing was carried out using the SOCPROG 2.9 compiled version software [45] developed for the comprehensive analysis of a social structure of animal communities based on the data on associations or interactions of identified individuals [43]. The analysis is based on calculation of the association index in pairs of individuals

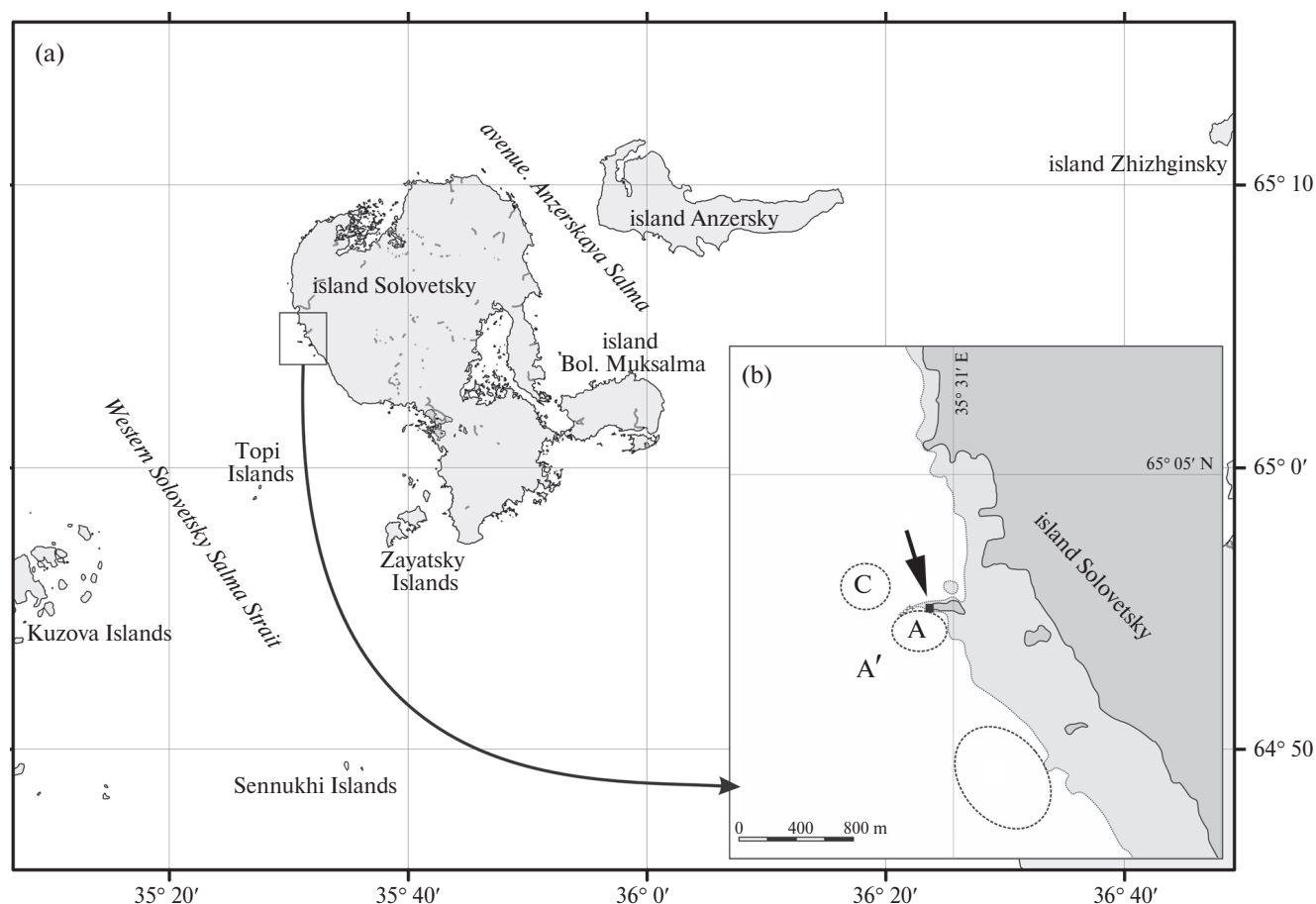


Fig. 1. A: map of the Solovetsky Islands and adjacent water area. B: map of the study area (A, B, C and A' — preferred areas of beluga whales' stay near Beluzhiy Cape, Solovetsky Island. The arrow indicates the location of the observation point).

(hereinafter referred to as “pairs” meaning the combination of any two individuals) which generally represents the proportion of time these pairs spend together. It takes values from 0 (individuals were never observed together) to 1 (individuals were always observed together) and is usually symmetrical. The observation data are divided into sampling periods for each of which it is determined whether the pair was associated or not.

We considered pairs to be associated if both individuals were observed at the central site A (where the whales were photographed) during the same photographic session. Only belugas of the ad/subad age category found in four or more sessions were included in the social structure analysis. Separate analyses for males and females were not performed because the sex was not determined for most of the identified animals. A simple association index was used to assess the association strength in pairs. It is the ratio of the number of sampling periods when two individuals were recorded as associated to the number of sampling

periods when at least one of them was identified [43]. One day was chosen as the sampling period.

To estimate how varied the social system of the Solovetsky belugas is, the social differentiation S was calculated using the maximum likelihood method [43]. S is expressed by the coefficient of variation of the true association indices and indicates the variability of association indices within a community: if S is close to 0, the interactions of individuals within the community are homogeneous, and if it is about 1 or more, they are variable. The following gradation is adopted: at $S < 0.3$ the community is rather homogeneous; at $S > 0.5$ — differentiated; at $S > 2$ — highly differentiated [45]. The accuracy of social representations can be assessed by the correlation coefficient (r) between the true and estimated association indices, where r being close to 1 means an excellent representation, and 0.4 indicates “a somewhat representative pattern” [43]. Standard errors for S and r were calculated by the bootstrap method (100 replicates).

A social network (sociogram) was constructed based on the matrix of association indices: a graphic representation of connections between individuals in a community, where a distance between nodes (individuals) is inversely related to their association indices.

Hierarchical cluster analysis and community division using the eigenvector modularity method [45] were carried out to identify possible groups (clusters of individuals) in the gathering. In the first case, single-linkage, complete-linkage, average-linkage, and Ward's were used as clustering methods. The cophenetic correlation coefficient (CCC) was calculated to assess the effectiveness of the cluster analysis performed. $CCC > 0.8$ indicates the dendrogram is a good representation of the association matrix. In the second case, clusters were defined in such a way that the association indices were generally high between individuals from the same cluster and generally low between individuals from different clusters [46]. The quality of the resulting division is estimated using a modularity (Q). The optimum division is the one that maximized Q ; if $Q \geq 0.3$, the division is considered useful [45].

SOCPROG allows us to study temporal patterning of social interactions. For this purpose, a measure called "lagged association rate" (LAR) [44] is used: LAR estimates the probability of association of a pair τ time units after a previous association. LAR can be generalized to the entire population of identified individuals. This parameter is often given as a plot against lag τ to indicate how the associations change over time. We calculated LAR for all identified ad/subad individuals ($N = 114$) regardless of the number of sightings [43]. To compare with LAR, a "null association rate" (NAR) was calculated: the expected association rate value in the absence of preferred associations, taking into account the number of associates of an individual in any sampling period. The jackknife method was used to calculate standard errors.

Based on the individual history of encounters with 114 of ad/subad individuals, SOCPROG was used to study the "lagged identification rate" (LIR): the probability that an individual identified in the study area at any time will be identified during any single identification in the study area τ time units later [42, 43]. LIR allows us to study movements of animals from/to the research area and can also help in interpreting the temporal variability of pair associations. A decrease of LIR indicates that animals permanent leave the research area, while its leveling off suggests that some individuals are residents or return back after emigration (re-immigrate) [42].

RESULTS

Among 122 identified belugas, 24 individuals were found in the gathering once; 36 individuals – 2–3 times; 62 individuals – 4 or more times (maximum, 18 times). The accumulation curve of identified individuals (Fig. 2) demonstrates reaching a plateau in the last observation week.

Social Organization

Of the 114 ad/subad individuals, 59 individuals (20 females, 5 males, and 34 of unidentified sex) were identified at least 4 times and included in the social structure analysis. The social differentiation S of 0.33 ($SE = 0.06$) was indicative of low differentiation of the community ("community" refers to a set of 59 individuals). The correlation coefficient between the true and estimated association indices r was 0.48 ($SE = 0.05$).

For the individuals analyzed, the average association indices were 0.20 ± 0.05 , and the average maximum was 0.60 ± 0.17 ($N = 59$). The distribution of association indices in pairs of individuals (N pairs = 1711) is shown in Fig. 3. Table 1 shows examples of pairs with the highest association indices (> 0.67).

Visual analysis of the sociogram (Fig. 5), community division by modularity, and hierarchical cluster analysis revealed no obvious clusters among the identified individuals. The maximum modularity Q was 0.11 (below the 0.3 threshold); the CCC did not exceed 0.67 for any clustering method (below the threshold of 0.80 for effective representing of an association matrix).

During the study period, LAR decreased, having reached the NAR values by the end of the study (Fig. 6).

Visiting Pattern of Solovetsky Gathering Based on Individual Identification History

Lagged identification rate for 114 ad/subad individuals plotted against lag τ is shown in Fig. 7. It is best described by a mathematical model with an exponential decrease followed by stabilization at some nonzero level (Fig. 7, blue curve). According to this model, there are some resident individuals in the gathering and/or some individuals leave the gathering, but then return.

DISCUSSION

The history of encounters with identified individuals during the 2022 summer field season confirms the conclusions obtained from long-term monitoring of the Solovetsky gathering [11, 14]:

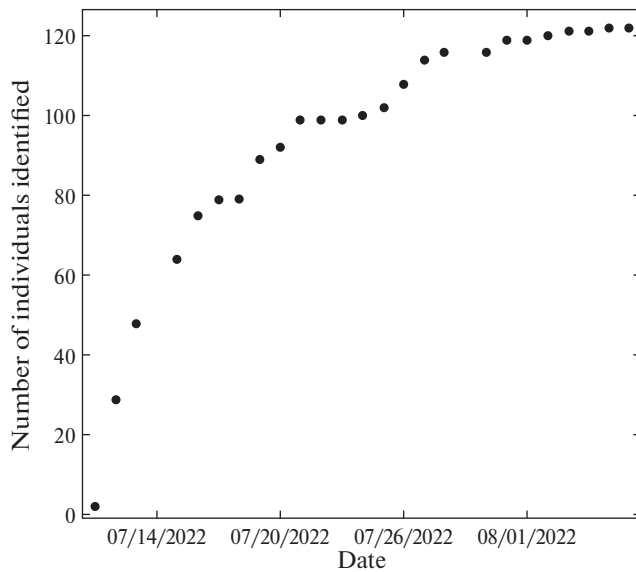


Fig. 2. Accumulation curve of identified individuals during the observation period (July 11-August 6, 2022).

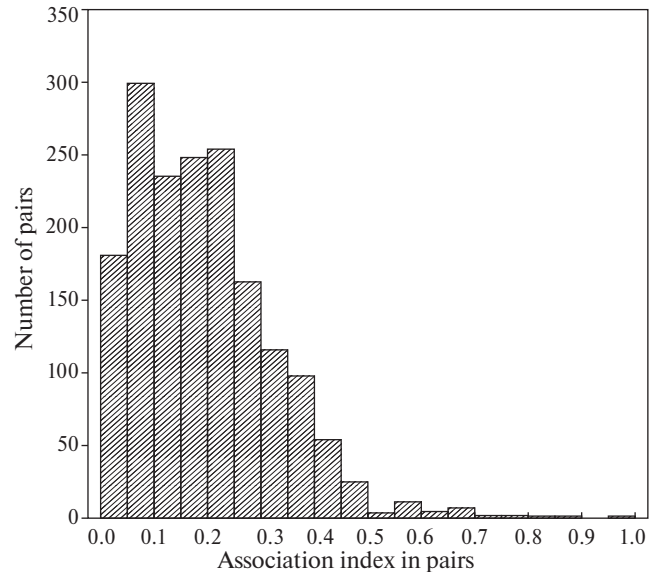


Fig. 3. Distribution of association indices in pairs of individuals.

Beluzhy Cape of Solovetsky Island is part of the summer habitat of the Solovetsky belugas, which have varying degrees of fidelity to this water area. The social structure of this community is apparently not entirely homogeneous, but we identified no social clusters with a stable individual composition. The similar study

conducted for belugas from Cook Inlet, Alaska, also found no evidence of distinct clusters or subgroups among the identified individuals [31, 32].

However, some pairs of individuals were regularly observed in the gathering at the same time and therefore had high association indices. Most often, these pairs

Table 1. Examples of pairs of belugas with highest association indices

Association index	Pair composition. Age category and sex (F is female, M is male, and U is unidentified)	Comments
1	Ad U/Ad U	Two light gray individuals in group with active sociosexual interactions involving males
0.89	Ad F + calf/Ad U	Observed next to each other, both adults and calf had visually similar skin lesions (Fig. 4)
0.83	Ad M/Ad U	Ad U is large white individual without skin lesions; probably male [12]
0.80	Ad F + calf/Ad U	
0.78	Ad F + calf/Ad F + calf	
0.75	Ad U/Ad U	
0.71	Ad F + calf/Ad U	
0.70	Ad F + calf/Ad U	Ad U is light gray individual that prefers to be in female groups
0.70	Ad F + calf/Ad F + calf	Both females had visually similar skin lesions.
0.68	Ad F + calf/Ad U	Ad U is light gray individual which prefers to be in female groups
0.68	Ad F/Ad U	Observed next to each other. Ad U is light gray individual which prefers to be in female groups



Fig. 4. An animal of undetermined sex (Ad U) and a female (Ad F) with her calf (Calf), which were observed together in the Solovetsky cluster. All three individuals have visually similar skin lesions.

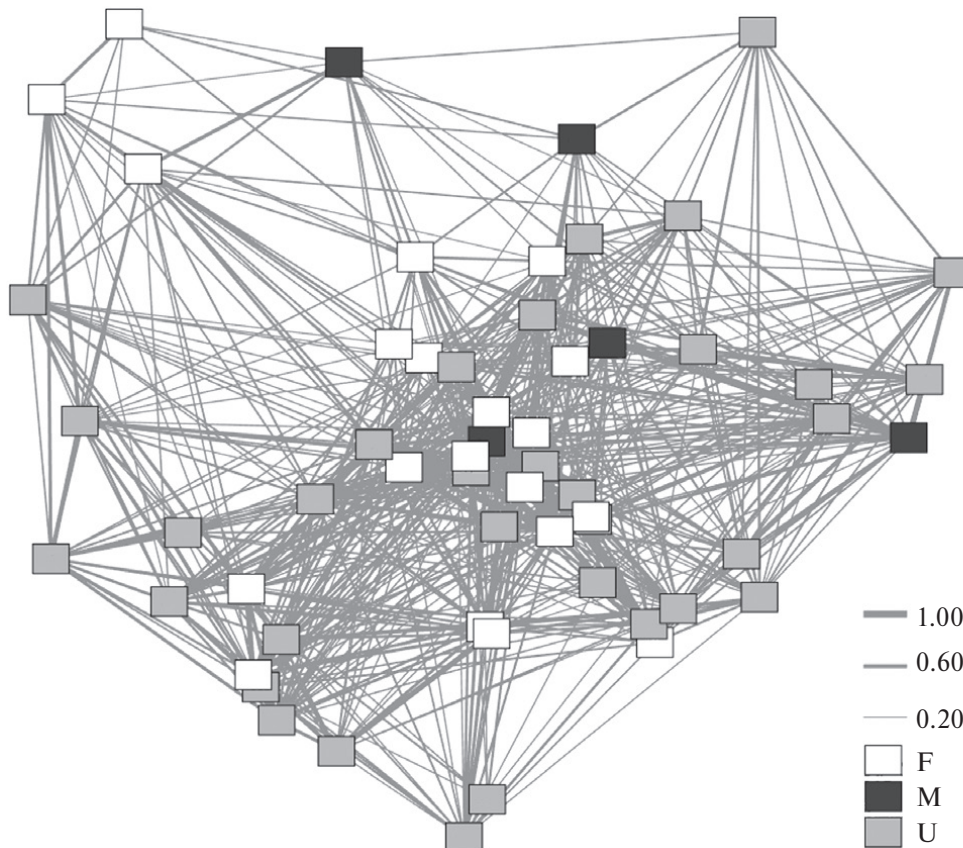


Fig. 5. Sociogram constructed from the association matrix in pairs of identified individuals (N individuals = 59). The thickness of the lines reflects the value of the association index; values less than 0.2 are not presented. The color of rectangles indicates sex: white – females (F), black – males (M), gray – sex not determined (U).

included a female with a calf. Due to the peculiarities of the method (all individuals recorded at site A during one photographic session were considered associated), high association indices are not unambiguous evidence of social preferences of individuals but may indicate a similarity of their visiting patterns in the study area. In females, for example, it could be dictated by general needs related to giving birth and caring for calves in the comfortable water conditions near Beluzhy Cape [10, 11]. According to visual observations (Krasnova, field observations), in some cases, animals from these pairs did stay together. In the Solovetsky gathering, females with calves were observed in temporary associations with other females over several days [11]. It is interesting that the belugas from two pairs with high association indices had visually similar skin lesions (Fig. 4, Table 1) suggesting the formation of social ties can contribute to the spread of infectious diseases [12].

We found no evidence of the identified males joining together into so-called “alliances”, stable groups of 2–4 individuals known in other toothed whales with a fluid social structure such as bottlenose dolphins [48]. However, male belugas do tend to form groups with individuals of their own sex: both herds of several dozen animals and small pods (from 4 to 10–15 individuals) within mixed herds [2, 11, 35, 39]. Tracking belugas using satellite telemetry showed that males captured in the same group and satellite tagged could continue to move together [40]. In captivity, males also prefer to join other males and do so more

often than females [25, 30]. Hence, the formation of male groups in belugas is rather a rule, but the small number of identified males in the sampling set did not make it possible to study this phenomenon under this study.

The association strength in pairs of individuals decreases toward the end of the study period. Apparently, this decrease is caused not only and not so much by social factors (associations break up over time), but also by changes in the individual composition of belugas visiting Beluzhy Cape in summer [14]. The occurrence trend of identified belugas corresponds to the “emigration + reimmigration” model [42, 46] which implies that some individuals are residents, while others leave the gathering, but can then return. Hence, beluga associations outside the study area, as well as beyond the observation period, remain unknown. Seasonal changes in the beluga lifestyle related to movements between wintering grounds and summer habitats suggest that grouping patterns can also vary throughout the year. For example, the genetic analysis of samples obtained during the aboriginal beluga harvest across Hudson Bay, Hudson Strait, and southern Baffin Island have revealed strong differences in relatedness patterns among animals sampled in the summering areas and during migration [18].

Limitations of This Work: Future Studies

Interactions between individuals are basic elements in studies of the social structure of animal communities [26, 47]. In the case of cetaceans or other animals hard

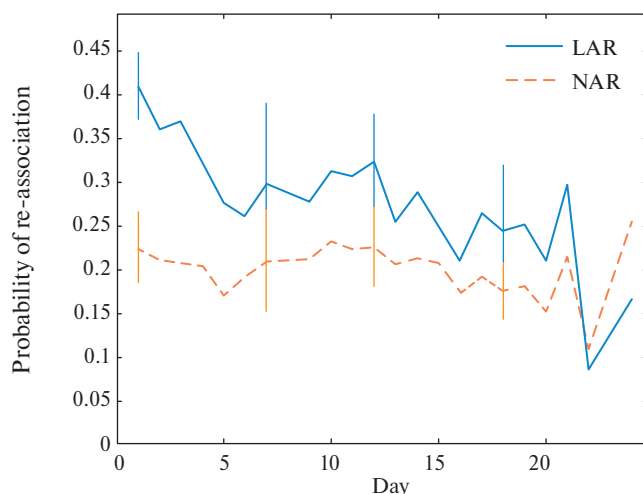


Fig. 6. Dynamics of the probability of re-association of pairs of LAR individuals and the “null” association rate NAR (mean \pm SE).

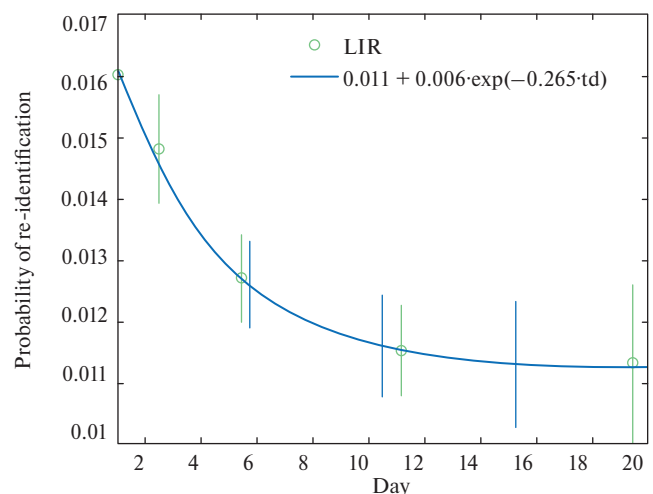


Fig. 7. Dynamics of LIR re-identification probability (mean \pm SE) plotted against encounter histories of 114 individuals in the ad/subad age category. The blue curve is the mathematical model “Emigration + Re-immigration” described by the equation $a_2 + a_3 \cdot \exp(-a_1 \cdot td)$, where a_1 is the emigration level; $a_2/(a_2 + a_3)$ is the proportion of the population in the study area at any given time [46].

to observe in the wild, "interactions" can be replaced by "associations," which in turn can be calculated based on the presence of individuals in the same social group. Despite some disadvantages [27, 47], this approach is the most accessible alternative in some cases.

In our study, the association criteria relied on the natural rhythm belugas adhere to when visiting area near Beluzhy Cape: those individuals which gathered here during regular low tides were considered as associated, assuming that they could be not only in visual and tactile, but also in acoustic contact (e.g., [3]). However, when many animals are present, the number of associations could be overestimated; in this case, it would be appropriate to distinguish smaller groups. Although interactions among belugas in the area subjected to visual observations and photo survey are generally dynamic [5], separate groups of females, immature individuals, or males can be observed in the whole crowd of whales [4, 14]. Identifying and tracking such groups within the Solovetsky gathering, and moreover, specifying their individual composition, is a complicated issue beyond the scope of this study. Further studies of the social structure of the Solovetsky belugas could focus on these groups. We suggest that such studies, although more labor-intensive, would be more efficient.

FUNDING

The study was supported by the Russian Science Foundation (project no. 23-24-00181).

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any experimental studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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