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Keys for the status of killer whales in Eastern Kamchatka, Russia: foraging ecology and acoustic behavior

Karina K. Tarasyan[1], Olga A. Filatova[1], Alexander M. Burdin[2,3], Erich Hoyt[4], and Haruko Sato[5]

[1]*Department of Vertebrate Zoology, Faculty of Biology, Moscow State University, Vorobiovy gory, 1/12, Moscow 119992, Russia*

[2]*Kamchatka Branch of Pacific Institute of Geography of Russian Academy of Sciences, Prospect Rybakov, 19a, Petropavlovsk-Kamchatsky 683024, Russia*

[3]*Alaska Sealife Center, P.O. Box 1329, 301 Railway Avenue, Seward, AK 99664, USA*

[4]*WDCS, the Whale and Dolphin Conservation Society, 29A Dirleton Avenue, North Berwick, Scotland EH39 4BE, UK*

[5]*Far East Russia Orca Project, 274-8 Churui, Shibetsu-cho, Shibetsu-gun, Hokkaido 086-1601, Japan*

Abstract The foraging ecology and acoustic behavior of the killer whale *(Orcinus orca)* was studied in Avacha Gulf, Kamchatka Peninsula in the Russian Far East from 1999 through 2003. Two main forms of foraging behavior were observed: the "carousel" type, when killer whales surround a school offish and swim into the center one after another, and the "asynchronous diving" type, when a killer whale group forages within a determined area, either in a tight group or in subgroups of 2-5 animals. Killer whale groups contained from 1 to 49 animals (mean = 9.56), but the typical group size ranged from 6 to 10 animals. No examples of killer whale aggression or hunting behavior directed toward other marine mammals were witnessed. Kamchatkan killer whale groups proved to be highly vocal, producing calls, whistles, and echolocation sounds in different behavioral contexts. Call type repertoires defined for the seven groups within the study population showed that each of these groups shared at least one call type with another group, which by definition means that all these groups belong to the same acoustic clan and the same population. Killer whales observed during this study represent one population and have biological features (group size, foraging and acoustic behavior) similar to the northeast Pacific resident killer whale populations.

Key words: killer whale, *Orcinus orca,* foraging ecology, group size, acoustic behavior, Kamchatka

INTRODUCTION

The killer whale, or orca, *Orcinus orca* - the largest member of the oceanic dolphin family, Delphinidae, suborder Odontoceti - is widespread throughout all of the world's oceans from the Arctic to the Antarctic, but the ecological characteristics of this species vary dramatically from region to region. At present, scant information about numbers, population structure, distribution patterns, territory size or other biological traits of the killer whale is available from most areas where the species is found. In the northeast Pacific (British Columbia, Washington and Alaska), however, regular investigations of the population structure, behavior and vocal repertoire of killer whales have been conducted since the early 1970s (Bigg et al. 1983, 1987, Ford 1984, 1989, 1991, Deecke et al. 2000, Miller and Bain 2000, Yurk et al. 2002). On the basis of these long-term studies, scientists in the northeast Pacific now recognize two ecotypes of killer whales: resident and transient, which differ in their ecology, social organization, genetics and vocal activity (Ford 1984, Bigg et al. 1990, Ford et al. 1994, 1998, Baird and Whitehead 2000). These ecotypes were originally termed resident and transient based on their presumed associations with particular areas (Bigg et al. 1976); this has since

become less clear, but the two names have been retained. Residents feed mostly on fish, while transients hunt marine mammals (Bigg et al. 1990, Ford et al. 1998). Groups of resident whales usually consist of more than five animals, while transient groups have five or fewer members (Baird and Whitehead 2000). Residents produce calls during most of their activities, while transients are less vocal (Ford 1984, Morton 1990).

Killer whales produce whistles, echolocation clicks and pulsed calls. Most killer whale pulsed signals fall into discrete types with greater or lesser variability within them. Long-term investigations of killer whale acoustic behavior in different parts of the world such as the northeast Pacific (Ford 1984, 1991, Yurk et al. 2002) and the northeast Atlantic (Moore et al. 1988, Strager 1995) have shown that each pod has its own unique repertoire of discrete calls, which remains stable for tens of years and which is passed from mother to offspring through vocal learning. Some of the calls are shared by several pods and some are unique. Pods that share calls belong to the same acoustic clan. Different clans appear to represent independent maternal lineages that have persisted for many generations, and have independent call traditions (Ford 1984).

In Russian waters regular investigations of killer whales began only in 1999. Information collected during whaling in the mid-20th century included mainly morphological descriptions and gastric contents analysis of killed animals (Слепцов 1955, Томилин 1957, 1962, Бетешева 1961, Иванова 1961). More recent publications (Шунтов 1993) provide mostly general information about killer whale abundance and sightings made opportunistically.

In this paper we focus on two aspects of killer whale behavior: acoustic and feeding behavior. We hope to help define the status of killer whale populations in Kamchatka and the Russian Far East in order to estimate the possible impact of capturing the species for aquaria, and other threats, and to obtain results that will help the management and protection of these

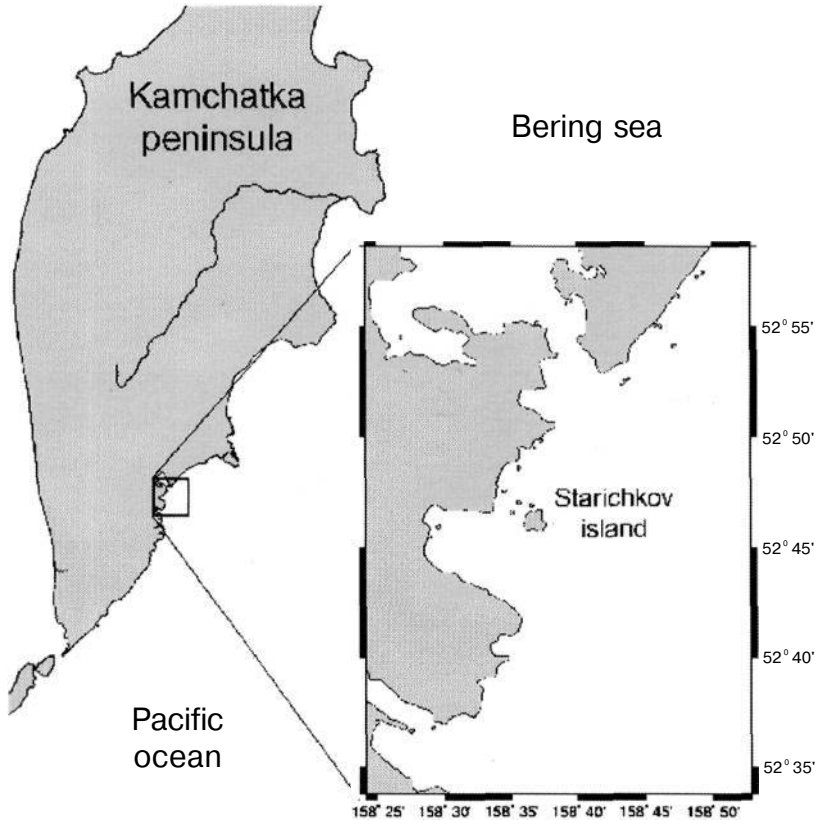

Fig. 1. Location of study area.

whales in Russian waters.

METHODS

Materials and data used for this study were collected through the Far East Russia Orca Project (FEROP) with participants from the Kamchatka Branch of the Pacific Institute of Geography, Russian Academy of Sciences, Moscow State University, Sevvostrybvod, and WDCS, the Whale and Dolphin Conservation Society. This study was based around Starichkov Island in the central Avacha Gulf, Kamchatka (Fig. 1), for 15 days in September 1999-2000 and for 62 days in August-September 2001-2002. In total, we spent 152.5 hours observing killer whale behavior.

Land-based observers situated on the top of Starichkov Island focused on group size and composition, type of activity, direction of movement and location of animals. Observations were made using binoculars (Baigish 10x50) and field scopes (Geoma-65-S 25x) in 2000 and 2001, and in 2002 we used the theodolite method of tracking individual killer whale pods which allowed us to describe whale locations more accurately. We employed a Nikon DTM-520 theodolite with a laptop computer. Theodolite data was processed with Pythagoras software (Gailey and Ortega 2000), which allowed us to compute the coordinates where killer whales foraged. These coordinates were then put on a map that showed depth measurements for the study area. We estimated the arrangement of the areas utilized by killer whales and their prey, using the Kernel method, usually used for home-range studies (Worton 1989). In areas where foraging was most probable (95% certainty), the depths shown on existing maps were correlated with known fish distribution using MapInfo Professional Version 6.5 Release Build 19. Kernel analysis was done using ArcView GIS 3.2a. We analyzed 47 examples of foraging in the year 2002 and 111 occasions in total.

The photographic identification method (Bigg et al. 1983) was used to log individual killer whales and for temporal group identification. At present, a total of about 250 individuals have been identified through the surveys described above.

Underwater sound recording was conducted from an inflatable boat using a Sony TCD-D100 DAT recorder with a mono-hydrophone. The hydrophone used in 1999 (Shizuoka Oki Electricity Co., Japan) had a frequency range from 100 Hz to 10 kHz; in 2000-2003 the hydrophone (Offshore Acoustics, Canada) had a frequency range from 10 Hz to 40 kHz. The hydrophone was lowered to a depth of 5-10 m. Spectrographic analysis was carried out by means of a digital sonograph, Avisoft-Sonograph Pro. Spectrographic analysis was conducted in a frequency window from 0 to 11.025 kHz with the following parameters: sampling frequency 22.05 kHz; overlap - 87.5 %; FFT - 512 points; Hamming window; frame - 100%.

For the description of group repertoires 35 hours of recordings from 2000-2002 were used. Discrete calls were classified according to the existing catalogue (Филатова с соавт 2004).

For the analysis of sound distribution among the different behavioral contexts, 20 hours of recordings from 2002-2003 were used. Sounds were classified into the following categories: echolocation clicks, discrete calls, variable calls, aberrant calls, whistles and underwater tail slaps. We counted the number of sounds from each category in each 10-second space of recordings. For each activity type the number of sounds from each category was summarized. Then we compared the distribution rate of sound categories during different types of activity with random values. To calculate the random values for each type of activity we counted the number of sounds for each category as if they were distributed proportionally to the ratio of total duration of each activity type. Then the rates of sounds for each given category for the real and random distribution were compared using the White test using the program Statistica 6.0.

RESULTS

Foraging behavior

Several types of foraging behavior were observed. "Carousel" behavior was defined as when killer whales

Table 1. Descriptive statistics of types of killer whale foraging behavior.

Foraging activity	Mean min	Range min	SDmin	Total time hh:mm	n
carousel	6.67	1-25	6.7	01:14	15
asynchronous diving	44.84	2-211	46.84	23:41	96

surrounded a school of fish and swam into the center one after another. "Asynchronous diving" was defined as when a group was foraging within a determined area, either in a tight group or in subgroups of 2-5 animals. The foraging times, using these two methods, differed: "carousel" foraging lasted 7 min on average, whereas foraging by "asynchronous diving" lasted 45 min on average. Other descriptive statistical parameters of these behavior types are shown in Table 1.

Observations of foraging were evenly distributed during the daytime with a slight increase in the period from 11:00 to 14:00 (Fig. 2).

Visual observations conducted in both 2000 and 2001 showed that killer whales foraged in the same areas of Avacha Gulf during both survey periods. In 2002, with the use of a theodolite, we assigned these places geographic coordinates. By means of the kernel method (h = 0.014, n = 119) we confirmed the density of area utilization by killer whales and calculated the probability distribution of foraging within the area (Fig-3).

We witnessed no examples of killer whale aggression, or hunting behavior, toward the other marine mammals that we observed in the gulf (largha seals *Phoca largha;* Steller sea lions *Eumetopias jubatus;* sperm whales *Physeter macrocephalus;* minke whales *Balaenoptera acutorostrata;* and Dall's porpoises *Phocoenoides dalli).* We occasionally saw non-aggressive inter-species interactions between killer whales and Dall's porpoises.

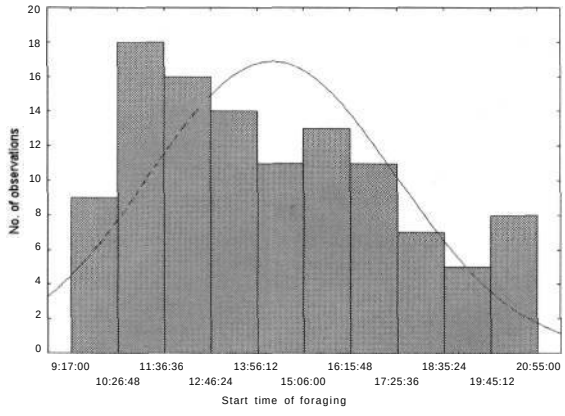

Fig. 2. Distribution of the start time of foraging during the daytime.

Group size

We analyzed the size of 106 groups observed in Avacha Gulf in the period 2000-2002. The average period of observation for each group was 30 minutes (range 15-420 minutes). Groups contained from 1 to 49 animals (mean = 9.56), but the typical group size ranged from 6 to 10 animals (Fig. 4).

We compared the group size of Kamchatkan killer whales with data from the two ecotypes of northeast Pacific killer whales - residents and transients (Morton 1990) (Table 2). The group size of Kamchatkan killer whales was closer to the resident than the transient group size.

Acoustic behavior

The killer whale groups we observed proved to be highly vocal, producing sounds during most of the recordings. The majority of sounds can be classified as discrete (Fig. 5). Such calls were detected in 84.5% of recordings in different behavioral contexts.

For the seven groups which were recorded separately and which could be individually recognized, we identified individual group repertoires. Each of these groups shared at least one call type with another group (Table 3).

From the analysis of recordings made during different behavioral contexts we found a strong correlation between the signals and the type of activity (Table 4).

Foraging During foraging, echolocation and dis-

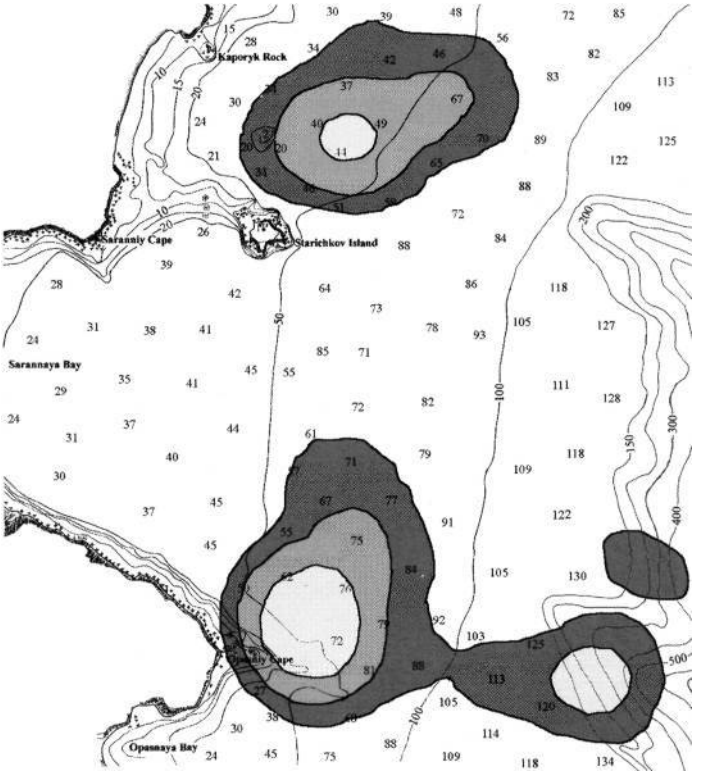

Fig. 3. Kernel areas in Avacha Gulf (dark gray - 95% probability of foraging; mid gray - 80% probability, and light gray - 50% probability).

crete calls were predominantly used, but all other sound categories were also detected. The number of echolocation clicks, discrete calls, and underwater tail slaps during foraging was significantly higher than the random values ($p<0.001$, White test). The number of variable and aberrant calls and whistles did not differ from the random values.

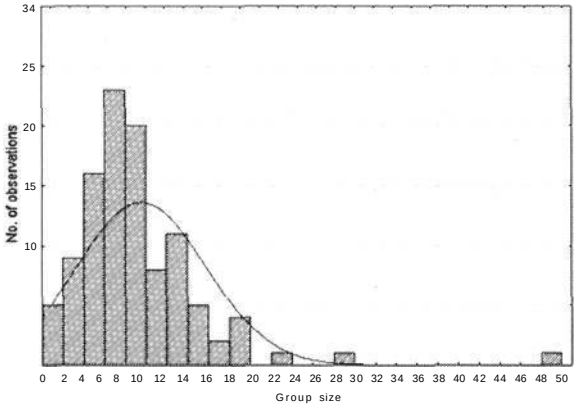

Fig. 4. Group size of Kamchatkan killer whales observed in central Avacha Gulf in September 2000 and August-September 2001-2002.

Traveling The ratio of sound categories detected during traveling was similar to the ratio found during foraging, except for underwater tail slaps, which were rarely detected during traveling. However, the total number of sounds from all categories during traveling was lower than during foraging. The number of discrete and variable calls, whistles and underwater tail slaps was significantly fewer than the random values ($p<0.001$, White test). The number of echolocation

Table 2. Comparison of group size of Kamchatkan and northeast Pacific killer whales (data for northeast Pacific population are cited from Morton 1990).

Studied populations	Range	Mean
Northeast Pacific transient killer whales	1-12	4.7
Northeast Pacific resident killer whales	3-39	10.6
Kamchatkan killer whales	1-49	9.56

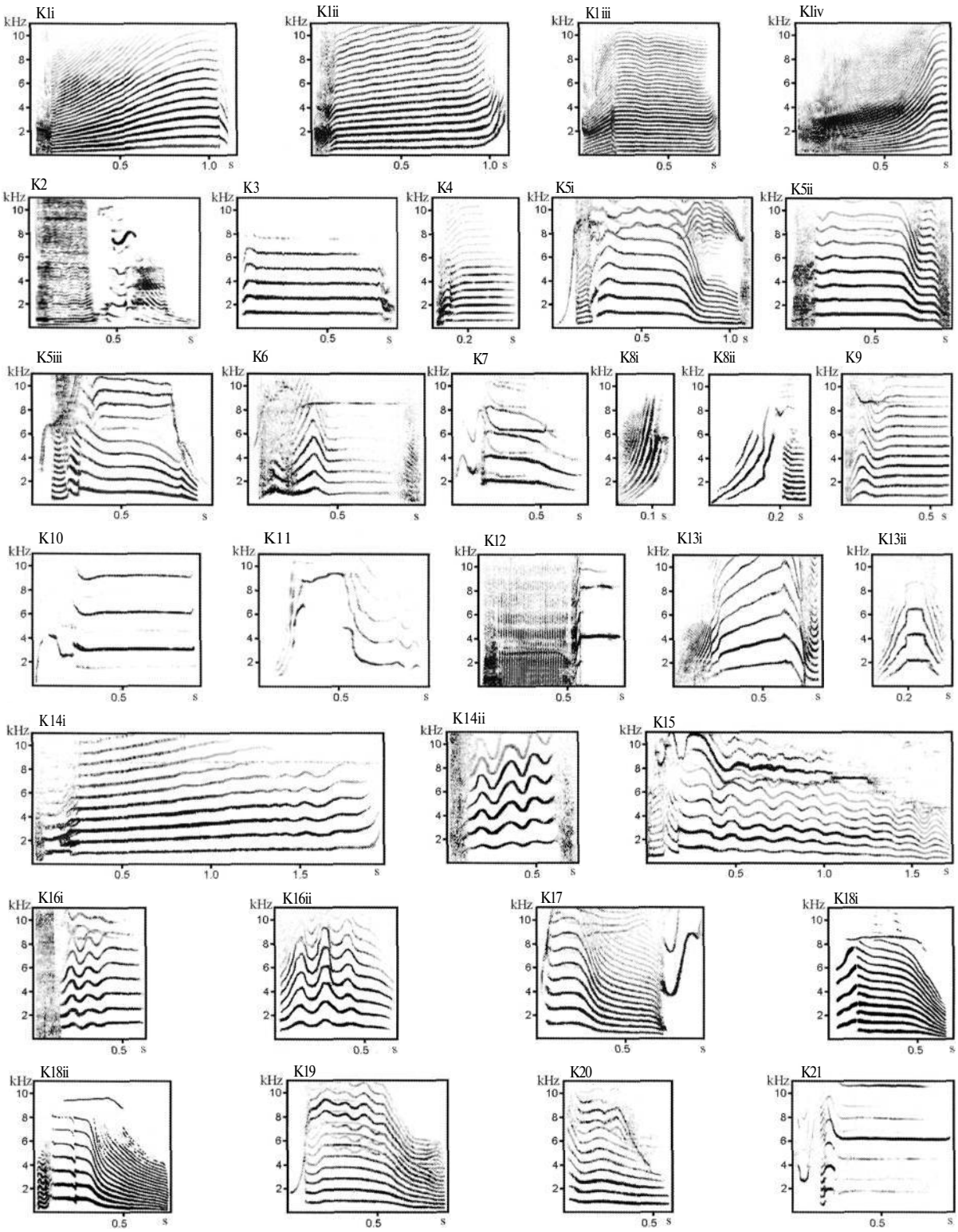

Fig. 5. Types and subtypes of discrete calls produced by Kamchatkan killer whales.

Table 3. Discrete call repertoires for seven groups of Kamchatkan killer whales.

	0209	0128c	02811b	9929b	KB	0106	0017a
K1i		+					
K1ii					+	+	+
K1iii	+		+	+			
K1iv					+		
K2						+	
K4					+	+	+
K5i	+	+	+	+	+	+	+
K5iii					+		+
K7	+	+	+	+	+	+	+
K8i					+		
K8ii					+		
K11			+				
K12i	+			+			
K12H		+			+		+
K13i					+	+	
K14i					+		
K14ii	+	+					
K15							+
K17	+		+	+			
K18i						+	+
K18ii		+			+		

Table 4. Comparison of killer whale call rates for different call categories during four activity types with the random values (values differ significantly when *p=0.001*; values significantly above the random value are shown in bold, values significantly less than random value are shown in italic)

	echolocation	discrete calls	variable calls	aberrant calls	whistles	underwater tail slaps	random value
foraging	**0.320**	**0.381**	0.292	0.135	0.293	**0.897**	0.279
p	0.000	0.000	0.430	0.088	0.654	0.000	
traveling	0.554	*0.501*	*0.307*	0.766	*0.288*	*0.103*	0.582
p	0.025	0.000	0.000	0.039	0.000	0.000	
resting	*0.001*	0.000	0.002	0.000	0.000	0.000	0.006
p	0.001	1.000	0.040	0.418	0.039	0.295	
socializing	0.124	0.118	**0.398**	0.099	**0.419**	*0.000*	0.133
p	0.317	0.130	0.000	0.434	0.000	0.000	

clicks and aberrant calls did not differ from the random values.

Resting During resting only two sound categories were detected - echolocation and variable calls, and their numbers were lower than during other activity types. The number of echolocation clicks was significantly smaller than the random values ($p<0.001$, White test). The number of variable calls did not differ from the random values.

Socializing During socializing the number of variable calls and whistles was significantly greater than the random values ($p<0.001$, White test). The number of echolocation clicks, discrete and aberrant calls did not differ from the random values. No underwater tail slaps were detected during socializing.

DISCUSSION

The relationship between foraging behavior, food and group size

The prey type of killer whales can be determined not only by direct observation, but also by indirect signs such as the behavior of animals during foraging and the location of foraging sites. "Carousel" hunting is typical for various Delphinidae species foraging on schooling fish such as *Theragra chalcogramma,* and *Gadus macrocephalus,* whereas asynchronous diving occurs when the expected prey does not gather in large schools (such as various flatfishes and mackerels). As the distribution of foraging behavior during the daytime showed a slight increase in the period from 11:00 to 14:00, this may be connected with the peak of activity of certain day active fish species, such as mackerel and herring.

Comparison of foraging regions with data from the literature (Золотов 1992) allowed us to relate these regions to the feeding grounds of Atka mackerel *Pleurogrammus monopterygius,* including female mackerel, non-breeding young males and a small number of juveniles. In addition to Atka mackerel, the larger *Hexagrammos lagocephalus,* which hunts in big groups, also occurs in these areas (Гомелюк 2000), thus being of potential interest to a large predator such as the killer whale.

Killer whales also hunt at depths between 300 and 500 meters (see Fig. 3). Fish species found in Avacha Gulf include *Sarritor frenatu, Podothecus acipenserinus, Liparis ochotensis, Careproctus furcellus* and different species of the *Pleuronectidae* family (Коростелев 2001, Токранов с соавт 2001). But the killer whale is a large predator, which is interested in larger, more numerous prey. In Avacha Gulf such species are *Theragra chalcogramma, Gadus macrocephalus* and *Clupea pallasi* (Коростелев 2001).

Killer whale group size depends directly on prey type and method of hunting (Felleman et al. 1991). When approaching prey, mammal-eating killer whales tend to use stealth with an optimal group size of one or two, or only a few animals. In comparison, foraging on a school offish requires many animals and, when successful, provides sufficient food for all individuals, which allows them to live in a larger group. The average group size we observed in 2000-2002 was closer to the group size of the fish-hunting form (resident type in the northeast Pacific), than that of the mammal-hunting form (transient type).

Foraging and vocalization

Killer whales foraging on different prey types also differ in their vocal behavior (Ford 1984, Morton 1990, Barrett-Lennard et al. 1996). Fish-feeding residents frequently emit echolocation clicks while foraging, but transients forage either in silence, or produce only isolated clicks (Barrett-Lennard et al. 1996). Transients make calls during play and after a kill, while residents produce calls during all forms of behavior (Morton 1990). Kamchatkan killer whale groups proved to be highly vocal, producing sounds in different behavioral contexts. The greatest percentage of echolocation, discrete calls and underwater tail slaps was made during foraging, which indicates that the whales were foraging on fish prey. This finding is in agreement with the results of foraging behavior observations, allowing us to consider the killer whale groups we observed in Kamchatka to be closer in behavioral terms to the northeast Pacific resident (fish-eating) killer

whales than to transient (mammal-eating) ones.

Call type repertoires defined for the seven killer whale groups studied in Kamchatka showed that each shared at least one call type with another group. This means that all these groups belong to the same acoustic clan, and thus are part of a single population (Ford 1989).

In conclusion, we can surmise that the Kamchatkan killer whales observed during this study represent one population, foraging mostly on fish, at least during the months we have made observations (August-September). We have found that these whales have biological features similar to those of northeast Pacific resident killer whale populations. They live in large groups, actively vocalize and show no interest in other marine mammal species. We cannot estimate the total number of killer whales in Kamchatkan coastal waters because of lack of data, but it is known that resident populations throughout the northeast Pacific number between fewer than 100 to no more than 600 individuals (Baird 1999, Matkin and Saulitis 1994). Recently, the northeast Pacific southern resident killer whale population obtained the status of threatened species in Canada (Baird 1999) and is being considered for threatened or endangered species status in the United States; a transient pod in Alaska representing a small separate population is now also being considered for US endangered species status (Hoyt pers. comm.). Thus, no further removals of killer whales from Kamchatkan waters should be contemplated without complete population data. However, if Kamchatkan killer whale populations are as small as those in the northeast Pacific, no removals will be advisable. At present, based on limited data, the killer whale is considered to be a common species in Russia, it is not included in the Red Book and it is protected only by the general Russian regulations for the protection of marine mammals.

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