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Occurrence of killer whales *Orcinus orca* off the Commander Islands and Avacha Gulf from 2008–2021 and its relation to the sea otter *Enhydra lutris* population decline

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ABSTRACT. Killer whale is an apex predator which plays an important role in marine ecosystems. In the Russian waters, killer whales are represented by two ecotypes — fish-eaters (R-type) and marine-mammal eaters (T-type). In our study we focused on two study areas: Commander Islands and Avacha Gulf of Kamchatka. The numbers of some species of marine mammals in the North Pacific are declining, and mammal-eating killer whales are often blamed for the decline. For example, the decline in the numbers of sea otters in Alaska is linked by some specialists to the increased predation of mammal-eating killer whales. In the Commander Islands, a decrease in the numbers of sea otters has also been observed in recent years. We analyzed the number of sightings of killer whales in the Commander Islands and Avacha Gulf to find out whether the occurrence of mammal-eating killer whales increased during the study period 2008–2021. We found no definite trend in the occurrence of mammal-eating killer whales over time in both areas. We conclude that our data provide no support to the hypothesis that the decrease of sea otter numbers in the Commander Islands was caused by the increased killer whale predation.

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KEY WORDS: killer whale, *Orcinus orca*, ecotypes, sea otter, *Enhydra lutris*, population decline, predation.

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Встречаемость косаток (*Orcinus orca*) у Командорских островов и в Авачинском заливе с 2008 по 2021 год и ее связь с сокращением популяции калана (*Enhydra lutris*)

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РЕЗЮМЕ. Косатка — хищник верхнего трофического уровня, играющий важную роль в морских экосистемах. В российских водах косатки представлены двумя экотипами — рыбоядным (R-тип) и питающимся морскими млекопитающими (T-тип). Наши исследования проходили в двух основных районах: в водах Командорских островов и в Авачинском заливе Камчатки. Численность некоторых видов морских млекопитающих в северной части Тихого океана сокращается, и в этом часто обвиняют косаток T-типа. Например, сокращение численности каланов на Аляске некоторые специалисты связывают с возросшим хищничеством косаток. На Командорских островах в последние годы также наблюдается снижение численности каланов. Мы проанализировали количество встреч косаток на Командорских островах и в Авачинском заливе, чтобы выяснить, увеличилась ли встречаемость косаток в период исследования 2008–2021 гг. Мы не обнаружили какого-либо тренда изменения встречаемости косаток T-типа с течением времени в обоих районах. Мы пришли к выводу, что наши данные не подтверждают гипотезу, что снижение численности калана на Командорских островах было вызвано усилением хищничества косаток.

КЛЮЧЕВЫЕ СЛОВА: косатка, *Orcinus orca*, экотипы, каланы, *Enhydra lutris*, сокращение популяции, хищничество.

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Introduction

Top predators play an influential role in the structure of ecosystems with a top-down effect. In the marine ecosystems, the killer whale *Orcinus orca* (Linnaeus, 1758) is considered the apex predator and its position at the top of the trophic pyramid is incontrovertible. Killer whale is a predator with a broad ecological niche (Ford, 2009; Lefort *et al*., 2020) with a diverse diet ranging in size from small schooling fish to cetaceans like blue whales (*Balaenoptera musculus*) (Ford *et al*., 1998; Krahn *et al*., 2008; Totterdell *et al*., 2022). Three ecotypes have been characterized in the Northeastern Pacific Ocean (Ford *et al.*, 1998): 'residents' that specialize on fish, live mainly in coastal waters and usually travel in large stable social units of maternally related animals (Ivkovich *et al*., 2010); 'transients' or Bigg's killer whales that hunt primarily marine mammals and typically travel in smaller, more fluid social groups (Baird & Dill 1996; Ford *et al.*, 1998), and 'offshores' that appear to feed on sharks (Ford *et al*., 2011) and occur away from shore travelling in large groups (50+) with an unknown social structure. Fish-eating 'resident' and mammal-eating 'transient' killer whales often occur in the same regions but do not socialize or interbreed (Hoelzel & Dover, 1991; Hoelzel *et al.*, 1998; Barrett-Lennard, 2000; Hoelzel *et al.*, 2007; Morin *et al.*, 2010; Parsons *et al.*, 2013; Filatova *et al.*, 2015; Foote *et al.*, 2016). They have substantial differences in morphology (Baird & Stacey, 1988; Kotik *et al.*, 2023), behaviour (Morton, 1990), acoustic communication (Deecke *et al*., 2005), social structure (Baird and Dill 1996) and other aspects. For example, a recent drone study showed that mammal-eating killer whales were on average about 7% longer than fish-eating killer whales of the same sex and age (Kotik *et al.*, 2023). There have been multiple suggestions to recognize the North Pacific fish-eating and mammal-eating killer whales as different subspecies or species based on morphological, behavioural and genetic divergence (Baird & Stacey, 1988; Reeves *et al.*, 2004; Morin *et al.*, 2010).

In the Russian waters, killer whales are represented by two ecotypes: 'residents' (fish-eaters) and they are referred to as R-type while 'transients' (marine-mammal eaters) are referred to as T-type (Filatova *et al*., 2019). The diet of killer whales varies depending on their location. The R-type in Avacha Gulf feed mainly on Atka mackerel *Pleurogrammus monopterygius* and different species of salmon (Nagaylik, 2011), while in the Commander Islands, they feed on cod *Gadus macrocephalus* (Marakov, 1967) and different salmon species that present in that area. No attacks of fish-eating killer whales on other marine mammals were observed despite they are regularly found in the same area (Filatova *et al*., 2015). On the other hand, T-type in the coastal waters of the western Okhotsk Sea, hunt on bearded seals *Erignathus barbatus* and bowhead whales *Balaena mysicetus* according to Shpak (2012). In Avacha Gulf, they have been spotted attacking a minke whale (Filatova *et al*., 2013). In the Commander Islands, hunting on seals have been repeatedly observed near fur seal *Callorhinus ursinus* rookeries (Mamaev *et al*., 2006; Belonovich *et al*., 2012) in addition to their predation on the Dall' porpoise in the waters of the islands (Filatova *et al*., 2015). Additionally, in 2020 a carcass of T-type killer whale was found during exploring the coast of northwestern Bering Island in the Commander Islands and seven sea otters *Enhydra lutris* (Linnaeus, 1758) were found in its stomach (Fomin, 2021).

By the early twentieth century, the unregulated exploitation of sea otters in the maritime fur trade reduced the species to near extinction until they were protected by the international Fur Seal Treaty (Kenyon, 1969). After that, there was a remarkable recovery of the sea otter population in their habitat (Doroff *et al*., 2011). Unfortunately, in the early 2000s the decline in the sea otter population has been noticed again in the Aleutian archipelago (Estes *et al*., 1998; Doroff *et al*., 2003; Tinker *et al*., 2005). Through previous studies, it is proved that this decline persisted (Tinker *et al*., 2021).

All the assumptions for the sea otter population declines included reduced fertility, translocation, or the increased mortality. Estes *et al*. (1998) and Doroff *et al*. (2003) assumed that the predation of killer whales played a vital role in the decline of sea otters' population. While there is a decline in the sea otters' population in the Aleutian Islands, surveys in the western Pacific Ocean (Commander Islands) have showed that the population of sea otter is at equilibrium density (Doroff *et al*., 2011), likewise in 2007 indicated the highest rate of the population has been determined in this region. Nevertheless, recently, there has also been a decrease in the numbers of sea otters in the Commander Islands (Mamaev, 2018).

In the waters of Bering Island (the largest of the Commander Islands), T-type groups mostly occur in the north and northwest of the island adjacent to two large fur seal rookeries while in the waters of the west coast both types exist. In the present study, we analyzed the number of encounters of fish-eating R-type and mammal-eating T-type killer whales in the waters of the west coast of Bering Island and Avacha Gulf to determine whether the occurrence of T-type killer whales increased during the study period (2008–2021) and if there is any relation between their occurrence and the sea otter's population decline.

Material and methods

Data collection

This study was conducted during the summer months (May–September) from 2008–2021 off the southwestern shore of Bering Island (Commander Islands) and in Avacha Gulf of Kamchatka as part of the dedicated killer whale research by the Far East Russia Orca Project (FEROP). Bering Island is a part of the protected waters of the Commander Islands Nature and Biosphere Reserve. The Commander Islands (54.93°N, 166.53°E) are located at the western edge of the Aleutian Islands

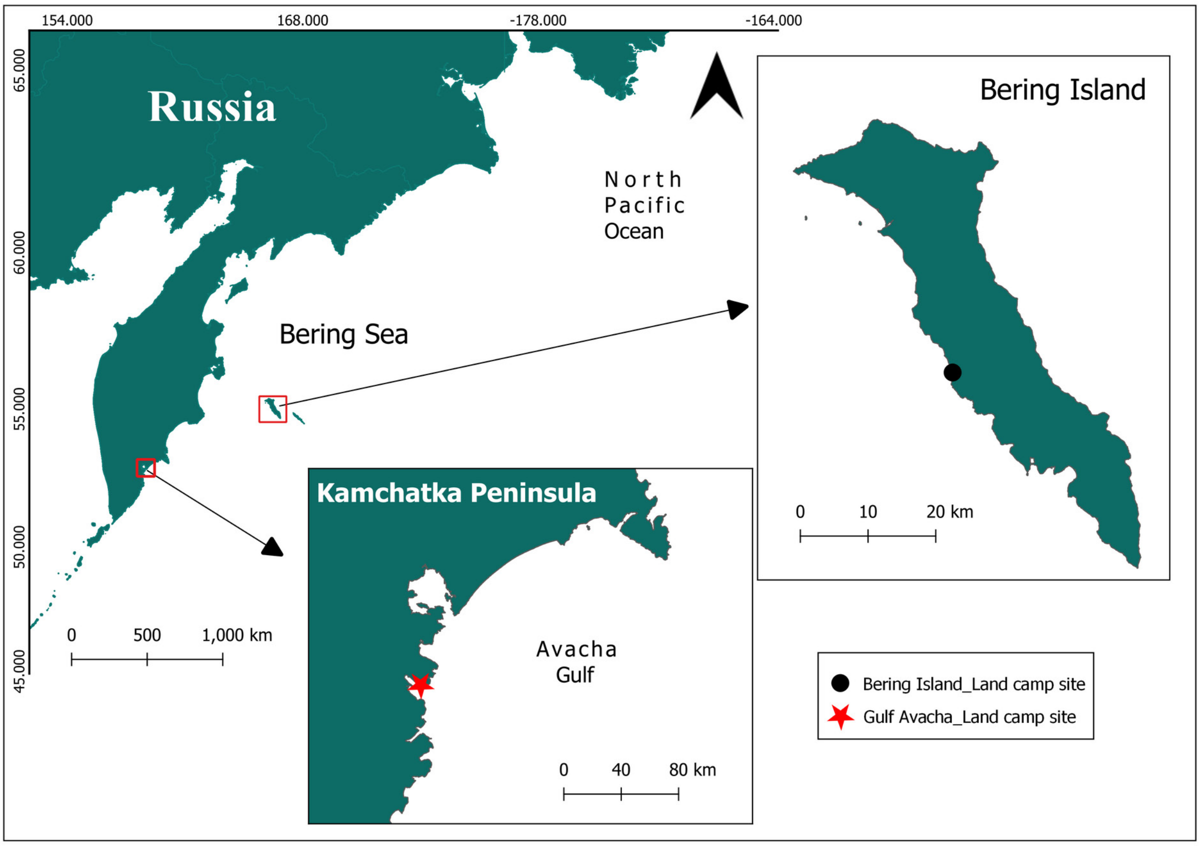

Fig. 1. Map of Russian Far Eastern seas showing the regions of the study areas (Avacha Gulf and Bering Island).

which are surrounded by the Bering Sea and North Pacific Ocean. The survey has been accomplished through camp-based observations with daily small boat surveys (weather permitting). The field camps are located in Poludennaya Bay on the western shore of Bering Island (54.98°N, 166.18°E) and in Viluchinskaya Bay of Avacha Gulf (52.62°N, 158.496°E). In Avacha Gulf, the work at sea was conducted using inflatable boats 4–5 long with outboard engines. The study area accessible by the boat ranged along the shore from Avacha Bay in the north to Listvennichanaya Bay in the south, spanning about 60 km. In the Commander Islands, inflatable boats with various lengths (4.5–5.2 meters) were used from 2008–2010, and then a 7.6m plastic boat was used in the remaining periods (Fig. 1). The study area covered the waters off the whole southwestern shore of Bering Island from Cape Severo-Zapadny to Cape Monati, spanning about 90 km. Due to the substantial area sizes covered by the surveys, the data on the occurrence of killer whales can be considered generally representative for the corresponding regions.

When a killer whale group was encountered through land observation, the team crew would attempt to approach the group while respecting a distance from 30–50m for about 10–20 min to photograph each whale. Photo identification was managed by taking photos using various Canon professional digital cameras (Canon EOS 1D, Canon EOS 5D, Canon EOS 7D) with 70–200 mm or 100–400 mm lenses. Only left side photos of the whales were used for the individual identification by the details of the dorsal fin and saddle patch.

Data on the sea otter abundance in the Commander Islands were derived from the existing publications (Kornev *et al*., 2006; Nikulin *et al*., 2008; Zagrebel'nyi, 2014; Mamaev, 2018). This study did not consider all the aspects of the influence of killer whales on sea otters, for example, during the study we did not observe the sea otters' reaction toward the presence of killer whales, neither did we assess the stress hormones in their blood. No sea otter surveys were performed in Avacha Gulf during the study period, so we used our opportunistic observations in order to roughly assess the presence of this species in the study area.

Ecotype identification (differences in R-type and T type in photo)

According to previous studies, killer whales in the Russian waters are represented by two ecotypes, resident (R-type) and transient (T-type) (Burdin *et al*., 2004; Shulezhko *et al*., 2018; Filatova *et al*., 2019), and identifying their ecotypes depends on several parameters.

First one is morphological variation in the dorsal fin and the saddle patch. Those variations have been specified as distinguishing features to determine the killer whale ecotypes in the eastern and western North Pacific Ocean (Baird *et al*., 1988; Filatova *et al*., 2015; Emmons *et al*., 2019). During the examination of the photographs that were taken during the encounter, some whales show typical distinct patterns characteristic of a particular ecotype, which allows to identify the ecotype. Since some whales are identified in a group based on morphological characteristics, the whole group can be classified as R- or T-type because killer whales from different ecotypes are socially and genetically isolated (Hoelzel *et al*., 2007; Miller *et al*., 2010). For example, only R-type whales are known to have open saddle patches (Baird *et al*., 1988); therefore, all the groups that had any whales with open saddles were classified as R-type. On the other hand, the combination of a large, closed saddle patch and sharp triangular dorsal fin is more common in the T-type whales (Emmons *et al*., 2019) (Fig. 2). Although individual animals do not always have unambiguous external features identifying their ecotype, observations of the appearance and behavior of a whole group in all cases allowed to determine its ecotype. Also, for some encounters, genetic analysis of biopsy samples based on the sequence variation of the control region of mitochondrial DNA was used to identify the ecotype (Parsons *et al*., 2013).

Results

In the Commander Islands, it was found that the highest occurrence of T-type killer whales was noted in the first year of the study (2008). In this year, mammal-eating killer whales were observed in 18% (4 out of 22) working days. Fish-eating killer whales in the same year were encountered in 100% of working days, because in the first year we only went out when killer whales were observed. In subsequent seasons, we went out to work at sea weather permitting even if no killer whales were present, and the occurrence of R-type killer whales ranged from 76% in 2009 to 43% in 2018, averaging 63%. The occurrence of T-type killer whales in subsequent seasons ranged from 0–9% and averaged 6%. No sightings of mammal-eating killer whales were recorded in 2014 and 2018. During 2009, 2012, 2013, 2015, 2019 and 2021, the occurrence of mammal-eating killer whales was more than the average (6%) while in 2008, 2010, 2011, 2016 and 2017 was lower than the same average. No particular trend in encounter rates was obvious through the years.

In Avacha Gulf (Kamchatka Peninsula), the encounter rates of killer whales also showed no trend over the study years (Fig. 3). The data from Avacha Gulf were added to this analysis in order to illustrate the lack of correlation between species abundance. No sea otter surveys have been performed in Avacha Gulf during our study period, but our opportunistic observations suggest

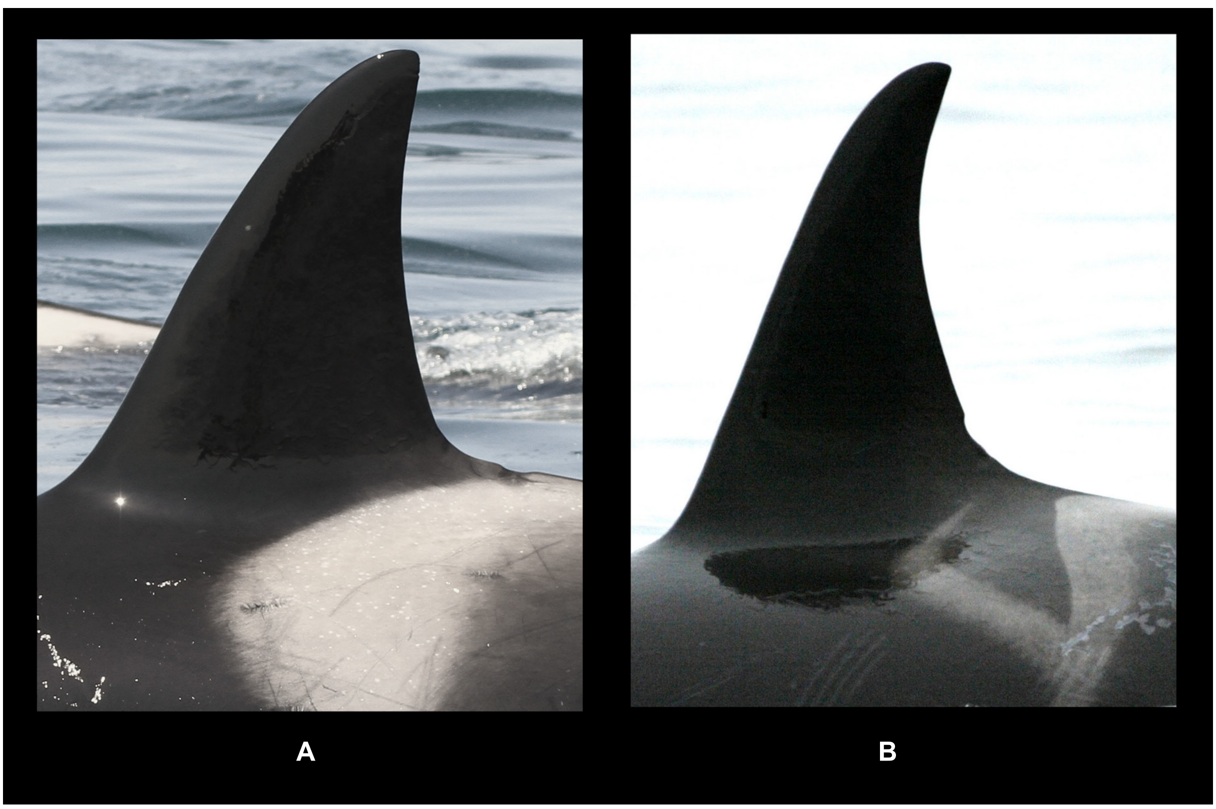

Fig. 2. Variation in the saddle patches and dorsal fins of T-type (A) and R-type (B) killer whales.

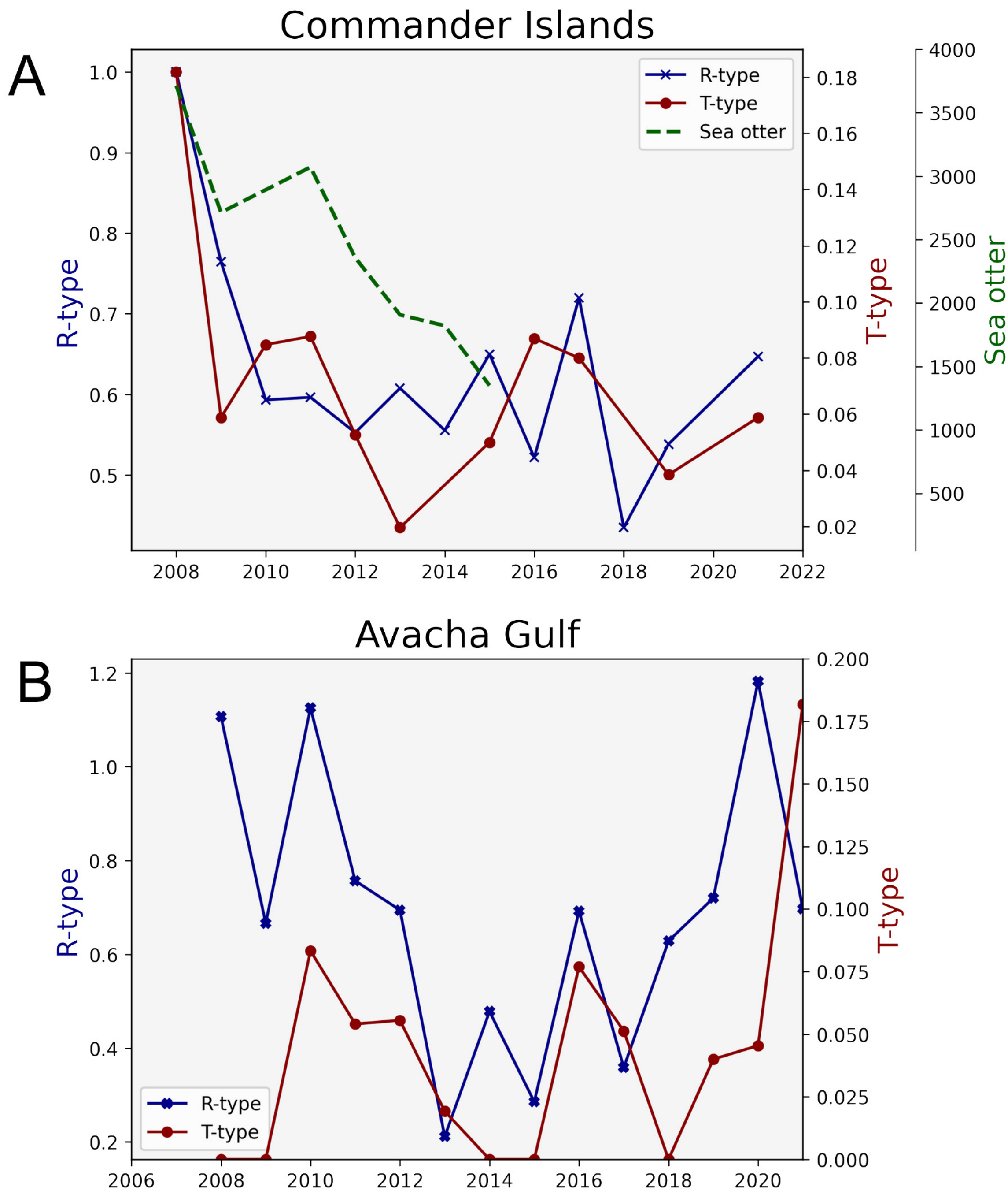

Fig. 3. A — Encounter rate (encounters per day at sea) of the R-type and T-type killer whales in the Commander Islands during the study period (2008–2021) and abundance of sea otters in the waters of Bering Island from 2008–2015 (according to Mamaev, 2018); B — encounter rate of the R-type and T-type killer whales in the Avacha Gulf during the study period (2008–2021).

that sea otters became more common in that area across the study years. In the early 2000s, sea otters were almost never observed in Avacha Gulf, and in the last years they became a common species in the area.

Simple linear regression was used to test if the occurrence of T-type killer whales across the years is significantly predicted. The overall regression of Commander Islands and Avacha Gulf were statistically insignificant (Commander Islands: R2 = 0.2678, df = 11, $p = 0.0700$; Avacha Gulf: R2 = 0.1722, df = 12, $p = 0.1401$). This means that the presence of the T-type killer does not increase or decrease within years nor follow any trend.

Discussion

Over the last 20 years, sea otters *E. lutris* in the Aleutian Islands, Alaska, USA, experienced a drastic decrease in their population size. This unexpected decline started to be noticed by 1991–1998 (Estes *et al*., 1998). This decline occurred after a century of recovery to their near maximum densities (Lentfer, 1988). According to an aerial survey and a skiff survey from 1991–2000, the decline of sea otter population was described as one of the most widespread and steep population declines for a mammalian carnivore in the recorded history (Doroff *et al*., 2003) while surveys that have been conducted on the sea otters at the same period in the Commander Islands, Russia confirmed a stable population since 1992 (Bodkin *et al*., 2000).

Any changes in the population size can occur only by three demographic processes: births, translocation (immigration or emigration) and mortality (Gotelli, 2001). However, lately fertility was excluded as an explanation for the sea otter population decline because it was found that the birth rates of adult females and pup survival rates from birth to weaning were similar to stable populations. Furthermore, even a complete failure in reproduction cannot explain the rapid rate of population decline in 1990 (25% per year) (Estes *et al*., 1998; Gerber *et al*., 2004). Additionally, in view of the fact that sea otters barely travel long distances (more than 1000 km), translocation (either immigration or emigration) has been ruled out as a reason for the decline (Garshelis & Garshelis, 1984; Ralls *et al*., 1996; Bodkin *et al*., 2000; Tinker *et al*., 2008; Laidre *et al*., 2009); moreover the declines were simultaneous over large areas and there was no population accumulation on some islands to explain the losses in others (Estes *et al*., 1998). This assumed that the mortality was the only possible reason for the sea otter decline in the Aleutian Islands. Some possible reasons for this mortality, including diseases, toxins, and starvation, were excluded because of the lack of any evidence (Hanni *et al*., 2003; Tinker *et al*., 2021), leaving predation as the most likely reason for the decline.

At the same time, the lack of decline in the neighboring Commander Islands remained a mystery (Doroff *et al*., 2003). Status of the sea otter in the Russian waters has different aspects. Sea otters' distribution after the recovery occurs in three regions: Commander Islands, Kamchatka Peninsula, and the Kuril Islands (Wilson *et al*., 1991; Murata *et al*., 2008; Ovsyanikova *et al*., 2020). Surveys of 1980 which have been conducted in the Commander Islands showed that population of sea otter was at equilibrium density (Riedman *et al*., 1988). In 1991, estimation of the sea otter population and their mortality in the same region showed that the rate of mortality was high in the age group older than 8 years. On the contrary, this was not noticeable in the middle age classes. All the information has been collected from stranded animals and it cannot be reliable to determine the age and sex structure of the population as a whole (Zagrebel'nyi, 2004). Further, surveys in 2007 indicated the highest sea otter counts obtained for this region (> 7000) according to IUCN report (Doroff *et al*., 2011). Over the Kamchatka Peninsula, the majority of sea otters are settled along the southern region of the Peninsula because of the sea ice in the northern regions, and the sea otter population was estimated approximately at 2500 (Doroff *et al*., 2011). During the later years, the population of sea otter in the Commander Islands was considered stable (Kornev *et al*., 2006; Nikulin *et al*., 2008; Zagrebel'nyi, 2014) until 2015. After 2015, surveys have discovered a decline in the Commander Islands sea otter population (Mamaev, 2018). The total sea otter population of the Commander Islands was estimated at 3259 individuals, including 450 juveniles. Contrary to the Aleutian Islands, reduction in food supply in their habitat hasn't been excluded as a reason of sea otter population decrease in the Commander Islands. Mamaev (2018) assumed that the recovery of sea otters' population influenced the stocks of the most preferred food item (sea urchin), where the sea urchin biomass in 1970 was 969 g/m^2 and in 1989 — 11 g/m^2 and the population of big crabs, hermit crabs, holothurians and octopuses also significantly declined (Oshchurkov, 1990). Therefore, it was assumed that a gradual reduction in the sea otter population will occasionally stabilize to a lower level.

Many previous studies in the central and western Aleutian Islands have suggested the killer whale predation as the primary cause of the sea otter decline (Estes *et al*., 1998; Williams *et al*., 2004; Tinker *et al*., 2005). This theory was based on some indications like the increasing numbers of killer whale sighting nearshore, a substantial increase of killer whale attack rate on sea otters, an ongoing increase in the number of sea otters in the habitats that provided protection for them from the predation of killer whales (Stewart *et al*., 2015). The influence of killer whales (R-type and T-type) on marine ecosystems varies greatly due to their trophic level positions: The nutrition of R-type depends mostly on large fish while the T-type feeds largely on seals and porpoises, that prey on large or small fishes, and occasionally feed on baleen whales that feed on plankton, krill, and small schooling fish (Baird *et al*., 1995). Therefore, their expansion may have different consequences for ecosystems. Moreover, it was presumed that killer whales included sea otters in their diet due to the drop in the population of their preferred prey, harbor seals *Phoca vitulina* and Steller sea lions *Eumetopias jubatus* (Estes *et al*., 1998). In contrast, neither sea otter nor pinniped populations in the Commander Islands have declined to the degree that they have in the Aleutian Archipelago (Bodkin *et al*., 2000).

In addition to that, there was a hypothesis proposed by Springer *et al*. (2003) that killer whales (T-type) might take sea otter as an alternative food resource due to commercial whaling which led to the decimation of the great whales. The great whales likely provided an important food resource for killer whales (Baldridge, 1972; Goley *et al*., 1994). Nonetheless, all the published data and theoretical considerations for socially foraging mammals (both marine and terrestrial) obviously point that unidirectional prey switches of extended duration are seldom and maladaptive (O'Donoghue *et al*., 1998; Van Baalen *et al*., 2001).

Despite the fact that many studies identified the predation of killer whales as the most likely cause of the sea otter decline (Estes *et al*., 1998; Williams *et al*., 2004; US Fish and Wildlife Service, 2013), there is an opposing view which consider it as an uncertain hypothesis because the supporting data are limited and uncertain (Kuker *et al*., 2010).

The predation of any species other than killer whales rarely considered as a factor in the decline of the sea otter population. Sharks could be another predator of sea otters like killer whales. For example, in California it is known that white sharks *Carcharodon carcharias* prey on sea otters (Ames *et al*., 1980); however, white sharks are relatively rare in the Aleutian Islands (Martin, 2004). On the other hand, there are other types of sharks such as Pacific sleeper sharks *Somniosus pacificus* and salmon sharks *Lamna ditropis* which are very common in the Aleutians Islands (Gaichas, 2003) and in addition to that, their abundance increased in various places at the Gulf of Alaska, the Bering Sea, and Aleutian Islands region (Gaichas, 2003; Mueter *et al*., 2002; Courtney *et al*., 2007; Okey *et al*., 2007). Until now, these increments are not confirmed, however it is supposed that this is a reaction to the increased availability of prey, which could be sea otters. Predation of those sharks on sea otters cannot be observed because they hunt at night and under the water. Sleeper shark and sea otter habitats overlap during the night (Hulbert *et al*., 2006; Van Den Hoff & Morrice, 2008). Although there is no direct evidence that Pacific sleeper sharks and salmon sharks prey on sea otters, it was found that 14% of stomachs of 165 Pacific sleeper sharks consisted of marine mammal tissue (Sigler *et al*., 2006) and also the diets of Pacific sleeper sharks and Greenland sharks have been shown to include living marine mammals (Crovetto *et al*., 1992; Lucas *et al*., 2000; Kubodera *et al*., 2007; Van Den Hoff & Morrice, 2008).

While there is direct evidence that at least one population of killer whales feed on sea otters (Vos *et al*., 2006; Fomin, 2021), there is no confirmation that changes in the distribution or abundance of killer whales in the Aleutian Islands occurred simultaneously with the decline of the sea otter, but in the case of sharks there is evidence of an increase in numbers with no direct evidence of predation as described above. Overall, all these assumptions do not exclude sharks however, they are considered less accused than killer whales due to the lack of any direct evidence or observations of their consumption.

In fact, all those previous hypotheses about the role of killer whale on the sea otters decline are realistic and can be taken into consideration in the Aleutian Islands. But in the Commander Islands and Kamchatka Peninsula, the situation is different due to several aspects.

Despite the fact there was a T-type killer whale carcass with a stomach filled with sea otters (seven otters) in the winter of 2020 (Fomin, 2021), this cannot be considered solid evidence of the dependence of killer whales on sea otters as their prey especially since it is the only case. It can be explained as a reaction to a lack of food supply during this time period (winter) due to the migration of the fur seals (Kenyon *et al*., 1953; Ream *et al*., 2005). Moreover, in the Commander Islands and near areas, it is considered that northern fur seal is the most important and preferred prey for T-type killer whales. Most recorded killer whale attacks on the Commander Islands occurred close to the northern fur seals rookeries and almost all attacks were on northern fur seals. Therefore, fur seals are considered as a shield for other marine mammals' species from killer whale predation (Belonovich, 2011). Furthermore, according to our data during the study period from 2008–2021, the occurrence of T-type killer whales did not increase significantly within this study period. Thus, it can be concluded that the decrease in the number of sea otters in the waters of the Commander Islands, obviously, is not a consequence of the increase in the number of mammal-eating killer whales. In the Avacha Gulf of Kamchatka, no sea otter surveys have been performed, but our opportunistic observations suggest that sea otters became much more common in that area across the study years. When we started our work with killer whales in early 2000s, sea otters were almost never observed in Avacha Gulf, and in the last years they often occur there.

Combined with the lack of trend in T-type killer whales encounter rates, these data suggest that killer whale predation in Avacha Gulf is also not the driver of change in sea otter population abundance. Therefore, our data in both study areas provide no support to the hypothesis that mortality induced by killer whale predation is a significant factor in sea otter population trends in the Russian Far East.

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