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NESTING ECOLOGY OF PEREGRINE FALCON IN SOUTHERN YAMAL

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Nesting ecology of Peregrine Falcon in southern Yamal.

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Cold Region Environmental Landscapes Integrated Sciences (CORELIS) / 05.04.06 Ecology and Nature Management

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Abstract. This study aim is to investigate nesting ecology of peregrine falcon in southern Yamal *(a twenty-four-year monitoring regarding reproductive success and occupancy of nest territories).*

Экология гнездования сапсана на южном Ямале.

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ВМ.5710.2022 «Комплексное изучение окружающей среды полярных регионов (CORELIS)» / 05.04.06 Экология и природопользование

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Аннотация. Целью данной работы является изучение экологии гнездования сокола-сапсана на Южном Ямале (двадцатичетырехлетний мониторинг репродуктивного успеха и занятости гнездовых территорий).

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Оглавление

Introduction

The ecosystems of the northern regions are under severe transformations as a result of climate change and anthropogenic and natural disturbance (Anisimov et al, 2007; J.J. Taylor et al, 2020). Numerous projects of international organizations (IASC, ACIA, CAFF) are devoted to this problem. In this context, one of the main directions in Arctic research is the study of the ecological features of various animal groups (Chernov, 2008; Franke, 2019; J.J. Taylor et al, 2020). The influence of various factors on the state of the ecosystem increases from one trophic level to the next (Anisimov et al, 2007). In this regard, birds are a convenient model object for monitoring, showing the state of fragile ecosystems (J.J. Taylor et al, 2020). Comprehensive studies of the ecology of birds of prey, including the development of simple non-invasive methods for studying abundance, spatial distribution, nesting success and nutrition spectrum, will help to assess changes occurring at all levels of Arctic ecosystems (Franke et al, 2011).

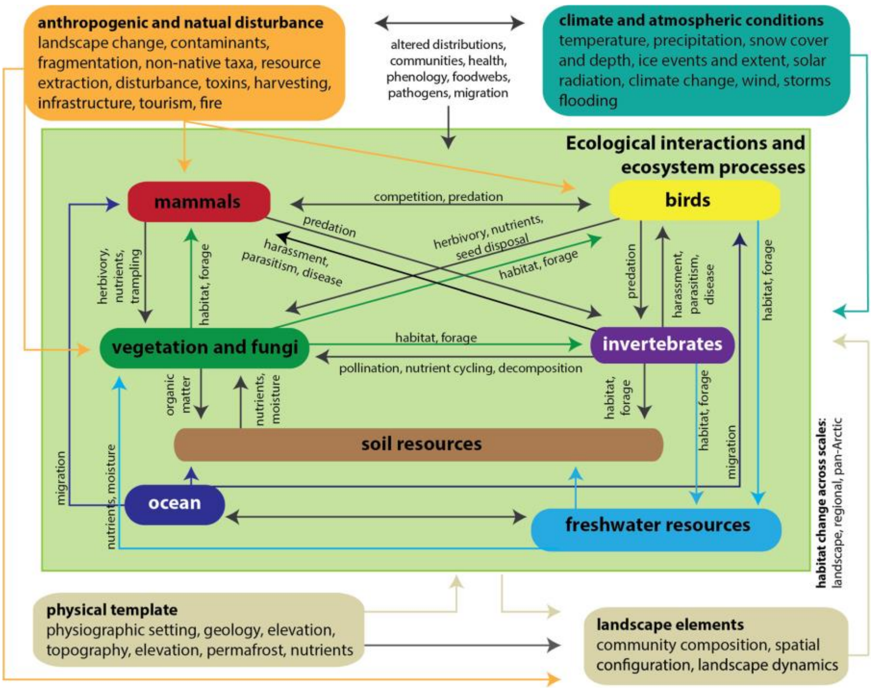

Fig.1. Jason J. Taylor et al, 2020 Arctic terrestrial biodiversity status and trends: A synopsis of science supporting the CBMP State of Arctic Terrestrial Biodiversity Report.

The number of terrestrial bird-monitoring studies across the Arctic has enhanced but spatial coverage is uneven with most monitoring in the low Arctic (and sub-Arctic), Iceland, and Scandinavia, and relatively few in high Arctic; the Arctic Archipelago and Canada, Greenland, and central and eastern Russia are relatively poorly covered for all FECs (focal ecosystem components) (J. Taylor et. al, 2020).

The northeast of Yamal region, Russia suffered from intense anthropogenic impact in the second half of the 20th century. Due to the new wave of anthropogenic activities and natural disturbance (i.e. the development of gas condensate fields on the territory of Yamal region), the study of the ecology of birds of prey as indicators of the state of ecosystems of the southern tundra is becoming especially relevant.

Therefore, we want to pay attention to nesting ecology of peregrine falcon in southern Yamal, Russia. Nowadays in southern Yamal monitoring of 20+ nest sites in permanent area is performed since 1999.

The work presented here is a synopsis of peregrine falcon nest monitoring at the Erkuta river area, southern Yamal.

Peregrine falcon (*Falco peregrinus*) is a top avian predator within Arctic food webs and a Red-data book species. It is one of the key species of long-term field site monitoring in Erkuta area in southern Yamal (68°130N 69°090E), Russia.

Peregrine falcon is exposed to the effects of climate change, including shifts in weather regimes that can affect breeding phenology and success directly (Franke et al. 2010; Anctil et al.2014; Lamarre et al. 2018), or indirectly from habitat loss mediated through shrubification (Wheeler et al. 2018), and changes in food supply (Nielsen et al, 2011).

Besides, being a top predator along with gyrfalcon (*Falco rusticolus*) (Franke, 2019), peregrine falcon is very important species for geese and some ducks, their nests are often found near peregrines nests, protecting their own nests from other avian predators and foxes' peregrine falcon also protect birds nesting close to them ("umbrella effect"), but it's not always a safe case (Danilov, 1984, Pokrovskaya, 2023). Thus, on Erkuta study area two endangered goose species are almost obligatory nest close to falcons (Lesser white-fronted goose and Red breasted goose) (Sokolov et al, 2014). Monitoring of such species gives us a complex understanding of fragile ecosystems.

The aim of this work is to investigate nesting ecology of peregrine falcon in southern Yamal *(a <u>twenty-four-year</u> monitoring regarding reproductive success and occupancy of nest territories).*

The objectives of the study were:

(1) to analyze the literature on peregrine falcons;

(2) to identify and verify factors influencing the peregrine falcons' productivity and breeding success;

(3) to reveal the occupancy of nest territories during the study period

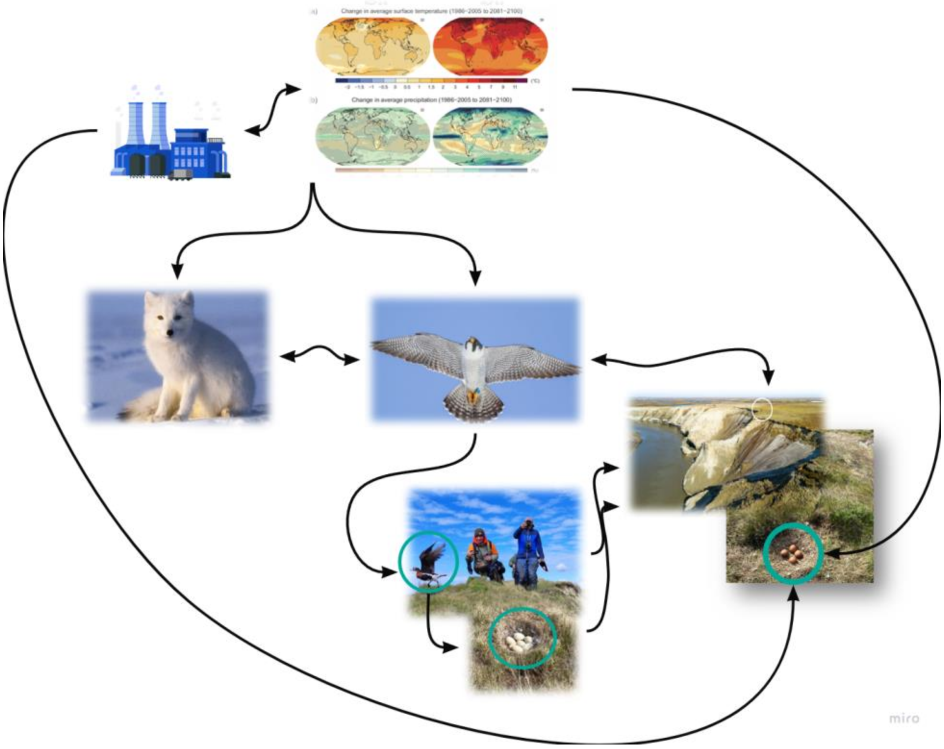

Fig.2. The scheme representing the connections between peregrine falcon and ecological interactions and ecosystem processes (IPCC-report,2013; Franke et al, 2019).

The hypothesis of the work are follow:

- We assumed that breeding success depends on slope exposure (Wheeler et al, 2018; Beardsell et al,2016).

There is the highest breeding productivity on the southern exposition slopes than on any other exposition.

- We assumed that there is a dependence of hatching ratio on climatic conditions (i.e. temperature, precipitation) (Franke et al, 2011; Anctil et al, 2014; Lamarre et al, 2018).

The hatching ratio decreases with an increase of temperature and precipitation.

- We assumed that the occupancy of the nest sites could be either stable, decline, increase or cycling

If the occupancy is stable the population is super resilient to changing environmental factors during the study, if not - environmental factors have some effect.

Material and Methods

Literature analysis on Peregrine Falcon

Peregrine falcon (*Falconidae, falco*) is a medium-sized raptor with long, pointed wings, dark hood and face, with distinct dark malar stripe, slate gray back, and barred belly, legs, and tail (Franke, 2019) (Fig.3). This species is highly – territorial, cosmopolitan: breeding population occur on every continent, except Antarctica and on many ocean islands (White et al,1968; Danilov, 1984).

Fig.3. *Peregrine falcon (Franke et al. 2019)*

The peregrine falcon is considered to be a generalist predator that predominantly consumes avian prey (White et al, 2013). The prey range in size from small passerines weighing less than 10 grams to large waterfowl (geese) and herons where they are available. (White et al, 2013; Danilov, 1984). Also the variety of prey depends on the region where peregrine falcon is found. On Yamal region, the feeding of peregrine falcons on the Yamal was established by 25 species of birds, among which sandpipers prevailed in terms of the number of species and wasps (48%), followed by white chickens (17%), sparrows (17%) and ducks (14%) (Osmolovskay, 1948 Danilov, 1984). This year we found the ring of purple plover, which had been ringed in Norway, on the nest of peregrine falcon (Fig.4). In tundra regions peregrines catch lemmings and voles in the "peak years" when the rodents are superabundant, but otherwise small terrestrial mammals constitute an insignificant fraction of prey (White et al, 2013; Danilov, 1984, Franke et al, 2019).

Fig.4. The ring of purple plover on Peregrine falcon nest site.

Like other species of falcons, the peregrine falcon is limited in is use of nesting sites by its inability to construct a nest, other than to make a shallow scrape in soil or similar loose materials. Despite it peregrine falcons are able to nest in a remarkably wide variety of locations. Throughout its worldwide range, a ledge or hole on the sheer face of a rocky cliff or crag is the favored type of nesting site (White et al, 2013). The sheer face can range from a few meters to hundreds of meters high, depending on geographical location, degree of safety from nest predators and population pressure for nesting sites.

Sometimes peregrines take over the old stick nests of other cliff-nesting species such as the raven, rough-legged buzzard, or golden eagle. Usually peregrine falcons' cliffs overlook a lake, river or sea (Osmolovskay, 1948; Danilov, 1984). Peregrine falcons also nest on other formations that range from rocky cliffs through steep earthy slopes and cut banks along rivers to mounds on flat tundra, sand dunes (rarely), and low lying bog nests. The ground-nesting sites occur only in restricted parts of the total range (i.e. on Yamal Peninsula). On Yamal Peninsula peregrine falcons mainly nest on the coastal cliffs of the southern exposure, typically, nest has a form of a scrape (Fig.5, Fig.6). The Peregrine nests up to the north ridge of the Yamal Peninsula (Paskhalny and Golovatin, 2009).

Fig.5. *Typical sandy cliff breeding habitat for peregrine falcons on the Yamal Peninsula, Russia (Franke et al. 2019).*

On Yamal Peninsula, peregrine falcons usually appear in late April - May (later on the northern peninsula). They depart, apparently, in September - early October (Osmolovskay, 1948; Danilov, 1984). Peregrine falcons have close contact with their nesting territories for many years, although a nest locality can change annually for different reasons (Danilov, 1984, Paskhalny and Golovatin, 2009, Sokolov et al, 2014). In territories of regular nesting birds, the same nest site plots can be occupied for many generations. For example, Osmolovskaya in 1942 found a peregrine nest in the same hill Tir-sede where it was first found by Zhitkov in 1908 (Danilov, 1984). Sometimes these sites are used most years with the odd absence in some years. Therefore, Peregrine nest sites may be potentially used also only once or twice over several years. In tundra nesting territories are generally considered to be associated with rugged terrain (particularly coastal, lake-shore and river-side cliffs, and rock outcrops), but peregrine falcons also utilize thermokarst bluffs in northern Alaska (Franke el al, 2019), and commonly nest on the ground in the peat bogs of Fennoscandia (Lindberg et al., 2008). The optimal area for the Peregrine in the Yamalo-Nenetsky region (the region of study) is now in the south subarctic or shrubby tundra, between 68 and 69 parallels.

Fig.6. *Typical nest-site, Yamal Peninsula, Russia*

The number of eggs in a clutch varies from 2 to 4 (Danilov, 1984). The first eggs are laid in early June, the incubation period lasts on average about 33-35 days (Osmolovskaya, 1948, Danilov, 1984) (Fig.7). In Erkuta study area one documented 5 eggs clutch appeared in 2018, discovered by A. Sokolov and working team, the nesting territory Per Khanado. Female peregrines undertake the majority of incubation (Ratcliffe, 1993), and this pattern was evident in Sokolov et al, 2014 study as they only caught one male in the ten birds trapped during incubation period.

Fig.7. *2- 3 days old chick, Yamal Peninsula, Russia*

The population of peregrine falcon was severely depressed by pesticides (Lindberg, 2008.), but now considered to have increased (Franke et al, 2019) nowadays. After experiencing lows in abundance in the 1970s, the peregrine falcon has recovered from pesticide induced population crashes throughout the Nearctic and Palearctic (J. Taylor et. al, 2020).

In Soviet Union times the population of peregrine falcons was rather imprecise, it seemed to be that there might be around 1000 pairs in European Russia to Caucasus region and eastward to the Volga River. (White et al, 2013). In tundra and taiga, it was hard to give a proper estimation of nesting pairs. Referring to the period before the pesticide crash, some suggested that a population of several thousand pairs occurred east of the Ural Mountains. After pesticide depression the population of peregrine falcon was thought to be rare in these regions (Danilov, 1984). In the next two decades, as a result of direct persecution and a sharp increase in the death factor, the peregrine falcon practically disappeared from all previously known nesting sites, and the total number of its encounters significantly decreased (Danilov, 1984).

Nowadays in Russia, the peregrine falcon is listed in the Red Data Book, although the population has the least-concerned status.

The peregrine falcon monitoring in Russia has a sporadic nature (J. Quinn and Y. Kokorev, 2000; A. Franke et al, 2019, J. Taylor et al, 2020). The peregrine falcon monitoring researches were conducted in the low mountains of the Middle Urals (V. Korovin et.al, 2017), on the Kola peninsula, where the last stable Peregrine *(Falco pereginus*) population in European Russia, has retained (Ganusevich, 2004), the detailed estimation on population status in Yamal and lower Ob region was given by Sergey P. Paskhalny and Mikhail G. Golovatin in 2009, in 2014 the site fidelity and home range variation was estimated by A. Sokolov et.al.

For the top avian predators, (Franke et al., 2019) provided the first overview of monitoring sites for gyrfalcons and peregrine falcons. The authors analyzed long-term trends in occupancy and productivity and summarized information for recommended CBMP FEC attributes. At the circum-Arctic scale, for peregrine falcons, 9 of 12 monitoring sites indicated that occupancy was either stable or had increased over the course of monitoring, and three monitoring sites resulted in trends that indicated occupancy had declined. Seven of 10 peregrine falcon monitoring sites presented productivity trends that were either stable or increasing, and three resulted in trends that had declined. On Yamal peninsula the declining trend was shown, but the decreasing population trend in peregrine falcon occupancy was shown in A. Franke et al. 2019, but the validity of the decreasing trends is uncertain, and it is possible that they are confounded with survey methods. The actual article by A. Franke was one of the reasons to conduct our further research for to estimate the situation with peregrine falcon in southern Yamal.

In this work we concentrated on natural factors influencing peregrine falcon in the most vulnerable period – nesting period.

As outlined in the CBMP Arctic Terrestrial Biodiversity Monitoring Plan (Christensen et al. 2021), ‘‘birds, as keystone consumers in Arctic ecosystems, are highly affected by the processes and drivers (biotic, abiotic and anthropogenic) that affect their food base… Furthermore, for many of the long-[distance] migrant species, the major factors affecting the abundance of avian species may operate outside of…the annual cycle when the birds are present in Arctic regions.’’ The latter point makes birds unique because other FECs (focal ecosystems components) must cope with the Arctic winter, whereas the majority of Arctic-breeding bird species leave the Arctic in winter. Many of them move relatively short distances to temperate regions, while some winter in the tropics and the southern hemisphere. Thus, compared to other terrestrial FECs, birds are affected by a range of drivers over wider scales (Taylor et al, 2020).

As stated in Paskhalny and Golovatin, 2009, peregrine falcon is tolerant to human disturbance if there is no presence of persecution. During the development of the Bovanenkovsky gas field in 1988-90, the workers' houses were located next to the peregrine falcon nest, placed 100 meters from the cliff. According to the documents, people appeared near the nest, all-terrain vehicles, helicopters flew, motorboats sailed along the river. Nevertheless, the birds raised chicks every year - unfortunately, the chicks died because they fell off a cliff when they were disturbed. In 1997, a nest with four chicks was found in the same place. In 2005 and 2006, the pair successfully nested at an altitude of 200 meters on a nearby cliff (Paskhalny and Golovatin, 2009).

In many cases Peregrines that have been disturbed moved to a more secure place at a greater distance away while staying in the limits of their nesting territory.

In Yamal region there is one more specific fact that can impose pressure on peregrine falcons except human disturbance is the grazing by reindeer. This region is experiencing the biggest constantly increasing population of these animals in the world. On the seashore near the mouth of the Yundyyaha river (70º30'N) on the 7th July 2006 peregrine nest was found with the presence of numerous traces recent reindeer tracks. In the nest was a broken egg; birds demonstrated very weak anxiety. The male disappeared completely when observers were at a distance 300 m from the nest (

At the moment, after the slow recovery of the population, the echoes of which are noticeable around the globe, the peregrine falcon is exposed to new, more significant risks. According to IPCC reports, under conditions of rapid climate change, weather conditions will be strongly modified (IPCC – report, 2013). For several decades, surface air temperatures in the Arctic have warmed at approximately twice the global rate. The really averaged warming north of 60°N has been 1-2°C since a temperature minimum in the 1960s and 1970s. The most recent (1980 to present) warming of much of the Arctic is strongest (about 1°C/decade) in winter and spring, and smallest in autumn. Precipitation in the Arctic shows signs of an increase over the past century, although the trends are small (about 1% per decade) (Anisimov et al, 2007). The Arctic region will warm more rapidly than the global mean, and mean warming over land will be larger than over the ocean (very high confidence) (Fig.8, Fig.9).

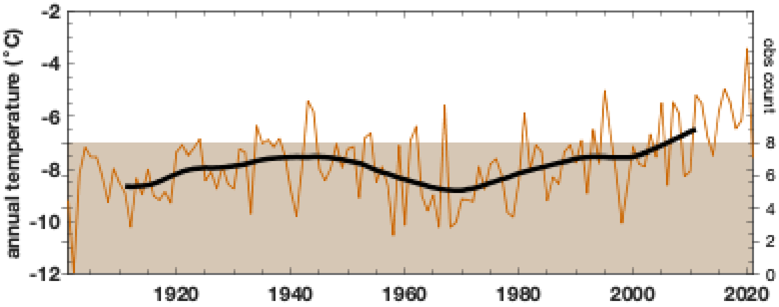

Fig.8. Annual temperature on southern Yamal (in study area) (cru.data source, Harris et al. (2020) doi:10.1038/s41597-020-0453-3)).

Many polar species are particularly vulnerable to climate change because they are specialized and have adapted to harsh conditions in ways that are likely to make them poor competitors with potential immigrants from environmentally more benign regions (Peck et al, 2006). Other species require specific conditions, for example winter snow cover or a particular timing of food availability (Peck et al, 2006). In addition, many species face multiple, concurrent human-induced stresses (including increased Ultraviolet-B radiation, increasing contaminant loads, habitat loss and fragmentation) that will add to the impacts of climate change (Anisimov et al, 2007).

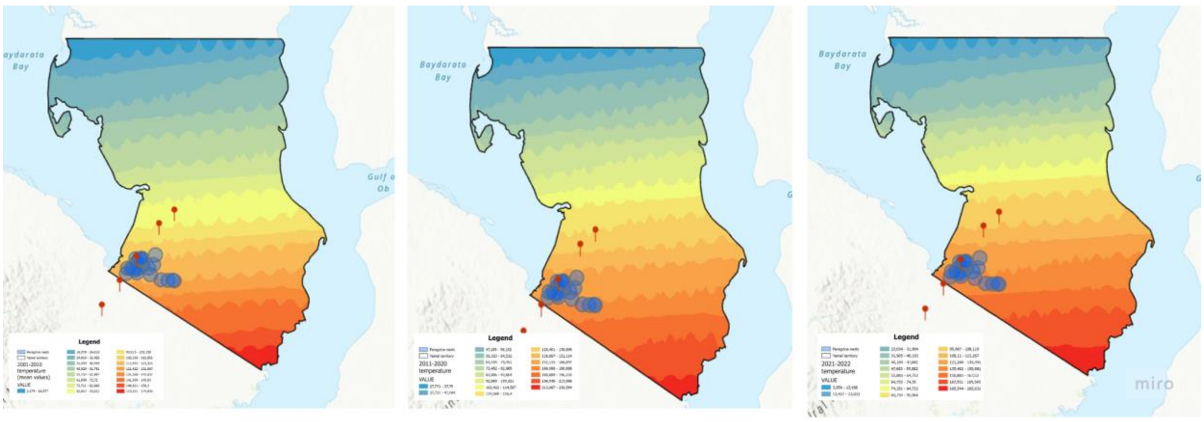

Fig.9. Map showing the process of temperature rising on Yamal peninsula 2001-2022 (blue circles – area of approximate peregrine falcons' nests) (cru.data source, Harris et al. (2020) doi:10.1038/s41597-020-0453-3)).

Plants and animals in the polar regions are vulnerable to attacks from pests and parasites that develop faster and are more prolific in warmer and moister conditions (Anisimov et al, 2007). Many terrestrial polar ecosystems are vulnerable because species richness is low in general, and redundancy within particular levels of food chains and some species groups is particularly low. Loss of a keystone species could have cascading effects on entire ecosystems. In the context of rapid climate change, weather patterns are predicted to be strongly modified (IPCC – report, 2013). In order to assess the vulnerability of animal populations to such changes, an understanding of the nature of the mechanisms linking weather and individual breeding success is crucial.

As we mentioned earlier birds that nest in high Arctic are convenient model object because as most studies on the effects of climate change on animal populations have been conducted in temperate regions. Raptorial species are seldom studied in relation to climatic conditions and the influence of climate on raptor populations remains poorly understood, especially in the Arctic (Franke et al, 2011). Despite this drawback, long-term monitoring of raptors is essential in order to improve our understanding of the effects of fluctuating climatic conditions. In addition, gaining insight into the effects of climate on long distance migrants is challenging. It is extremely difficult to characterize the effect of local environmental conditions (including weather) across geographic regions and multiple life history stages, notwithstanding the importance of pinpointing periods and locations where individuals are most vulnerable (Franke et al, 2011). This is particularly true when the effects of climate change on long distance migrants are most likely different in time and space across the annual life cycle. In this context, this will help us to understand a scale of changes: local, regional or global.

Peregrine falcon is a migratory species, meaning that it might be affected not only during the migration period but also while breeding season. Despite the fact that the peregrine falcon is a highly territorial and migratory species, the nesting period is considered the most vulnerable, namely the period of hatching and chicks' stages (Franke et al, 2011). The connection between the influence of climate on the success of nesting was observed in (A. Franke et al, 2010). However, their findings indicated that reproductive success of peregrine falcons in the study population declined despite concomitant reductions in pesticide loads. The overall decline in reproductive success can likely be explained in part by the presence of fewer pairs attempting to breed each year.

However, it is important to note that productivity, which accounts for the number of occupied territories, also declined significantly. Considered together, these results indicate that in recent years' fewer pairs have attempted to breed, and in addition, those that were successful in breeding raised fewer young to banding age. In general, the pesticides examined in the study cannot mechanistically explain either the reduction in occupancy or the decline in reproductive performance. Although the mechanism or mechanisms (e.g., disease, predation) associated with the reported declines are unclear, the proximate effects of local weather patterns—ultimately associated, either directly or indirectly, with overall climate change—may be noteworthy in regard to explaining the altered demographic features evident in the Rankin Inlet (Canada) falcons' population.

A. Franke et al, 2011; M. Paskhalny and Golovatin, 2009; Lamarre et al, 2018 made observations on this issue, in the studies of A. Franke et al, 2013, the influence of precipitation negative correlation of heavy rains (catastrophic weather conditions) on the survival of chicks' negative correlation has been reported. In Russia, observation of the peregrine falcon has a sporadic nature, but nevertheless M. Paskhalny and Golovatin, 2009 in their work noted a decrease in the peregrine falcon population with an increase in average summer temperatures "…the data is analogous with the previous population estimate at the Peninsula – 355-370 pairs. A comparison of the density dynamics of the population in the optimal part of the species' area – on the Yuribey river – with summer temperature (deviation of summer average temperature from perennial average) *demonstrates a decrease in falcon numbers in comparatively warm years…*" (see plot 1 in Appendix).

As stated, peregrine falcon is exposed to the effects of climate change, including shifts in weather regimes that can affect breeding phenology and success directly (Franke et al. 2010; Lamarre et al. 2018), or indirectly from habitat loss mediated through shrubification (Wheeler et al. 2018), and changes in food supply (Nielsen et al, 2011). In the context of rapid climate change, weather patterns are predicted to be strongly modified (IPCC-report, 2019). In order to assess the vulnerability of animal populations to such changes, an understanding of the nature of the mechanisms linking weather and individual breeding success is crucial.

However, our knowledge of the main climatic factors affecting populations remains limited because the exact causes by which weather affects individuals have been mostly inferred rather than experimentally tested (Franke et al, 2011).

Climate change can not only damage the peregrine falcon, but also species depending on it. The good examples in Erkuta study area are – lesser white fronted goose and red breasted goose. Lesser white-fronted geese have been reported nesting under the protection of birds of prey such as falcons (Peregrine Falcon *Falco peregrinus*, Gyrfalcon *F. rusticolus* and Merlin *F. columbaris*) or Rough-legged Buzzards *Buteo lagopus*. Nesting under the protection of avian predators is well documented for many goose species as a strategy to avoid predation from foxes *Vulpes* sp., skuas *Stercorarius* sp. and other predators, and is especially common among *Branta* species (Pokrovskay et al, 2023).

Nesting in association with birds of prey is not a behavior characteristic of the lesser white-fronted goose throughout its range. It is possible that with an increase in the strength of this association, the number of lesser white-fronted goose decreases. This may be due to the fact that relatively small geese living in low-density nesting areas are more vulnerable to predation than larger species of geese, so dispersed nesting in areas with high predator density may represent a much less favorable predation prevention strategy compared to seeking “protection" by nesting closer to nests of birds of prey. The importance of this association may also be related to the overall high predation pressure (Pokrovskay et al, 2023).

The high predation pressure occurs under the abundance of the main food source in high arctic – small rodents that show a significant decline in their numbers in Russia: “There were also indications of a negative trend in Russia, where several of the decreasing mixed community populations were located” (Taylor et al, 2020). Due to climate change and as following shrubification (Wheeler et al., 2018) number of small rodents decreasing, increasing the predator pressure on other species (Barbero-Palacios et al, 2024).

Study area

The southern border of Yamal is drawn from the Baydaratskaya Bay to the beginning of the Ob Bay. In this case, the Yamal Administrative Region partially captures the Ob region, which should include the Shchuchya and Khadytayakha rivers. At the same time, the geographical boundaries of the peninsula coincide with the landscape boundaries. The subarctic strip of forest tundra here has a fairly clear and well-defined border with the northern pre-tundra woodlands. It can be carried out with great accuracy from the Polar Urals along the railway line going to Labytnangi (Danilov, 1984). Therefore, the territories lying south of Yamal proper form a single whole with it in landscape terms and cannot be separated from it. The natural boundary of the landscape zone runs along the eastern foothills of the Polar Urals, and in the southwest along the aforementioned railway. When we talk about Yamal, we no longer mean its narrow geographical designation, but the Yamal District of the Yamalo-Gydan-West Taimyr subprovincion of the subarctic tundra and the Yamal section of the Arctic tundra (Danilov, 1984).

Relief.

Yamal is a plain rising gently towards the axial part of the peninsula. The highest heights do not exceed 90 m. Usually, the elevation difference of the area does not exceed 25-50 m. The surface is quite strongly dissected by river valleys, streams and lake basins. The coasts have a smoother relief. In places, there are mounds formed as a result of permafrost heave (Danilov, 1984; Paskhalny and Paskhalny and Golovatin, 2009).

The hydrographic network is represented by a large number of rivers flowing from the elevated middle part of Yamal to the Ob. and the Gulf of Ob in the south and east, the Baydaratskaya Bay and the Kara Sea in the west and north. The largest rivers are Shchuchya, Yuribey and Mordyakha. The rivers have a winding course and are deeply cut only where they flow through the hills. Here, the height of the coastal cliffs can be from 10 to 30 m. Due to the small slope of the riverbed, the current is slow (Danilov, 1984). In the lower reaches of the rivers of the southern part flowing into the Ob, extensive shallow sores are formed. The water in the rivers contains a large amount of mineral suspensions. The Ob near Salekhard is usually opened in the last decade of May, the Shchuchya and Khadytayakha rivers - in the first decade of June. Further north, the delay increases. The northern part of the Gulf of Ob is freed from ice in the second half of July, but in some years floating ice lasts all summer.

The maximum level of flood waters falls at the end of the ice drift. The height of the flood depends on the amount of precipitation in winter and the course of melting. On the Khadytayakhe River, the differences over the years were up to 2 m in average. The total duration of the flood was 1.52 months. The rate of level drop depended on the amount of precipitation in summer and the water level in the lower reaches of the Ob River (Danilov, 1984). Freezing in the southern regions usually occurs in the middle to the end of the second decade of October. A large number of thermokarst lakes of different sizes are located in the interfluves. In Southern Yamal, where the water in shallow lakes warms up, unicellular algae and invertebrate fauna develop relatively abundantly in them. That's why they are quite important in the life of birds (Danilov, 1984; Sokolov et al, 2014).

Climate

The climate features are determined by low total solar radiation and the movement of air masses. Average January temperatures are almost the same throughout the territory and are equal to - 21.5-21.8 °C in the west on the west coast, -22.924.8 °C on the east. In the summer months, the latitudinal temperature distribution is well expressed.

The average July temperature in Southern Yamal decreases from 13.8 to 11.0 °C north, in Middle Yamal it is 5.5-8.1°C, in the North - 4.4-5.5 °C. The transition from negative daily average temperatures to positive ones occurs in the southernmost part of the territory in the third decade of May, in most of Southern Yamal - in the first decade of June, in the rest - on June 11-15. Average daily temperatures of 5 °C and above are set on average in the south in the first decade June, in the middle part of the peninsula - in the last decade of June. The transition from positive to negative average daily temperatures is observed in late September in the north and early October in the south.

The amount of precipitation decreases from 350 mm per year in the south to 250 mm in the north. The largest amount (58-66%) falls during the frost-free period. Stable snow cover is formed everywhere in the last days of September - the first days of October, descends on Southern Yamal in the first decade of June, on Average - in its last decade. Depending on changes in the circulation of air masses in the spring-summer season, noticeable differences in temperature conditions are observed, shifting the course of spring phenomena up to two weeks. With the brevity of the breeding season, this affects the distribution of birds and their breeding efficiency.

Here are the data taken from the descriptions made by Osmolovskaya, 1941, Danilov, 1984. Currently, climatic changes are taking place on the territory of Yamal with an increase in average temperatures and the amount of precipitation: “The most recent (1980 to present) warming of much of the Arctic is strongest (about 1°C/decade) in winter and spring, and smallest in autumn…” (Anisimov et al, 2007).

“Precipitation in the Arctic shows signs of an increase over the past century, although the trends are small (about 1% per decade) …” (Anisimov et al, 2007).

“Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be in the ranges … 0.3°C to 1.7°C, 1.1°C to 2.6°C, 1.4°C to 3.1°C, 2.6°C to 4.8°C. The Arctic region will warm more rapidly than the global mean, and mean warming over land will be larger than over the ocean (very high confidence) …” (IPCC-report, 2019).

Vegetation.

Southern Yamal almost to the latitude of the village Yaptiksale is occupied by a subzone of shrubby, mainly spruce-moss with areas of lichen and moss tundra. The abundance of shrubs decreases to the north. Lichen communities with patches of spruce, willow, and moss tundras develop on higher sections of the watersheds. In the depressions of the relief, the slopes of the elevations are usually bumpy and hummocky shrub-lichen-moss swamps, along the shores of lakes - sedge-pushy-moss swamps. In the very south along the river. The Ob extends to the Shchuchya river strip larch woodlands and larch woodlands. They are common not only in river valleys, but also on watersheds. Birch is mixed with larch in significant quantities, and alder in river valleys. The valleys of rivers and streams are overgrown with willow, there are areas of alder bushes. Spruce-birch-larch forests grow in the middle parts of the Shchuchya, Hadytayakhi, Yadayakhodyakhi rivers and their tributaries in which, along with willow, honeysuckle, red currant and even individual cherry trees are found. These forests run in a strip from a few meters to 1 km along the rivers.

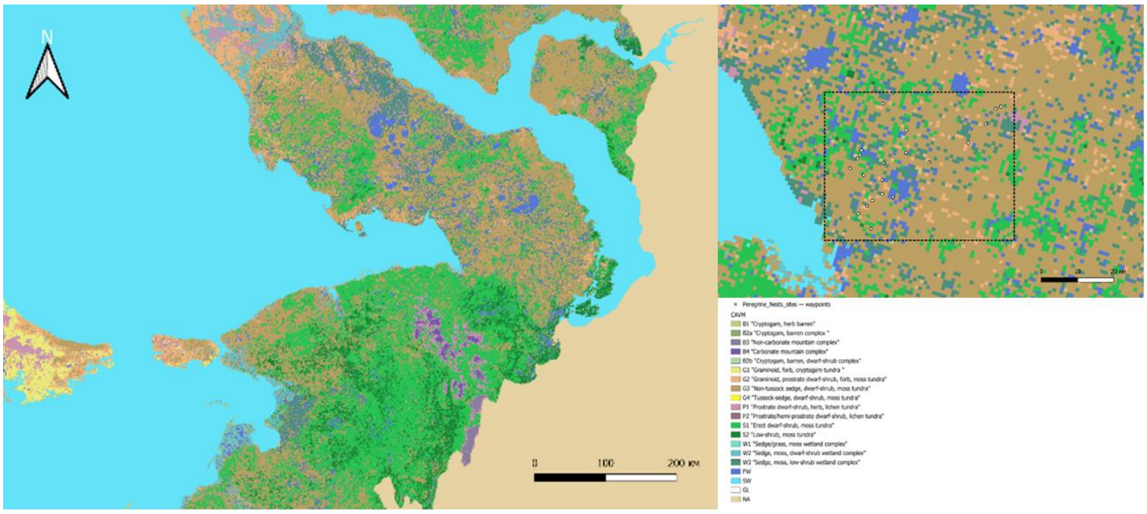

Fig.10. Vegetation map legend (according by Walker, et al. 2005). The study area is the border of several vegetation zones:

- "Erect dwarf-shrub, moss tundra" (Tundra dominated by erect dwarf-shrubs, mostly < 40 cm tall. Zonal type in continental areas with acidic soils of Subzone D).
- "Low-shrub, moss tundra" (Tundra dominated by low shrubs > 40 cm tall. Zonal type in warmer, maritime portions of Subzone E, and in areas with deep, moist active layers).
- "Non-tussock sedge, dwarf-shrub, moss tundra" (Moist tundra dominated by sedges and dwarf shrubs < 40 cm tall, with well-developed moss layer. Barren patches due to frost boils and periglacial features are common. Zonal type on nonacidic soils in Subzones D, some C and E) (Walker et al, 2005).

In the black dotted square, zone of approximate peregrine nests is located.

The forests have all the conditions for the habitat of forest bird species. Islands in the delta of the river. The Ob is occupied by floodplain arctophyll and sedge meadows with patches of litter vegetation, thickets of willows, and alder patches are common here. On the coast of the Baydaratskaya Bay, especially in the estuaries of rivers, halophyte meadows are widespread, attracting a lot of waterfowl and waders, especially during migrations (Danilov, 1984).

Field survey method and materials:

Our observations on the of the peregrine falcon from 1999 to 2023 were conducted at the Erkuta river (68°130N 69°090E), southwestern Yamal peninsula, Russia. This region is classified as low-shrub tundra zone low arctic; (Walker et al. 2005), a landscape characterized by a treeless mosaic of ponds, lakes and bogs, with numerous patches of willow thicket. Our study area included the Erkuta and Payuta rivers interspersed with small hills (ca. 50 m high) and sand cliffs up to 40 m high along rivers and lake banks, which offer potential nesting sites for peregrines. Where the Erkuta river, and the more southerly Enzor and Baydarata rivers, enter the Kara Sea there is a large expanse of low lying, saline marshes in the Baydaratskaya Bay. This network of rivers, marshes and lowland tundra is a hotspot on the Yamal peninsula for migrating and molting birds (Danilov et al. 1984; Sokolov et al, 2014). The area is located on the border of two vegetation zones: erect dwarf tundra and low-growing shrub tundra. Low-growing shrubby tundra is more common in this area than the drier, lichen-rich erect dwarf tundra [38]. Vegetation cover is usually continuous (80-100%), but on dry ridges it can be rare (5-50%). Along streams and lakes there are dense thickets consisting of willows and in some places of alder (*Alnus fruticosa*) (Fig.10) (Sokolov et al, 2012).

Peregrine falcon nest surveys were carried out within whole Erkuta study area (over 250 km2), including upstream Erkuta and Payuta rivers (может карту). We chose this study area because 1) it contained all major landscape elements typical for the region, elements which are also characteristic of the southern tundra in Russia in general (Walker et al. 2005), and 2) the size of the area was small enough to carry out the survey several times per season and by the same observer (Sokolov et al, 2012).

Within this area 21 nesting sites of Peregrines and 17 nesting territories are known (Fig.11). We check these particular sites and also look for new potential nest sites if we observe a territorial pair or a nesting behavior in an unknown before place. Usually Peregrine Falcons use the same cliff (nest site) every year. But the exact location of the clutch may vary a lot between years so the whole cliff should be checked carefully every year (Sokolov et al, 2014).

During the field practice in 2023, we visited 13 nesting territories, to reach quite remote places we used motorboats. Regular distance was (circa 18 km on foot per day). Some places were impossible to get to because of the shoal. For each nesting territory, we determined the presence of peregrine falcons, nest, number of eggs, and exposure of the slope on which the nest is located. The data was documented and added into tables. We acted according to the protocol that was made by A. Sokolov and working team. The procedure consists of visiting the nest locations and checking for the presence of adults, eggs and/or chicks. Usually nests are situated on high (up to 40 m) fragile sandy cliffs.

- In case of approaching the nest, the picture of every chick for age determination is taken.
- If it is not possible to climb to the nest, binoculars are used to count the chicks where possible.
- Recording of all prey remains in and around the nest is held.

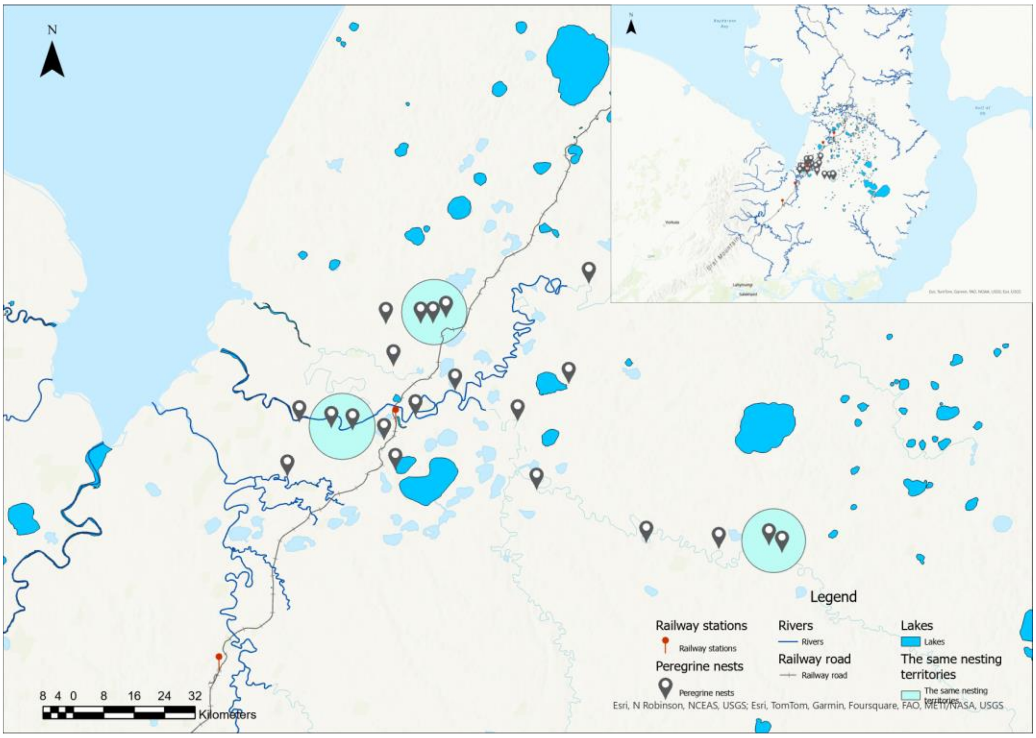

Fig. 11. Nesting sites and territory map (see more in Appendix).

Nest-sites grouping:

We analyzed and grouped all nesting sites by year, starting in 1999 and ending in 2023, when the number of known nesting sites was 21, and the nesting territories were 17. We have compiled tables for each year, where, since 1999, we assigned the status of 1 or 0 to the breeding territory, depending on the presence or absence of a nest on the site. We also divided the breeding stages into (Sokolov et al, 2014) several stages – eggs, chicks and flocks (checked nesting sites with chicks after July 25 each year), we established the slope exposure and type (river or lake). Overall, during 24 years we operated by 17 nesting territories; 21 nesting sites and 290 nest-observation-years.

Exposition analysis

In the data for 2023, we set the exposure of the slope being directly in the study area, in other cases we set the exposure by coordinates. Every year, the coordinates of the nest site were entered into the general database of observations, we analyzed the data on the coordinates since 1999 and determined the exposure for each year. The exposure determination was done using web application “Google Earth” (Fig.12).

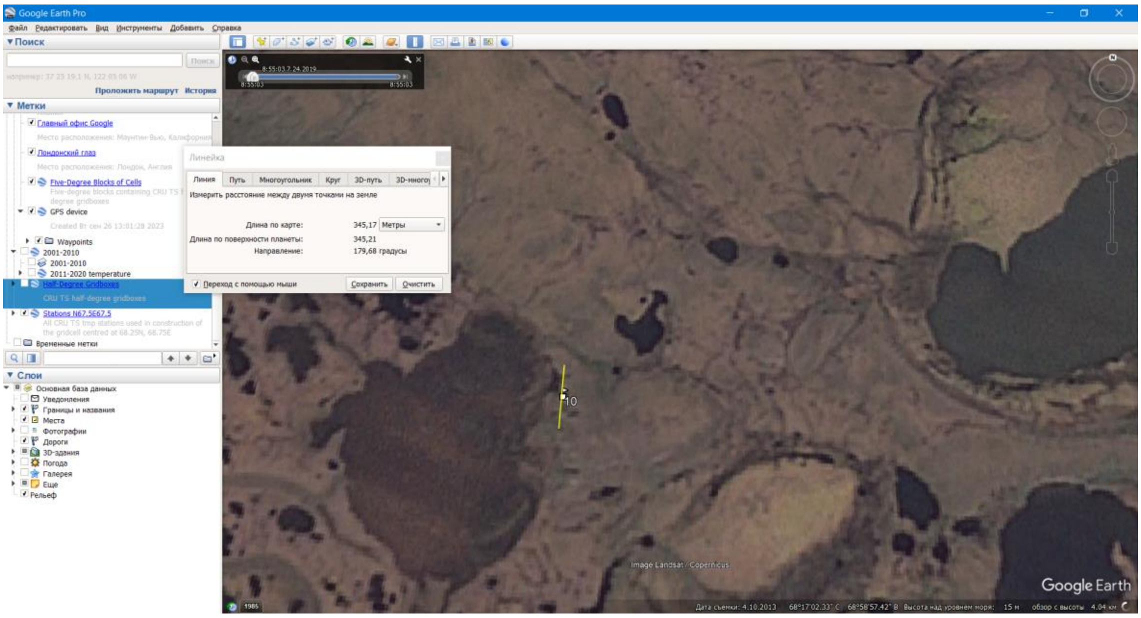

Fig.12. Determination of exposure.

Climate estimation method:

Precise weather conditions measurements: we used local meteostation data because nearest WMA Station situated at least 250 km away to any direction from study area and High-resolution gridded datasets (Harris et al, 2020). We analyzed weather data on average for June, July, and August since 1999.

Results:

We processed the results of observations since 1999. According to the results of observations in the southern Yamal region, there were 21 nesting sites and 17 nesting territories in the research area. To process the results, we chose the period from 2008-2023 to show more accurate results, since there is no data on the number of chicks and fledglings from 1999 to 2007. We used the program R Statistical Environment version 4.3.3 (R Development Core Team 2010) to analyze our data.

Exposition analysis

To begin with, we divided the nesting sites according to their exposures. In Graph 1., it is shown that the number of nests for adjacent exposures, which is (NE, NW, SE, SW), does not exceed the number of nests for the main exposures. For convenience, we have divided the nest sites into four exposures (S, N, E, W). We have compiled boxplots for eggs, chicks and fledglings, distributing them according to the main expositions (Fig. 13).

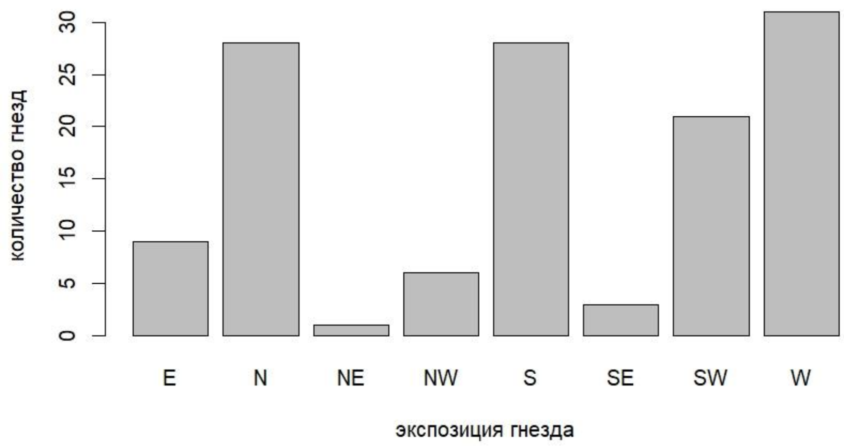

Fig. 13. Boxplot 1. Distribution of the number of nests by exposure (E-east, N-north, NE- north-east, NW-north-west, S-south, SE-south-east, SW-south-west, W-west), this graph shows the number of nests for the designated study period (2008-2023).

The regression model of dependence of number of eggs on exposure was **not significant** (p-value=0.5) (Fig. 14). From the presented figures we can see that number of hatched chicks and fledglings are lower on the cliffs with S exposure;
Regression models showed a significant difference between the southern and the eastern exposures for chicks (p-value=0.01) and fledglings (p-value=0.009) (Fig.15; Fig.16). A Tukey test was performed for each model, for a pairwise comparison, which also showed a statistical difference in the model of the *fledgling~exposure* (Fig.16). Based on our data, it can be concluded that the exposure of the nest does not affect the reproductive output. There are few nests with an eastern exposure, but the reproductive output for chicks and fledglings is high, unlike nests with a southern exposure, where the sample size is larger. We came to the conclusion that there are no significant dependencies according to the exposure criterion. We acknowledge that sample size slightly different for N,S,W, and E cliffs that has lower amount of nests. However, our dataset is relatively unique with any

published data, hence we must operate by all found nests and used all available information.

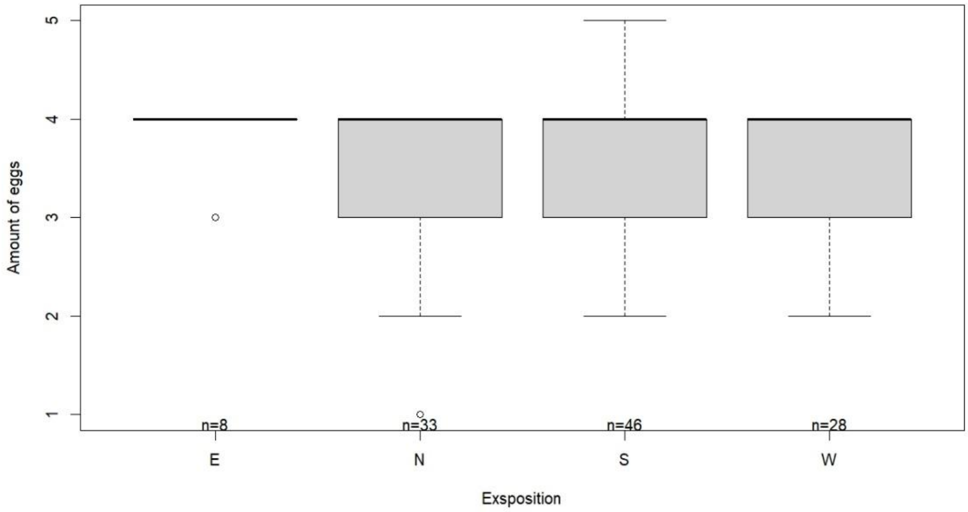

Fig. 14. Boxplot 2. This graph shows the exposure in four main directions and the number of eggs for the entire study period (2008-2023), n is the sample size. The largest sample size for the southern exposure.

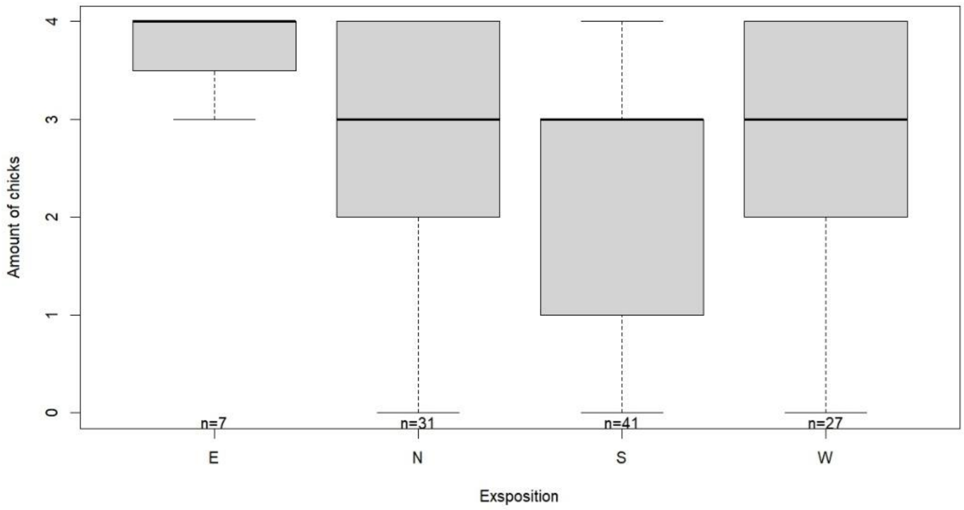

Fig. 15. Boxplot 3. This graph shows the exposure and the number of hatched chicks during the study period (2008-2023), the sample size is the largest on nests with a southern exposure.

As for the second part of our hypothesis. We assumed that *"breeding success depends on slope exposur*e" (Beardsell et al, 2016; Wheeler et al, 2018)."

"There is the highest breeding productivity on the southern exposition slopes than on any other exposition." But our data shows a trend different from our

assumption. As it can be seen in the graphs (Fig.15., Fig.16.), the southern exposure is the most unsuccessful in terms of the number of fledglings, when compared with the north and west exposures with an approximate similar large number of samples. According to our data, it is clear that the southern exposure is the most unsuccessful, so this moment requires further observations. With our research, we not only refuted the hypothesis we had previously suggested, but also proved the opposite. The southern exposure in our research area has the lowest breeding productivity.

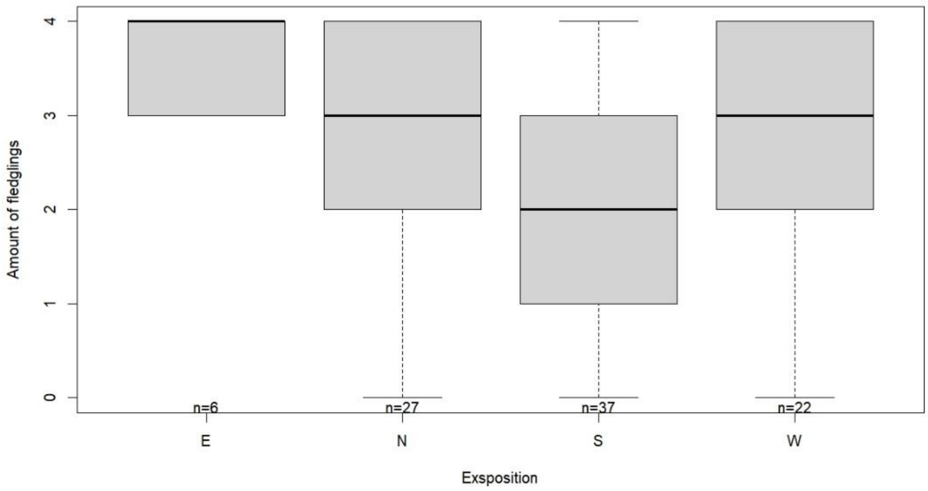

Fig. 16. Boxplot 4. This graph describes the number of fledglings and exposure over the study period (2008-2023), according to the sample size, the slopes with the southern exposure have the maximum values. Differences in the median are also visible, on slopes with a southern exposure it fell to a value of two, for slopes with a northern and eastern exposure it remained at the same value of 3, and on slopes with an eastern exposure it remained at a value of 4 (as for eggs and hatched chicks).

Temperature analysis

Analysis of the data on the dependence of the percentage of hatching on the average temperature in July showed a direct relationship (Fig.17). We made two models – the percentage of hatched and the average temperature in July and the percentage of hatched, the average temperature in July and exposure, where exposure was included as an additive factor. The regression model, where exposure was an additive factor, also reflected a significant difference in flakes between slopes with southern exposure and eastern expE~EXPs=0.01. Both models were statistically significant, p-value (proportion of hatching~ temperature) = 0.05 p-value (proportion of hatching~ temperature+exposure) =0.04. Both models were compared using the Aic information criterion, which showed that the model without an additive factor explains the data better:

proportion of hatching~temperature AICc=65.27; proportion of hatching~ temperature + exposure = 65.48. We took this model as a sample.

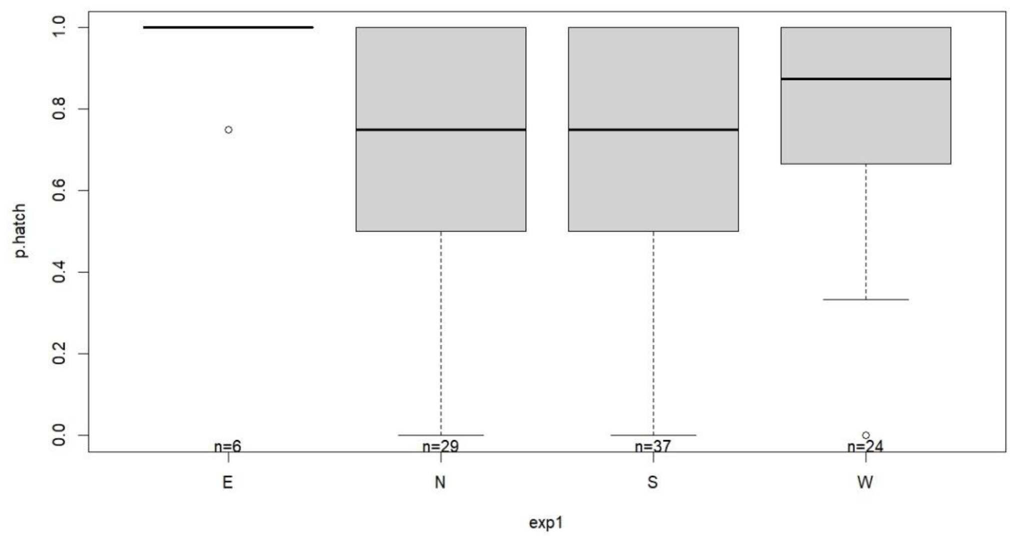

Fig. 17. Boxplot 5. The proportion of hatching distributed by exposure (2008-2023). As on the slopes with the southern exposure, and on the slopes with the northern exposure, the proportion of hatching reached 0. At the southern exposure, the sample is represented by a large number of values.

After that, we performed a variance analysis of this DHARMa residual model, KS test p=0.07, dispersion test p=0.8, deviation n.s, outliner test p=1 (Fig.18). During additional calculations, we found out that with an increase in average temperatures in July by 5 °C, the probability of hatching decreases by 18%, therefore, with an increase in average temperatures by 1 °C, the probability of hatching decreases by 0.033 or 3% (Fig. 19).

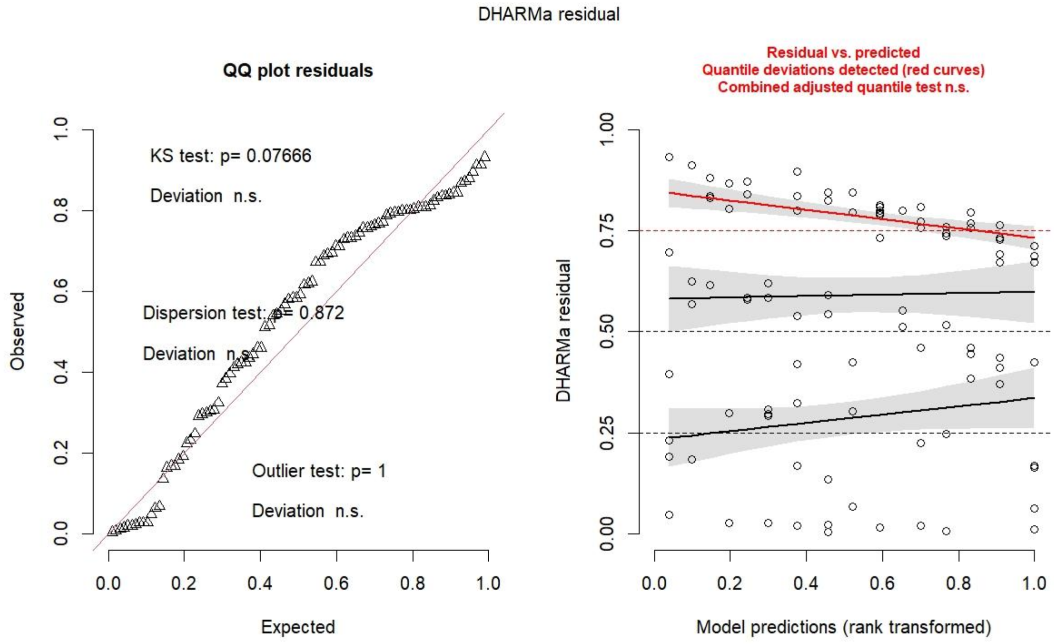

Fig.18. Testing the model for variance deviation. KS test p=0,07, dispersion test p=0,8, deviation n.s, outliner test p=1.

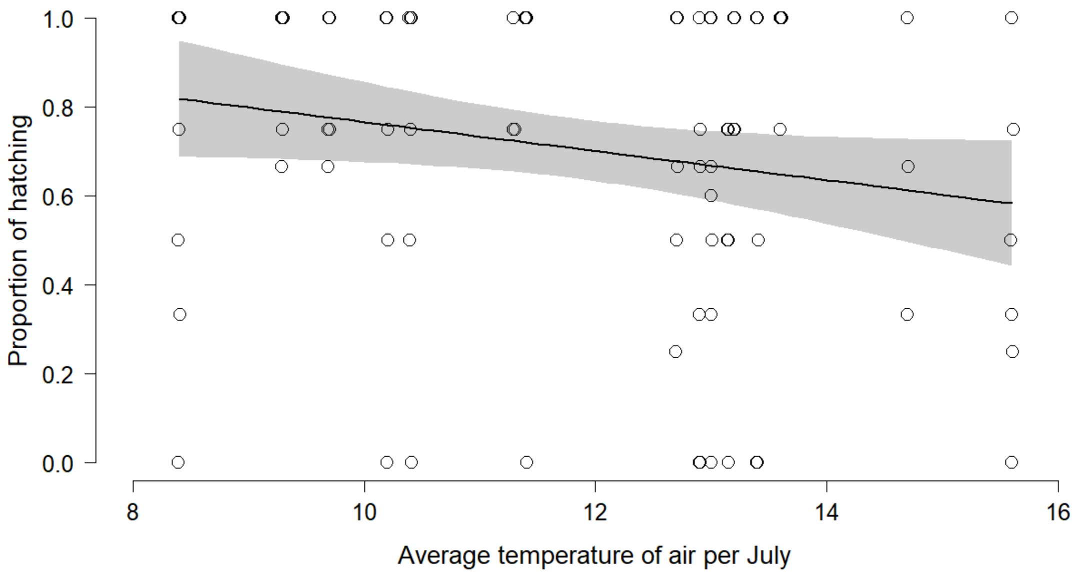

Fig. 19. The dependence of hatching on average temperatures in July. On the graph, hollow circles indicate the proportions of hatched eggs coming at degrees of average temperature for July. The trend line falls.

Precipitation analysis.

We acknowledge that the dependence of the effect of heavy precipitation on the nestlings of birds of prey, in particular on the peregrine falcon, has been revealed (Anctil et al, 2014). We assumed that this trend would also be observed in southern Yamal, but our model was not statistically significant p-value=0.20. This model did not pass the KS test p=0.014, and showed a significant deviation from the average. The graph shows that the model we use reflects incorrect results (Fig. 20).

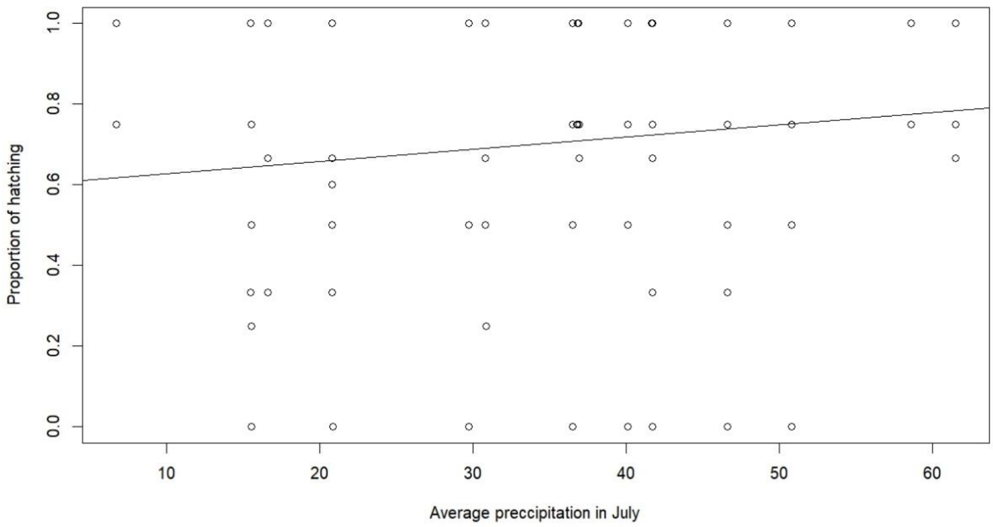

Fig. 20. Graph for the model of the dependence of the proportion of hatched on the temperature of July.

The dispersion analysis of our model confirmed that our hypothesis is incorrect. We also analyzed the dependence of the average precipitation level and the percentage of fledglings, but the analysis did not show statistical significance either (Fig. 21).

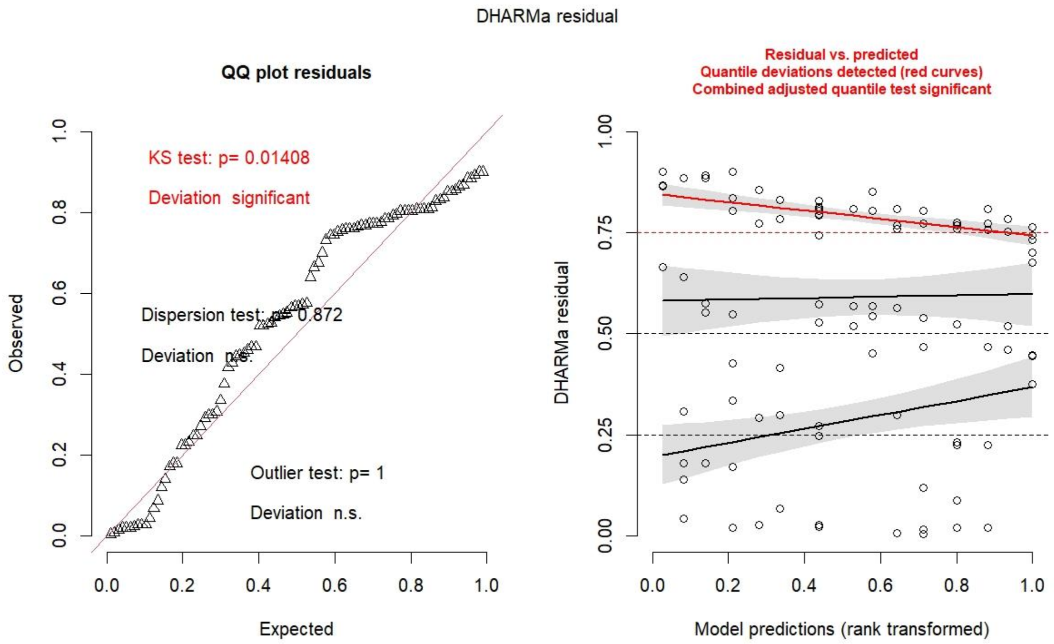

Fig. 21. The graph shows the variance test for the hatching~precipitation, significant deviation model.

Occupancy trend analysis:

To analyze the occupancy of nesting sites, we needed to analyze not the occupancy of the nest, but the occupancy of the nesting territory (see Appendix1). The analysis of nesting territories showed that the occupation of nesting territories decreases every year, which is confirmed by the data of Franke, 2019, which assumed a decrease in the population of the peregrine falcon in southern Yamal.

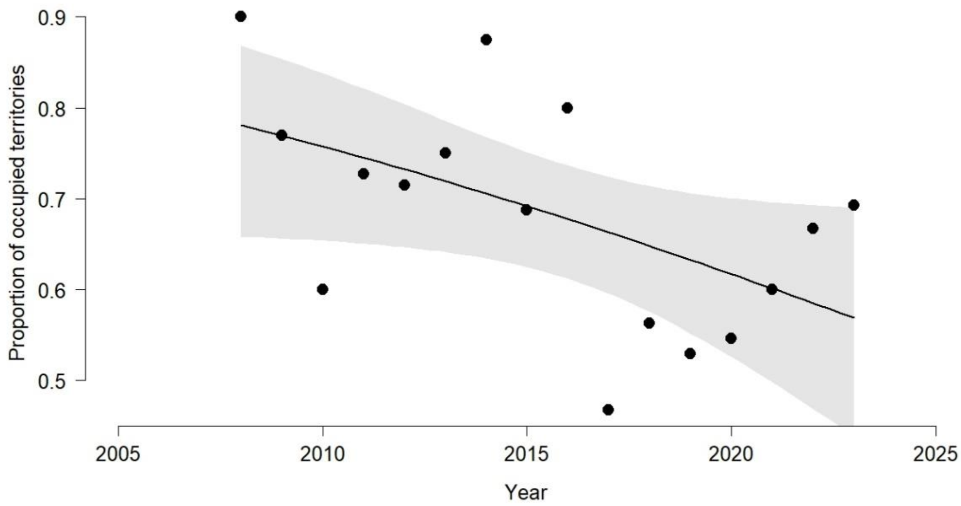

Fig. 22. Proportion of occupied territories vs Year. This graph shows the trend of the share of occupation of nesting territories and the year, the black circles on the graph show the share of occupied nests each year.

This model is statistically significant, p-value=0.04 for this model (Fig. 22). We also performed a variance analysis for this model, which showed that our model really works: KS-test p= 0.3, Dispersion test: p=0.856 (Fig.23.).

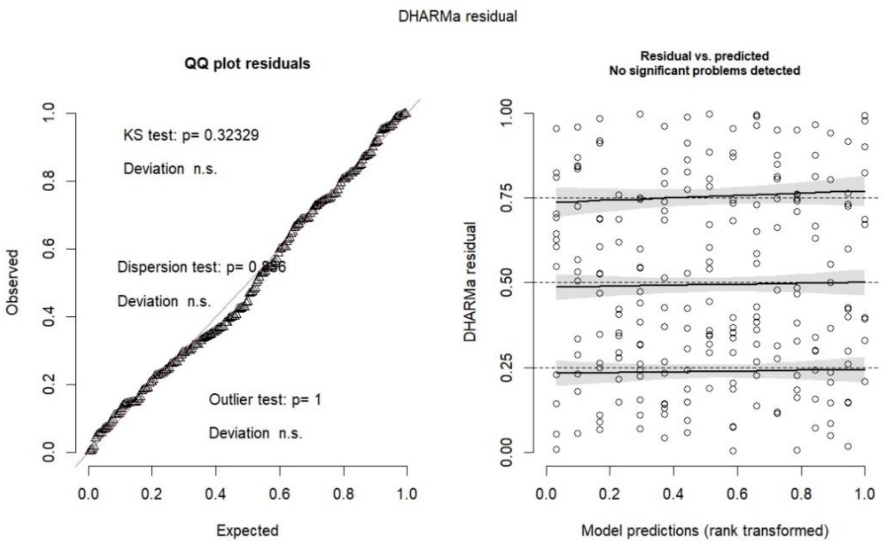

Fig.23. Dispersion test results on the occupancy analysis.

Discussion:

Although the greatest impacts of climate change are expected to occur in the Arctic (IPCC –report, 2013), little is known about the mechanisms linking weather to reproduction and survival of most Arctic-breeding species (Anisimov et al, 2007; Barbero-Palacios, et al, 2024). This is especially true for arctic predators, which are seldom studied. The direct effects of weather have long been suspected to influence early survival in northern wildlife (Anisimov el, 2007; Franke et al, 2010; Laamare, 2018 etc). In peregrine falcons, rainfall has previously been identified as a potential driver of nestling mortality (Ratcliffe, 1993;).

Exposition analysis.

On the whole it is possible to state that falcons prefer to nest on warming slopes and/or in places defended against prevailing cold winds (Osmolovskaya 1948; Danilov et al. 1984). Nests are situated predominantly at elevated points, in places where access to it is limited (on promontories, narrow spines, ground outliers etc.).

It is known that the peregrine falcon has nesting conservatism (Osmolovskaya 1948; Danilov et al. 1984, Paskhalny and Paskhalny and Golovatin, 2009), during the study it was found that 17 breeding territories with different coordinates every year are regularly occupied, but the peregrine falcon does not radically change the orientation of the nesting site, that is, most often the bird arrives at that the same nesting territory. Therefore, it is not uncommon for Peregrines to change their nesting site from time to time. A shift of nesting place along the boundary of a territory can also occur when there are no obvious dangers to the old nests. The old nests can then exist alongside the new ones (Paskhalny and Golovatin, 2009).

We assume that it occurs due to the fact that the peregrine falcon's main diet includes near-water birds such as waders, some small ducks, etc. and the breeding pair needs an open space with access to a reservoir (Paskhalny and Paskhalny and Golovatin, 2009). But why the peregrine falcon chooses exactly the same slope exposure from year to year, even if several seasons are skipped and a new pair inhabits the breeding territory, is still unknown and this topic involves further discussion.

During the analysis of our data, we found that slope crashes occurred on slopes with different exposures. However, there is a sufficient and wide set of possible variants of nest locations relating to height, orientation and other features of its placement and choice. The vast content of ice in the Yamal’s ground means dynamic processes of erosion caused by the ice slowly effect slopes and bluffs through summer melting, wash-out by thaw, pluvial and river waters. Evidently a proportion of nesting places are destroyed over time by the effects of ice and erosion. This may be as high as 30% of such nests. But for all the years of observation, a small number of crashes were observed, so we did not include this factor in our hypothesis.

In our study, the results of the analysis of the hypothesis of the influence of slope exposure on reproductive output were presented. As described in the results, we divided the slopes into 4 main exposures, we decided that for statistical analysis it is not the number of possible exposures that is important to us, but their quality. When analyzing the resulting plots, we noticed that the median for chicks and fledglings is changing, we made a regression model for each position (eggs, hatchings, fledglings). The eggs~exposure model did not pass the p-value test; the model was statistically insignificant. For the hatchings~exposure and fledglings ~ exposure models, the relationship between the southern exposure and the eastern exposure turned out to be statistically significant. We compared all the data in pairs using the Tukey test and the test showed statistical significance only between the categories “south” and “east”. We explain this result by the fact that the sample size among nests with an eastern exposure for chicks is n= 7, and for fledglings n=6, while the sample size for nests with a southern exposure is n= 41 for chicks and n=37 for fledglings.

Nevertheless, the second part of our hypothesis was disproved, contrary to our expectations, breeding productivity on slopes with a southern exposure was the lowest, especially as seen in Fig.16., where the median drops to a value of 2. We assume that breeding success of peregrine falcon, nesting on slopes with southern exposure, depends on climate change, to be more precise – on increasing average summer temperature.

Temperature analysis

We have considered one of the key factors that can affect the hatching of peregrine falcon chicks. Recently, reports on the influence of climatic factors on avianpredators in high latitudes have begun to appear (Franke et al, 2010; Anctil et al, 2014; Taylor et al, 2020). We considered the average temperature in July, because it is in July that the peregrine falcon hatching process begins (Danilov, 1984), we decided that it was at this time that eggs are most vulnerable to high average temperatures (Franke et al, 2010), since the nesting ecology differs significantly for birds nesting in high latitudes from all other birds (Taylor et al, 2020). We did not compare the temperature indicators and their effect on the hatching process for June and July together, since July was chosen as the model month, because it is in this month that hatching occurs and temperature fluctuations begin.

We found the dependence of the proportion of hatched eggs on the increase in average temperatures in July. Due to an increase in the average temperature by 1℃, the hatching rate decreases by 0.033 or 3%. We didn't find any modern works on measuring this factor in Russia, the only work was published in 2009 by M. Golovatin, in which the dependence of the population density of the peregrine falcon on average temperatures for the period June-July was determined, during the years of increasing average temperatures, the population density fell (Paskhalny and Golovatin, 2009) (see more in Appendix). Turning to our previous analysis of the impact of exposure on reproductive output, we can see that the number of hatchings decreases in slopes with southern exposure, and the number of fledglings drops to a median value of 2. We assume that there is a dependence of greater vulnerability of slopes with southern exposure on rising average summer temperatures (Fig.24). Of course, do not forget about the press of predators in the years of low rodent numbers (Danilov,1984), the collapse of slopes and other natural factors.

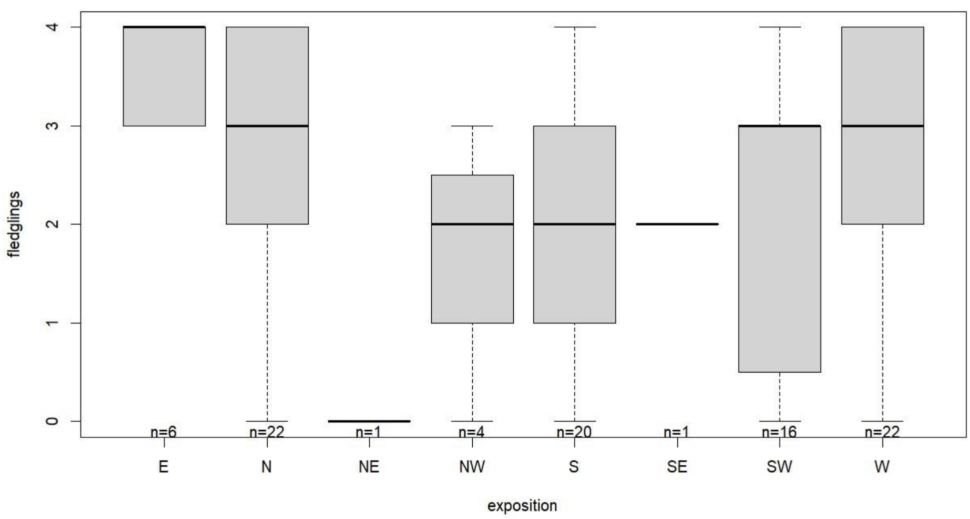

Fig. 24. The distribution of the number of fledglings across 8 exposures, the graph shows a large sample of nests with a southern exposure and the widest range in the number of fledglings.

According to the IPCC, the temperature in the Arctic will rise much more intensively than in all other regions, only with an increase in the average daily temperature by 1.5℃, the probability of hatching with an increase in average summer temperatures drops by 0, 13 or 13%, which, with a range of 1℃, will be approximately 0.26 or 26%. Of course, we cannot state such figures with a high degree of probability, and we also do not know how the peregrine falcons will react if such a change occurs. But we assume that the climatic changes that affect birds nesting in the high Arctic will affect them negatively (Taylor et al, 2020). Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be in the ranges derived from the concentration-driven CMIP5 model simulations, that is, 0.3°C to 1.7°C, 1.1°C to 2.6°C, 1.4°C to 3.1°C, 2.6°C to 4.8°C. The Arctic region will warm more rapidly than the global mean, and mean warming over land will be larger than over the ocean (very high confidence) (IPCC-report, 2019).

Precipitation analysis

Rain is an important component of the weather, which is often associated with the breeding success of various bird species. The amount of precipitation in different time periods was associated with either an increase or decrease in the number of successful nests, as well as with the timing of breeding and the duration of the breeding season. In addition, a negative correlation has been reported between rainfall and nestling survival (Anctil et al, 2014).

We assume that in order to build a working model, more accurate daily data on heavy rains and snow for the June - July period for the study period are needed, we do not have such data, but a direct dependence of the influence of atmospheric precipitation on the hatching process and the death of chicks can be traced (Anctil et al, 2014). Perhaps the effect of heavy precipitation needs to be recorded directly, using cameras or field observations (Anctil et al, 2014). We believe that in southern Yamal, in our research area, weather conditions are less severe than in the rest of the Yamal Peninsula. But even in our study area, changes in precipitation intensity over a long period of time are visible (Fig.25).

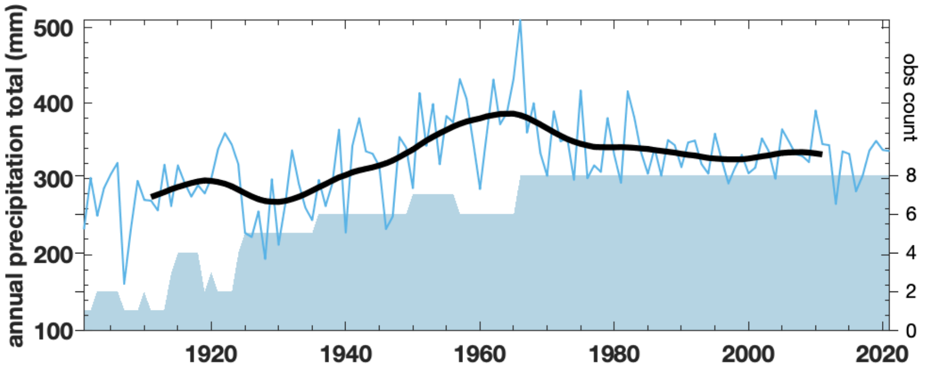

Fig.25. A graph showing an increase in the average annual precipitation intensity for our study area.

We assume that the model will need to be built according to not the average monthly rainfall, but specifically the number of days with extreme weather conditions, heavy rains, snow-storm, high wind, etc., and look at the survival rate of clutches, chicks and pups directly using cameras and additional equipment.

Nest occupancy analysis

In 2019 (Franke et al, 2019) noted a downward trend in the number of peregrine falcons in Yamal: “Decreasing trends in peregrine falcon occupancy were observed for Norrbotten (n = 19 years), Lapland (n = 38 years), and Yamal Peninsula (n = 11 years). However, the validity of these trends is uncertain, and it is possible that they are confounded with survey methods.” We also decided to check whether this trend can be traced over a longer period of the study.

The share of occupied territories decreases during the observation period (2008-2023), according to our model it can be seen that the occupancy of nesting territories is really falling. We found that since 2008, occupancy has fallen by about 22%. That is, for every year for 15 years, the occupation of territories by peregrine falcons fell by about 1.46%. Our results confirm the results described in the paper (Franke et al, 2019). In accordance with the decrease in the number of nesting sites, we can assume that the population of peregrine falcons nesting in our research area in Yamal is really falling. The situation remains unknown for the entire territory of the Yamal Peninsula.

Conclusion

We refuted the hypothesis with southern exposures, where we assumed that breeding areas with southern exposure had the largest productive yield. The situation varies significantly for the ecosystems of southern Yamal. As in principle, and for the entire Arctic as a whole. We see that nesting on slopes with a southern exposure occurs more often, so many researchers repeatedly noted a preferential choice of location by Peregrines to nest on slopes facing a southerly direction (Osmolovskaya 1948; Danilov et al. 1984). Both Sergey P. Paskhalny and Mikhail G. Golovatin and ourselves found birds will use bluffs that face different directions, however, the nest itself in the majority of places will be on a side, promontory or brow oriented in a south direction (S, SW and SE) and is often defended against prevailing cold winds. You can see it on our boxplots (Fig.15., Fig.16., Fig.17.) But due to climate change in general, slopes with a southern exposure are becoming more prone to overheating, here we can assume that this affects not only the hatching chicks, as seen in Fig.21., but also the flocks in general. We have not found any articles describing this in the conditions of the high Arctic.

Temperature analysis by hypothesis of “dependence of hatching ratio on climatic conditions (i.e. temperature, precipitation) (Franke et al, 2011; Anctil et al, 2014; Lamarre et al, 2018). The hatching ratio decreases with an increase of temperature and precipitation”, He showed a direct dependence of the average temperature in July on the hatching of peregrine falcon chicks, that is, with an increase in average temperatures, the percentage of hatched ones' decreases – our hypothesis was confirmed.

We came to the conclusion that further more detailed studies are needed to analyze precipitation, as we described earlier.

The most important conclusion can be drawn from the analysis of the occupancy of nesting territories, we assumed that the occupancy of the nest sites could be either stable, decline, increase or cycling. If the occupancy is stable the population is super resilient to changing environmental factors during the study, if not - environmental factors have some effect. In the course of our study, it was found that the occupancy of nesting sites has fallen by 22% since 2008, which means that peregrine falcons in the area of our study in southern Yamal are significantly affected by climate change in the high Arctic.

With our study, we expect to show that Arctic ecosystems cannot withstand the stress they are exposed to. Using the peregrine falcon as a model object, we see the fragility of a system that was formed for many years before us. And how easily seemingly minor changes can and are already destroying it. Peregrine falcon is a top avian predator within the Arctic food webs, decrease in peregrine falcon population puts under danger species depending on it (Lesser white-fronted goose and Red breasted goose).

We expect that our study contributes to an understanding of mechanisms affecting peregrine falcon productivity and breeding success, particularly in abiotic (e.g., temperature and precipitation) variables.

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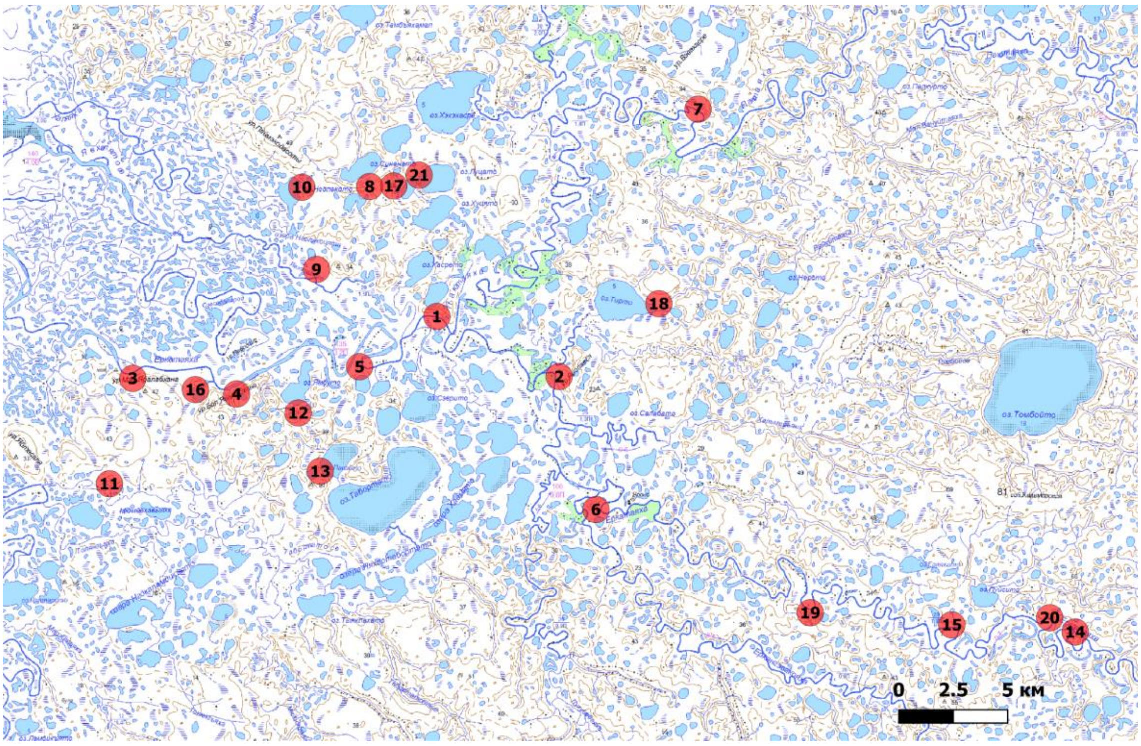
Appendix



Map 1. Approximate locations of Peregrine's cliffs and nest sites (the map was provided by Dr. A. Sokolov).

№ of nest	Name	Approximate coordinates, degrees	
		N	E
1	Per Khenado	68,222842	69,126106
2	Per Payusa	68,195762	69,274074
3	Per Malaya Labakhana	68,194930	68,757801
4	Per Bolshaya Labakhana	68,187901	68,883607
5	Per Meloyakha	68,200201	69,032405
6	Per Yarono	68,135676	69,318707
7	Per Payuta	68,316103	69,442360
8	Per Lake	68,281360	69,044710
9	Per Island	68,244020	68,980350
10	Per Nigel	68,281000	68,962520
11	Per Kostya	68,147335	68,729550
12	Per Takuchi	68,179340	68,958200
13	Per Dixon	68,153000	68,984840
14	Per Erkuta_1 (Yabsi)	68,080220	69,899120
15	Per Erkuta_2	68,083460	69,749700
16	Per Lake Bol Labakhana	68,189863	68,833601
17	Per Lu	68,281620	69,073870
18	Per Tirto	68,228610	69,394840
19	Per Erkuta_3	68,088950	69,578230
20	Per Erkuta_4	68,086683	69,868206

21	Per Lucato	68,28643	69,10460

Table 1. Approximate coordinates of nest sites (the coordinates were provided by Dr. A. Sokolov).

Id	**Name**	
1	Khenado	
2	Payusa	
3	Malaya Labakhana	
4	Bolshaya Labakhana/Lake Bol Labakhana	
5	Meloyakha	
6	Yarono	
7	Payuta	
8	Lake/Per Lu/Per Lucato	
9	Island	
10	Nigel	
11	Kostya	
12	Takuchi	
13	Dixon	
14	#1 Erkuta/#4 Erkuta	
15	#2 Erkuta	
18	Tirto	
19	#3 Erkuta	

Table 2. Nesting territories.

Plot 1. Dynamics of the Peregrine density at the Yuribey river (1) and deviation of average summer temperatures (June – July) from average perennial summer temperature (Paskhalny and Golovatin, 2009).