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Біологічні дослідження

Biological research

Коротке повідомлення / Short Note

Accuracy of time-lapse camera data and variability in Gentoo penguin breeding phenology on Galindez Island

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Abstract. The condition and dynamics of penguin populations are among the key indicators for assessing Antarctic marine living resources and developing a krill fishery strategy. The Argentine Islands are the southern border of the range of one of the most numerous penguin species — the Gentoo penguin, *Pygoscelis papua*. The *P. papua* colony on Galindez Island (CEMP site GAI), where the Ukrainian Antarctic Akademik Vernadsky station is located, is the second southernmost colony of this species, and one of the largest in the region, with a penguin population of about 7 000 adults in peak season (2025/2026) and growing from year to year. Over the past five years, both parts of the colony, one near the main station building and one on the Penguin Point, have expanded significantly towards each other. The largest of the newly formed areas of the colony is located near the Magnetometers Pavilion of Vernadsky Station. This study aims to assess the accuracy of determining the chronology of the main events of the reproductive cycle of *P. papua* by comparing time-lapse camera data with visual observations of nests, and to examine phenology in the newly formed part of the colony. It was found that the most accurate determination was made for the date of the crèche formation — the time difference was less than 1 day. The dates of first egg laying and first chick hatching were determined with somewhat lower precision, as visual observations and camera recordings differed by about 2 days for both events. Camera data typically lag behind visual observations of events. A larger number of photos captured at 30-minute intervals throughout the daylight hours will help to significantly increase the accuracy of identifying reproductive cycle events. A study of a new part of the Galindez Island colony near the Magnetometers Pavilion (GMP site) showed that all events of the reproductive cycle in this area occur 6–10 days earlier than in the old parts of the colony. This observation is not related to differences in penguin arrival times across different parts of the island and requires further research.

Keywords: Argentine Islands, automatic camera, chronology, *Pygoscelis papua*, reproductive cycle, validation

1 Introduction

Studying penguin colony breeding success and chronology is crucial for evaluating the status of populations and habitats of major Antarctic krill consumers and for identifying areas where their habitats may overlap with areas of intensive commercial krill fishing. Observations and research on penguins of the genus *Pygoscelis* on the territory of the Wilhelm Archipelago, Antarctic Peninsula, have been conducted for more than a century (Gain, 1914). Large colonies of these birds, recorded on Petermann, Yalour, and Booth islands, have been studied by both British (C. Muller-Schwarze & D. Muller-Schwarze, 1975; Croxall & Kirkwood, 1979; S. Poncet & J. Poncet, 1987) and Ukrainian scientists (Peklo, 2001; 2007; Loparev, 2003; Chesalin et al., 2009; Peklo & Dykyy, 2010; Dykyy, 2013; Smagol & Molchanoff, 2016). Between 1999 and 2017, the southern boundary of the Gentoo penguin (*Pygoscelis papua* Forster, 1781) range shifted, with six new colonies forming, the southernmost of which is on Green Island (Dykyy et al., 2018).

The first unsuccessful attempt of gentoo nesting was observed in the 1996/1997 season. The successful nesting of Gentoo penguins on Galindez Island was recorded in 2007. The colony began as two separate nesting sites – one near the station building (GBV) and one on Penguin Point (GPP) (Dykyy et al., 2018). Since then, the colony has grown rapidly; according to the latest data (Davydenko et al., 2025), the number of adult penguins on Galindez Island reached 4 thousand during the 2024/2025 breeding season. The colony on Galindez Island is important because it is one of the largest colonies on the southern border of the *P. papua* distribution range. At the same time, this colony continues to grow: both the number of nesting pairs of penguins and the territory on which they breed are increasing; considering the data of recent years, subcolonies GBV and GPP have expanded towards each other.

The dynamics of the *P. papua* population on Galindez Island were monitored by wintering biologists during visual surveys, and, since 2015, using time-lapse cameras (Dykyy et al., 2018). A network of time-lapse cameras was installed and maintained on Galindez, Petermann, and Yalour islands as part of the program of monitoring and forecasting the krill population size (CCAMLR Ecosystem Monitoring Program CEMP) of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Time-lapse camera observation allows to assess breeding phenology shifts depending on climate change and/or geographic position of the colony, breeding success, chronology, demographic rates, and the state of bird colonies on remote islands and has already proven its effectiveness in other areas of Antarctica (Black et al., 2018; Hinke et al., 2018; Korczak-Abshire et al., 2021; Flynn et al., 2026; Juarez Martinez et al., 2026).

Previous studies assessing the accuracy of camera data showed a discrepancy between the actual date of a particular event in the penguin reproductive cycle and the date obtained from analysing photographs. Thus, one study (Black et al., 2018) noted a difference in the date of arrival of penguins at nesting sites of 0–2 days, and in the date of appearance of the first egg, up to six days. In other cases, the differences in the dates of laying the first egg and hatching the first chick were insignificant, but a difference of up to two days was observed in determining the date of crèche formation (Hinke et al., 2018). In addition, accuracy is highly dependent on the skills of the person analysing the photographs (Jones, 2019).

The objective of this study is to determine this difference in the conditions of the Argentine Islands and to develop recommendations for camera settings to reduce the discrepancy between camera- and visual-survey-based observations. An additional aim of the study is to compare the phenology of penguin reproductive events in the older parts of the colony, which have long been monitored, and in areas where penguins have begun nesting in recent years. In Section 2, we describe the methods, followed by the results of the time-lapse camera setting validation and breeding phenology shift study in Section 3. In the Discussion section, the results were compared to other similar research, followed by conclusions in Section 5.

2 Methods

The breeding colony of *P. papua* on Galindez Island is the object of the study. A part of the existing network of time-lapse cameras deployed within the CEMP program was used to photograph the events of the penguin reproductive cycle (Dykyy et al., 2018). For this study, photos taken with time-lapse cameras on sites GBV (Marina Point, one camera, location 65.245207°S, 64.256407°W) and GPP (Penguin Point, two cameras, location 65.248773°S, 64.240298°W) were processed (Fig. 1). Remote automatic cameras Reconix HP2X and Spy-Point Force 20 were used during the study period. Each camera captured 10 images per day at 30-minute intervals between 10:00 a.m. and 2:30 p.m. local time (LT). Cameras are maintained throughout the year.

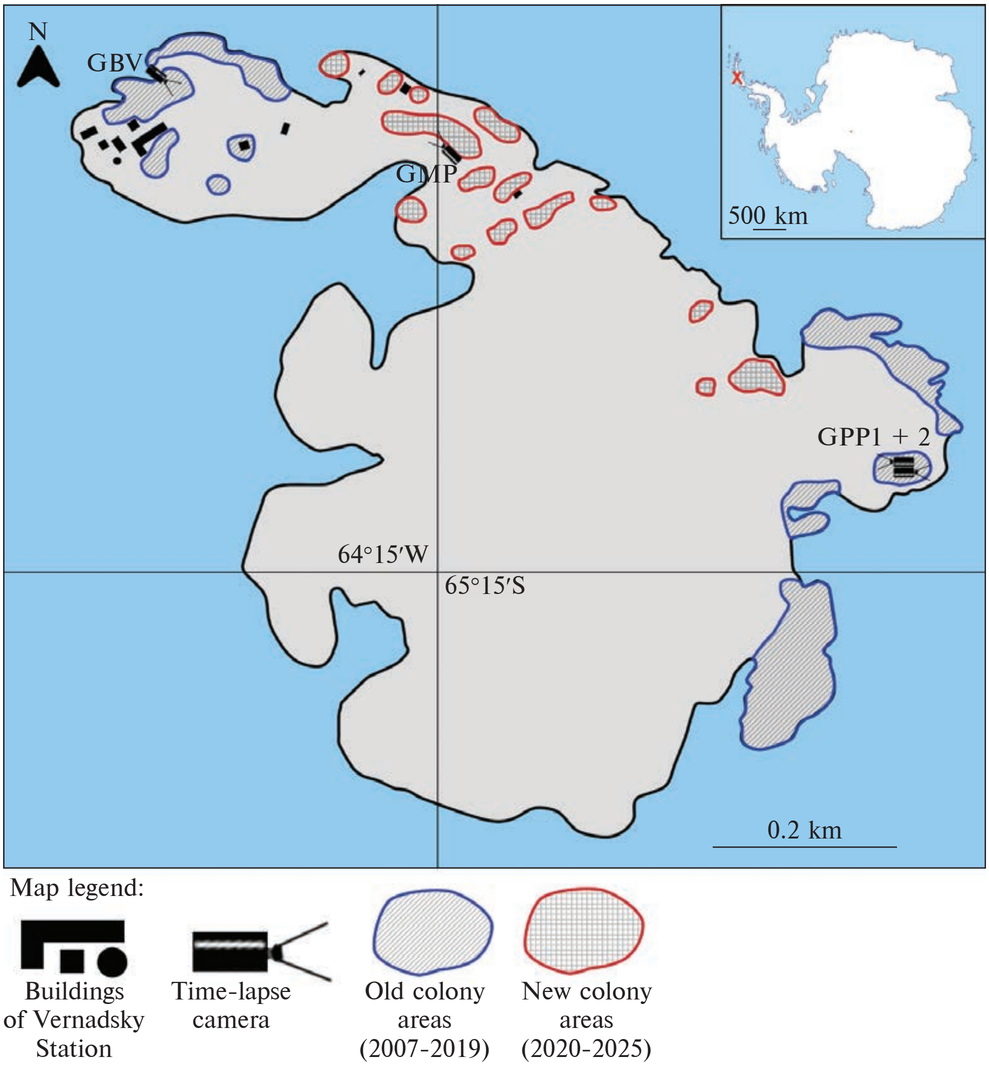

Figure 1. Map of the *Pygoscelis papua* colony borders and time-lapse camera positions on Galindez Island as of 2024/2025 season. Names of CEMP sites: GBV (Galindez Base Vernadsky), GPP (Galindez Penguin Point; two cameras GPP1 and GPP2) and GMP (Galindez Magnetometers Pavilion). Inset showing the position of Galindez Island (marked with red cross)

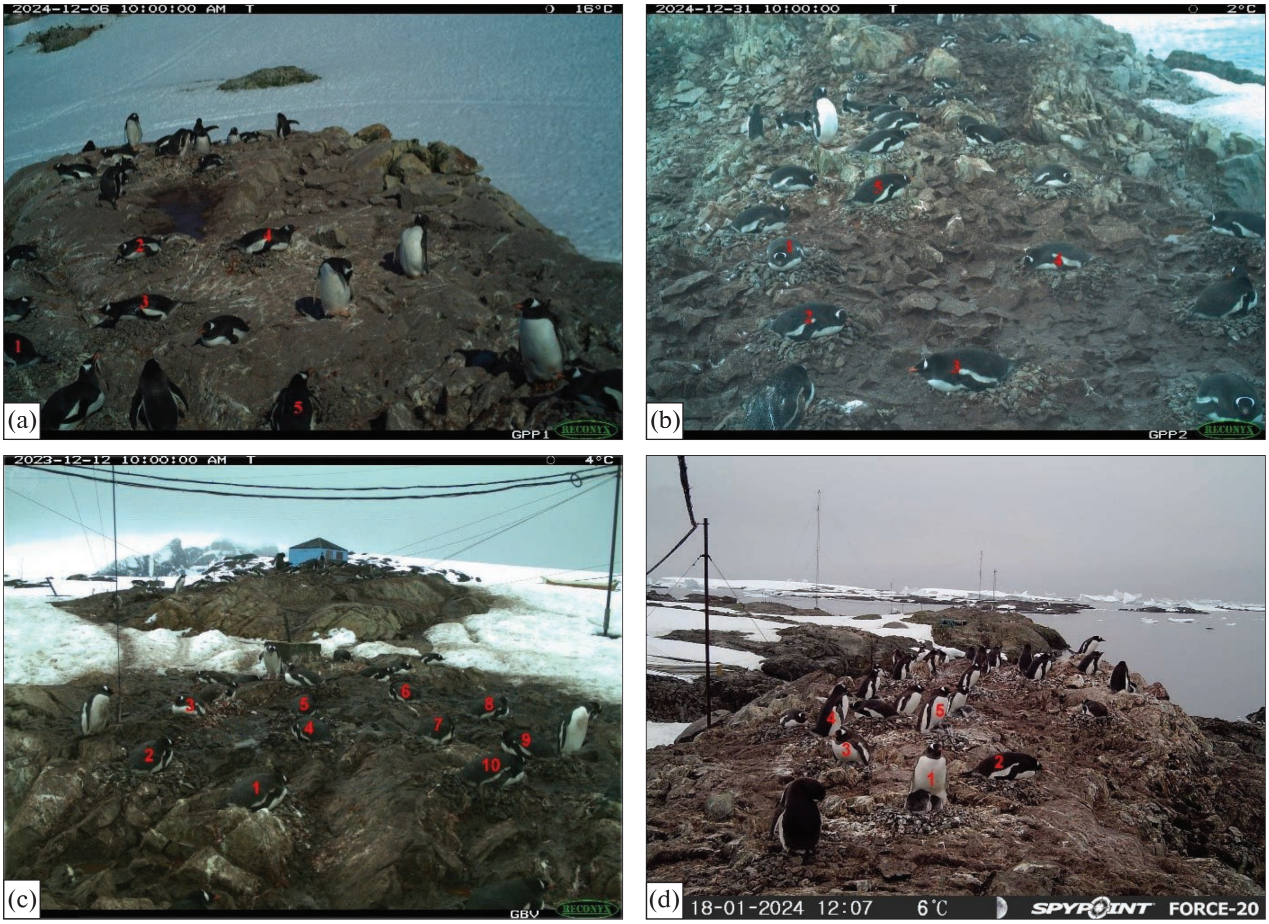

Figure 2. Examples of photos captured by time-lapse cameras at the sites GPP1 (a), GPP2 (b), GBV (c), and GMP (d). Red numbers mark nests for visual observation during camera validation experiment

For each photo, the camera recorded the date and time of capture. During the 2021/2022 season, cameras captured additional photos throughout the day (24 hours with a 30-minute interval; 48 photos per day). Photos taken from the 2020/2021 season (25th Ukrainian Antarctic Expedition (UAE)) to the 2024/2025 season (29th UAE) were used for analysis. The total number of processed photos is 19 533. The dates of the main events of the reproductive cycle chronology were registered using the photos: the lay of the first and second eggs; the hatch of the first and second chicks; and the date when the chicks leave the nest and form a crèche. To validate the accuracy of detecting the dates of these events from photos, 5–10 nests were selected in front of each camera, numbered (Fig. 2), and inspected daily, with subsequent recording of reproductive cycle events. The same nests were used to record the dates of events from time-lapse photos. During a visual inspection, the nest contents are checked by the researcher in person. For each nest, the actual date of clutch appearance, chick hatching, and crèche formation is recorded. In some cases, monitoring was conducted every other day, due to unfavorable weather conditions.

Reproductive phenology in the newly formed part of the colony was determined by visual monitoring and one additional time-lapse camera, installed near the Magnetometers Pavilion (GMP,

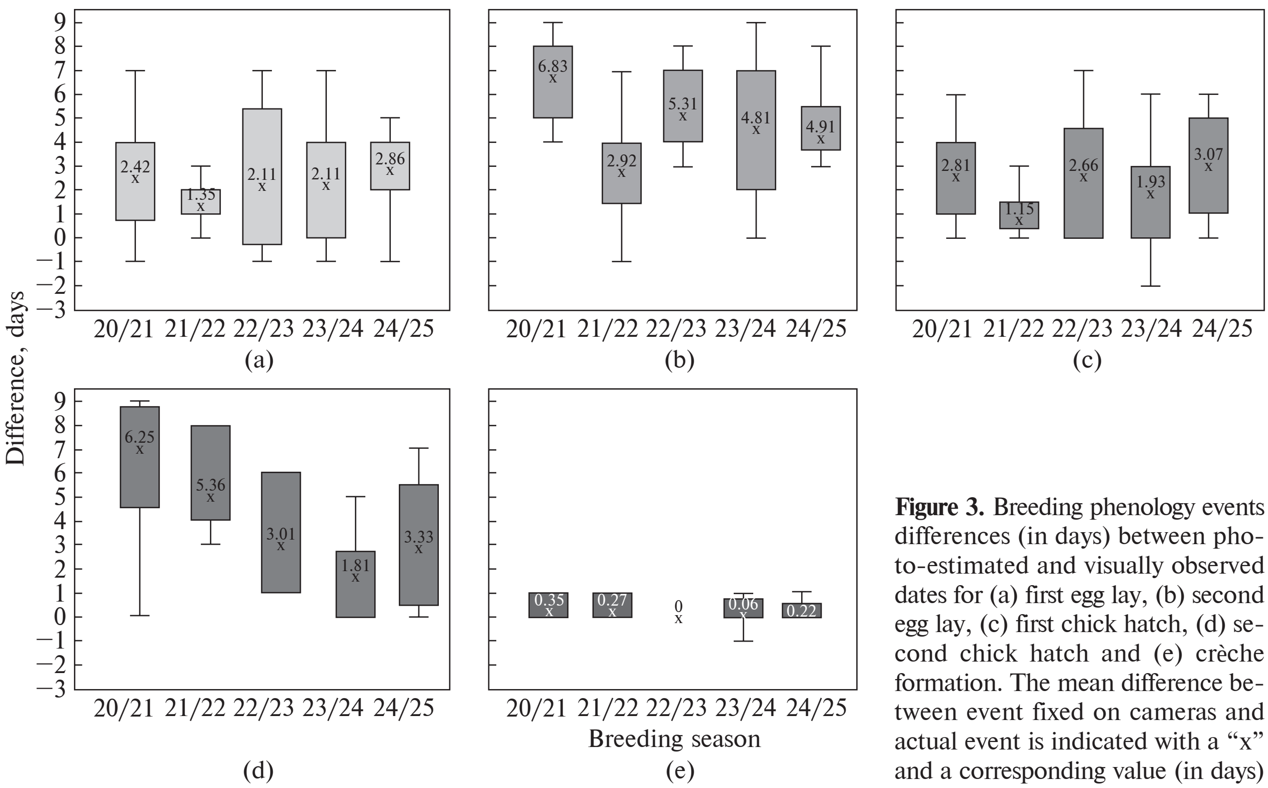

Figure 3. Breeding phenology events differences (in days) between photo-estimated and visually observed dates for (a) first egg lay, (b) second egg lay, (c) first chick hatch, (d) second chick hatch and (e) crèche formation. The mean difference between event fixed on cameras and actual event is indicated with a "x" and a corresponding value (in days)

65.245547°S, 64.251050°W). Current colony borders were defined based on aerial photos taken with a quadcopter DJI Phantom 4 Pro V2.

3 Results

3.1 Validation of time-lapse camera method

A comparison of determining the date of lay the first egg (CID – clutch initiation date) using time-lapse cameras and visual records yielded the following accuracy rates: in 2020/2021 season mean difference between CID fixed on cameras and actual event was 2.42 days (number of nests used in the experiment is 14, standard deviation is ±2.06); in 2021/2022 the difference is 1.35 days (n = 14; SD = ±0.71); in 2022/2023 it is 2.11 days (n = 10; SD = ±2.84); in 2023/2024 it is 2.11 days (n = 18; SD = ±2.55) and in 2024/2025 it is 2.86 days (n = 14; SD = ±1.74) (Fig. 3a). The mean difference across all seasons for CID is 2.17 ± 0.49 days. In several cases during photo processing, when the difference between the visually observed and photo-estimated dates exceeded 6 days within individual nests, the comparison values were excluded from the analysis as outliers. These cases are associated with specific penguin behaviour at the nest, such as increased speed and reduced frequency of nest relief (C. Muller-Schwarze & D. Muller-Schwarze, 1980) associated with particularly unfavorable conditions for certain nests (*e.g.*, greater exposure to wind and predator attacks at the edge of the sub-colony). This prevents the phenology event from being determined on time.

Confirmation of a second egg lay using cameras is less precise: in 2020/2021 the difference is 6.83 days (n = 12; SD = ±1.77); in 2021/2022 it is 2.92 days (n = 13; SD = ±1.97); in 2022/2023 it is 5.31 days (n = 10; SD = ±1.55); in 2023/2024 it is 4.81 days (n = 15; SD = ±2.94); in 2024/2025 it is 4.91 days (n = 10; SD = ±1.51)

(Fig. 3b). The mean difference across all seasons for second egg lay is 4.95 ± 1.24 days.

Hatch of the first chick was recorded with the mean difference: in 2020/2021 mean difference is 2.81 days (n = 15; SD = ±1.75); in 2021/2022 it is 1.15 days (n = 13; SD = ±0.94); in 2022/2023 it is 2.66 days (n = 9; SD = ±2.66); in 2023/2024 it is 1.93 (n = 15; SD = ±2.11), and in 2024/2025 it is 3.07 days (n = 14; SD = ±1.91) (Fig. 3c). The mean difference across all seasons for first chick hatch is 2.32 ± 0.69 days. Accuracy of detection of hatch of a second chick is 6.25 days (n = 8; SD = ±2.81) in 2020/2021 season; 5.36 days (n = = 11; SD = ±1.87) in the 2021/2022 season; 3.01 days (n = 3; SD = ±2.16) in the 2022/2023 season; 1.81 days (n = 16; SD = ±2.11) in the 2023/2024 season, and 3.33 days (n = 9; SD = = ±2.41) in the 2024/2025 season (Fig. 3d). The mean difference across all seasons for second chick hatch is 3.95 ± 1.62 days. It should be noted that the majority of observations of second-chick hatch (65–70%, up to 85% in the 2023/2024 season) reflect cases when in the nest both chicks hatched almost simultaneously. Analysis of the photos showed that the difference between the actual and camera-recorded formation of the crèche was less than one day throughout the entire study period (Fig. 3e). The mean difference across all seasons for crèche formation is 0.18 ± 0.13 days.

3.2 Breeding phenology difference between the old and new formed sub-colonies

Phenology of newly formed parts of colonies (sub-colony at GMP site, first nests recorded during 2020/2021 season) near the Magnetometers Pavilion (Fig. 1) was compared with older sub-colonies at GBP, GPP1, and GPP2 sites where the CEMP cameras were located since the 2016/2017 season. Thus, during the 2023/2024 season, it was found that at the GMP sub-colony, CID occurred on November 26 (n = 15; SD = ±0.95 days), while at the GBV and GPP sites, CID began on December 4 (n = 27; SD = ±1.23 days). The hatch of chicks also occurred earlier: in the new GMP site sub-colony, it occurred on January 1 (n = 14; SD = ±1.05 days), while in the GBV and GPP sites, it occurred on January 10 (n = 25; SD = = ±1.33 days). The transition of chicks to the crèche also took place earlier – on January 30 (n = 13; SD = ±0.35 days), while in the older sites this process occurred on February 5 (n = 20; SD = ±0.41 days). A similar situation was observed during the 2024/2025 season. CID at the GMP site occurred on November 20 (n = 17; SD = ±1.22 days), while at GBV and GPP sites – on November 28 (n = 29; SD = ±1.44 days), first chick hatch on December 30 (n = 17; SD = = ±1.04 days) at the GMP site *vs* January 5 (n = = 26; SD = ±1.57 days) at the GBV and GPP sites, and formation of the crèche on January 31 (n = 13; SD = ±0.28 days) on at the GMP site *vs* February 5 at the GBV and GPP sites (n = 23; SD = ±0.47 days).

4 Discussion

Based on the comparisons between direct observation and time-lapse camera data, the dates of CID and hatch for the first chick are most accurately determined by camera data across all years of the study (except for the crèche formation date). The accuracy of CID determination varies from 1 to 3 days (rounded to whole numbers). The accuracy of first-chick hatch is also between 1 and 3 days. Among all the seasons studied, the most accurate data was obtained during the 2021/2022 season. During this season, the cameras captured photos throughout the entire day; the greater number of photographs allowed the dates of reproductive cycle events to be determined more precisely.

Previous studies based on time-lapse cameras have chosen a time period of 9:00 a.m. to 3:00 p.m. based on the length of daylight in other parts of Antarctica, such as the South Shetland Islands (Hinke et al., 2018). Cameras on the territory of Wilhelm Archipelago were set up in a similar way to ensure comparable results (Dykyy et al., 2018). The experience of the 2021/2022 season has shown that expansion of the camera shooting period to 24 hours a day will significantly increase the accuracy of determining the dates of penguin reproductive cycle events, which will be especially relevant for studying colonies at distant islands where frequent visual monitoring is not possible, such as Petermann and Yalour Islands. Moreover, during the 2021/2022 season, no nests had to be excluded from the analysis due to outliers in the difference between the data observed visually and that estimated from photographs. The presence of such nests during the other seasons is explained both by the insufficient number of photographs taken during the day combined with the disadvantageous position of some nests, which made them more vulnerable to weather and predators and reduced the time it took to nest relief (C. Muller-Schwarze & D. Muller-Schwarze, 1980), which in turn reduced the likelihood of an egg or chick getting into the frame.

When comparing the results with a previous study on time-lapse camera validation (Hinke et al., 2018) conducted on King George Island, it was found that the accuracy of CID and hatch determining was higher (within 1 day) there, at more northern latitudes, compared to Galindez Island (about 2 days average, maximum — 3 days). Interestingly, the accuracy reported by Hinke et al. (2018) was based on aggregate data for different species of the genus *Pygoscelis* (*P. papua*, *P. adeliae* Hombron & Jacquinot, 1841, and *P. antarcticus* Forster, 1781). When analysing each species separately, accuracy drops slightly, but it remains within one day (for CID and hatch). At the same time, the date of *P. adeliae* crèche, analysed separately, is detected earlier by cameras by 2.4 days, in contrast to our data on *P. papua*, where there is no difference between visually observed and photo-estimated dates. The differences in breeding events' determination accuracy suggests species-specific differences in nesting behaviour.

The light conditions in the study region allow increasing the camera shooting period; during the penguin breeding season, which lasts throughout the Antarctic summer, daylight hours last about 22 hours. As an alternative, a 15-minute photo interval in the 10:00 a.m. — 2:30 p.m. period is being tested during the current 2025/2026 season. Both shooting options will produce sets of photos suitable for comparison with other areas within the CEMP program.

Monitoring of the newly formed section of the colony (GMP site) showed that the onset of reproductive cycle events in penguins here precedes that in other parts of the colony. Thus, the difference between the CID is 8—10 days, between the dates of first-chick hatch is 7—10 days, and between the dates of crèche formation is 6—7 days. A similar situation is observed in new parts of colonies of the auk, the common murre (*Uria aalge* Pontoppidan, 1763), but in this case, it is because these birds occupy the most convenient nesting sites long before the start of the breeding season (Bennett et al., 2022). At the same time, visual observations show that penguins arrive at the GBV, GPP, and GMP sites almost simultaneously in late August. The rate of nest construction at different sites also does not differ. It is possible that the uneven phenology in different parts of the colony is related to the age structure of the *P. papua* population. Testing this hypothesis requires further multi-year studies using individual tagging methods, such as band/transponder tracking.

5 Conclusions

A difference between visually observed and photo-estimated dates of events of the *P. papua* breeding cycle was determined. It varies for different events: for first egg lay (CID), it is 2.17 ± 0.49 days; for second egg lay, 4.95 ± 1.24 days; for first chick hatch, 2.32 ± 0.69 days; second chick hatch, 3.95 ± 1.62 days; and for crèche formation, 0.18 ± ± 0.13 days. Increasing the daily interval during which photos are taken significantly improves the accuracy of determining breeding event dates.

A considerable shift in *P. papua* breeding phenology was noted for the new sub-colony at the GMP site near the Magnetometers Pavilion: during the 2023/2024 and the 2024/2025 seasons, all reproductive cycle events occur 6–10 days earlier than in the older parts of the overall Galindez Island GAI colony. This shift is unlikely to be related to differences in the timing of penguin arrival at nesting sites; its causes require further research.

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Точність даних автоматичних фотокамер та мінливість фенології розмноження субантарктичних пінгвінів на острові Галіндез

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Реферат. Стан та динаміка популяцій пінгвінів є одними з ключових показників для оцінки морських живих ресурсів Антарктики та розробки стратегії промислу криля. Аргентинські острови є південною межею ареалу одного з найчисленніших видів пінгвінів – субантарктичного пінгвіна, *Pygoscelis papua*. Колонія *P. papua* на острові Галіндез (ділянка CEMP GAI), де розташована Українська антарктична станція «Академік Вернадський», є другою найпівденнішою колонією цього виду та однією з найбільших у регіоні, з популяцією пінгвінів близько 7000 дорослих особин у пік сезону (2025/2026) та зростанням з року в рік. За останні п'ять років обидві частини колонії, одна з яких розташована біля головної будівлі станції, а інша на мисі Пінгвін-Пойнт, значно розширилися в напрямку одна до одної. Найбільша з новоутворених ділянок колонії розташована біля магнітометричного павільйону станції. Метою дослідження є оцінка точності визначення хронології основних подій репродуктивного циклу *P. papua* шляхом порівняння даних автоматичних фотокамер з візуальними спостереженнями за гніздами, а також вивчення фенології у новоутвореній частині колонії. Було виявлено, що найточніше визначення було зроблено для дати формування ясел — різниця становить менше одного дня. Дати відкладання першого яйця та вилуплення першого пташеняти визначаються дещо менш точно, так як різниця між візуальними спостереженнями та даними камери становить приблизно 2 дні для обох подій. Дані камери зазвичай відстають від візуального виявлення подій. Більша кількість фотографій, зроблених з 30-хвилинними інтервалами протягом світлового дня, допоможе значно підвищити точність визначення подій репродуктивного циклу. Дослідження нової частини колонії острова Галіндез на ділянці GMP, яка сформувалася поблизу магнітометричного павільйону, показало, що всі події репродуктивного циклу в цій зоні відбуваються на 6–10 днів раніше, ніж у старих частинах колонії. Ця особливість не пов'язана з відмінностями в часі прибуття пінгвінів у різні частини острова та потребує подальших досліджень.

Ключові слова: *Pygoscelis papua,* Аргентинські острови, валідація, репродуктивний цикл, фотопастка, хронологія