The Level of reproduction synchronization in early and late colonies gull birds (on the example of the White-winged Black Tern)

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Abstract. Based on many years of research (1972-82) in the delta of the river. Selenga (Lake Baikal, Eastern Siberia) the level of synchronization of bird reproduction in white-winged tern colonies is considered. This region is distinguished by an extremely dynamic mountain-floodplain water regime, which determines the high mortality of nests from flooding. For such an analysis, we used a specially developed multiplication synchronization index, I_{sr}. Its use makes it possible to compare, on this basis, dense nesting clusters of any species of birds, as well as their breeding seasons, which differ in nesting conditions. It has been shown that the synchronization of reproduction is most pronounced in small colonies that form at the beginning of the nesting season. In some cases, all birds of a small colony (up to 15, and extremely rarely 20 birds) can start breeding in one day. By the end of the nesting season, this index in the colonies decreases. The high mortality of nests and the massive repeated (compensatory) nesting of birds determine the high variability of the breeding synchronization index. Nevertheless, its use makes it possible to quite clearly determine the level of breeding synchronization in any dense flocks of birds. It can be one of the criteria for distinguishing between colonial and non-colonial bird species in certain situations that form dense nesting concentrations.

Keywords: Eastern Siberia, Selenga river delta, White-winged Black Tern, colonial nesting, breeding synchronization index.

Introduction

The ecology of colonial birds of many species is understood not fully, which hinders the solution of many practical issues related to determining their role in coastal ecosystems. The special questions of the biology of their reproduction are also poorly known. This does not allow the development of clear criteria for the separation of colonial and non-colonial bird species, many of which often form local dense nesting aggregations. The level of nesting density in such aggregations often reaches values characteristic of optional and sometimes obligatory colonial species [4, 13], although they clearly do not belong to colonial birds.

At the same time, it is well known that colonies of gull birds are often characterized by a well-pronounced synchronization of reproduction [6]. It can change depending on the size of the colonies. As a rule, with an increase in colony size, the synchronization of bird reproduction greatly decreases, although there are exceptions to this rule [6, 7]. In addition, it is known that the level of synchronization can be associated with the timing of colony formation; at the end of the bird breeding season, it can decrease [2-3, 9. 11]. The particular significance of this parameter is due to the fact that reproductive success in birds is often associated with it [3, 9, 11]. However, this issue is still

very poorly studied. The main reason for this is due to the need to collect and analyze a very large field material. In this regard, the solution of this problem requires a very large investment of time and is distinguished by high labor intensity. Despite this, we have undertaken special work to study this phenomenon, the results of which are presented in this communication.

Purpose of the study

The main purpose of this publication is, on the basis of long-term research (1972-82), to analyze the features of changes in the level of synchronization of bird reproduction in gull colonies (using the example of the white-winged tern) during the full nesting season. Show the features of the dynamics of this parameter depending on the size of the colonies and the timing of their formation. Despite the fact that this work was carried out a very long time ago, its results, for a number of objective reasons, have not yet been published. At the same time, despite the rather intensive study of birds of this group, this issue remains very poorly studied and the materials we have collected have not lost their relevance.

Materials and methods

The work was done in the Selenga river delta (Lake Baikal, Eastern Siberia) (1972-82) during the full 11-year climatic cycle, characterized by abnormally high and low water levels at the beginning and end of its formation. For all mountain basins of rivers in Eastern Siberia, one common feature is characteristic - an extremely unstable mountain-floodplain water regime. Its main signs are short-term, but very strong spring floods and several summer floods (from 2 to 7, extremely rarely up to 11), sometimes reaching the force of catastrophic floods. Constant and often very strong rises in the water level cause a large death of nests and, along with other limiting factors (early spring burning of last year's vegetation, predation of birds and mammals, grazing, haymaking and intrapopulation factors), greatly reduce the success of bird reproduction.

Our field work covered the entire nesting period, which made it possible to obtain acceptable estimates of the main parameters of their reproduction, incl. and phenological periods, especially egg-laying, using the flotation method [7-8]. Annually, within a key site with an area of 150 km^2 in the central part of the Selenga river delta., covering all the main habitats of birds, a survey of colonies of all species of gull birds was carried out. In this case, we consider the peculiarities of the synchronization of reproduction in the colonies of the White-winged Black Tern *Chlidonias leucopterus.* Due to its very high number, it was possible to collect a large amount of material that allows a full analysis of the considered issues of the ecology of this species. Within the colonies selected for continuous study, all found nests were marked with numbered pegs. The eggs were marked with indelible paint (KTs-52) with stripes (gulls and waders) or Roman numerals (rails and ducks) at the narrow end of the egg, the number or value of which corresponded to the order of laying determined by the

flotation method [6-8]. The control of nests was carried out after 2 days, but in the case of a long period of unfavorable weather after 3-4 days, up to a specific final state: the death of clutches for various reasons or hatching and rearing of chicks.

The work during the full field season made it possible to collect massive and high-quality material on the timing of egg-laying, incubation of clutches and the peculiarities of egg incubation, which are necessary to develop methodological approaches associated with the use of the flotation method [1, 7-8, 12]. It should be noted that the flotation method for determining the date of appearance of the first egg in clutches, the timing of the formation of which is unknown, is standard and generally accepted in studies of the biology of bird reproduction. Based on our data, it was possible to refine the scoring system for the degree of incubation of white-winged tern eggs by their position in the water [5]. Comparison of the course of the water level, the death of nests from various factors and the appearance of repeated clutches leaves no doubt that the graphs of the course of egg-laying, built on the basis of the flotation method, reflect these processes well.

In the general series of studies of various stages of the nesting cycle of birds, it is very important to accurately identify the mass periods of egg-laying, which is always associated with certain difficulties. They are minimal with a unimodal distribution of the dates of appearance of the first eggs in clutches. However, for most breeding seasons of birds, under conditions of an unstable hydrological regime, bimodal distributions of the dates of their formation are more characteristic. With a large mortality of nests occurring at different periods of egg-laying, due to massive repeated, and sometimes even third attempts to restore them, polymodal distributions are formed. Isolation of mass periods in them is often a very difficult task. Its solution is possible on the basis of the graphical method used in our work [7].

The total duration of egg-laying, as well as the proportion of birds that nested during the period of mass formation of clutches, can vary greatly in different seasons [6-8]. Mass death of nests as a result of strong fluctuations in the water level - up to 70.0% and more - has a particularly large effect on these parameters of the nesting cycle of birds [7]. In such situations, only the nests of birds nesting on high islands and terraces above the floodplain remain. The proportion of birds that started breeding during mass egg-laying is often determined by weather factors in a particular nesting season, causing a significant lengthening or, conversely, a reduction in the breeding season. Most often, there is a shift in the period of mass egg-laying to the beginning or end of the nesting season, forming a well-pronounced asymmetry in the distribution of the timing of formation of clutches. An accurate assessment of such changes is impossible without special approaches, one of which is to determine the level of synchronization of bird reproduction.

A large number of compensatory clutches greatly extends the breeding season of birds (Table 1). They also make it very difficult to determine the period of mass nesting of birds in different

colonies. In large colonies, which are most characterized by a polymodal distribution of the timing of the formation of clutches, the first mass peak of bird reproduction is taken as the time of the beginning of the formation of a colony, since there may be several such peaks. It often does not coincide with the period of the entire mass nesting of birds in the colony, which can combine several peaks of bird reproduction. In small colonies, most often this problem is absent - all birds start nesting in 5-10 days.

Table 1

The total duration of the White-winged Black Tern breeding season and the boundaries of the identified decades in the Selenga river delta (Lake Baikal, Eastern Siberia)

N o/p	The boundaries of the decade	Decade number
1	2	3
1	May 26 – June 4	I
2	June 5 – June 14	II
3	June 15 – June 24	III
4	June 25 июня – July 4	IY
5	July 5 – July 14	Y
6	July 15 – July 24	YI
7	July 25 – August 3	YII
8	August 4 – August 13	YIII

Source: compiled by the author.

The complex combination of various parameters makes it very difficult to quantify this phenomenon, which requires the use of special methods. In this case, the best option is to develop a complex index that includes several parameters that determine the characteristics of bird reproduction. As a result of long-term studies, we have developed an index of bird reproduction synchronization, which allows us to solve this problem [6-7]:

$$I_{sr} = \sqrt[2]{(n/l)/N}, \qquad 0 < I_{sr} < 1$$

where: n is the number of clutches started during the mass egg-laying period, in pieces, *l* is the duration of the mass egg-laying, in days up to tenths, N is the size of the colony, accumulation, aggregation or the total sample size from the population (number nests or pairs).

During the work, 143 White-winged Black Tern colonies were under constant control. All graphs are based on the date of laying of the first egg in each nest detected and monitored. A preliminary check was made of the correspondence of the distribution of egg-laying dates by day on the basis of actual and calculated information obtained by the flotation method. A comparison of these samples was carried out on the basis of the most stringent Kolmogorov-Smirnov homogeneity criterion [10]. It includes checking all kinds of distribution differences, scattering, skewness and kurtosis. The collected materials were analyzed using standard statistical methods [10]. Data processing and construction of tables and graphs were performed in Excel2016 and CorelDRAW2018 programs.

Results

Analysis of the collected materials shows that the synchronization of reproduction is clearly higher in small colonies and can in some cases 1.0 reach. With an increase in the colony size, the bird index reproduction synchronization decreases (Fig. 1). However, this pattern does not reach a high level, although it is reliable - P <0.05. The coefficient of determination (R^2), showing what proportion of the relationship falls on these signs is only 13.0%. Indeed, this regularity is violated often and there are small colonies with a low level of synchronization of bird reproduction and rather large colonies with a high level (at the level of the average value typical for the population of this region). The highest index of bird reproduction synchronization is in colonies of up to 40-45 nests observed. At the same time, in colonies of this size, there are often cases of very low synchronization of bird reproduction. In this regard, it makes sense to analyze the relationship between the synchronization index of bird reproduction in colonies and the timing of their formation.

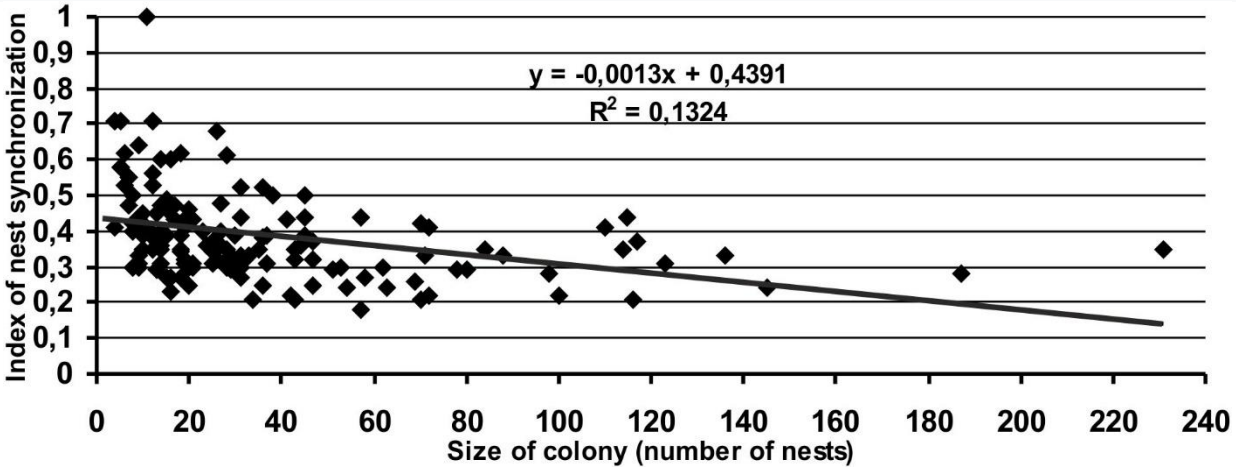

Fig. 1. The level of relationship between the index of reproduction synchronization and the colony size of the White-winged Black Tern in the dynamic conditions of the mountain-floodplain water regime of the Selenga river delta. *Source: Compiled by the author*.

The relationship between the synchronization index of bird reproduction in colonies and the timing of their formation does exist, but it is very low and does not reach reliable values. The coefficient of determination of features (R^2) reaches only 2.0% (Fig. 2). At the same time, it is clearly seen that at the end of the breeding season, colonies with average values of the synchronization index prevail. The general period of the nesting season is very extended and covers 8 decades, which is a very rare phenomenon for the main part of waterfowl and waterfowl in Eastern Siberia. However, most of the colonies are formed in the first half of the nesting season (Fig. 2). At the same time, there is clearly a higher average index of synchronization of bird reproduction in colonies in the second half of the nesting season. Its variability at this time (IY-YIII decades) is clearly less than in the first half of the nesting period. The main reason for this is undoubtedly the high nest loss observed already in

the first half of the nesting season (predation of large gulls and mammals, cattle grazing, herding dogs). Death from these factors in the first half of the breeding season is not very high. Therefore, birds that have lost their clutches at this time do not form independent colonies, but settle in already existing colonies. As a result, due to such single clutches, the total breeding period of birds in the colony increases sharply, and the level of their reproduction synchronization, even in small colonies, sharply decreases. This leads to a large variability of the index reproduction synchronization birds in the first half of the nesting season.

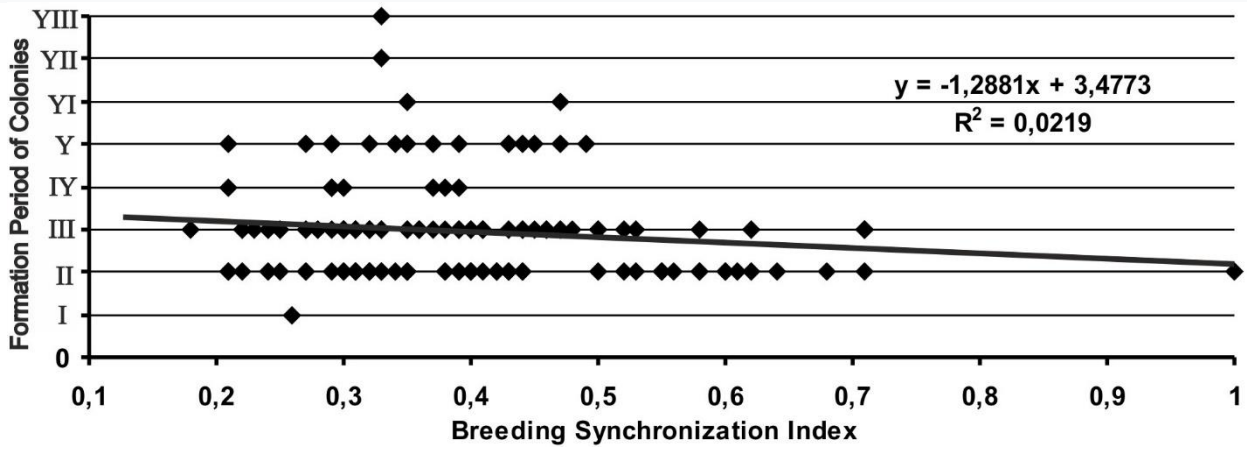

Fig. 2. The level of correlation between the synchronization index of bird reproduction in colonies and the duration of the period of their formation on the White-winged Black Tern in the dynamic conditions of the mountain-floodplain water regime of the Selenga river delta.

The ordinate shows decades in which the formation of new colonies is marked. *Source: Compiled by the author*.

At the same time, the relationship between the size of colonies and the total duration of the nesting season remains unclear, which requires additional consideration (Fig. 3). The connection between these features, as well as in other cases considered by us, is small. The coefficient of determination (R^2) selects only 7.0% of the total variability of these factors (Fig. 3). First of all, it should be noted that the main part of the later colonies is formed by birds that have lost the first and sometimes second clutches. Often, such birds settle in already existing colonies, the size and general breeding time in which sharply increase. In some cases, very large colonies (for a given species) can form, the breeding season in which covers almost the entire nesting period of birds. The proportion of colonies formed in the first half of the nesting season is also quite large, the size of which, subsequently, is determined by the number of birds that have settled in that have lost their first clutches. In some cases, they can reach sizes of 200-300 pairs, which is a rather rare event for this species (Fig. 3). However, it is clearly seen that in the first half of the nesting season, small colonies (up to 50 nests) predominate. The formation of large colonies at this time is a rather rare event.

In this case, it should be noted that usually the period of mass reproduction of birds in a colony is within one decade. However, in very large colonies, due to the repeated introduction of new groups of birds (small colonies), the total breeding period increases dramatically. As a result, the general appearance of the laying period in such colonies takes the form of a polymodal distribution. In such cases, it is very difficult to identify the period of mass nesting of birds (it is determined by the graphical method) [7], and the first peak of mass egg-laying is taken as the time of formation of such a colony. That is why the formation of the main part of large colonies occurs at the beginning of the nesting season. In fact, their total size is determined by the number and size of the populated groups of birds. Often, with a high mortality rate of nests in the middle or second half of the nesting season, new groups of birds settle in colonies in which mass hatching of chicks is observed, and quite often some of the young birds have already "risen on the wing".

Fig. 3. The level of relationship between colony size and the time of its formation on the White-winged Black Tern in the dynamic conditions of the mountain-floodplain water regime of the Selenga river delta. *Source: Compiled by the author*

Analysis of the graphs does not give a clear answer to the question of whether the early and late colonies differ in the level of the bird reproduction synchronization index. Therefore, we conducted a correlation analysis between these factors (Table 2). He showed that the index of synchronization of bird reproduction in early small colonies is reliably and significantly higher than in other colonies differing in size and timing of formation. There are significant high-level differences ($P < 0.001$) between early and late small colonies. These differences persist up to the size class of colonies of 41-60 nests, but the level of significance of differences decreases ($P < 0.05$) (Table 2). The lack of significant differences between these characters in the largest colonies (61-80 and more than 81 nests) is clearly due to the insufficient sample size of colonies of these size classes. Consequently, differences in the index of synchronization of bird reproduction in early and late colonies do exist, but in larger colonies these differences are clearly smoothed out (Table 2). Undoubtedly, the main reason for this is the complex nature of their formation, which is also confirmed by the polymodal

distributions of the egg-laying course in large colonies. In small colonies, the course of egglaying, in most cases, is characterized by positive excess and positive asymmetry caused by a high level of synchronization of bird reproduction [6].

During the analysis of the distribution features of the reproduction synchronization index in colonies of different size classes, first of all, its high variation attracts attention. In all size classes in colonies formed at different times, there are both high and very low indices. The coefficient of variation of the average value of this index in different size classes of colonies is gradually increasing (from 4.08% to 9.82%), and the average value of the synchronization index is constantly decreasing (Table 2). The increased variability of this trait is also well traced in the late colonies (in the early ones from 4.08% to 9.82%, and in the later from 5.71% to 6.62%). Consequently, there is still a certain pattern in its changes, but it is strongly veiled by random manifestations of various factors.

Table 2

The level of synchronization of reproduction in colonies of the White-winged Black Tern *Chlidonias leucopterus* formed at different periods of the nesting season

Colony size, nests	Colony formation time*	Number colonies	Index of Breeding Synchronization	
			Middle	Limit
Up to 20	I-III	48	**0,49±0,02*****	0,27-1,0
	IY-XIII	17	**0,35±0,02*****	0,23-0,49
21-40	I-III	25	**0,39±0,02****	0,27-0,68
	IY-XIII	9	**0,32-0,02****	0,21-0,44
41-60	I-III	8	**0,39±0,04****	0,22-0,52
	IY-XIII	12	**0,3±0,02****	0,18-0,43
61-80	I-III	5	0,31±0,03	0,26-0,41
	IY-XIII	6	0,29±0,03	0,21-0,42
81 and more	I-III	6	0,34±0,03	0,22-0,44
	IY-XIII	8	0,31±0,02	0,21-0,37

Note: *Decads, which account for the peak of the mass egglaying of the species in colonies of this size (see Table 1). The level of significance of differences in the synchronization index of bird reproduction in colonies differing in terms of formation: **P <0.05, ***P <0.001. Significant differences in the reproductive synchronization index between early and late colonies are in bold highlighted. *Source: compiled by the author.*

The synchronization of reproduction is clearly reduced in later colonies, which are formed mainly by birds, which compensate for the death of the first clutches by repeated reproduction. By settling in other colonies, even as part of a group with synchronous breeding (small colonies), such birds sharply reduce the synchronization index of their reproduction. At the same time, at the beginning of the nesting season, large colonies with synchronous reproduction can sometimes form, which, in general, is not typical for this species. This situation is observed when several small colonies, which do not differ in terms of formation, occupy one small area for nesting, forming a very large nesting accumulation (colony) of birds.

Discussion

The most interesting question in the analysis of the peculiarities of the synchronization of bird reproduction is to find out the reasons for the appearance of large colonies. Why do birds choose only certain colonies and do not settle in others that are found in the neighborhood? This issue was not considered in this context in any known work on the synchronization of bird reproduction [2-3, 9, 11]. In unstable environmental conditions, birds prefer to nest in small colonies characterized by a high synchronization of reproduction. This is confirmed by observations of all species of gull birds in the Selenga river delta [6] and only Black-headed Gull *Larus ridibundus* is an exception. It forms large colonies in this region in the areas of an extensive network of small channels and extensive silt shoals. There is a high abundance of small molluscs, which the birds use to feed their chicks. All large colonies of white-winged tern formed in the lower delta among vast shallow waters occupied by thickets of horsetails and reed beds. The highest abundance of aquatic insects with which they feed their chicks is here observed. Undoubtedly, the migrating birds choose areas with an increased abundance of forages, which leads to the formation of very large colonies.

During periods of mass death of clutches, part of the colonies often perishes completely. When embarking on re-nesting, birds usually choose the remaining colonies, increasing their chances of successful breeding. They increase sharply under conditions when the first flood is higher than all subsequent ones. Such floods can no longer have a significant impact on the survival rate of birds. At the same time, the proportion of large colonies in the population is growing, despite the fact that they are based on small colonies. Consequently, a large number of small colonies at the beginning of the breeding season allows us to occupy as many areas as possible, which, according to feeding conditions, allow them to grow chicks normally. The high synchronism of bird reproduction in the colony increases the chances of successfully completing the nesting season as soon as possible.

The high mortality of nests includes the following mechanism for increasing the success of bird nesting - compensatory breeding. Occupying areas with preserved colonies or colonies with a low proportion of dead clutches, birds reduce the synchronization of reproduction of, in fact, a new colony. However, in the new site, the chances of successful breeding of birds increase, compensating for the losses associated with a decrease in its synchronicity. It should be noted that these are territories with an increased abundance of forages, which increases the reproductive success of birds. The complex and multifaceted formation of colonies in extremely unstable environmental conditions dramatically increases the chances of birds to raise offspring, in fact, in critical situations. The important thing here is that the reproductive success of the entire population is ensured by special adaptations based on the "trial and error" method.

Conclusion

Long-term studies of the ecology of the white-winged tern show that one of the main features of this species is a very high synchronization of bird reproduction in small colonies. However, a large number of strongly acting limiting factors and, above all, an extremely unstable hydrological regime, lead to a large death of nests during the breeding season. Massive compensatory reproduction significantly increases the total duration of the bird nesting season. It also, in most cases, sharply reduces the general synchronization of bird reproduction in early colonies, which is well reflected by the index of bird reproduction synchronization. In addition, co-nesting of several small colonies with very different breeding times, even at normal times typical for the population, can also significantly reduce the synchronization of bird reproduction in a common larger colony. A decrease in the reproduction synchronization index in late colonies is determined by a high proportion of compensatory clutches. As a result, the general nesting rhythm in colonies of any size is disrupted and the reproductive synchronization index decreases.

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