DYNAMICS OF THE TIMING OF MASS SPAWNING OF THE SAFFRON COD *ELEGINUS GRACILIS* IN THE AMUR BAY, SEA OF JAPAN

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The dates of the beginning and end of mass spawning and their interannual variability were determined based on the data of long-term monitoring of the sexual maturity of the saffron cod *Eleganus gracilis* during its under- ice spawning period in the Amur Bay of the Sea of Japan. A tendency to shift spawning to earlier dates and several shifts in this process associated with changes in environmental conditions, in particular, with climatic changes caused by global warming were found in the Sea of Japan in 1988–1989. The dates of spawning of saffron cod depend on the conditions of the summer-autumn feeding and maturation of fish in previous seasons: the warmer the subsurface water layer, the earlier saffron cod spawns. As a result, the period of mass spawning of the species in the study area, which began on average on December 25 and ended on January 12 in the 1970s, shifted to the period from December 18 to December 30 by 2021–2023. Besides,

intraseasonal patterns of the spawning process are found, as several spawning runs in some years. The early run is presumably characteristic of younger fish that feed in the coastal zone, while older individuals of saffron cod run later due to feeding at greater depths and at lower temperatures. The early approach is presumably typical for younger-aged individuals that forage in the coastal zone, while older ones approach later, possibly because of their feeding at greater depths and at lower temperatures.

Keywords: saffron cod *Eleginus gracilis*, timing of spawning, feeding conditions, climate change, Amur Bay, Sea of Japan.

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INTRODUCTION

Far Eastern saffron cod *Eleginus gracilis* (Tilesius, 1810) is a mass arctoboreal elittoral species of the cod family (Gadidae), distributed in the coastal waters of the North Pacific almost everywhere, from Primorye to Alaska. An important biological feature of saffron cod is its winter spawning, which allows its offspring in early ontogenesis to use plankton food resources during the period of their greatest abundance - in spring and early summer. Probably, this feature allows the species to reproduce successfully under conditions of modern climate change towards warming, in which the bioproductivity of the subarctic waters of the Sea of Japan is decreasing. This adversely affects the state of populations of the previously dominant planktophagous species in the ecosystem - walleye pollock (Zuenko, Nuzhdin, 2020; Krovnin et al., 2022). On the contrary, the biomass of saffron cod in most local populations is growing as winters become less severe, which is explained by improved spawning conditions (Novikova et al., 2023). The exception is the southernmost population of saffron cod, reproducing in Peter the Great Bay of the Sea of Japan. In the waters of Amur Bay, which is covered with fast ice in winter, one of the main spawning grounds of this population is located (Fig. 1). During the spawning period, 60-80% of its stock is concentrated here, on which the winter fishing of the species with passive fishing gear is based (Vdovin, 1996). In the 20th century, the largest catches of saffron cod were observed here in the 1940-1950s and early 1980s (Gavrilov, 1998; Chernoivanova, 2000). After the "regime shift" of the Sea of Japan climate in the late 1980s towards warming (Khen et al., 2020), the population stock sharply decreased, and it remains in depression to this day (Fig. 2). It seems that after the climate shift, environmental conditions in the spawning area became generally unfavorable for saffron cod reproduction.

The well-known Cushing (1979) concept about the influence of changes in seasonal rhythms of natural processes on fish reproduction success (the "match-mismatch" hypothesis) applied to the reproduction dynamics of saffron cod in Amur Bay showed that such a dependency exists (Zuenko et al., 2010). In the 1990-2000s, the time interval between mass spawning (in December-January) and mass development of early stage zooplankton (usually in April) began to differ from the optimal value corresponding to the duration of saffron cod egg development due to an emerging shift in spawning timing to earlier dates. In those years, this shift was still small, but the warming process of the Sea of Japan, after some slowdown in the early 2000s, continued again. According to our observations, the trend of shifting saffron cod spawning dates also continued – now mass spawning in Amur Bay not only begins but also often ends in December. The duration of the warming period has exceeded 30 years, a timeframe that in climatology is considered a formal threshold for studying ongoing changes as a climate-scale process. Therefore, the opportunity and necessity arose to examine the dynamics of mass spawning timing of saffron cod in Amur Bay during the period after the climate shift of the late 1980s, to identify the characteristic trend of timing changes in the new environmental conditions, and to understand its causes, which became the aim of this study.

During the work, original methods were developed or improved, which in itself is an important result. First of all, this is a method for precisely determining the dates of the beginning and end of mass spawning based on monitoring data of fish reproductive products. The second methodological task solved within this research was the identification of factors determining these dates, as applied to a species spawning in very stable conditions. The rationale and description of these methodological approaches are highlighted in separate subsections of the article.

MATERIAL AND METHODS

Observations of the physiological state of spawning saffron cod . The study uses observational data on the biology and fishing of spawning saffron cod in Amur Bay (Peter the Great Bay, Sea of Japan) for 1953-2023. Biostatistical data for 1953-1993 were obtained from archival materials stored in the Regional Data Center of TINRO, while in 1994-2023 the authors conducted their own collections.

Industrial fishing of saffron cod in the Amur Bay is carried out during winter months, from December to March, using fyke nets installed on the ice at depths from 2-3 to 17-19 m. Random samples (50-100 specimens) of saffron cod were selected from catches for biological analysis, and additional mass measurements of 200-300 specimens were carried out. During biological analysis, Smith's body length was measured, the weight of each individual was determined, as well as gonad maturity stage, stomach fullness, and qualitative contents of the food mass, and otoliths were collected. Further processing of the obtained data was carried out according to standard methods (Pravdin, 1966) accepted in ichthyological practice. The most important data, without which the study of the dynamics of saffron cod spawning timing would be impossible, are the results of frequent, albeit irregular, determinations of the state of reproductive products of saffron cod from catches during the spawning period (December-January, less often February-March). This unique series of observations has been conducted from 1953 to the present. The stages of gonad maturity in spawners were determined visually using a six-point scale (Sakun, Butskaya, 1963): IV, IV-V – pre-spawning individuals; V, V-VI – ready to spawn and spawning; VI, VI-II – post-spawning.

The state of the saffron cod stock spawning in Amur Bay was assessed using commercial indicators (annual catch of spawning saffron cod and the number of fyke nets deployed in fishing areas of Amur Bay) for 1965-2009 from the information of the Primorsky branch of the Main Basin Directorate for Fisheries and Conservation of Aquatic Biological Resources, and for 2010-2023 from the information of the Monitoring and Communication System Center (Eastern branch) and the industry system "Monitoring." Since the under-ice fishing of saffron cod in Amur Bay is conducted precisely during the spawning period of the species, interannual changes in spawner biomass can be roughly estimated by saffron cod catches per unit fishing effort, in our case - catch per fyke net, which was determined as the ratio of the total catch of saffron cod by fyke nets for the entire fishing season to their number (Fig. 2).

Oceanological Observations on the Shelf of Peter the Great Bay . TINRO monitors conditions under the ice of the Amur Bay, but for our study, the results of these measurements are useless (and not used) since they record stable negative water temperatures that hardly change from year to year or between winter months. More important are data on thermal conditions during feeding and maturation of spawners in summer-autumn, when saffron cod inhabits the bottom layer of the sea. Such observations have been conducted since 1981 on a standard transect across the shelf of Peter the Great Bay along 132°E. Under summer stratification conditions, the bottom layer in the upper part of the shelf is occupied by the subsurface shelf water mass (SSW), and saffron cod is distributed within its limits during the warm period of the year (Chernoivanova et al., 2011). The habitat conditions of the species during the inter-spawning period can be characterized by the average May-October temperature of the SSW. The modal temperature indicator is convenient, being least sensitive to changes in the surveyed area's contours and measurement discreteness. In recent years, the transect along 132°E has been performed irregularly, so gaps in the interannual dynamics of SSW temperature were filled using data from other standard observations - the oceanological monitoring of Amur Bay conducted since 2009 with monthly surveys from May to October. Interannual changes in the average May-October SSW temperature for the two series of observations reveal a close statistical relationship (positive, linear, $r^2 = 0.64$), which allowed the reconstruction of an almost continuous data series on the modal temperature of SSW during the warm period for 1981-2023 (Fig. 3). The temperature dynamics over these 40 years is characterized by a statistically significant positive trend, formed mainly due to the temperature difference between the 1980s and 2000-2010s, with a noticeable increase during the 1990s. Although this increase does not coincide in time with the climate regime shift of 1988-1989, it is likely its consequence, delayed due to the thermal inertia of the deep sea layers.

Method for Determining the Dates of the Beginning and End of Mass Spawning of Saffron Cod. In each sample for bioanalysis, female saffron cod with gonads of different maturity stages were in a certain ratio, and based on the dynamics of this ratio during spawning, the dates of the beginning of mass spawning and its end were identified.

First of all, it is necessary to decide which moments during spawning, which for saffron cod in the Amur Bay lasts several weeks, should be considered the beginning and end of mass spawning. During spawning, the proportion of pre-spawning females (with gonads at stage IV maturity or less) decreases, the proportion of post-spawning females (gonads at stage VI maturity or with a new egg development cycle beginning) increases, while the proportion of spawning females (gonads at stages V and V-VI maturity) first increases and then decreases, with these changes occurring rather gradually. Therefore, the moments of beginning and end of mass spawning are determined conditionally - by the ratio of the number of females that have entered spawning to the number of post-spawning females. The beginning of mass spawning is defined as the moment when the combined proportion of spawning and post-spawning females reaches half of the total number of mature females (starting from which the majority of females enter spawning), and the end of mass spawning is the moment when the proportion of post-spawning females reaches half (starting from which the majority of females exit spawning). These ratios change very quickly, so to determine such dates through direct observation, it would be necessary to assess the physiological state of fish daily. In fact, biological analysis of saffron cod from ice fishing catches in the Amur Bay was conducted at best once a week, and usually even less frequently. Nevertheless, averaging the data on the maturity of saffron cod reproductive products accumulated over many years with ten-day intervals reveals a smoothed long-term average dynamics of the ratio between pre-spawning and post-spawning females, approximately reflecting the nature of this process in most winters, with the exception of relatively rare cases of spawning in several "waves" (Fig. 4).

Judging by the dynamics of the proportion of spawning females, navaga clearly strives to reproduce en masse, ideally simultaneously, which ensures better fertilization of eggs, therefore, at some point, almost half of the females spawn simultaneously (and in some years, more than half of the females). However, for various reasons, most likely random, some individuals enter spawning earlier, some later than others, so even at the moment of the most intensive spawning, there are already both post-spawning individuals and those not yet ready to release eggs. Therefore, the graph of the dynamics of the proportion of spawning females has the characteristic form of a Gaussian probability density curve, decreasing with distance from the mathematical expectation point, and the graphs of the proportion of pre-spawning and post-spawning females have the form of probability integral curves (Laplace function), the first of which decreases from 100 to 0%, and the second increases from 0 to 100% (Zuenko, 2009):

$$f_{pre} = \frac{1-\Phi\left(\frac{T-T_S}{\sigma_S}\right)}{2};\ f_{post} = \frac{1-\Phi\left(\frac{T_F-T}{\sigma_F}\right)}{2},$$ where $$\Phi(t) = \frac{2}{\sqrt{2\pi}}\cdot\int_0^T e^{-\frac{t^2}{2}}dt$$ is the probability integral of the pre-spawning or post-spawning state of females, $t = (T - T_0)/\sigma$; f_{pre}, f_{post} – the proportion of pre-spawning and post-spawning females, respectively; T – time in days (counted from January 1, i.e., for this date $T = 1$); T_S, T_F – dates of the beginning and end of mass spawning, respectively; σ_S, σ_F – standard deviations of the dates of the beginning and end of mass spawning, days.

From the multi-year average graphs in Fig. 4 with a ten-day discreteness, it is easy to determine the points where these curves cross the 50% level – these are December 23 and January 9 for the beginning and end of mass spawning, respectively. However, it is important that the Laplace function is nonlinear, which is why when reducing the discreteness of the data (for example, if the maturity of navaga gonads was determined only once a month), the simplest linear interpolation method cannot be applied, which can lead to large errors. Therefore, for all winters when the determination of the maturity of navaga reproductive products was carried out at least twice, an approximation of changes in the proportions of pre-spawning and post-spawning females over time was performed using the functions indicated above, from which the values of T_S and T_F were determined. Gonad maturity observation data for the remaining years were discarded.

RESULTS

The Laplace function has two parameters: mathematical expectation (in the case of analyzing the dynamics of proportions of pre-spawning and post-spawning female navaga corresponding to the dates of reaching 50% levels, taken as the dates of the beginning and end of mass spawning) and standard deviation σ (which characterizes the elongation of spawning - over a period of ± 0.68σ, half of the individuals enter or exit spawning). For each year of observations, such values of these parameters were selected to minimize the mean square error of approximation of the real data. For most years, the observational data were well approximated by Laplace functions, with correlation coefficients exceeding 0.9, although in some years the quality of approximation decreased sharply because the maturity of navaga's reproductive products changed non-monotonically, probably due to several spawning runs. The average correlation coefficients of the approximating functions with real data for all years were 0.96 for the proportion of pre-spawning females and 0.90 for the proportion of post-spawning females, with mean σ values of 10 and 15 days, respectively. A large variability in the interval between the dates of the beginning and end of mass spawning was noted, which in some years increased to approximately a month, while in other years it averaged 12 days (Fig. 5). In all cases, the sharp increase in spawning duration was due to the late completion of mass spawning and was accompanied by an increase in the standard deviation of determining the date of the end of spawning and a deterioration in the quality of approximation of spawning dynamics by the Laplace function, presumably due to the presence of several spawning runs.

From year to year, the dates of the beginning and end of mass spawning changed quite abruptly and within wide limits. Against the background of apparent chaos, several periods of their gradual shift to later dates can be observed, interrupted by sharp transitions to earlier spawning (Fig. 6).

According to available observations, such a transition is confidently detected in the mid-2000s (probably there were more, for example, in the mid-1950s and late 1980s, however, during these years, observations of the dynamics of saffron cod spawning were not conducted every winter). The sharp transition to earlier spawning in the mid-2000s was preceded by a delay in the completion date of mass spawning, an increase in its duration, an increase in the standard deviation of determining the dates of its beginning and end – all these are signs of the formation of several spawning approaches.

The dynamics of the proportion of pre-spawning females was similar in different years, with mass spawning typically beginning in late December. In contrast, the dynamics of the proportion of post-spawning females differed significantly between periods, especially in transitional years (Fig. 7). For example, in 2005-2006, the proportion of pre-spawning females in the 3rd ten-day period of December was 83%, and in the 2nd ten-day period of January it was 32%, meaning mass spawning began in late December, which is quite normal. At the same time, the proportion of post-spawning females in catches during the 2nd ten-day period of January approached 50%, but in the next two ten-day periods decreased again to 26-37% and only exceeded 90% in mid-February. This dynamic was only very roughly ($r = 0.84$) approximated by the function mentioned above, with the expected date for reaching 50% post-spawning females determined as January 29, which is significantly later than the typical end of mass spawning in both the previous and subsequent decades. The reason for the extended spawning in this case is quite obvious - the arrival of a new group of spawners in the second half of January. According to biological analysis, the age composition of fish in several spawning runs within the same year showed almost no difference, with spawners always predominantly represented by two-to-three-year-olds. However, based on indirect indicators (fatness, fecundity), it can be assumed that the late runs were formed by individuals that had been feeding not in Amur Bay and its surroundings, but in some distant areas with better feeding conditions and, apparently, with lower water temperatures, which predetermined their delayed spawning. According to trawl survey data, it is known that during the feeding period, saffron cod in Peter the Great Bay is distributed both in the coastal zone with depths up to 50 m, including Amur Bay, and in the elitoral zone, occurring even in the mesobenthal (Izmyatinsky, 2005, 2006).

Outside of years with abnormally prolonged mass spawning, the timing of the beginning and end of mass spawning changed from year to year approximately synchronously ($r = 0.78$), while until the last decades, there was no long-term trend toward shifting spawning to earlier dates, despite the positive dynamics of thermal conditions. Thus, in 1958-1977, the beginning and end of mass spawning occurred on average on December 26 and January 11, and in 1988-2004 on December 28 and January 9. But in 2005-2008, there was a sharp shift in spawning dates to earlier dates, which in 2007-2023 fell on average on December 23 and January 3, with mass spawning repeatedly ending already in December. In 2021-2023, mass spawning began on average on December 18 and ended on December 30.

Interannual differences in spawning dates are associated with changes in the conditions of fish maturation during the interspawning period; at least the dependence of the duration of maturation (the interval from the end of mass spawning to the beginning of the next mass spawning) on the SST temperature is statistically significant ($p < 0.02$). The relationship is negative, which is natural (the warmer it is, the less time is needed to prepare for spawning), but weak ($r = -0.58$) and barely accounts for a third of the variance in this indicator (Fig. 8). The range of interannual changes in average temperature within 1-9°C causes variations in the duration of navaga maturation within 11 to 12 months (350 days on average), but in specific years, the actual duration may deviate from the regression shown in Fig. 8 by up to half a month. Probably, the selected parameter of thermal conditions (modal SST temperature), despite its generalizing nature, is still not representative enough to characterize the very diverse habitat conditions of navaga, which, in fact, feeds inside the thermocline, where the temperature can vary greatly depending on depth.

DISCUSSION

Based on the obtained results, although spawning timing of saffron cod in Amur Bay clearly depends on changing environmental conditions, this dependence is not rigid, as saffron cod shows some ecological flexibility, adapting to changing conditions. In particular, this is manifested in the extension of spawning periods, up to the formation of several "waves," which allows at least some of the spawners to reproduce at the optimal time. The mechanism of extending the spawning periods of saffron cod appears to be as follows. Young-of-the-year and two-year-old fish form feeding aggregations presumably near spawning grounds in the coastal zone, while older individuals feed in a more extensive area. As the population size increases, the feeding area naturally expands, and larger saffron cod move to greater depths where temperatures are lower and food resources for the species are significantly less (Marti, 1980; Chernoivanova et al., 2011). As a result, different age groups of saffron cod develop varying inter-spawning periods. Initially, smaller and younger individuals that have fed in the coastal zone begin spawning, while larger saffron cod of older ages arrive at spawning grounds later. With increasing population size, the timing of mass spawning, especially its completion, gradually shifts to later dates, and conversely, decreasing fish numbers are accompanied by shifts in spawning timing to earlier dates. On the other hand, after a sharp deterioration in reproduction, as apparently happened in 2005 and led to a significant decrease in catches in subsequent years, the relative proportion of older-age fish in the spawning stock temporarily increases, resulting in several spawning approaches and delayed spawning. During the study period, the saffron cod population in Amur Bay went through stages of high abundance (until 1990), attempts to restore high numbers (1991-2005), and finally, stable depression (after 2006), while its mass spawning timing shifted from January to December, with two episodes of sharp shifts to earlier dates observed - in the late 1980s and mid-2000s. In both cases, during one or two years before the sharp shift to earlier spawning dates, extremely late (and extended) spawning was observed.

The strategy of stretching the spawning duration in order to "guess" the optimal timing has been previously noted in spring-spawning herring *Clupea pallasii* of Peter the Great Bay, whose spawning grounds are also located in Amur Bay. Unlike saffron cod, whose spawning, despite all the noted nuances, proceeds quite quickly, herring is characterized by an extremely extended process beginning in February-March (sometimes in early April) and ending in late May. In herring, the generational succession at spawning grounds is well noticeable: initially, large older individuals lay eggs at water temperatures close to zero, followed by progressively smaller younger individuals, the last of which spawn at water temperatures of 6-10°C (Ambroz, 1931; Posadova, 1985; Chernoivanova, 2022). As a result, some clutches develop in unfavorable winter conditions, but larval hatching occurs during the spring plankton bloom; others develop very quickly due to high temperatures, but the larvae find themselves in conditions of unstable food resources; while still others possibly enter into some kind of compromise. For saffron cod, it is impossible to characterize the differences in conditions and consequences of early and late spawning in the same way, as the temperature regime under ice is very stable, and the period of mass plankton development in Amur Bay is extended and can last until the end of spring (Zuenko, Nadtochiy, 2018).

While the timing of navaga spawning depends on the temperature conditions during feeding, sharp shifts in spawning to earlier periods always coincide with a decrease in the population of navaga in Amur Bay, as far as can be judged by catches. That is, unlike herring, these changes do not give a positive effect for reproduction, but appear to be more of a species' reaction to changes in environmental conditions rather than a survival strategy. Another winter-spawning species of the Sea of Japan – the Far Eastern sardine *Sardinops melanostictus* – also changes its spawning timing depending on thermal conditions during maturation, and in a wide time range: from December to May (Zuenko, 2011). It has been noted that successful reproduction of sardines is possible when spawning occurs at optimal times (in March, early April), while shifting spawning to either earlier or later periods is unfavorable. In contrast, for Pacific cod *Gadus macrocephalus* , which spawns in winter in the Gulf of Alaska, shifting spawning to earlier periods with increased water temperature is considered a favorable factor for the development of larvae and juveniles (Almeida et al., 2024). For navaga, it was not possible to determine the nature of the influence of spawning timing on recruitment numbers. Although the tendency to shift the reproduction period to earlier dates relative to the traditional timing in January coincides with the negative dynamics of the population, the correlation of interannual changes in spawning timing and recruitment numbers is not statistically significant, in particular because the sharp decline in numbers occurred in the early 1990s, while the shift in spawning to earlier periods occurred much later, in the mid-2000s. In our view, the question of the influence of spawning timing on navaga reproduction requires serious study with more complete and accurate data on reproductive efficiency and is beyond the scope of our research.

In conclusion, it should be noted that the results of experimental observations on the dynamics of spawning timing are rarely published, apparently due to the difficulties in organizing such observations and methodological complexities in data processing. In this sense, the conducted research is an example of high productivity in this scientific direction. Despite the generally low quality of the initial material due to irregularity and insufficient number of observations, as well as a number of related problems that could not be solved, several important scientific and practical results were obtained:

– the interannual variability of saffron cod spawning timing in the Amur Bay of the Sea of Japan was quantitatively determined;

– a long-term trend towards shifting saffron cod spawning to earlier dates was revealed, along with shifts in this process, resulting in the peak spawning period, which previously occurred mainly in January, moving to December in recent decades;

– it was established that saffron cod spawning timing depends on the conditions of its feeding and maturation in the preceding seasons (summer-autumn): the warmer it is, the earlier the fish spawn;

– in certain years, intra-seasonal dynamics of saffron cod spawning were detected, caused by several "waves" of spawners approaching the spawning grounds. This phenomenon requires additional study based on more frequent observations.

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COMPLIANCE WITH ETHICAL STANDARDS

The collection of material and its processing did not contradict international standards for the treatment of animals, in accordance with Directive 2010/63/EU of the European Parliament and of the Council of the European Union dated 22.09.2010 on the protection of animals used for scientific purposes (https://ruslasa.ru/wp-content/uploads/2017/06/Directive_201063_rus.pdf).

CONFLICT OF INTEREST

The authors of this work declare that they have no conflict of interest.

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FIGURE CAPTIONS

Fig. 1. Schematic location of the main spawning area (*1*) of saffron cod *Eleginus gracilis* and the nursery area for its larvae (*2*) in the Amur Bay of the Sea of Japan.

Fig. 2. Dynamics of average commercial catch of saffron cod *Eleginus gracilis* in Amur Bay during fishing seasons.

Fig. 3. Interannual changes in the average modal temperature from May to October of the subsurface shelf water mass (SSWM) of Amur Bay at the standard section along 132° E.: (—●—) – observational data from the standard section, (—○—) – reconstructed data from observations in Amur Bay, (— —) – results of 5-year moving average, (- - -) – linear trend ($y = 0.055x + 3.285$, $R^2 = 0.433$).

Fig. 4. Ten-day changes from December to March of the average proportion for 1957-2023 of pre-spawning (—○—), post-spawning (—◆—) and spawning (— —) female saffron cod *Eleginus gracilis* in Amur Bay. Females with gonad maturity stages V, V-VI are classified as spawning. Here and in Fig. 7: (——) – 50% level, the decrease to which in the proportion of pre-spawning females is considered the beginning of mass spawning; the increase to this level in the proportion of post-spawning females is considered the end of mass spawning.

Fig. 5. Duration of mass spawning of saffron cod *Eleginus gracilis* in Amur Bay (interval between the dates of beginning and end of mass spawning in years when both dates were determined); *years with sharp increase in spawning duration.

Fig. 6. Timing of the beginning and end of mass spawning of saffron cod *Eleginus gracilis* in Amur Bay, determined by approximating the dynamics of female maturity with functions (see in the text). For each year of observations, symbols show the dates when 50% proportion of pre-spawning (◆) and post-spawning (●) females was reached in catches; bars up and down from symbols – intervals of ± 0.68σ from these dates, during which half of the individuals

entered and exited spawning. (– – –) – linear trends of interannual variations in timing for 1958-1977, 1988-2004, and 2007-2023.

Fig. 7. Intra-seasonal dynamics of the proportions of pre-spawning and post-spawning females of saffron cod *Eleginus gracilis* in catches at the spawning ground in Amur Bay by groups of years, approximated by functions (see in the text): (—) – 1993–2004, (– –) – 2005–2006, (—) – 2007–2023; (● , ○ , ●) – averaged proportions of post-spawning females by the corresponding groups of years.

Fig. 8. Dependence of the duration of the period between the end of mass spawning of saffron cod *Eleginus gracilis* in Amur Bay and the beginning of the next mass spawning on the average modal temperature of the subsurface shelf water mass (SSW) for May–October on the standard section along 132° E: (—) – approximation of the dependence by a linear function: $y = -3.368x + 364.373$, $R^2 = 0.337$.