

**EXPRESSION AND HORMONAL DYNAMICS DURING SEXUAL MATURATION IN
PIKEPERCH (SANDER LUCIOPERCA)**

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Annotation: This study examines the hormonal regulation and gene expression dynamics involved in the sexual maturation of pikeperch (*Sander lucioperca*). Sexual development in this species is governed by the hypothalamic–pituitary–gonadal (HPG) axis, which regulates gametogenesis through coordinated changes in gonadotropins, sex steroids, and reproductive gene expression. The article highlights the fluctuations of key hormones such as GnRH, FSH, LH, estradiol, testosterone, 11-ketotestosterone, and maturation-inducing steroids during different maturation stages. Additionally, stage-specific expression patterns of genes including *gnrh*, *fsHβ*, *lhβ*, *vtg*, *cyp19a1a*, *dmrt1*, and *mpr* receptors are analyzed. Environmental factors such as temperature, photoperiod, nutrition, and stress are also discussed in relation to their impact on reproductive physiology. The findings contribute to a deeper understanding of pikeperch reproductive biology and provide practical insights for improving aquaculture breeding strategies and broodstock management.

Keywords: Pikeperch, *Sander lucioperca*, sexual maturation, hormone dynamics, gene expression, HPG axis, reproduction, aquaculture, gonad development, steroid hormones.

Introduction

Pikeperch (*Sander lucioperca*) is a commercially significant freshwater fish species widely distributed across Eurasian aquatic ecosystems. Due to its high market value, rapid growth performance, and desirable flesh quality, it has become an important species in both wild fisheries and intensive aquaculture systems. Effective reproduction and controlled breeding, however, remain major challenges in pikeperch aquaculture, largely because the species exhibits strong sensitivity to environmental fluctuations, stressors, and endocrine disturbances during gametogenesis.

Sexual maturation in pikeperch is regulated by a complex neuroendocrine network known as the hypothalamic–pituitary–gonadal (HPG) axis. This axis integrates external cues such as photoperiod, temperature, and nutrition with internal physiological signals to regulate the synthesis and release of key reproductive hormones. At the hypothalamic level, gonadotropin-releasing hormone (GnRH) stimulates the pituitary gland to produce gonadotropins — follicle-stimulating hormone (FSH) and luteinizing hormone (LH). These hormones, in turn, orchestrate gonadal development by modulating gametogenesis, steroidogenesis, and final maturation processes.

Understanding the hormonal fluctuations and molecular mechanisms underlying sexual maturation is essential for improving reproductive efficiency in cultured pikeperch populations. Previous research has highlighted the importance of steroid hormones such as estradiol-17β (E2), testosterone (T), 11-ketotestosterone (11-KT), and maturation-inducing steroids in regulating oocyte growth, spermatogenesis, and spawning readiness. However, the dynamic interplay between these hormones and the expression of reproductive genes — including *gnrh*, *fsHβ*, *lhβ*, *cyp19a1a*, *dmrt1*, and vitellogenin-related genes — remains insufficiently understood.

Moreover, environmental conditions and husbandry practices in aquaculture can significantly affect hormonal balance and gene expression. Stress resulting from handling, stocking density, or suboptimal water quality may suppress HPG axis activity, leading to reduced spawning success or asynchronous maturation. Therefore, detailed physiological knowledge is critical for designing effective broodstock management strategies, optimizing photothermal manipulation programs, and enhancing the reliability of induced spawning techniques.

In this context, investigating the expression and hormonal dynamics across different sexual maturation stages provides valuable insights into the reproductive biology of Sander lucioperca. A comprehensive understanding of these processes contributes not only to the scientific knowledge of teleost reproduction but also to the development of sustainable and efficient aquaculture practices.

Sexual maturation in pikeperch (*Sander lucioperca*) proceeds through several well-defined physiological stages, each characterized by specific morphological, endocrine, and molecular changes. During the immature stage, the gonads are still undeveloped, and levels of circulating steroid hormones remain low. At this point, gametogenic activity is minimal, and the reproductive system shows little responsiveness to hormonal stimulation.

The early maturation stage marks the initiation of gametogenesis. Gonadosomatic index (GSI) begins to increase, reflecting early gonadal growth, while the hypothalamic–pituitary–gonadal (HPG) axis becomes progressively activated. This phase corresponds to the first significant rise in gonadotropin production and the onset of germ cell differentiation.

In the mid-maturation stage, gonadal development accelerates considerably. Rapid proliferation of germ cells is observed, accompanied by intensified steroidogenesis. Mitotic activity in oocytes or spermatogenic cells is high, and hormonal fluctuations become more pronounced as the fish moves toward reproductive readiness.

The late maturation or pre-spawning stage represents the final phase of gamete differentiation. In females, vitellogenesis reaches its peak, oocytes undergo final growth, and maturation-inducing steroids (MIS) rise sharply. In males, spermatogenesis culminates in the production of mature spermatozoa. Endocrine activity also reaches its maximum during this stage, preparing the fish for spawning.

The spawning stage involves ovulation in females and spermiation in males. Hormonal peaks decline shortly after gamete release, and physiological resources are redirected toward post-spawning recovery. During the post-spawning stage, gonads regress, metabolic demands decrease, and hormone concentrations drop, marking a temporary cessation of reproductive activity.

Each of these stages is governed by distinct endocrine signals and gene expression patterns that regulate gametogenesis, steroidogenesis, and reproductive behavior.

The sexual maturation process in pikeperch is tightly regulated by a coordinated set of hormones produced along the HPG axis. One of the earliest signals is gonadotropin-releasing hormone (GnRH), secreted by the hypothalamus. During early maturation, GnRH expression and release increase significantly, stimulating the pituitary gland to produce gonadotropins and initiating the reproductive cascade.

Follicle-stimulating hormone (FSH) plays a central role during the first stages of gametogenesis. In females, FSH promotes follicular growth and stimulates vitellogenesis by enhancing estradiol production. In males, it regulates the proliferation of spermatogonia. Consequently, FSH levels rise sharply during early and mid-maturation.

Luteinizing hormone (LH) becomes dominant during the late maturation and spawning phases. It triggers final oocyte maturation and ovulation in females and stimulates the final stages of sperm maturation and spermiation in males. LH concentrations peak during the pre-spawning period when reproductive readiness is at its highest.

Sex steroid hormones also undergo dynamic changes. In females, estradiol-17 β (E2) increases markedly during vitellogenesis and stimulates hepatic synthesis of vitellogenin (VTG), a key protein required for oocyte development. Just before ovulation, levels of maturation-inducing steroids, such as 17 α ,20 β -dihydroxy-progesterone (17 α ,20 β -DHP), rise significantly. In males, testosterone (T) and 11-ketotestosterone (11-KT) regulate spermatogenesis and secondary sexual characteristics, reaching their highest levels during mid- to late maturity.

Stress hormones such as cortisol can negatively influence reproduction by suppressing gonadotropin secretion and interfering with steroidogenesis. Therefore, minimizing stress in aquaculture broodstock is essential for maintaining healthy hormonal cycles and ensuring successful spawning.

Sexual maturation is also accompanied by stage-specific changes in the expression of key reproductive genes. Genes such as *gnrh*, *fsh β* , and *lh β* regulate the synthesis of hypothalamic and pituitary hormones, and their expression typically increases progressively through the maturation process.

During vitellogenesis, the vitellogenin (*vtg*) gene shows high expression in the liver of females, induced primarily by estradiol. Similarly, *cyp19a1a*, which encodes aromatase, is responsible for converting testosterone into estradiol. Expression of this gene peaks during active follicular growth, supporting steroidogenesis.

Male-specific genes, including *dmrt1* and *sox9*, are critical for testicular development and spermatogenesis. Their expression rises during mid- and late maturation as sperm production intensifies. Additionally, *mpr α* and *mpr β* , encoding membrane receptors for maturation-inducing hormones, become upregulated during the pre-spawning phase and play essential roles in final oocyte maturation.

These gene expression patterns reflect the complex regulatory mechanisms underlying reproductive development and highlight the molecular synchrony required for successful gametogenesis.

Environmental conditions exert significant control over hormonal activity and gene expression during pikeperch maturation. Temperature is one of the most critical factors, with optimal maturation occurring between 12–16°C. Exposure to low temperatures can suppress hormone production and delay maturation.

Photoperiod also plays a major role by influencing GnRH release and synchronizing spawning cycles. Extended daylight hours stimulate reproductive hormone synthesis, aligning maturation with seasonal environmental conditions.

Proper nutrition—particularly diets high in protein and essential fatty acids—supports gonadal growth, increases GSI, and enhances steroid hormone production. Conversely, nutritional deficiencies can impair reproductive capacity.

In aquaculture environments, various stressors such as handling, transport, crowding, or poor water quality can elevate cortisol levels. This, in turn, inhibits reproductive hormones and disrupts gametogenesis. Effective management of these factors is crucial for maintaining healthy broodstock and achieving reliable spawning outcomes.

A detailed understanding of endocrine and genetic regulation during sexual maturation has significant practical applications in pikeperch aquaculture. Knowledge of hormonal cycles helps improve the timing and efficiency of induced spawning procedures. Broodstock management can be optimized by aligning photothermal regimes with natural reproductive rhythms and reducing stress-related disruptions.

Furthermore, enhanced reproductive performance leads to higher fertilization rates and improved larval output. Monitoring hormone levels and gene expression patterns allows aquaculture practitioners to identify high-quality breeders, synchronize maturation among broodstock, and predict spawning periods more accurately.

Overall, integrating physiological, hormonal, and molecular knowledge into aquaculture practices supports sustainable production, improves reproductive success, and enhances the reliability of pikeperch breeding programs.

Conclusion

Sexual maturation in pikeperch (*Sander lucioperca*) is regulated by a highly integrated network of endocrine pathways, molecular signaling mechanisms, and environmental cues that collectively coordinate the progression of gametogenesis and reproductive readiness. The interaction of the hypothalamic–pituitary–gonadal (HPG) axis with stage-specific fluctuations in gonadotropins, sex steroid hormones, and maturation-inducing steroids ensures the precise timing of follicle growth, spermatogenesis, and final gamete maturation. Parallel to hormonal regulation, dynamic changes in reproductive gene expression—such as *gnrh*, *fsh β* , *lh β* , *vtg*, *cyp19a1a*, *dmrt1*, and *mpr* receptor genes—play a critical role in mediating tissue-specific responses and guiding the developmental transitions of germ cells.

Environmental factors such as temperature, photoperiod, nutrition, and stress strongly influence these endocrine and genetic processes, highlighting the sensitivity of pikeperch reproduction to external conditions. Therefore, a comprehensive understanding of the species' hormonal rhythms, gene regulatory networks, and maturation physiology is essential for optimizing aquaculture operations. Such knowledge enables the development of more precise photothermal manipulation programs, improved broodstock conditioning protocols, and effective induced-spawning techniques. Moreover, integrating hormonal assays with gene expression profiling provides powerful tools for monitoring reproductive status, selecting high-quality broodstock, and synchronizing spawning schedules.

Overall, elucidating the hormonal and molecular foundations of sexual maturation in pikeperch contributes not only to advancing scientific understanding of teleost reproductive biology but also to establishing more sustainable, efficient, and predictable aquaculture production systems. Continued research in this area will further refine breeding strategies, enhance larval output, and support the long-term development of pikeperch as a valuable aquaculture species.

References:

1. Bobe, J., & Labbé, C. (2010). Egg and sperm quality in fish. *General and Comparative Endocrinology*, 165(3), 535–548. <https://doi.org/10.1016/j.ygcen.2009.02.011>
2. Cuisset, B., Pradelles, P., Kime, D. E., Kuhn, E. R., Babin, P., Davail-Cuisset, B., & Le Menn, F. (1994). Enzyme immunoassay for 11-ketotestosterone using acetylcholinesterase as label: Application to the study of 11-ketotestosterone levels in male and female rainbow trout (*Oncorhynchus mykiss*). *Fish Physiology and Biochemistry*, 13, 31–40.
3. Falahatkar, B., Poursaeid, S., & Shiri Harzevili, A. (2014). Reproductive biology and induced spawning of pikeperch (*Sander lucioperca*). *Reviews in Aquaculture*, 6(1), 1–20. <https://doi.org/10.1111/raq.12015>
4. Fostier, A., Jalabert, B., Billard, R., Breton, B., & Zohar, Y. (1983). The gonadal steroids. In W. S. Hoar, D. J. Randall, & E. M. Donaldson (Eds.), *Fish Physiology: Reproduction* (Vol. 9, pp. 277–372). Academic Press.
5. Hassin, S., Holland, L., Zohar, Y., & Popper, D. M. (1999). Early maturation in cultured female striped bass (*Morone saxatilis*): Accelerated vitellogenesis and high plasma estradiol-17 β concentrations. *Aquaculture*, 171, 349–359.
6. Hermelink, B., Wuertz, S., Trubiroha, A., Rennert, B., Kloas, W., & Schulz, C. (2011). Influence of photoperiod manipulation on the seasonal reproductive cycle of pikeperch (*Sander lucioperca*). *Aquaculture*, 315(3–4), 338–348.
7. Jalabert, B. (2005). Particularities of reproduction and oogenesis in teleost fish compared to mammals. *Reproduction Nutrition Development*, 45, 261–279.
8. Klenke, U., Strobel, C., Wuertz, S., Rennert, B., & Schulz, C. (2020). Effects of thermal and photoperiod manipulation on the reproductive endocrinology of female pikeperch (*Sander lucioperca*). *General and Comparative Endocrinology*, 286, 113–122.