Reproductive adaptation in fish: A case study on female Eurasian perch, *Perca fluviatilis*

[1]Sulaeman Sulaeman, [1]Herlinah Herlinah, [2]Ravi Fotedar

[1] National Research and Innovation Agency (BRIN), Cibinong, Indonesia; [2] Department of Environment and Agriculture, Curtin University, Bentley, Australia. Corresponding author: S. Sulaeman, sulaeman.marhali@gmail.com

Abstract. Eurasian perch (*Perca fluviatilis*) is a promising new candidate species for inland aquaculture. However, the development of its reproductive system is largely influenced by water temperature in certain periods. The present study aimed to elucidate the annual reproductive cycle of Eurasian perch, at different water temperature profiles, more than one century since its introduction from a colder environment in Europe to a warmer place, in Western Australia. Female fish (mean body weight of 133±43 g and total length of 175±9 mm) were caught monthly from colder temperatures in Manjimup (34°11′08.97″ S, 116°04′18.09″ E), and compared every two-months with samples from a warmer temperature in Gingin (31°20″05.53″ S, 115°46′20.51″ E) and in the Curtin Aquatic laboratory, Bentley (31°59′38.26″ S, 115°53′18.09″ E) for a period of one year. From the sampled fish, the gonadosomatic index (GSI) was calculated and oocyte diameters (OD) were measured. The results showed that the gonad development of the colder temperature population commenced in May and spawning lasted until October. However, no gonadal development and spawning were observed in warmer temperatures either in ponds or in tank populations. Even if redfin perch has been adapted to Western Australia's environment for a long time, it could not breed naturally in warmer temperatures.

Key Words: reproduction cycle, Eurasian perch, *Perca fluviatilis*, Western Australia.

Introduction. The Eurasian perch or English perch or more popularly called a redfin perch in Australia, *Perca fluviatilis* (Hoese et al 2006), is originally from northern Europe (Morgan et al 2002) but was introduced into Tasmania in 1862, to Victoria in 1868 (Hoese et al 2006), and to Western Australia during the 1890s (Weatherley 1977). In Western Australia, Eurasian perch is commonly found in Donnelly and Warren River systems in the Manjimup area (Morgan et al 2002) and is considered good for sporting and meat consumption (Allen 1982). Mature adults commonly reach 400-450 mm in total length and 1-2 kg in weight (McDowall 1980). Its success in adapting to the Australian environment is attributed to its ability to reach early maturation, broad environmental and habitat tolerances, and the absence of predators (Morgan et al 2002). Gonadal development is initiated in late summer, with peak spawning between August and September. Males and females attain earlier maturity than reported for most Northern Hemisphere populations which is the result of their adaptation to a warmer climate (Morgan et al 2002).

Seasonal spawning behavior is common for temperate fish species (Bromage et al 2001) which can halt the production of its seed. Similarly, the reproductive cycle of the Eurasian perch needs to be controlled and confined to a season, to manage its spread under natural conditions and maintain its seed production, when required,under farming conditions (Migaud et al 2002; Migaud et al 2004; Migaud 2006; Wang et al 2006). The decreased temperature and the photoperiod are the two most important environmental factors that affect the reproductive induction in Eurasian perch (Wang et al 2006).

Further, this species has successfully adapted to much higher temperatures (Weatherley & Lake 1967) for more than a century since its introduction into Australian waters. Therefore, the reproductive cycle and growth performance of the species in Australian waters may differ from European populations. The species has also been considered a promising new candidate species for inland aquaculture (Fontaine et al

1996; Kestemont 1996) due to its positive attributes such as its possibility to be weaned onto dry artificial diets (Kestemont et al 1996), cultural possibilities in a variety of production systems, for example, floating net cages, recirculating tanks and flow through systems (Fontaine et al 1997) and tolerance to high stocking densities.

The peak spawning season of the species in Western Australia is estimated between August and September while in the northern hemisphere, it occurs between March and July (Morgan et al 2002). Further details about the reproductive biology of the Eurasian perch in Western Australia are necessary to manage its natural population in the wild and support the seed production techniques for its aquaculture development. The present study aimed to compare the reproductive biology between colder and warmer temperature populations of female Eurasian perch in Western Australia.

Material and Method. This experiment was approved by the Animal Ethics Committee of Curtin University (approval number AEC_2011_70) and performed according to the Australian Code of Practice for the care and use of animals for scientific purposes.

Fish sampling. Two groups of female fish were collected from Manjimup, at 34°11’08.97” S, 116°04’18.09” E, and stocked into a 1,000 m^2 pond (depth 0.5-1.5 m) in Gingin, at 31°20”05.53” S, 115°46’20.51” E (ponds population), and another group was held in two 5000 L fiberglass tanks at Curtin Aquaculture Research Laboratory in (CARL) Bentley, at 31°59’38.26” S, 115°53’18.09” E (tanks population), Western Australia, two months before the commencement of the trial in 2012. The pond population was fed on natural food available in the pond while tank populations fed once every two days with fresh prawns, *Metapenaeus monoceros*. The rearing tanks were set as semi-close recirculating systems equipped with gentle aeration. The tanks were cleaned once every week. Another group of female fish was caught monthly from natural waters in Manjimup, Western Australia, at 34°11’08.97” S, 116°04’18.09” E (wild population), and compared every two-months with samples from all pond and tank populations. The wild population of Eurasian perch from Manjimup waters was sampled monthly with hook and lines, from January to December 2012 where pond and tank populations were sampled once every two months. At least three female fish were sampled at each sampling time for reproductive examination. After the fish were caught, the total length (TL) and weight (W) of each fish were measured to the nearest millimeter and 0.1 g, respectively.

Natural temperature and day length of sampling sites. Water temperatures at four sampling sites , in the wild and in confined waters (pond and tank), were recorded using a temperature data logger (Onset HOBO). Day lengths for the wild population were gathered from the day-length records of Albany, Western Australia, and for the pond population, based on the day length data records from the Perth region (http://wwwtimeanddate.com).

Gonadal maturity stage. The sex of each fish was confirmed to be female after performing dissections on them; the gonads were removed, weighed to the nearest milligram, and their maturity was determined following the characteristics, as described by Laevestu (1965). Based on the developmental stages of the gonads, they were grouped into various stages such as stage I, virgin; stage II, maturing virgin or recovering spent; stage III, developing; stage IV, developed; stage V, mature or gravid; stage VI, spawning; stage VII, spent; and stage VIII, resting. The stages of gonadal maturity were based on the most developed oocytes (West 1990). The gonadosomatic index (GSI) was calculated as follows:

$$GSI=(GW \times 100)/BW$$, where GW is the weight of the eggs (g) and BW is the weight of the body.

Statistical analysis*.* All quantitative data were expressed as means±SE (standard error). Statistical analysis of regularly analyzed GSI for each three populations was performed using the SPSS with general linear model (GLM) procedures for unbalanced one-way analysis of variance (ANOVA) (IBM SPSS Statistic 22). The comparison of the maximum GSI and OD between the three populations was performed using one-way ANOVA. The mean differences between data were analyzed using the Tukey test. Before statistical analysis, inhomogeneous values were transformed, using a logarithmic or square-root transformation, to satisfy tests for normality and homogeneity of variances. Statistical analysis was applied to transformed data, but untransformed data was used to provide real measurements. Normality was tested by the Shapiro-Wilk test (sample size n<2,000). A few data were excluded from statistical analysis because of the abnormality of distribution, even after the logarithmic transformation of the data. The GSI of each population was also compared to the previously recorded GSI reported by (Morgan et al 2002) using a one-sample t-test. The correlation between GSI and temperature or GSI and day length was calculated using the Pearson correlation method. An independent-sample t-test was conducted to compare temperature and day length between populations. The minimum level of all significance was set at p<0.05.

Results. The water temperature varied from 10°C in July to 29°C in January, from 11°C in July to 32°C in January, and from 16°C in July and 24°C in January for wild, pond and tank waters, respectively (Figure 1). The water temperature pattern of the wild and pond site followed a natural seasonal pattern, with higher temperatures recorded in mid-summer (January) and lower temperatures recorded during mid-winter (July). The water temperature pattern in the tank deviated from the natural pattern above: higher temperatures occurred from late spring to mid-autumn and lower temperatures were recorded between mid-autumn and mid-winter. An independent-sample t-test conducted to compare temperature between populations showed that there was a significant difference (P<0.05) between wild and pond, between wild and tank, and between pond and tank. Like water temperature, day length also varied along the year during the experiment. The lowest day length recorded at 9.8 and 10.1 h for wild and pond populations, respectively, occurred in wintertime (June). From June, the day length increased during the rest of the year and reached the maximum in summer, 14.5 and 14.2 h in December, for wild and pond populations, respectively (Figure 2). However, there were no significant differences (p>0.05) between the wild and the pond.

The wild population was dominated by immature gonads (stages I and II) from January to March and gonad development (stage V) did not initiate until May (Figure 3). Mature gonads (stage V) were first observed in June, 60 % of the total, and increased to maximum values in July, when all fish were at the matured stage. The first spawning was detected in August and gonad stage VII (spent), which was evident from September to November, with a maximum contribution in September. During the rest of the year (October to December), similar to the period from January to March, gonadal stages I and II dominated.

The gonads of the wild population (mean TL 219 mm) stayed undeveloped from January to February, with the mean GSI ranging between 0.6 and 0.7%. The GSI in this period had no significant (p>0.05) difference in monthly variations. However, the GSI showed a significant increase *(*p<0.05*)* each month from March to July when it reached the maximum value of 11.62±0.36%. Significant decreases in GSI (p<0.05) were observed in September and fell to the lowest value in October (0.5±0.06 %), when the gonad development cycle restarted (Figure 3).

The onset of ovarian development occurred in April followed by the early deposit of yolk vesicle and endogenous vitellogenesis. This corresponds to a decrease in water temperature (Figure 4). The GSI is negatively correlated to temperature: the maximum GSI coincides with the minimum temperature during wintertime in July (Figure 4). August is the peak of the spawning season when water temperature starts rising. There was a significant negative relationship between GSI and temperature, r(10)=0.94, p=0.000, and also between GSI and day lengths r(10)=0.94, p=0.003 (Table 1).

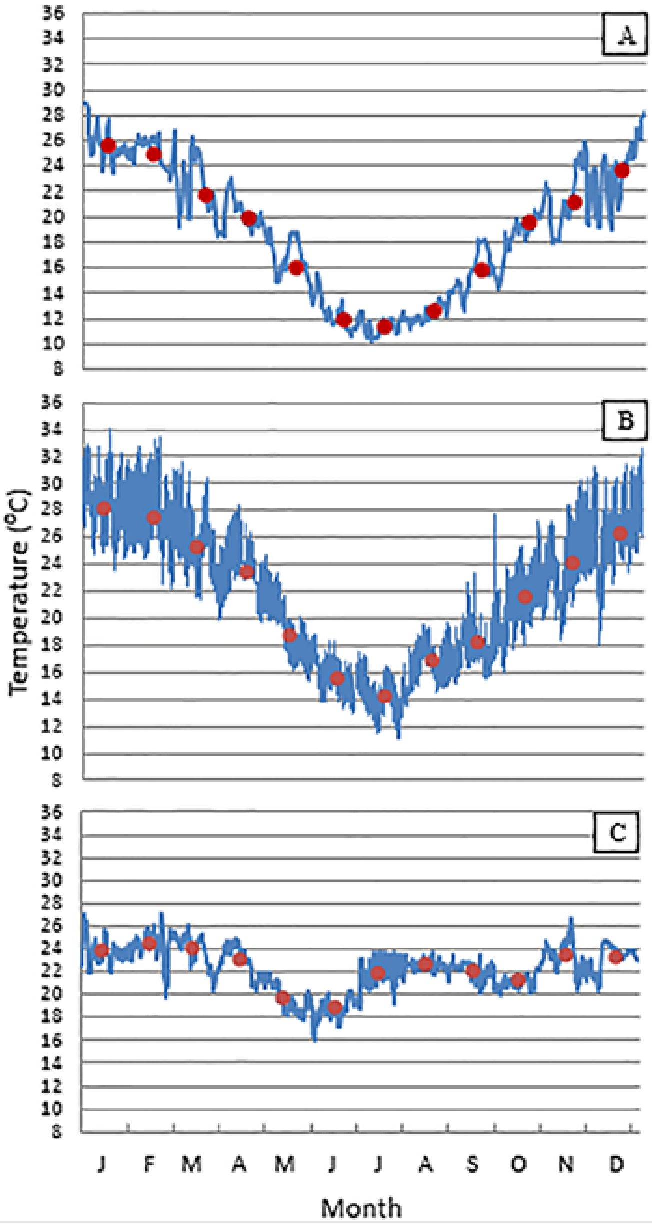

Figure 1. Water temperature profile recorded in the wild (A), ponds (B), and captive tanks (C). Solid line: daily fluctuation of water temperature and solid circle: monthly mean water temperature.

Like the wild population, the gonad maturation of ponds-stocked Eurasian perch steadily increases from January to July when all females reach their maximum stage of maturity. In January, all fish had immature gonads of stage I or II, and gonadal development started in March. However, no matured and higher gonadal stages nor spawned fish were observed during the experimental period. Following maturity development, the trends of GSIs of the ponds population of Eurasian perch increased sharply from January to July, where the maximum mean GSI reached 7.02±0.0%, which is significantly higher ($p<0.05$) than the other monthly GSIs (Figure 5). This increase coincided with the growth of the gonadal maturity, before a steep decrease through September, which in turn corresponds to the decrease of water temperature during winter (Figure 1 and Figure 5). The GSI is negatively correlated to temperature:the maximum GSI coincides with the minimum temperature during wintertime in July (Figure 6). Like the wild population, there was a significant negative relationship between GSI and temperature, r(4)=0.92, p=0.008 as presented in Table 1. On the other hand, GSI and day length did not show any significant relationship r(10)=0.67, p=0.143 (Table 1).

Table 1

Pearson correlation (r), between GSI and water temperature and between GSI and day length of wild, ponds, and tank populations of Eurasian perch

Parameters	*Pearson correlation (r)*	*df*	*Significance*
Wild			
GSI vs temperature	-0.857	10	0.000
GSI vs day length	-0.770	10	0.003
Pond			
GSI vs temperature	-0.927	4	0.008
GSI vs day length	-0.673	4	0.143
Tank			
GSI vs temperature	-0.843	4	0.035
GSI vs day length	-0.655	4	0.158

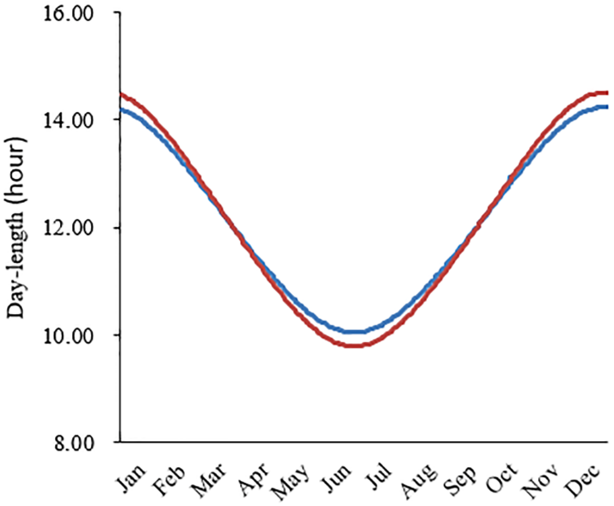

Figure 2. Day-length profile recorded in the wild (red); ponds and captive tanks (blue).

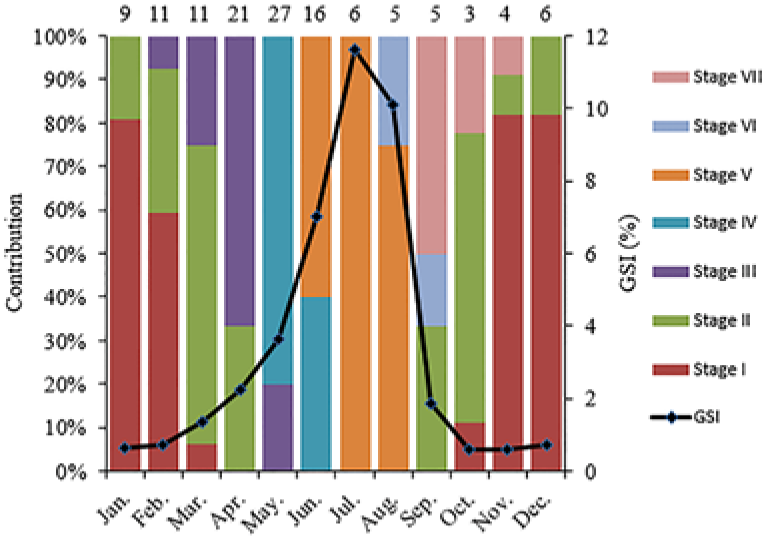

Figure 3. The monthly percentage contribution of different gonadal maturity stages for wild female Eurasian perch from Manjimup waters (the number of fish (above) and the variations in the gonadosomatic index (GSI) during an annual reproductive cycle (January-December) are also given for each month).

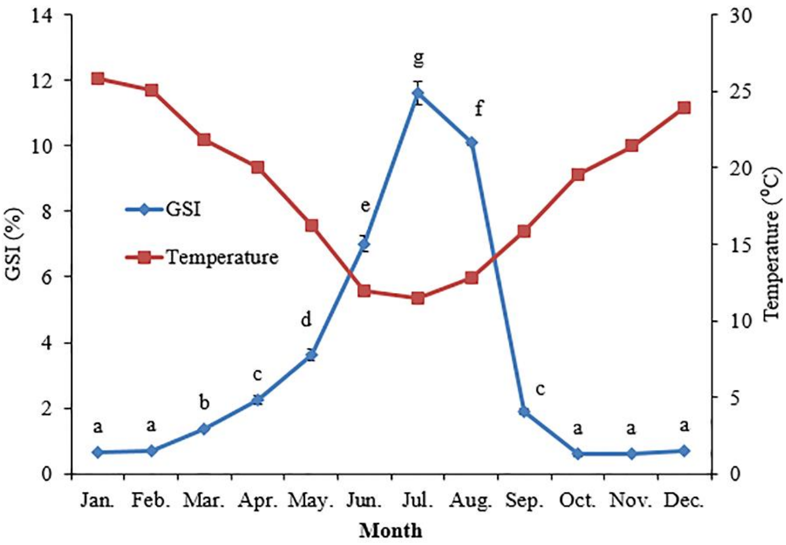

Figure 4. Mean gonadosomatic indices for wild female Eurasian perch from Manjimup waters showed an inverse relationship against water temperature during the year 2012. The monthly GSI with the same superscript was not significantly different ($p<0.05$).

The pattern of gonad maturation of captive tank-reared Eurasian perch is like in the ponds-reared fish (Figure 6). Both ponds-reared and captive populations reached the maximum gonadal development at stage IV in July and then declined to stage III in September and November, without spawning. The difference was shown by the contribution of gonadal maturity in March and May, when all tank-reared fish reached stages III and IV, the pond-stocked females reached stages II, III, and IV. The highest GSIs of the captive population reached 8.02±0.03% in July (Figure 3B), while the lowest value (1.58±0.00%) was recorded in January. GSI increased steadily from January to July, coinciding with the growth of gonadal maturity, before a sudden decrease through September and November. There is a significant negative relationship between GSI and temperature, r(10)=0.84, p=0.035 (Figure 5). Similarly, GSI and day length also demonstrated a significantly negative relationship r(10)=0.65, p=0.158 (Figure 6).

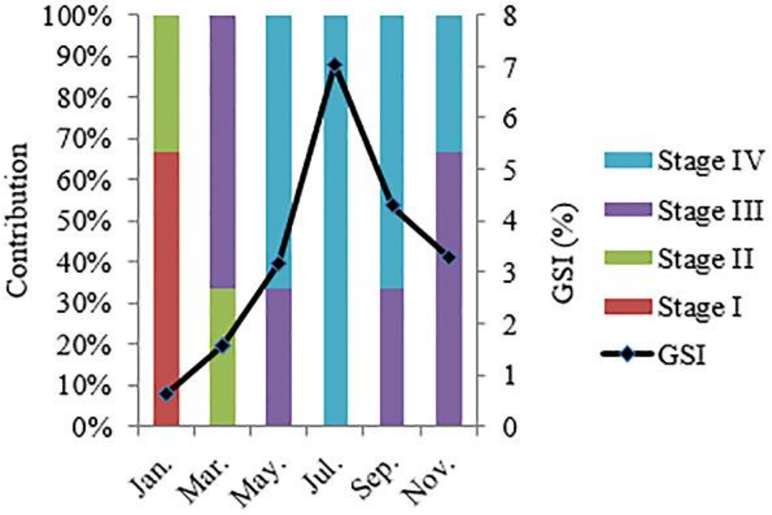

Figure 5. The bimonthly percentage contribution of different gonadal maturity stages and the variations in the Gonadosomatic Indices (GSI) for female Eurasian perch reared in ponds (3 samples bimonthly) during an annual reproductive cycle (January-November).

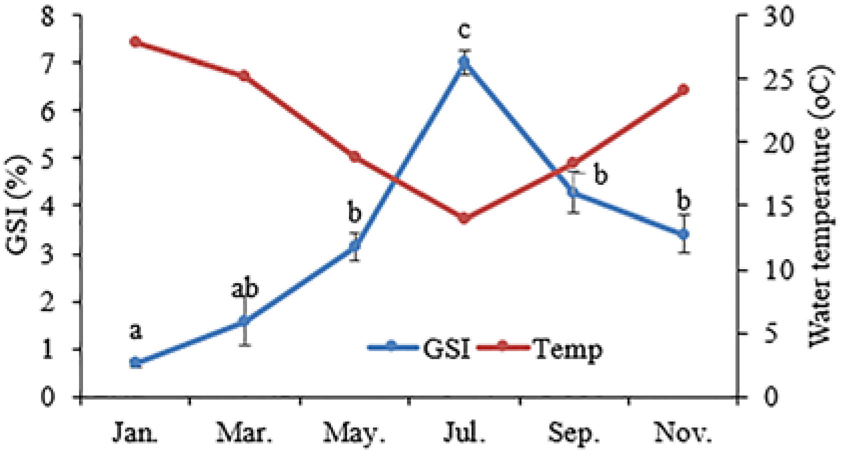

Figure 6. The mean gonadosomatic indices for female Eurasian perch reared in ponds showing an inverse relationship against water temperature during the year 2012. The GSI with the same superscript were not significantly different ($p<0.05$).

Discussion. Eurasian perch, reared in indoor recirculated tanks showed that they can survive even if they are exposed to temperatures up to 32°C for several hours per day during a week, in the summer season. This could be the new level of temperature tolerance after their introduction to Western Australia. The spread of Eurasian perch is limited to the cooler, non-saline waters (Morgan et al 2002) of southern Western Australia mainly because of their inability to tolerate water temperatures of more than 31°C (Weatherley & Lake 1967). The temperature plays an important role in the control of final gametic maturation, ovulation, and spawning (Pankhurst et al 1996). Despite the adaptation to the warm climate in Australia, the gonadal maturation pattern remained similar to freshwater species of the northern temperate hemisphere, where the females undergo significant ovarian development during winter (Brasfield et al 2013).

The difference in temperature profiles (Figure 1) at different regions has led to different maturity stages and GSI of Eurasian perch (Figure 2 and Figure 3) during the year 2012. At lower temperatures and for a longer fish exposure to low temperatures during the winter months, a higher maturity stage and GSI are reached. The wild population of fish exposed to lower daily average temperatures (10-15°C) for more than three months (June-August) has reached higher gonadal maturity (at least stage VI) compared to the pond and tank populations which could only reach as high as stage IV. The temperature in ponds and tanks during winter (June-August) were 12-17°C and 16-20°C respectively, which were probably too high and outside the favorable range for optimal gonad development of Eurasian perch. The gonad development and spawning success may be delayed at high temperatures for the fish that spawn naturally at low temperatures (Mylonas et al 2010), as occurred in rainbow trout, *Orcorhynchus mykiss* (Pankhurst et al 1996; Pankhurst & Thomas 1998). According to Lake (1967), supported by Thorpe (1977) and Gillet et al (1995), Eurasian perch require temperatures from 4 to 14°C to spawn in its original European climate. The Eurasian perch had also been reported to spawn when temperatures increased from 10-11°C to 14-15°C (Sulistyo et al 1998). This is quite similar to the spawning season in Big Broom Dam, down south of Western Australia, with temperatures between 11 to 15°C (Morgan et al 2002), which is comparable to the range found in this study for the wild population at Manjimup waters (11 to 16°C). Other temperate species that also show female gonadal development over the wintertime include the roach, *Rutilus rutilus*, bleak, *Alburnus alburnus*, white bream, *Blicca bjoerkna* (Rinchard & Kestemont 1996; Rinchard et al 1997) and chub, *Leuciscus pyrenaicus* (Encina & Granado-Lorencio 1997).

In the Murray-Darling waters, Eurasian perch begin to spawn at temperatures of 12°C (Weatherley & Lake 1967), which is similar to that in the Windermere population in England (Bagenal 1982; Le Cren 1951). Even if Lake (1967) suggested a possible disruption of egg development by high pre-spawning temperatures in Eastern Australia, Eurasian perch could still spawn at 15°C, and yellowfin perch, *Perca flavescens* (the closely related species) can produce viable spawn over the ambient range of 3.9-18.6°C (Hokanson 1977). Following the development of the gonad maturity stage, the GSI grows; wild fish reached significantly higher GSI, 11.6%, compared to 7.0%, and 8.2% for pond and tank populations, respectively. The GSI of wild fish here is ready for spawning. However, in comparison to the maximum GSI, recorded by Morgan et al (2002) for the sample captured from Big Brook Dam, of 14%, the results in this study were significantly lower ($p<0.05$). The maximum GSI, reported by different studies on fish of European origins, was even higher (14-25%) compared to the GSI in this study (Jellyman 1980; Morgan et al 2002; Sulistyo et al 1998).

Not only temperature, but photoperiod is also known as a key of success for Eurasian perch maturation and spawning (Bromage et al 2001). The combination of temperature and photoperiod in pond and tank populations did not support the development of gonads to the mature stage. The combination of the lowest temperature and the lowest day length could promote gonad maturity, which leads to spawn, as it occurs only in the wild population. According to Migaud et al (2002), in early spring spawners like percids, both variations of temperature and photoperiod are involved in the initiation of the reproductive cycle. The decrease of photoperiod from 14h in January to about only 10h in June succeeded in promoting spawning in the wild population. A high decrease in photoperiod (more than 4 h) is recommended to induce ovarian development and obtain out-of-season spawning in Eurasian perch (Abdulfatah et al 2011). The cycle of gonad development of female wild population Eurasian perch here was similar to the population from Big Broom Dam, but the development in gonad tissue was much lower than reported by Morgan et al (2002) and Sulistyo et al (1998), although still higher than in pike, *Esox zucius* L. (Treasurer 1990). This may be a feature of fish populations under severe climatic conditions.

Conclusions. Even if the Eurasian perch has been adapted to Western Australia's environment for a long period, it could not breed naturally in the pond and tank in Gingin and Bentley respectively. Therefore, an effort on environmental and hormonal manipulation of Eurasian brood stock may need to be performed to attain oocyte maturation and spawn in respective environments.

Acknowledgements. The authors would like to thank to Trevor Blinco, who kindly provided fish and his pond for ponds-stocked fish population at his farm at Gingin. and Simon Longbottom, who provided technical assistance for tank population rearing and the laboratory work. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest. The authors declare no conflict of interest.

References

Abdulfatah A., Fontaine P., Kestemont P., Gardeur J. N., Marie M., 2011 Effects of photothermal kinetics and amplitude of photoperiod decrease on the induction of the reproduction cycle in female Eurasian perch, *Perca fluviatilis*. Aquaculture 322–323:169-176.

Allen G. R., 1982 Inland fishes of Western Australia. Western Australian Museum, Perth, 86 p.

Bagenal T., 1982 Experimental manipulations of the fish populations in Windermere. The International Journal of Aquatic Sciences 86:201-205.

Brasfield S., Tetreault G. R., McMaster M. E., Bennett J., Munkittrick K., 2013 Seasonal patterns of gonad size, liver size, and in vitro gonadal steroidogenic capacity in slimy sculpin (*Cottus cognatus)*. Water Quality Research Journal of Canada 48:243-254.

Bromage N. R., Porter M., Randall C., 2001 The environmental regulation of maturation in farmed finfish with special reference to the role of photoperiod and melatonin. Aquaculture 197:63-98.

Encina L., Granado-Lorencio C., 1997 Seasonal variations in the physiological status and energy content of somatic and reproductive tissues of chub. Journal of Fish Biology 50:511-522.

Fontaine P., Gardeur J. N., Kestemont P., Georges A., 1997 Influence of feeding level on growth, intraspecific weight variability and sexual growth dimorphism of Eurasian perch *Perca fluviatilis* L. reared in a recirculation system. Aquaculture 157:1-9.

Fontaine P., Tamazouzt L., Capdeville B., 1996 Growth of the Eurasian perch *(Perca fluviatilis*) reared in floating cages and in water recirculating system: first results. Journal of Applied Ichthyology 12:181-184.

Gillet C., Dubois J., Bonnet S., 1995 Influence of temperature and size of females on the timing of spawning of perch, *Perca fluviatilis*, in Lake Geneva from 1984 to 1993. Environmental Biology of Fishes 42:355-363.

Hoese D. F., Bray D. J., Paxton J. R., Allen G. R., 2006 Fishes. ABRS & CSIRO, 2178 p.

Hokanson K. E. F., 1977 Temperature requirements of some percids and adaptations to the seasonal temperature cycle. Journal of the Fisheries Research Board of Canada 34:1524-1550.

Jellyman D. J., 1980 Age, growth, and reproduction of perch, *Perca fluviatilis* L., in Lake Pounui. New Zealand Journal of Marine and Freshwater Research 14:391-400.

Kestemont P., Me´lard C., Fiogbe E., Vlavonou R., Massou G., 1996 Nutritional and animal husbandry aspects of rearing early life stages of Eurasian perch *Perca fluviatilis*. Journal of Applied Ichthyology 12:157-165.

Laevestu T., 1965 Manual of methods in fisheries biology. Food and Agriculture Organisation, Rome, Italy, pp. 1-12.

Lake J. S., 1967 Rearing experiments with five species of Australian freshwater fishes. II. Morphogenesis and ontogeny. Australian Journal Marine Freshwater Research 18(2):155-176.

Le Cren E. D., 1951 The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20(2):201-219.

McDowall R. M., 1980 Family Percidae, Freshwater Perches. In: Fresh water fishes of South-Eastern Australia. McDowall R. M. (ed), pp. 158-159, A. H.& A.W. REED PTY LTD, Sydney.

Migaud H., Fontaine P., Sulistyo I., Kestemont P., Gardeur J. N., 2002 Induction of out-of-season spawning in Eurasian perch *Perca fluviatilis*. Effects of rates of cooling and cooling durations on female gametogenesis and spawning. Aquaculture 205:253-267.

Migaud H., Gardeur J. N., Kestemont P., Fontaine P., 2004 Off-season spawning of Eurasian perch *Perca fluviatilis*. Aquaculture International 12:87-102.

Migaud H., Wang N., Gardeura J. N., Fontaine P., 2006 Influence of photoperiod on reproductive performances in Eurasian perch *Perca fluviatilis*. Aquaculture 252:385-393.

Morgan D. L., Hambleton S. J., Gill H. S., Beatty S. J., 2002 Distribution, biology and likely impacts of the introduced redfin perch, *Perca fluviatilis* (Percidae) in Western Australia. Marine and Freshwater Research 53:1211-1221.

Mylonas C. C., Fostier A., Zanuy S., 2010 Broodstock management and hormonal manipulations of fish reproduction. General and Comparative Endocrinology 165(3):516-534.

Pankhurst N. W., Purser G. J., Van Der Kraak G., Thomas P. M., Forteath G. N. R., 1996 Effect of holding temperature on ovulation, egg fertility, plasma levels of reproductive hormones and in vitro ovarian steroidogenesis in the rainbow trout *Oncorhynchus mykiss*. Aquaculture 146:277-290.

Pankhurst N. W., Thomas P. M., 1998 Maintenance at elevated temperature delays the steroidogenic and ovulatory responsiveness of rainbow trout *Oncorhynchus mykiss* to luteinizing hormone releasing hormone analogue. Aquaculture 166(1–2):163-177.

Rinchard J., Kestemon, P., 1996 Comparative study of reproductive biology in single-and multiple-spawner cyprinid fish I. Morphological features. Journal of Fish Biology 49:883-894.

Rinchard J., Kestemon P., Heine R., 1997 Comparative study of reproductive biology in single and multiple-spawner cyprinid fish. II. Sex steroid and plasma protein phosphorus concentrations. Journal of Fish Biology 50:169-180.

Sulistyo I., Rinchard J., Fontaine P., Gardeur J. N., Capdeville B., Kestemont P., 1998 Reproductive cycle and plasma levels of sex steroids in female Eurasian perch, *Perca fluviatilis.* Aquatic Living Resources 11:101-110.

Thorpe J. E., 1977 Morphology, physiology, behavior, and ecology of *Perca fluviatilis* L. and *P. flavescens* Mitchill. Journal of the Fisheries Research Board of Canada 34:1504-1514.

Treasurer J. W., 1990 The annual reproductive cycle of pike, *Esox zucius* L., in two Scottish lakes. Journal of Fish Biology 36:29-46.

Wang N., Gardeur J. N., Henrotte E., Marie M., Kestemont P., Fontaine P., 2006 Determinism of the induction of the reproductive cycle in female Eurasian perch, *Perca fluviatilis*: Identification of environmental cues and permissive factors. Aquaculture 261:706-714.

Weatherley A. H., 1977 *Perca fluviatilis* in Australia: zoogeographic expression of a life cycle in relation to an environment. Journal of the Fisheries Research Board of Canada 34:1464-1467.

Weatherley A. H., Lake J. S., 1967 Introduced fish species in Australian inland waters. In: Australian Inland Waters and their Fauna-Eleven Studies. Weatherley A. H. (ed), pp. 213-239, Australian National University, Canberra, Australia.

West G., 1990 Methods of assessing ovarian development in fishes: a Review. Australian Journal of Marine and Freshwater Research 41:99-222.

*** http://www.timeanddate.com

Received: 19 June 2024. Accepted: 30 September 2024. Published online: 14 October 2024.

Authors:
Sulaeman Sulaeman, National Research and Innovation Agency (BRIN), Cibinong, Indonesia, e-mail:sulaeman.marhali@gmail.com
Herlinah Herlinah, National Research and Innovation Agency (BRIN), Cibinong, Indonesia, e-mail: herl011@brin.go.id
Ravi Fotedar, Department of Environment and Agriculture, Curtin University, Bentley, Australia; e-mail: R.Fotedar@curtin.edu.au

How to cite this article:
Sulaeman S., Herlinah H., Fotedar R., 2024 Reproductive adaptation in fish: A case study on female Eurasian perch, *Perca fluviatilis*. AACL Bioflux 17(5):2086-2095.