Fecundity of migrating European eel (Anguilla anguilla) from Polish waters

Marta Dębowska,1 Joanna Nowosad,1 Katarzyna Targosińska,1 Daniel Zarębski,1 Maria Bifas,1 Joanna Łuczyńska,1 Marta Dębowska1
1Department of Lake and River Fisheries, University of Warmia and Mazury in Olsztyn, Poland
2Department of Commodity Science and Food Analysis, University of Warmia and Mazury in Olsztyn, Poland

Abstract

This study demonstrated that individual fecundity of 34 migrating European female eels Anguilla anguilla increases linearly with body weight (BW) and total length (TL). The total individual fecundity of fish from 560 to 1960 g BW was between 981 x 10^3 and 6320 x 10^3 eggs, respectively. The mean relative individual fecundity equaled 2415 x 10^3 (± 524 x 10^3) eggs per kg BW. The values of this parameter ranged from 1753 x 10^3 to 3224.5 x 10^3 kg^-1. Based on the results, it might be suggested that A. anguilla has lower total individual fecundity than New Zealand longfin eel (Anguilla dieffenbachii), American eel (Anguilla rostrata) and Japanese eel (Anguilla japonica) although it has one of the highest fecundity values per kg BW. Total fecundity was strongly depended from fat level in muscle (R² = 0.9523) and ovary (R² = 0.9531) as well as level of DHA content in ovary (R² = 0.8967) and muscle (R² = 0.6274) (N=10). There were no important relationship between total fecundity and protein level as well as in muscle and ovary.

Introduction

In recent years, the population of European eel (Anguilla anguilla L. 1738) has dramatically diminished; it is now below the safe biological level and is constantly declining (ICES, 2008). Since the 1970s, the recruitment of glass eel has decreased by 90-99% across the entire European continent (Dekker, 2000, 2003). The causes include intensivecatching, migration barriers, heavy metals and PCBs, the destruction of feeding grounds, viruses (e.g. Eel Virus European X) as well as the swim bladder nematode parasite Anguillicoloides crassus (van den Thillart et al., 2009). The changes in climate and ocean currents may also hinder migration and spawning as well as the development and survival of eggs and larvae (Friedland et al., 2007). Some European countries have made an attempt to save the population of European eel by limiting catches, transporting juvenile fish deep into the continent or periodically stopping the turbines of hydro-electric power stations which hinder fish migration (Vogel, 2010). As the explicit cause of the dramatic decline in the number of eels is not known, all attempts to restore the balance and save the populations are justified. A successfully developed method of artificial reproduction and larvae rearing might help in saving the European eel, but many aspects still need further study (Nowosad et al., 2014, 2015).

The determination of fecundity, especially for commercial and endangered fish species, allows for sustainable fisheries in seas, oceans and inland waters. This parameter is useful in characterizing the reproductive capability of individuals and whole populations. The differences in fecundity level observed between species usually result from the different biology of reproduction and reproductive strategies of individual fish species (Helfman et al., 1997; Murua and Saborido-Rey, 2003). Within a species, differences in fecundity may be related to the geographical location of a given population and its adaptation capacity (Wittthames et al., 1995; Barbin and McCleave, 1997). The nutritional status of the fish also has an impact on number and quality of eggs (Suworow, 1954; Scott, 1962; Kjesbu et al., 1991). Other factors, such as parasite infestations (Zawisza and Backiel, 1970) or water contaminants (Johnson et al., 1998), also negatively affect fecundity. Many reports have been published on the positive correlation between body length, body weight and fecundity of fish. However, data on the fecundity of European eel is limited to the papers by Kokhnenko et al. (1977), Boetius and Boetius (1980), van Ginneken et al. (2005) and MacNamara et al. (2012). Only Boetius and Boetius (1980) and MacNamara and McCarthy (2012) have described the relation between the body length of females and their fecundity. However, data on the fecundity in this species is ambiguous and sometimes conflicting (Kokhnenko et al., 1977; Boetius and Boetius, 1980; van Ginneken et al., 2005); it may be the result of population determinants or different methods of fecundity determination. On the other hand, Van Ginneken and Maes (2005) describe two hypotheses about European eel spawning in the Sargasso Sea region. The first is that eel reproduction and constitute a single, randomly mating population, the so-called panmictia, and that second theory that the eel population is genetically diverse, pointing to discrete spawning populations. Thus, due to this second hypothesis, the European eel populations might be also differ by fecundity (MacNamara et al., 2014). The ocean migration journey of this species is very long and is over 5500 km from Western Europe. This distance is about 1500 – 2000 km longer for eels from the Baltic Sea than from Irish waters. So, it is also interesting if the fecundity of European eel, which has a long, different journey to the spawning grounds, is the same or different. Therefore, it was decided to verify the data on the fecundity of A. anguilla on newly-caught fish during their migration from the Polish lakes to the Baltic Sea. There is also a lack of information about the possible relationship between protein, fat or fatty acids content in eel female body content and their fecundity. The aim of the study was to determine the total individual fecundity of European eel females and analyse the relationship between individual fecundity and fish body weight and length as well as the relationship between total fecundity and protein, fat and fatty acids content.
Materials and methods

Collection and treatment of eels

European eel females of 560 g to 1960 g body weight (BW) and total length (TL) ranging from 73.6 cm to 97.5 cm were obtained during their migration from the Warmia region (north-eastern Poland) near Szczyno towards the Baltic Sea. The fish originated from commercial catches. Fish samples (n=34) were submitted for investigation to the Department of Lake and River Fisheries, University of Warmia and Mazury (Olsztyn) where the BW (± 0.1 g) and TL (± 1 mm), weight of gonads (± 0.1 g) as well as eye diameter (± 0.01 mm) were measured, although the age was not determined.

The Eye Index was calculated using the following measurements (El, e.g. Mordenti et al., 2013; Nowosad et al., 2014):

\[ EI = 100 \times \frac{((D_h + D_v) \times 0.25)^2 \pi}{(L_t \times 10)} \]

where: \(D_h\) is eye diameter horizontal (mm); \(D_v\) is eye diameter vertical (mm); \(L_t\) is body length (cm).

The Gonadosomatic index was also calculated as:

\[ GSI = \left( \frac{GW}{BW} \right) \times 100\% \]

where: \(GW\) is gonad weight (g) and \(BW\) is body weight (g).

Sampling of gonads

The gonads were carefully prepared, blotted on absorbent paper and weighed to an accuracy of ± 0.01 g. A minimum of three samples was taken from different areas of the ovaries. The samples were blotted and weighed (± 0.01 mg; average sample weight 2.02 ± 1.57 mg). The fresh ovary samples were mixed with 2% acetic acid. Each sample was agitated daily, and all eggs ovarian tissue was separated with an increase in body size (Figures 1 and 2). The correlation between body weight and individual fecundity was almost complete (r = 0.96) whereas between body length and individual fecundity it was strong and distinct (r = 0.76). The range of total individual fecundity was between 981 x 10^3 and 6320 x 10^3 eggs for fish with BW of 560 to 1960g.

For a female measuring 73.6 cm, the total individual fecundity was 866 x 10^3 eggs, while for a female of 97.5 cm TL it reached 3107 x 10^3 eggs. In the study, the mean total individual fecundity was 2777 x 10^3 ± 1437 x 10^3 eggs per female. The maximal fecundity was 6320 x 10^3 (TL = 93 cm, BW = 1960 g) and the minimal value was 866 x 10^3 (TL = 73.6 cm, BW = 650 g).

Methods of egg counting

The prepared gonad samples were placed under a magnifying glass LeicaMZ 12.5 (Leica, Switzerland) equipped with a camera and computer with ProgRes®CapturePro 2.5 software (Jenoptik, Germany). The egg samples distributed in a single layer were photographed using B raker chamber and the number of oocytes was counted. The total number of eggs in both gonads was estimated based on the number of oocytes in each sample, which allowed for calculating the total individual fecundity.

Analysis of chemical composition of muscles and gonads

The chemical composition of gonads and muscles of ten eel females were analyzed. The analyzed features included the content of dry matter, protein, ash, fat and fatty acid profiles. Dry weight: approximately 1 g samples (± 0.0001 g) in duplicate were initially dried at 65-70°C in quartz tests, then dried to a constant weight at 105°C for 1 h.

Protein: the protein content was determined following the method of Kjeldahl according to PN-75 A-04018 (Katalog Polskich Norm, 1975).

Ash: the samples (about 1 g ± 0.0001 g) were dried at 600°C for 6 h in quartz tests.

Fat: the fat content was determined using the Schmidt-Bondzynski-Ratzlaff C method (Berg and Nilsson, 1997). To this end, approximately 2 g (±0.0001g) samples were hydrolyzed in 8M HCl and transferred to a 100 mL cylinder. 10 mL of 95% ethanol with an addition of 0.0001 g BHA (2-tert-Butyl-4-hydroxyanisole) and 25 mL ethylene ether and 25 mL of petroleum ether were then added in succession to all samples. The ether layer was collected to a 250 mL glass flask. Subsequently, 15 mL of ethylene ether and 15 mL of petroleum ether was added twice. Each time, the samples were shaken and were left overnight. The ether layer was distilled by means of aggregate for distillation of solvents. Odd fat was dried at 105°C for 6-7h to a constant weight and was then weighed.

The content of fat (%) was calculated according to the pattern: \(X = \frac{(b - a) \times 100}{c};\) where: \(a – weight\) of flask (g), \(b – weight\) of flask with extracted fat (g), \(c – weight\) of samples (g).

Fatty acids: In the case of fatty acid analysis, lipids were extracted with the use of Folch’s procedure (Christie, 1973). To this end, the studied material was broken up and mixed. 2 g of sample was homogenized for 1 min with 20 mL of methanol. Next, 40 mL chloroform was added and the course was continued for 2 min. The prepared mixture was filtered to a 250 mL glass cylinder. The solid residue was re-suspended in 60 mL chloroform: methanol (2:1 v:v) and homogenized again for 3 min. After filtering, the solid was washed once more with 40 mL chloroform and once with 20 mL methanol. The combined filtrates were transferred to the same cylinder. 0.88 % sodium chloride in water (determining 1/4 volume of filtrate) was added to the total filtrate and was then shaken and left overnight. The upper layer was removed and a water:methanol mixture (1:1 v:v) was added to the lower layer and the washing procedure was repeated. The remaining layer was filtered through anhydrous sodium sulfate and was distilled by means of aggregate for distillation of solvents. The fatty acid methyl esters were prepared from total lipid with the Peisker method with chloroform: methanol: sulfuric acid (100:100:1 v:v) (Zegarska et al., 1991).

Methyl esters of fatty acids of each sample were analyzed with capillary gas chromatography with a flame-ionization detector (FID) under the following conditions: capillary column (dimension 30 m x 0.25 m with a 0.32 mm internal diameter, liquid phase Supelcowax 10; Supelco, Bellefonte, PA, USA); temperature (flame-ionization detector - 250°C, injector - 225°C, column - 170°C); carrier gas (helium, flow rate 0.6mL/min).

Individual fatty acids were identified by comparing the relative retention time peaks to known standards of Supelco.

Statistical analysis

The correlations between total fecundity of female eels and their body weights and lengths were calculated and the coefficient of determination (R²) and Pearson correlation coefficients (r) for these relations were determined.

Results

The Eye Index (EI) in migrating female eels was between 7.1 and 12.2 (10.2±1.3), GSI ranged between 1.23 and 1.71 (1.51±0.17). There was no statistical relationship between the indexes and fecundity. It was found that the individual fecundity of 34 female A. anguilla was positively correlated with an increase in body size (Figures 1 and 2). The correlation between body weight and individual fecundity was almost complete (r = 0.96) whereas between body length and individual fecundity it was strong and distinct (r = 0.76). The range of total individual fecundity was between 981 x 10^3 and 6320 x 10^3 eggs for fish with BW of 560 to 1960g.

For a female measuring 73.6 cm, the total individual fecundity was 866 x 10^3 eggs, while for a female of 97.5 cm TL it reached 3107 x 10^3 eggs. In the study, the mean total individual fecundity was 2777 x 10^3 ± 1437 x 10^3 eggs per female. The maximal fecundity was 6320 x 10^3 (TL = 93 cm, BW = 1960 g) and the minimal value was 866 x 10^3 (TL = 73.6 cm, BW = 650 g).
g). The relative individual fecundity per female equalled 2415 x 10³ ± 524 x 10³ kg⁻¹. This parameter ranged from 1753 x 10³ to 3225 x 10³ kg⁻¹ for fish of 560 to 1960 g BW, respectively.

There was found a strong relationship between eel females’ total fecundity and fat content in muscle and ovary (Figure 3). There were no significant relationship between eel fecundity and protein content both in muscle and ovary. From fatty acids, the significant relationship was found for DHA. This fatty acid content was strongly correlated with females’ total fecundity (Figure 4).

**Discussion**

The determination of European eel fecundity plays a pivotal role since it allows an effective reproductive strategy to be devised for this species. Due to endangered status of this species, the data about fecundity are analysed on appreciate but limited number of individuals, ranged between 13 and 34 (MacNamara and McCarthy, 2012; MacNamara et al., 2014; present study). Research into the fecundity of *Anguilla anguilla* has shown that the total individual fecundity increases linearly with total body weight and body length. The same results have been reported for other *Anguilla* sp. (Wenner and Musick, 1974; Todd, 1981; Barbin and McCleave, 1997). Adequate nutritional status of the fish allows it to reach a larger body size, better condition and a higher fecundity level (Kjesbu et al., 1991). The correlation between feed ration levels and the number of eggs has been documented in many species (Suworow, 1954; Scott, 1962; Kjesbu et al., 1991). Kokhnenko and Bezdenyehnykh (1973) also suggested that larger *A. anguilla* females produce oocytes larger in diameter compared to smaller. But the development of European eel oocytes, as well as size, is complicated (MacNamara et al., 2014; Nowosad et al., 2015). The values of EI and GSI are similar to those reported by Mordenti et al. (2013), MacNamara et al. (2014) and Nowosad et al. (2014) for migrating silver eel females. In the literature, the data on the correlation between individual fecundity and body size of *A. anguilla* is limited (Boetius and Boetius, 1980; MacNamara and McCarthy, 2012; MacNamara et al., 2014). Data presented by Boetius and Boetius (1980) for females ranging from 570 to 1339 g BW ranged from 960 x 10³ to 2330 x 10³ eggs (Boetius and Boetius, 1980).

However, these values are lower than those observed in the present study, but the authors counted only oocytes with diameters over 0.2 mm. MacNamara et al. (2014) and Nowosad et al. (2015) showed that oocytes might differ in size in migrating European eel females.

Similarly, for other *Anguilla* spp. there is little data on the correlation between body size and fish fecundity. Todd (1981) studied this correlation in two New Zealand eel species. He measured the correlation between body weight, total body length and individual fecundity in New Zealand shortfin eel (*Anguilla australis* Richardson 1841) and in New Zealand longfin eel (*Anguilla dieffenbachii* Gray 1984). The number of eggs in migrating *A. australis* was 458 x 10³ and 3662 x 10³ for females measuring 51.6 cm and 93.3 cm, respectively. The results of the present study may indicate that *A. anguilla* females have higher fecundity than *A. australis* since the number of eggs in females of comparable body lengths (93 cm) was 6320 x 10³. The analysis of fecundity in migrating *A. dieffenbachii* showed that for a
female measuring 71.1 cm, the individual fecundity was 1046 x 10^3 and for a female of 145.2 cm TL it was 208.0 x 10^3 (Todd, 1981). These results might suggest that A. anguilla has a lower fecundity compared to A. dieffenbachii. In the present study, a female measuring 73.6 cm produced only 866 x 10^3 eggs. A positive correlation between body weight, total length and number of eggs was also determined for American eel (Anguilla rostrata (Lesueur, 1817)) (Wenner and Musick, 1974; Barbin and McCleave, 1997). Barbin and McCleave (1997) studied migrating females of total body length between 45.2 cm and 113.3 cm and calculated their individual fecundity to range from 1.8 x 10^3 to 19.9 x 10^3 eggs. In comparison with this study, A. anguilla seems to be less fecund. The individual fecundity in a 64 cm female was 1.8 x 10^3. According to Eales (1968), the total individual fecundity in A. rostrata was high and ranged between 15 x 10^4 and 20 x 10^4 eggs. However, in the latter study, this parameter is not related to body length. The level of individual fecundity determined by Edel (1975) for a single hormonally-stimulated A. rostrata female (564g) ranged between 1.3 x 10^4 and 1.5 x 10^5 eggs; this value is higher than the level calculated in the present study for a female with comparable body weight. In Japanese eel females (Anguilla japonica Temminck and Schlegel, 1846), the individual fecundity ranged from 7.2 x 10^4 (TL = 35.7 cm) to 12.7 x 10^4 (TL = 52.4 cm) (Matsui, 1952) and it is markedly higher than the values determined in the present study for A. anguilla.

A comparison of the relative fecundity presented in literature between A. anguilla and other eel species shows that A. anguilla females produce a relatively large amount of eggs per kg body weight. In the present study, the relative fecundity of migrating A. anguilla equalled 2414.9 x 10^3 ± 524.4 x 10^3 eggs kg^-1. Other authors reported 3 x 10^5 eggs per kg BW of A. anguilla female (Kokhnenko et al., 1977). It should be mentioned that this study was carried out on hormonally-stimulated fish from artificial breeding. Boetius and Boetius (1988) conducted a study on artificially-bred silver A. anguilla females which were hormonally stimulated in order to induce sexual maturity. The relative fecundity reported by these authors was 1.6 x 10^5 eggs kg^-1; although the calculation only included oocytes with a diameter larger than 0.2 mm and the fecundity may thus be underestimated. In migrating A. australis and A. dieffenbachii, the values of this parameter stand at 2.05 x 10^5 ± 0.09 x 10^5 kg^-1 and 1.95 x 10^5 ± 0.12 x 10^5 kg^-1 BW, respectively (Todd, 1981). Other reports concerning A. anguilla revealed that the mean individual fecundity reaches 1874 x 10^3 ± 1116 x 10^3 eggs (mean TL = 75.4 ± 7.6 cm) (van Ginneken et al., 2005). However, in the present study the mean individual fecundity was higher and equalled 2776.6 x 10^3 ± 1437 x 10^3 (mean TL = 83.1 ± 6.2 cm). MacNamara and McCarthy (2012) found the fecundity of European eel migrating females to be about 3 x 10^6 per kg. This was 0.5 x 10^6 kg^-1 higher than in the present study. The higher fecundity of European eel than in present study and in Irish waters (MacNamara and McCarthy, 2012) was recorded for population from North Aegean Sea (MacNamara et al., 2014). There are several possibilities for such differences in migrating eel females. It might be the results of different populations. Van Ginneken and Maes (2005) hypothesize that it is possible that different European eel population spawn separately. On the other hand, because eels from Baltic Sea basins have a much longer journey (1500 – 2000 km) to the spawning site in Sargasso Sea region than eels from western or southern Europe, this might also be an adaptation to much changed conditions.

A comparison of total individual fecundity and total body length of different Anguilla spp. demonstrates that A. anguilla might produce fewer eggs than A. dieffenbachii, A. rostrata and A. japonica. This may be related to the distance of spawning migration. A. anguilla has one of the longest spawning migrations and needs the greatest energy resources in order to reach its spawning grounds (Aarestrup et al., 2009; Clevestam et al., 2011). Lower fecundity was only reported in A. australis. As far as the number of eggs per kg BW is concerned, A. anguilla might be considered one of the most fecund eel species.

The present study demonstrates that the individual fecundity of A. anguilla females increases with the fish body size. The increase in body length of A. anguilla is accompanied by an increase in lipids in muscles (Boetius and Boetius, 1985). Young eels accumulate lipids which serve as an energy reservoir for migration and the development of gonads (Boetius and Boetius, 1980, 1985; Clevestam et al., 2011). It is suggested that appropriate lipid content in muscles (app. 28% for A. anguilla) initiates silvering and sexual maturation in eels (Larsson et al., 1990). Moreover, studies on Baltic herring (Clupea harengus membras L. 1761) have shown an increase in fecundity with increasing muscle lipid content (Anokhina, 1969). In the case of European eel, during spawning migration, the energy is usually taken from muscle. The fat (lipids) are transferred to the developing ovary (Nowosad et al., 2015). The present study confirmed that there was a strong relationship between fat content (both in muscle and ovary) and fish total fecundity. It suggest that fatter females will produce large amount of eggs. Similar observation was made by Bogevik et al. (2012) from Atlantic cod (Gadus morhua). Females fed with higher level of fat are fatter and produced larger amount of eggs. But such relationship are not present in all culture fish species. For example in Gulf killifish (Fundulus grandis) such relationship was not found (Patterson and Green, 2014). Some initial studies about the quality of eel eggs show some relationship between DHA content and egg quality. In case of Japanese eel was found such relationship (Furuita et al., 2006). Nowosad et al. (2015) reported that during maturation of ovary, content of DHA in this organ is increased. Recent biochemical analyses of body composition in yellow A. anguilla have revealed a decrease in lipid content in muscles compared with previous years (Belpaire et al., 2009). It is suspected that this factor may be indirectly responsible for the decrease in A. anguilla population size. It would therefore be interesting to carry out further research into the relationship between fecundity, age, size and lipid content in migrating A. anguilla females.

Conclusions

European eels have lower fecundity than other freshwater eels that have shorter migration distance to the spawning grounds. The total fecundity of European eels collected from Baltic Sea basins is lower in comparison with eels from western and southern Europe, which have a 2000 km shorter trip to spawning grounds. European eel fecundity from Polish waters was more related to fish weight than to length. There is an important relationship between total fecundity and fat content in muscle and ovary.

References

Aarestrup, K., Okland, F. Hansen, M.M., Righton, D., Gargan, P., Castonguay, M., Bernatchez, L., Howey, P., Sparholt, H., Pedersen, M.I., McKinley, R.S., 2009. Oceanic spawning migration of the European eel (Anguilla anguilla). Science 325:1660.

Anokhina, L., 1969. Regularities of fecundity in fishes after the example of Baltic Herring
from Spring and Autumn populations. Nauka, Moscow, Russia.

Barbin, G.P., McCleave, J.D., 1997. Fecundity of American eel Anguilla rostrata at 45° N in Maine, U.S.A. J. Fish Biol. 51:840-847.

Belpaire, C.G.J., Goemans, G., Geeraerts, C., Quataert, P., Parmentier, K., Hagel, P., De Boer, J., 2009. Decreasing eel stocks: survival of the fittest? Ecol. Freshw. Fish. 18:197-214.

Berg, H., Nilsson, S., 1997. Determination of fat content in meat and meat products with NMR or SFE. Proc. Euro-Food Chem IX, Interlaken, Switzerland, 26:59-64.

Boetius, I., Boetius, J., 1980. Experimental maturation of female silver eels, Anguilla anguilla. Estimates of fecundity and energy reserves for migration and spawning. Dana 1:1-28.

Boetius, I., Boetius, J., 1985. Lipid and protein content in Anguilla anguilla during growth and starvation. Dana 4:1-17.

Bogevik, A.S., Natario, S., Karlsen, Ø., Thorsen, D., Dekker, W., 2003. Did lack of spawners cause changes in European eel ovary development and spawning success in rock sole from Puget Sound, Washington. T. Am. Fish. Soc. 127:395-392.

Christie, W.W., 1973. The isolation of lipids from tissues. Recommended procedures. Chloroform-methanol (2:1, v/v) extraction and “Folch” wash. In: W.W. Christie and X. Han (eds.) Lipid analysis. Isolation, separation and identification and structural analysis of lipids. Pergamon Press, Oxford, UK, pp 39-40.

Clevesdam, P.D., Ogonowski, M., Sjöberg, N.B., Wickstrom, H., 2011. Too short to spawn? Implications of small body size and swimming distance on successful migration and maturation of the European eel Anguilla anguilla. J. Fish Biol. 81:1391-1405.

Christie, W.W., 1973. The isolation of lipids from tissues. Recommended procedures. Chloroform-methanol (2:1, v/v) extraction and “Folch” wash. In: W.W. Christie and X. Han (eds.) Lipid analysis. Isolation, separation and identification and structural analysis of lipids. Pergamon Press, Oxford, UK, pp 39-40.

Furuita, H., Unuma, T., Nomura, K., Tanaka, H., Okuzawa, K., Sugita, T., Yamamoto, T., 2006. Lipid and fatty acid composition of eggs producing larvae with high survival rate in the Japanese eel. J. Fish. Biol. 69:1178-1189.

Helfman, G.S., Collette, B.B., Facey, D.E., 1997. The diversity of fishes. Blackwell Science, Oxford, UK.

ICES, 2008. Report of the working group on eel (WGEEL). ICES CM 2008/ACFM:15. International Council for the Exploration of the Sea, Copenhagen, Denmark.

Johnson, L.L., Misitan, D., Sol, Y., Nelson, G.M., French, B., Ylitalo, M., Hom, T., 1998. Contaminant effects on ovarian development and spawning success of Atlantic cod (Gadus morhua) in relation to proximate body composition. Can. J. Fish. Aquat. Sci. 48:2333-2343.

Kokhnenko, S.W., Bezdenyeyzkhynk, V.A., 1973. Development of the ovocytes of the eel as a function of its size (Belorus). Vjes. Akad. Nauk BSSR Ser. Byal. Nauk. 2:90-94.

Kokhnenko, S.W., Bezdenyeyzkhynk, V.A., Gorovaya, S.L., 1977. Maturation of the European eel, Anguilla anguilla, when artificially reared. J. Ichthyol. 17:878-883.

Larsson, P., Hamrin, S., Okla, L., 1990. Fat content as a factor inducing migratory behaviour in the eel (Anguilla anguilla L.) to the Sargasso Sea. Naturwissenschaften 77:488-490.

Matsui, I., 1952. Studies on the morphology, ecology and pond culture of the Japanese eel (Anguilla japonica Temminck and Schlegel). J. Shimos. Colleg. Fisher. 2:1-245.

MacNamara, R., McCarthy, T.K., 2012. Size-related variation in fecundity of European eel (Anguilla anguilla). ICES J. Mar. Sci. 69:1133-1137.

MacNamara, R., Koutrakis, E.T., Sapounidis, A., Lachouvaris, E., Arapoglou, F., Panora, D., McCarthy, T.K., 2014. Reproductive potential of silver European eels (Anguilla anguilla) migrating from Vistonis Lake (Northern Aegean Sea, Greece). Medit. Mar. Sci. 15:539-544.

Mordenti, O., Biase, A.D., Bastone, G., Sirri, R., Zaccaroni, A., Parmeggiani, A., 2013. Controlled reproduction in the wild European eel (Anguilla anguilla): two populations compared. Aquacul. Int. 21:1045-1063.

Murua, H., Saborido-Rey, F., 2003. Female reproductive strategies of marine fish and their classification in the North Atlantic. J. Northw. Atlant. Fisher. Sci. 33:23-31.

Nowosad, J., Kucharczyk, D., Czarkowski, T.K., Kwasek, K., 2014. Changes in body weight and eye size in female European eel kept in fresh and saltwater. Ital. J. Anim. Sci. 13:382-386.

Nowosad, J., Kucharczyk, D., Łuczy ska, J., Targo ska, T., Czarkowski, T.K., Bilas, M., Krejzeff, S., Horváth, L., Müller, T., 2015. Changes in European eel ovary development and body and ovary chemistry during stimulated maturation under controlled conditions. Aquacult. Int. 23:13-27.

Patterson, J.T., Green, C.C., 2014. Physiological and reproductive response to varying quantitative lipid inclusion in diets for Gulf killifish Fundulus grandis Baird and Girard. Aquacul. Res. 1-12.

Katalog Polskim Norm, 1975. PN-75 A-04108. Produkty rolno-żywno ciowe. Oznaczenie azotu metod Klejdahla i przeliczenie na białko. Katalog Polskich Norm, Bydgoszcz, Poland.

Scott, D.P., 1962. Effect of food quantity on fecundity of rainbow trout, Salmo gairdneri. J. Fish. Res. Board. Can. 19:715-730.

Suworow, E., 1954. Podstawy ichtiologii. P. Wyd. Nauk, Warszawa, Poland.

Todd, P.R., 1981. Morphometric changes, gonad histology, and fecundity estimates in migrating New Zealand freshwater eels (Anguilla spp.). New Zealand J. Mar. Fresh. Res. 15:155-170.

Van den Thillart, G., Rankin, J.C., Dufour, S., 2009. Spawning migration of the European eel: reproduction index, a useful tool for conservation management. Springer, Dordrecht, The Netherlands.

Van Ginneken, V.J.T., Maes, G.E., 2005. The European eel (Anguilla anguilla, Linnaeus), its lifecycle, evolution and reproduction: a literature review. Rev. Fish Biol. Fish. 15:367-398.

Van Ginneken, V., Vianen, G., Muusze, B., Palstra, A., Verschoor, L., Lugten, O., Onderwater, M., van Schie, S., Niemantsverdriet, P., van Heeswijk, R., Eling, E., van den Thillart, G., 2005. Gonad development and spawning behaviour of artificially-matured European eel (Anguilla anguilla L.). Anim. Biol. 55:203-218.

Vogel, G., 2010. Europe tries to save its eels. Science 329:505-507.

Wenner, C.A., Musick, J.A., 1974. Fecundity and gonad observations of the American eel, Anguilla rostrata, migrating from...
Chesapeake Bay, Virginia. J. Fisher Res. Board. Can. 31:1387-1391.
Witthames, P.R., Greer Walker, M., Dinis, M.T., Whiting, C.L., 1995. The geographical variation in the potential annual fecundity of dorset sole, Solea solea, from European shelf waters during 1991. Netherl. J. Sea Res. 34:45-58.
Zawisza, J., Bakiel, T., 1970. Gonad development, fecundity and egg survival in Coregonus albula L. In: C.C. Lindey and C.S. Woods (eds.) Biology of coregonid fishes. University Manitoba Press, Winnipeg, Canada, pp 363-397.
Zegarska, Z., Jaworski, J., Borejszo, Z., 1991.
Ocena zmodyfikowanej metody Peiskera otrzymywania estrów metylowych kwasów tłuszczowych. Act. Acad. Agricult. Techn. Olst. 24:25-33.