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Is Global Warming The Cause For The Dwindling European Eel Population?

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Abstract

The European eel has been dwindling since the eighties of the previous century. Animals exhibiting temperature dependent sex determination (TSD), including eels, are perhaps most vulnerable to a warming of the Earth as highly skewed sex ratios can result, potentially leading to population extinction resulting from decreased male recruitment. Here we report based on time series dating from 1930 of annual catch of male and female silver eels from eight sites that are open for glass eel influx around Lake Ijssel, the Netherlands. We observed that the sex ratio was skewed gradually towards females. The significant female-skewness of the sex ratio validated that the population of European eels at these sites has declined to a very low level since the 1930s. From several field and laboratory studies we have indications that Environmental Sex Determination (ESD) is prevalent and that the temperature determines the ultimate sex of the eel. Comprehensive studies of the sexual differences of eels are important for conservation programs.

Keywords: European eel; *Anguilla anguilla*; Global warming; Spawners; Dwindling population

Introduction

Since the mid-nineteenth century, a notable increase (0.6-0.8°C) in the Earth's mean surface temperature has been documented and is continuing at an accelerated rate [1,2]. The European (Anguilla anguilla L.) an eel species of the moderate temperature zones- has been dwindling since the eighties of the previous centuries [3] and is an endangered species [4]. Possible causes for its decline were investigated in previous research manuscripts to mention

a. Swimbladder parasite *Anguillicola crassus* [5].

b. Eel viruses with mainly the EVEX virus in Europe [6,7] and PCBs [8].

Recently we have collected historical time series of fishermen around lake IJssel in the Netherlands which show a large corresponds in shape (after log transformation) in terms of changing sex ration for migrating silver eels with the global warming graph. The question arises what determines the ultimate sex of European eel. Environmental sex determination (ESD) has been detected in many vertebrates including turtles [9], many reptiles [10] and certain fish species [11-13]. Similar to reptiles, the incubation temperature during early phases of development is capable to modify sex ratios in a large number of fish species. This phenomenon, known as thermolabile sex determination (TSD) was reported for an increasing number of fish species [14] were in most cases females were found at low temperatures and males at high temperatures [15]. However, recently in the review of [16] the occurrence of TSD in fishes has to a large extent been taken into consideration. Many studies regarding the influence of temperature on the final sex ratios have been focused on the expression and activity of gonadal aromatase, the enzyme involved in the conversion of androgens into estrogens and encoded by the cyp19a1a gene [17]. In this regard, teleost fish, may be due to a whole genome duplication event, produce another aromatase enzyme, commonly named brain aromatase, encoded by the cyp19a1b gene [17]. However, the mechanism whereby temperature can induce the development of a testis or an ovary in fishes still remains elusive.

Material and Methods

In this letter a historical dataset going back to the thirties of the previous century of caught migrating silver eel split up to sex at eight locations around lake Ijssel, the Netherlands is discussed in relation to global warming. Local fishermen and trading places around the lake Ijssel with open retractable glass eels were visited which meet the criterion they didn't had any glass eel restocking program. This resulted in eight convenient locations around lake IJssel, the Netherlands (Figure 1). From

the archives and records from local fishermen the number of caught migrating silver eels (in kilograms) were recorded by year and split up to the sex. Criterion for sex differences were the weight of the animals. Eels in excess of 200 grams were referred to as females. Some records even dated from the fathers and grandfathers of these fishermen. The eight datasets were put chronologically in Excell and log transformed. The resulted log transformed graph of Figure 1 is depicted in Figure 2 and can be compared with Figure 3. The latter was composed of time series of annual values of global mean temperature anomalies from the National Centers for Environmental Information: National Oceanic and Atmospheric Administration [18].

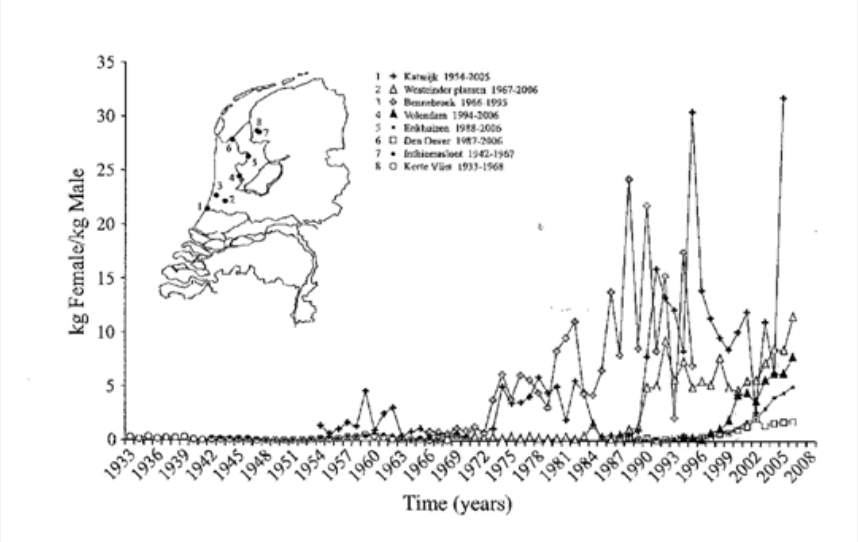

Figure 1: Historical time series dating from 1930 of annual catch of male and female silver eels from several sites that are open for glass eel influx in the Netherlands.

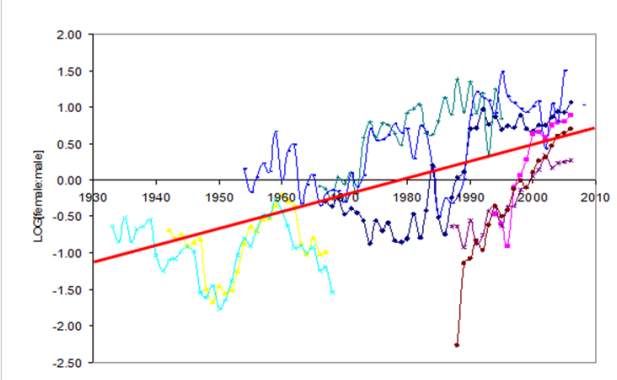

Figure 2: Log transformation of [female/male] ration expressed in kg of historical time series dating from 1930 of annual catch of male and female silver eels from several sites that are open for glass eel influx in the Netherlands.

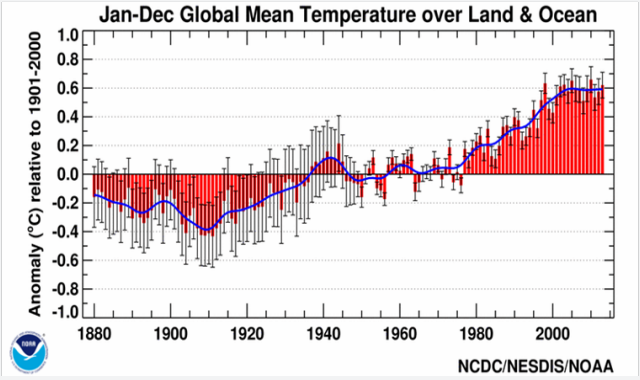

Figure 3: Time series of annual values of global mean temperature anomalies from the National Centers for Environmental Information: National Oceanic and Atmospheric Administration [18].

Results and Discussion

This study gives supportive evidence, that the effects of global warming will have enormous impacts on the European eel (*Anguilla anguilla*). In the present investigation, we observed in data series of annual catch data starting from the eighties of the previous century until 2006 in lake IJssel, the Netherlands, that the amount of kg caught eels remained more or less the same but that the sex ratio was skewed towards females. We observed a decrease of caught males with 50% and a threefold increase of caught females. This trend corresponds to the dramatic decline of glass eel influx at Den Oever, the Netherlands [19] over the last 30 years. So, it is likely that the reduced influx is the primary cause for the change in sex ratio. In fact the three eel species from the temperature moderate zones: The European eel (*A.anguilla*), the Japanese eel (*A.japonica*) and the American eel (*A.rostrata*) can be affected by global warming. The rate of global warming far exceeds the abilities of these fishes to adapt naturally to such dramatic environmental changes and as such these eels are endangered fish species [20]. As far as we know there are not many comparable long-term data sets available

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that have measured the sex ratio in the eel population in a few years and linked to TSD or global warming. In Europe solely one long-term records (1781-2013) of European eel (*Anguilla anguilla L.*) production in the Comacchio Lagoon (Italy) was published in relation to evaluation of local and global factors as causes of the population collapse but no correlation was made with global warming [21].

However, in another study performed over a time period of 5 year (1998-2002) in the Kaoping River in Taiwan a significant female-skewness of the sex ratio [22] was also observed which gave supportive evidence for our results and interpretation as presented in our study. Many investigations at sex differentiation of eels had the wrong assumption that food supply or stocking density were the major determinants for the ultimate sex of glass eel (reviewed: [23]). Their conclusions were that growth and sex ration are linked processes during eel development, with growth seeming to be sex dependant rather than being influenced by the density conditions in which glass eels are maintained [23]. The basic problem with sex differentiation studies was that they must take place over several years, and selective mortality and fluctuating husbandry conditions may also affect and bias the end result [24]. In addition, in eel farms at high temperatures of around 24-26°C most glass eels become male [24]. It is therefore logical that, until recently, first sex differentiation was attributed to food supply or density by these observations and secondly, that the theory of TSD for eel was put on the wrong track by observations in eel farms giving rise to skewed sex rations towards males. Fortunately, very recently a study was published showing a molecular gene for sexual dimorphism in eel [25] which makes the presented results of this study more plausible. Climate change effects on the sex ratio of animal species have solely until at present been inferred for the loggerhead turtle, a species with also TSD [9]. This is the first study where for a fish species the effects of global warming on skewed sex ration are presented. In addition to our awareness this is the first study with long term historical datasets for the European eel for which so clearly a correlation is made between sex differentiation and global warming. With declining European eel populations of 90-99% [4] and an overall reduced glass eel influx in Europe [19] this strategy to invest in females with a high fecundity "the fecundity advantage model" (reviewed: [26]) can be a natural mechanism to safeguard this species and be a final attempt to prevent extinction of this endangered fish species.

In addition, European eels exhibit a sexual size dimorphism model where females in the Netherlands can reach up to 1 meter long [27] and males have solely a length between 30 and 40 centimeters [28]. This difference in size has consequences for their points of departure (because both sexes swim at 0.5 body length per second) [29], where the males leave the European costs 2-3 months earlier (August-September), while the females departure is October-November, in order to arrive at the same time in the Sargasso Sea to spawn collectively and simultaneously [3]. For most evolutionary models with fish, the females are most important because of their higher fecundity which is called the "fecundity advantage" model, critically reviewed by [26]. But taking into consideration its life cycle-with spawning grounds 6000km far away in the Sargasso Sea [3,28] in combination with global warming [1,2] contribution of both sexes is equally important. Therefore restocking programs should take the "equal sex theory" into consideration to balance the sex ratio of the wild population in this way contributing to the spawning stock of the European eel [30].

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