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SEMI-EXTENSIVE PRODUCTION OF TURBOT FRY FED ON COPEPODS

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Introduction

Turbot (*Psetta maxima*) juveniles have been reared on copepods at Venøsund Fisk og Skaldyr Aps, Denmark, almost every year during the last 20 years for restocking purposes or for export. Copepods are small, free-living crustaceans and the main diet of wild turbot larvae.

Generally, in the semi-extensive production system, a succession takes place during each larvae production initiating with a bloom of small diatoms. After a crash in the diatom bloom, small algae cells and sometimes-filamentous bacteria take over. Nutrients are taken up very quickly and some elements are often sufficiently depleted as to be immeasurable within a few days. Usually P is in excess. In contrast to similar systems, the blooms in this system are closely monitored, and to a certain extent regulated. Well-nourished adult copepods are filtered and added to the production system before introducing the fish larvae. The adult copepods produce eggs that hatch into nauplii and develop into older stages of nauplii or copepodites unless eaten by the larvae (Engell-Sørensen et al., 2004; Jepsen et al., 2017).

Turbot larvae productions were monitored as part of the project IMPAQ with the aim to describe all trophic levels including primary producers, secondary producers and fish larvae during different seasons (spring, summer, and fall).

Materials and methods

A low-technology rearing system was used for rearing the turbot larvae. Juveniles were reared from the yolk-sac stage until metamorphosis in outdoor ponds relying on phyto- and zooplankton blooms, with copepods as their main food source. During each production, oxygen, temperature, salinity, phytoplankton biomass, zooplankton density, stomach contents of the larvae and final survival and quality of the fry were monitored regularly.

The production system consisted of six outdoor lagoons, each 1200m^3. A filtering system provided fresh 40-µm filtered seawater from the adjacent fjord, Limfjord, Denmark. The nutrient (N, P) levels at the onset of the productions were adjusted to levels similar to those in the fjord (several hundred µg nutrient-N l^{-1} and tens of µg nutrient-P l^{-1}) to encourage a phytoplankton bloom mimicking a natural bloom. Well-nourished, pre-cultured copepods, kept for several generations were introduced to the lagoons. Zooplankton was filtered and transferred between all lagoons as needed during the production process (Unik Filtersystems, Norway).

Mixed samples of phyto- and zooplankton, were taken twice a week from two fixed points in each production lagoon and two depths (0.5 and 1m) and were analysed to determine species composition and biomass. Phytoplankton (and microzooplankton) were monitored using an inverted microscope (Ütermöhl, 1958). Results were calculated using software (PlanktonSys, Orbicon, Denmark) based on standard methods for calculation of volume and biomass of phytoplankton (Olrik, 1991).

Newly hatched turbot larvae were obtained from Stolt Seafarm, Øyestranda, Norway and transferred to the lagoons. Growth rates were calculated from length (mm) using a relationship between length and dry weight (mg) of individual fish: DW (mg)=0.0019×((notochord L(mm)$^{3.3008}$) (Jepsen, pers. comm.). Growth rate (G) related to day-degrees from hatch was estimated from the exponential equations:

$$G_L = \ln(L_t)-\ln(L_{0)}/\Delta t$$

$$G_W = \ln(W_t)-\ln(W_{0)}/\Delta t$$

Where L_t = length at time t; W_t = dry weight at time t, t = time measured in day-degrees (day °C) from hatch, W_0 = dry weight at t =0, L_0 = length at t =0 and SGR (%) = 100×[(expG)-1].

Theoretical daily food consumption by the turbot larvae was calculated from age-specific growth rates for different prey sizes using a production/consumption rate of 0.2. Consumption rate of a given prey was only calculated when the type of prey was actually found in the stomach/gut of flounder larvae of that length. Consumed prey = dry weight (mg) × specific growth rate (% day°C^{-1}) × (share of energy used for growth)$^{-1}$ × (individual dry weight of prey (mg))$^{-1}$.

Results and discussion

Spring productions were initiated with a huge bloom of the diatom *Skeletonema costatum* (up to 100 million.l^{-1}) and probably because of the high biomass in the

lagoons, filamentous bacteria became numerous (up to 150 million.l^{-1}) by the end of the production resulting in low oxygen concentrations. At this point the lagoons had to be harvested quickly. Later, during summer different diatom species became dominant and productions were initiated by a bloom of *Dactyosolen fragillissimus* (up to 10 million.l^{-1}) and *Leptocylindricus danicus*. Summer productions were successful with what seemed to be a balanced algae community, sustaining the copepod production during the whole production and a low density of filamentous bacteria (up to 40 million.l^{-1}). Autumn productions were initiated by a quick, weak bloom of *Dactyosolen fragilissimus* (up to 4 million.l^{-1}) and *Leptocylindricus danicus* but very quickly small flagellates and *Prorocentrum minimum* (up to 7 million.l^{-1}), a potentially ichthyotoxic dinoflagellate took over. By the end of the production filamentous bacteria (up to 70 million.l^{-1}) dominated the microplankton entirely resulting in low oxygen levels and stressed fish with black pigmentation in the lagoons.

During spring *Acartia spp*. dominated the copepod population, during late summer and fall *Acartia spp* and *Centropages hamatus* were present in the lagoons. Normally up to 50-100 eggs per litre per day is produced by the copepods in the lagoon during a production season. But during fall, egg production decreased resulting in low densities of nauplii and copepodites and possibly also resulting in low fish larval survival during "first feeding". Most likely decreasing temperatures were the main reason for the reduced copepod egg production.

Table I. Growth rate and yield of turbot productions larvae in different seasons and batch productions in 2011. The numbers represent the sum of 3 lagoons from each season.

	Spring	**Late summer**	**Fall**
Yolk sac larvae released	300 000	300 000	300 000
Growth rate (% L.day°C^{-1})	0.3-0.4	0.4	0.3
Growth rate (% dw.day°C^{-1})	1.1-1.3	1.2-1.4	0.9-1.0
% fry discarded due to abnormalities	16	6	93
Harvest (number)	39 375	60 844	16 000

Turbot larvae with a notochord length of 3mm and larger had nauplii in their stomachs, even though the yolk sac would persist even to a notochord length of 3mm. At around 4.5mm in length turbot larvae would prey on copepodites, from a length of 6.5mm they would prey on adult *Acartia spp*., and from a length of 7.5mm they would prey on adult *Centropages hamatus*. From growth rate, temperature data, share of consumed energy used for growth and individual dry weight of prey types, the consumption of prey can be calculated– showing that in general, a turbot larvae needs to consume several thousand prey per day to sustain its growth, especially if only small sized prey is available (Table II).

Table II. Calculated consumption of different prey (number of prey per day per day-degree). It is assumed that (1) the larvae consume only one type of prey at a time, (2) 20% of the energy is used for growth, (3) Nauplii with a length of 100µm has an individual dry weight of 0.64µg, a copepodite 3 µg and an adult copepod 7.5µg and (4) SGR (specific growth rate) is 1152 (% day°C^{-1}), average for 2011 productions.

Notochord L (mm)	Calculated DW (mg)	Consumed nauplii (day°C^{-1})	Consumed copepodites (day°C^{-1})	Consumed copepods (day°C^{-1})
4	0.185	17	-	-
5	0.385	35	-	-
6	0.704	63	14	-
7	1.170	105	22	9
8	1.818	164	35	14
9	2.682	241	52	21
10	3.798	342	73	29
11	5.202	468	100	40
12	6.933	624	133	53

Conclusions

Growth rates of turbot larvae and production yield rates were highest during the late summer productions, and lowest in the Autumn. The initial diatom bloom was less prominent during Autumn compared to spring and summer, and production was taken over by dinoflagellates and other flagellates of minor size. Egg production of *Acartia* sp. and *Centropages hamatus* was reduced during Autumn, probably due to decreasing temperatures, resulting in low densities of nauplii and copepodites and possibly also in low survival and abnormal development during "first feeding". It is suggested to avoid production in the fall.

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