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Response of Marine Plankton Communities in Ponds to the Presence of Vertical Structures

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Abstract

The effects of bottom vertical structures like AquaMats® in enhancing plankton productivity was evaluated. One experimental earthen pond of 500 m^2 was provided with AquaMats® increasing the surface substrate area 12 times and water quality, phytoplankton and zooplankton populations developed during almost 100 days was compared with a pond without AquaMats®. Their presence favored the development of Dinoflagellates (Miozoa, Dinophyceae), mostly Gymnodiniales, which may be of some concern since some species of this group have been associated with toxic algal blooms while in the ponds without AquaMats® Diatoms (Bacillariophyta) predominate. In both ponds plankton production was very much sculptured by external nutrients added to the systems. The balance between different nutrients is extremely important to regulate the phytoplankton populations with Diatoms blooming at silicate concentrations higher than 2 μM and below this level and at low nitrate and high ammonium being more appropriate for Dinoflagellates. The linkage between phytoplankton and zooplankton population in ponds is strong with zooplankton exerting control over the phytoplankton population and vice-versa. The use of vertical substrates enhances plankton productivity by increasing the substrate area for periphyton fixation. The main zooplankton taxonomic groups associated with the presence of AquaMats® were Calanoid and Harpacticoid copepodites and nauplii, veligers of gastropods and trochophore of polychaets, larval stages of organisms that except for calanoid copepods are benthic and correspond to the meroplanktonic phase in the life cycle of those organisms.

Keywords: AquaMats®, phytoplankton, zooplankton, periphyton

1. Introduction

Decline in the world's fish stocks has led to an increasing demand for food from fish farming [1]. Much of this production is carried out in extensive and semi-extensive systems [2], mainly in Asia [1]. These systems are stocked with wild or farmed juveniles and rely on local natural productivity of lakes, earth ponds, reservoirs, and lagoons for feeding the fish and to maintain a good water quality and are characterized by low stocking densities and low to no inputs of food or fertilizers [2] and use of juveniles. Although intensification of these systems is a way to

augment production, increasing profits are not likely to come from higher stocking densities due to the biological limits of these systems [3].

One alternative for productivity enhancement in these production systems is to use artificial substrates to enhance the colonization of the surface in ponds by periphyton [4]. These are complex mixtures of algae, cyanobacteria, heterotrophic microbes, and detritus that are attached to submerged surfaces and are the primary producers in streams, providing food for benthic invertebrates, which feed fish and other invertebrates [4]. Many of these organisms possess life cycles with meroplanktonic phases that boost zooplankton abundance. This increase of plankton abundance can be used to advantage for rearing fish in the ponds since it provides food for their first larval stages and therefore adds to the profitability of such systems. Besides the saving in cost of fry, juveniles produced in these natural systems are better adapted to grow out conditions in ponds. Another benefit is the possibility of using such systems for species diversification since the small prey produced will enable the larviculture of some marine fish species with small mouth gapes such as groupers [5].

Types of artificial substrates used for periphyton-based aquaculture are mainly natural substrates such as tree branches used in some African countries and mangrove leaves and twigs used in Asia [6]. Also, in Asia, bamboo has been intensively studied and already incorporated successfully in farms with an established protocol. Pilot studies in periphyton have also been performed using plastic mesh sheets and nets [6].

AquaMats® are another artificial substrate used in aquaculture trials [7–9] and are widely used for advanced natural biofiltration in ponds/lakes. They are flexible curtains of highly specialized synthetic substrates used to increase the vertical surfaces of lagoons or ponds. Each curtain provides a three-dimensional surface with approximately 200 m^2 of effective surface area which is a benefit for fixation of live organism in a flat two-dimensional surface. The increase of pond surface area by the presence of vertical substrates leads to a larger colonization area for sessile biota that attach to the substratum. This biota will contribute to the enhancement of primary and secondary productivity (mainly benthic but also pelagic) that in addition to their larvae will increase the feed abundance for fish larvae. The present work presents the results of a trial to evaluate the effect of AquaMats® on the plankton species composition and productivity and water quality in earthen ponds.

2. Material and methods

Facilities of the Aquaculture Research Station (37° 02' N; 07 ° 49' W), of the Portuguese Institute for the Sea and Atmosphere (IPMA - for Instituto Português do Mar e Atmosfera), based in Olhão, southern Portugal, were used for the trial (**Figure 1**).

2.1 Experimental setting

Two rectangular earthen ponds of 750 m^3 each (1.4 m mean water depth) were used to study the effect of the presence of vertical substrates on the species composition and abundance of the phyto and zoo plankton populations. Before the experiment, the floor of the earthen ponds was thoroughly washed to remove organic sediment and dried for two weeks to allow better oxygenation of the anaerobic layers by direct exposure to air and sunlight [10]. After this period 30 bottom deployment format (BDF) AquaMats® were set up in one of the earthen ponds arranged in 10 rows perpendicular to the water flow. Each AquaMat® had an

Figure 1.
Geographical location of the Aquaculture Research Station (EPPO) of the Portuguese Institute for the Sea and Atmosphere and of the experimental ponds in blue and orange lines. Blue: Pond with AquaMats®; Orange: Control pond (without AquaMats®).

effective surface area of 208 m^2 (www.AquaMats.com) and their presence increased by 9 times the effective surface area of the pond (681 m^2). The second earthen pond remained without AquaMats® as a control. Earthen ponds were filled on May 9 with sand-filtered seawater from the Ria Formosa coastal lagoon (Algarve, Portugal). Additional water from adjacent ponds used for fish on-growing was pumped into each earthen pond as a fertilizer to boost initial plankton production. After filling, water exchange was set at 10% renovation day^{-1} during the entire trial. No aeration was provided during the experiment. Organic fertilizer (alfalfa pellets) at 28 g m^{-2} [11] were uniformly distributed in the two earth ponds two weeks after filling (May 22) and every 10 days thereafter. The trial ended on August 15.

2.2 Water quality and plankton monitoring

Temperature, salinity, dissolved oxygen, and pH were measured daily using a portable meter (HI9828 - Hanna Instruments®). Monitoring of major inorganic nutrients analysis (total ammonia nitrogen (TAN), nitrate and nitrite (NO_3-N and NO_2-N), orthophosphate (PO_4-P) and silica (SiO_2), was also performed daily during the first week after fertilization, every other day in the second week and weekly thereafter, as well as solid particulate matter (SPM), chlorophyl *a* and identification and enumeration of phytoplankton and zooplankton populations. Water samples of 10 L were collected near the water inlet, in the middle and at the outlet, pooled together. One liter of water was used for analysis of nutrients, half litter for chlorophyll *a* estimate, another half litter for phytoplankton analysis and the remaining water (28 L) filtered throughout a 55 µm plankton mesh for zooplankton counts.

Phytoplankton samples were preserved with a few drops of Lugol's iodine and zooplankton in 4% buffered formaldehyde.

2.3 Laboratorial analysis

Inorganic nutrients were determined by colorimetry [12] using a "Skalar" auto-analyzer with a detection limit of 0.2 μM for ammonium and 0.05 μM for nitrite, nitrate, phosphate, and silicate. Chlorophyll α was determined by spectrophotometry after passing the water sample through 0.47 μm cellulose nitrate membrane filters (Type 11306, Sartorius Stedim Biotech) and extracted using 10 ml acetone. Calculation was done using the formula from [13]:

$$\text{Chl } a\left(\mu g / L\right) = 11.0 \times 2.43 \times \left(665 - 665_a\right) \times 10 / \left(V_f\right) \tag{1}$$

where, 665 is the absorbance before acidification, 665_a is the absorbance after acidification, and V_f is the amount filtered water (liters).

Phytoplankton enumeration and identification was done under an inverted microscope, after sedimentation during 24 h of 50 mL sub-sample. Zooplankton present in 28 L water samples were identified and enumerated under a stereomicroscope.

2.4 Data analyses

Two diversity indices were calculated for each plankton sample: Taxa Richness and Margalef Diversity index. The taxa richness (T) was the number of taxa present in the sample while the Margalef diversity index, d = (T - 1)/ln N, was the number of taxa (T), weighted by N, the total number of individuals in the sample.

Data were analyzed for normality and ANOVA tests were used for comparison between means and the rejection level for the null hypothesis was P = 0.05. Comparison of means were based on log (x + 1) transformed data, but values depicted here are not transformed. Regression analysis were used to assess the significance of the relationship between time and the outcome variable.

3. Results and discussion

3.1 Environmental conditions

Temperature during the trial varied between 21.3°C and 26.5°C and salinity between 33.3 and 37.3 (**Figure 2**). The Control pond presented slightly higher temperatures after the first month of trial but neither of these parameters presented significant mean differences (**Table 1**). Both, Dissolved Oxygen (DO) and pH were significantly lower in the Control pond with a more noticeable descend 42 days after the beginning of the trial when salinity also increased.

Nutrient concentrations were below autoanalyzer detectable levels during the first three weeks of the trial but raised after the first addition of alfalfa, on the 22nd day after filling the ponds (**Figure 3**). In general, they showed spikes of increase responding to preceding fertilizations. Mean concentration of HPO_4^{2-} SiO^2, NH^{4+} and NO^{3-} were not significantly different between ponds (**Table 1**). Although DO and pH were significantly higher in the ponds with AquaMats®, suggesting higher primary production, chlorophyll *a* concentration was significantly lower (**Table 1**).
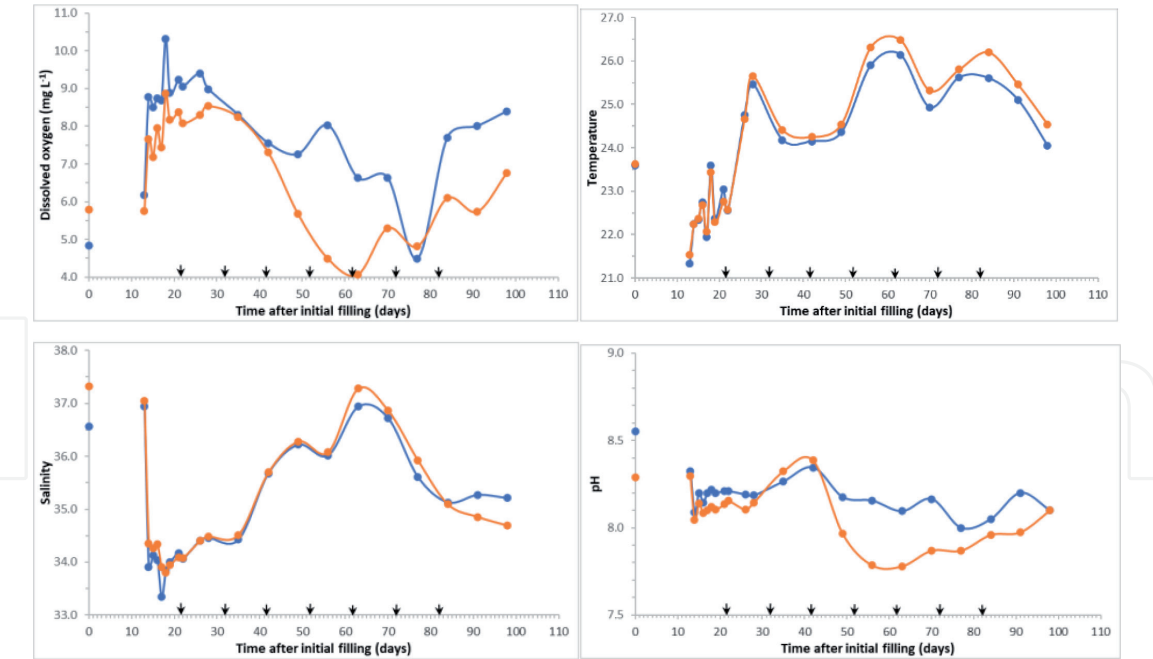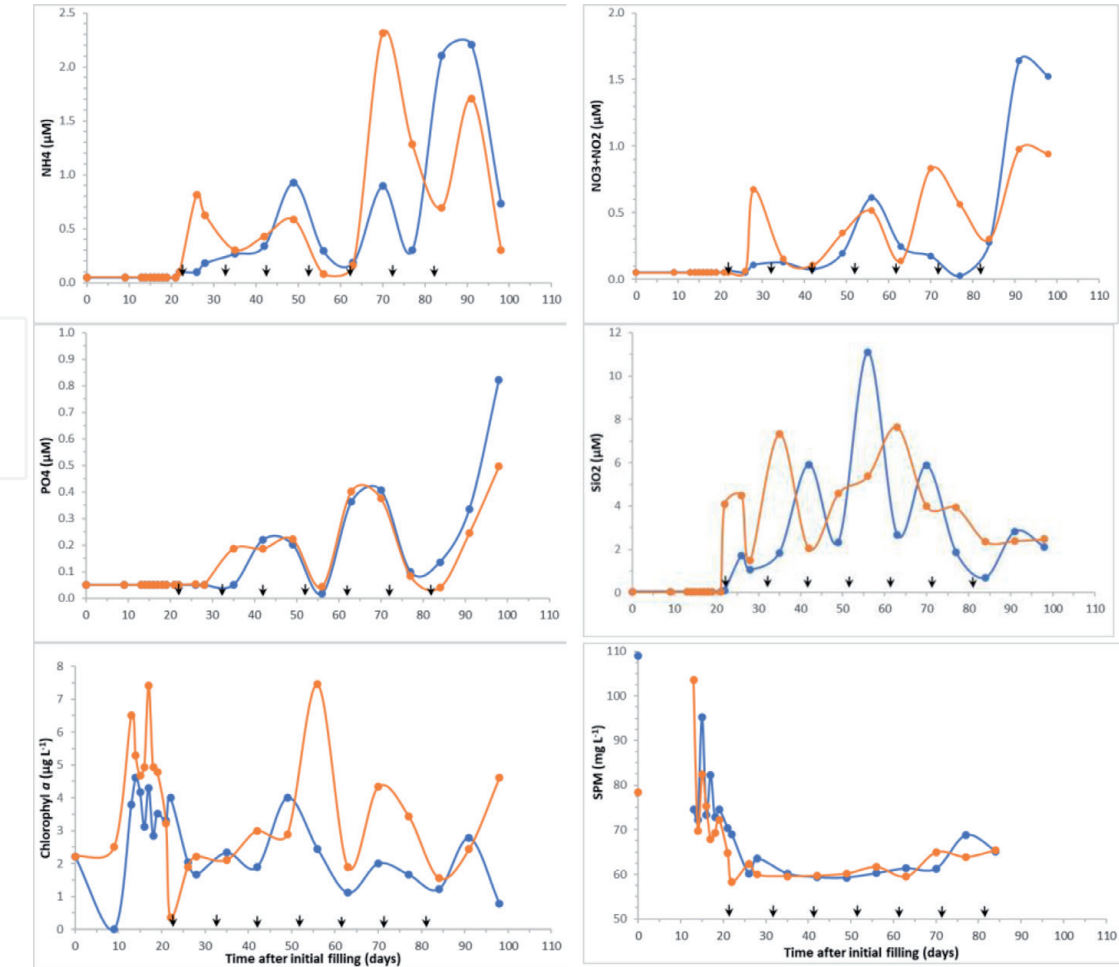
Figure 2.
Temporal evolution of temperature, salinity, dissolved oxygen, and pH in the ponds during the trial. Black arrows designate fertilization of the ponds. Orange dots and lines: Control pond; blue dots and line: Ponds with AquaMats®.

Parameters	N	Control pond	AquaMats®
Temp (°C)	23	24.1 ± (1.6)	23.9 ± (1.4)
Salinity	23	35.2 ± (1.2)	35.0 ± (1.1)
DO (mg L^{-1})	23	6.8 ± (1.5) *	7.9 ± (1.4) *
pH	23	8.1 ± (0.2) **	8.2 ± (0.1) **
NH$_4$ (μM)	23	0.43 ± (0.60)	0.40 ± (0.62)
NO$_3$ + NO$_2$ (μM)	23	0.27 ± (0.32)	0.24 ± (0.44)
Si(OH)$_4$ (μM)	23	2.29 ± (2.46)	1.77 ± (2.68)
HPO$_4^{2-}$ (μM)	23	0.13 ± (0.13)	0.14 ± (0.19)
Chl_a (μg L^{-1})	23	3.68 ± (1.88) *	2.60 ± (1.24) *
SPM (mg L^{-1})	23	68.0 ± (10.8)	70.6 ± (12.8)

*$P > 0.05$.
**$P > 0.01$.
SPM – Suspended particulate matter.

Table 1.
Mean concentration ± (S.D.) of the referred environmental paraments inside the ponds.

The trial started with similar concentration of chlorophyll *a* in both ponds and the concentrations rose after a short period of acclimatation (**Figure 3**). The increase in chlorophyll *a* due to the uptake of nutrients by the phytoplankton lead to a complete depletion of nutrients and to a consequent drop on the chlorophyll *a*. After the first alfalfa fertilization, that occurred on the 22nd day, there was an increase of Chl_a concentration in both ponds. In general, the addition of nutrients to the earthen ponds produce effect on the increase of the chlorophyll *a* concentration since it contributed to increase the availability of nitrogen, phosphorus, and silicate in the ponds (**Figure 3**). Solid Particulate Matter (SPM) concentrations, which included
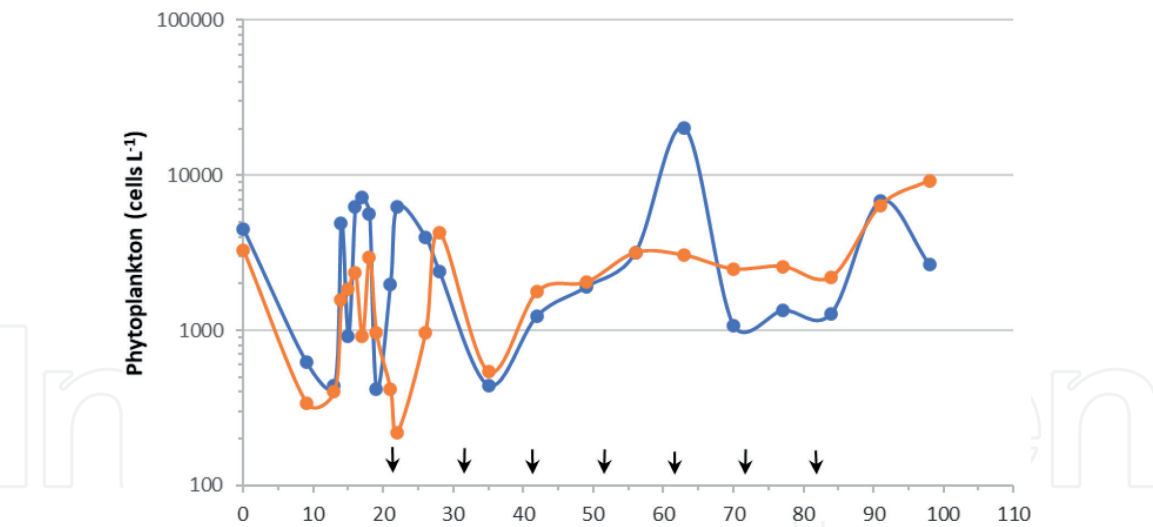
Figure 3.
Temporal evolution of ammonia, nitrate+nitrite, phosphate, silicate, chlorophyll a concentration and solid particulate matter (SPM) in the ponds during the trial. Black arrows designate fertilization of the ponds. Orange dots and lines: Control pond; blue dots and line: Ponds with AquaMats®.

plankton cells, were not significantly different among ponds. Concentrations were high at the start of the trial and decrease steadily during the first three weeks after which they increased slowly until the end of the trial.

3.2 Phytoplankton

Phytoplankton species and mean abundances in the ponds during the trial are presented in Appendix A. Phytoplankton densities in the Control pond and in the pond with AquaMats® showed similar patterns of evolution with four blooms followed by crashes during the monitored period (**Figure 4**). Initial cell abundances in the water of the two ponds were high followed by a sharp decrease in the phytoplankton. Recovery occurred after the first two weeks with a bloom that lasted for a week followed by a crash. After the initial fertilization, high concentrations were reached and phytoplanktonic abundance seemed to be sustained despite some decreases. Although, during the first month of the trial mean phytoplankton densities tended to be lower in the Control pond, mean concentrations for the entire trial were not significantly different between the two ponds (**Table 2**). The pond with AquaMats® have sharper variations in phytoplankton abundances and the Control pond had more steady densities that increased with time. Diatoms and dinoflagellates composed the bulk of the phytoplankton population in both ponds but non-identified phytoflagellates were significantly more important in the pond with Aquamats®.

Figure 4.
Temporal progression of phytoplankton abundance in ponds. Orange dots and lines: Control pond; blue dots and line: Ponds with AquaMats®; black arrows designate fertilization of the ponds.

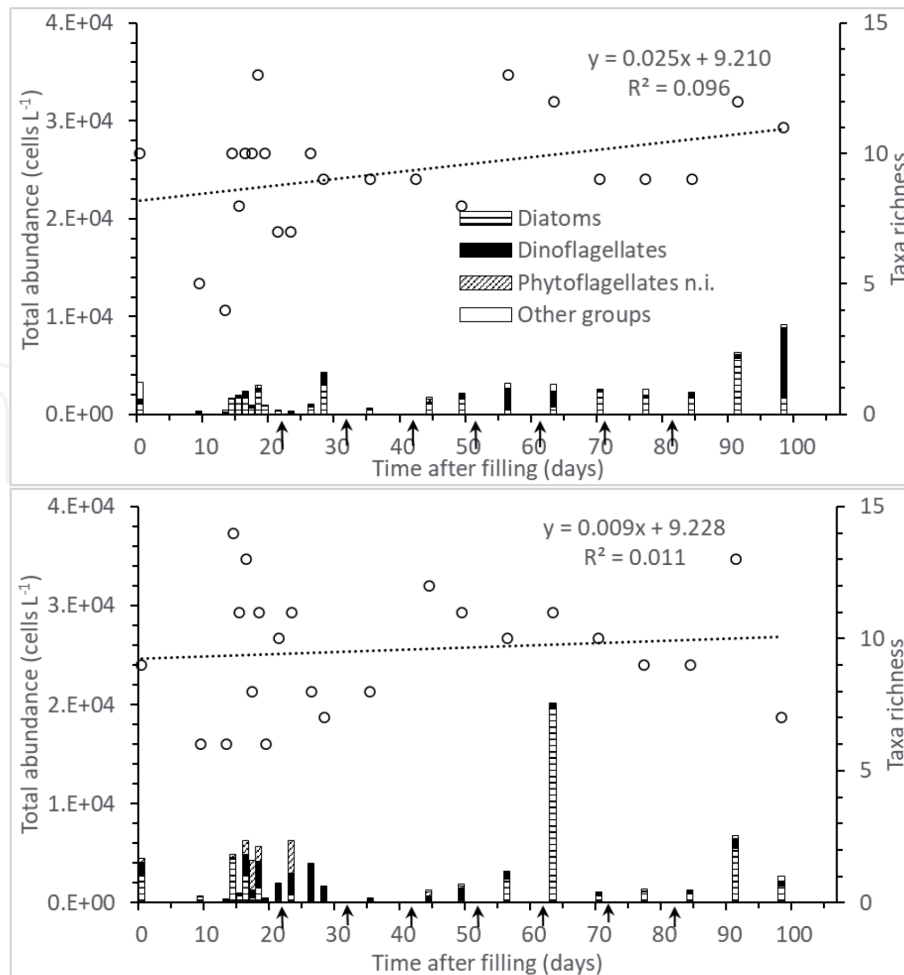|	N	Control	With AquaMats
Total phytoplankton (# L^{-1})	23	2,340 ± (2,082)	3,557 ± (4,174)
Taxa richness	23	9.3 ± (2.2)	9.5 ± (2.3)
Margaleff index	23	1.91 ± (0.40)	1.84 ± (0.42)
Diatoms (# L^{-1})	23	1,390 ± (1,242)	2,066 ± (4,073)
Dinoflagellates (# L^{-1})	23	693 ± (1,513)	951 ± (975)
Phytoflagellates n.i. (# L^{-1})	23	47 ± (90) *	465 ± (934) *
Others (# L^{-1})	23	210 ± (391)	75 ± (6)
*P > 0.05.			

Table 2.
Phytoplankton estimates and abundance of main groups in ponds.

Taxa Richness and the Margaleff Index were not significantly different between ponds with dominance of diatoms over dinoflagellates in both (**Table 2**). In general phytoplankton abundance was higher in the pond with AquaMats® but the difference was not statistically different from the Control (**Table 2**). Both ponds recorded taxa richness minima immediately after the beginning of the experiment followed by maxima two to three weeks after filling. Species richness remained relatively leveled afterwards (**Figure 5**). Regressions between taxa richness and time after filling, shown in the graphs, were not significant suggesting that the number of taxa present in the ponds were independent of the time.

The temporal succession of phytoplankton groups in the Control pond was essentially dominated by diatoms with the phytoplankton blooms preceded by silicate maxima (**Figure 3**). Exceptions were the first two weeks of the experiment and for two consecutive samples on days 56th and 63rd and again on day 100th after filling, when dinoflagellates of the genus *Gymnodinium* became the most abundant group. In this pond during this first month *Navicula* spp. predominate and after the first month of trial Diatoms were mostly *Cylindrotheca closterium*, (**Figure 5** and **Figure 6** – upper graphs). Comparatively, the pond with AquaMats® started, during the first two weeks, with higher relative abundance of diatoms, mostly *C. closterium*, followed by a sustained period of more than one month with higher
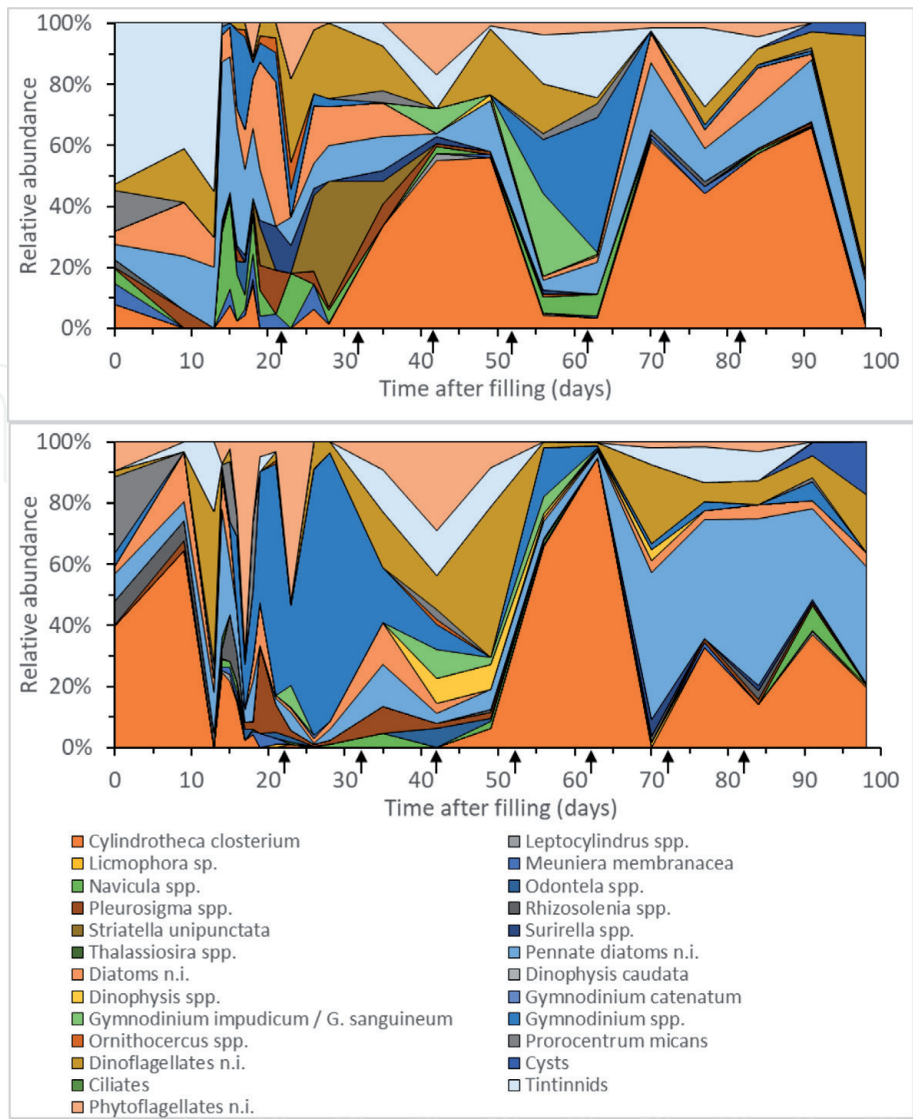
Figure 5.
Temporal evolution of the abundance of main phytoplankton groups and taxa richness. Upper graph – Control pond; lower graph – Pond with AquaMats®. Black arrows designate fertilization of the ponds.

concentrations of dinoflagellates although non identified phytoflagellates were also important (**Figure 5** and **Figure 6** – lower graphs). *C. closterium* and other Pennate diatoms, became more important in the second half with exception for the last sampling day when non-identified dinoflagellates dominate. The dinoflagellate community, initially dominated by *Prorocentrum micans*, was replaced by individuals of the genus *Gymnodinium* immediately after the first alfalfa fertilization dominating in the samples around the 30th day after filling. The highest abundances of dinoflagellates were observed at the end of the experiment in both ponds suggesting a seasonal effect.

3.3 Zooplankton

Both the mean abundance of zooplankton individuals and the taxa richness (T) were not significantly different among ponds but the Margaleff index was significantly higher in the pond with AquaMats® due to lower zooplankton abundance while the number of species remained similar (**Table 3**).

The temporal progression of zooplankton abundance was similar among the two experimental ponds and showed that after filling there was a decrease followed by a week of adjustment when biomass was low (**Figure 7**). This adjustment period ended with the progressive increase in the number of zooplankton organisms and, similarly to what happened to the phytoplankton temporal evolution, there were four peaks of higher abundance followed by crashes. The periods of higher
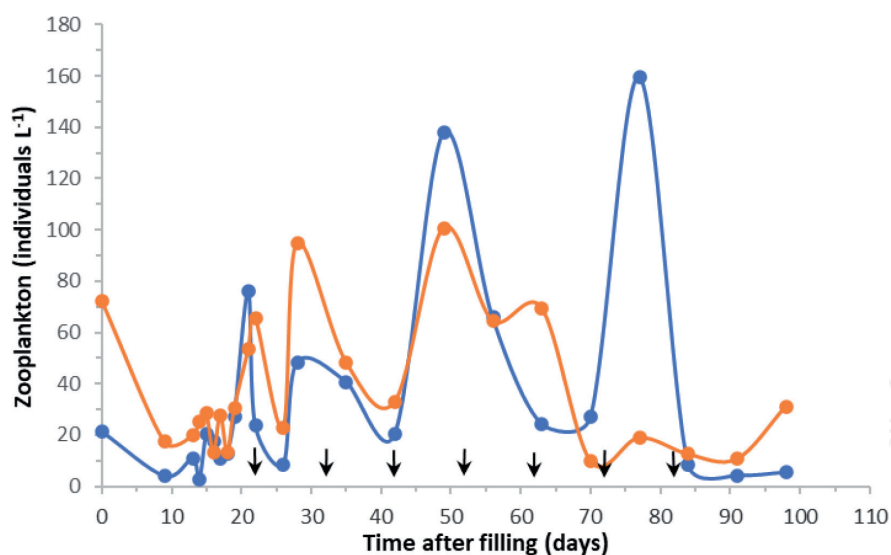
Figure 6.
Temporal succession of phytoplankton populations. Black arrows designate fertilization of the ponds. Upper graph – Control pond; lower graph – Pond with AquaMats®.

	Control	AquaMats®
Total zooplankton (# L^{-1})	38.5 ± (27.3)	33.8 ± (41.1)
Margaleff index	1.7 ± (0.5) *	2.2 ± (1.0) *
Taxa richness (T)	6.6 ± (1.0)	6.5 ± (1.2)

*$P > 0.05$.

Table 3.
Mean zooplankton estimates in ponds.

zooplankton abundance occurred days after the phytoplankton blooms suggesting a strong zooplankton control over the phytoplankton population. Although zooplankton abundance presented similar patterns of development of booms and crashes in the ponds, the abundance during the first half of the trial (45 days) was significantly higher in the Control pond (**Figure 7**). The taxa richness started also to be higher in the Control pond but remained relatively constant over time in this pond as suggested by the regression equation in **Figure 8** while in the pond with AquaMats® it was lower at the beginning of the trial but increased significantly with time.
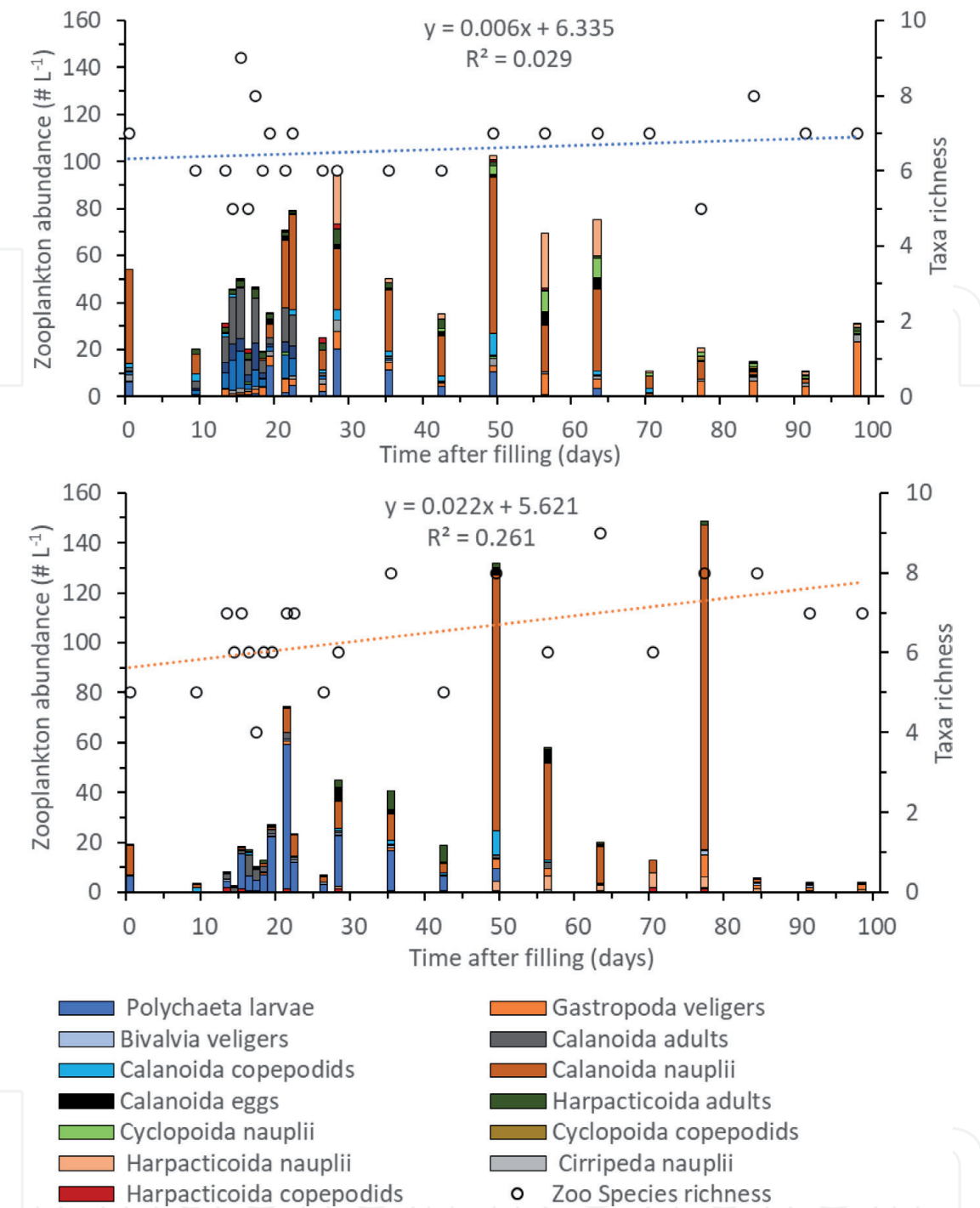
Figure 7.
Temporal progression of zooplankton abundance in ponds. Orange dots and lines: Control pond; blue dots and line: Ponds with AquaMats®.

Zooplankton species in the ponds and their mean abundances are listed in Appendix B. From the most frequent zooplankton groups, veligers (both Gastropoda and Bivalvia), adults from Calanoida copepods and Cyclopoida naplii were significantly more abundant in the Control pond. With exception of Polychaeta larvae, Calanoida nauplii, Harpacticoida copepodids and Cirripedia nauplii, were most abundant in the pond provided with AquaMats® although differences were not significant. The Calanoid copepod *Acartia clausi* was only present in the Control pond while *Paracartia grani* was mostly present in the pond with AquaMats®. Although not significantly different, their nauplii were more abundant in the pond with Aquamats®.

In both ponds there was a fairly number of Calanoida nauplii and Polychaeta larvae. Nine days after, Calanoid adults (*Acartia clausi*) became more important in the Control pond remaining the most important taxa during the following week (**Figure 8**, upper graph). The first boom, on day 21, was mostly composed by those adults and nauplii. The following booms were mostly formed by copepod nauplii (both Calanoida, Cyclopoida and Harpaticoida). Gastropoda veligers, that were always present, became more important by the end of the experiment. In the pond with AquaMats®, Calanoid copepod nauplii were also important at start of the experiment but in the following sampling period Polychaeta larvae became gradually more abundant and continued doing so for the following month (**Figure 8**, lower graph). By then Harpacticoid copepod adults became evident. Succeeding booms were composed mainly by copepod nauplii (mostly Calanoida but also Harpaticoida).

4. Discussion

There were no significant differences in phytoplankton and zooplankton densities among the two ponds, but parameters related to plant production, such as dissolved oxygen (DO) and pH, showed significantly higher values in the ponds with AquaMats® suggesting higher primary production in this pond. The combination of these two parameters with lower nitrate, ammonia, silicate and in the pond with AquaMats® further suggests greater overall algal production in this treatment, which was not reflected in the Chl_*a* concentration (**Table 2**). Therefore, the higher

Figure 8.
Temporal evolution of the abundance of main zooplankton groups and species richness. Upper graph – Control pond; lower graph – Pond with AquaMats®. Black arrows designate fertilization of the ponds.

primary production was probably associated with the periphyton developed in the AquaMats® and to a lesser extent to the slightly higher, although no significant, phytoplankton population.

The presence of diatoms, dinoflagellates and non-identified phytoflagellates are common in fish and oyster integrated production in earthen ponds that supplied the dissolved nutrients required by the phytoplankton [14]. In the present case, there were no fish and oyster production, but external nutrients were supplied by alfalfa. The temporal fluctuations in abundance of phytoplankton were very much connected to the regular supply of alfalfa with a strong increase immediately after fertilization. In general the phytoplankton blooms followed silicate maxima and they were dominate by diatoms, mostly

Cylindrotheca closterium, although Pennate diatoms started to be more important in the Control pond. The success of the diatom group seemed to be due to a high inherent growth rate at non-limiting silicate concentrations [15]. However Dinoflagellates and Phytoflagellates also marked their presence in the pond with AquaMats® when fertilization started and dominate for almost a month. This was a period of still low nitrate and silicate concentrations and relative higher rates of NH4⁺ in the pond with AquaMats® which may be a possible explanation for the higher number of dinoflagellates in this pond [16]. Among the dinoflagellates present in the pond with AquaMats®, Gymnodiniales were the most important group.

Zooplankton abundance presented similar patterns of development of booms and crashes in the ponds and occurred days after the phytoplankton bloom suggesting a strong zooplankton control over the phytoplankton population. The abundance during the first half of the trial was significantly higher in the Control pond and the taxa richness was also higher remaining relatively constant over time. Calanoida (*Acartia clausi*) adults and nauplii and Polychaeta larvae composed mostly of the population during this time. In the pond with AquaMats®, zooplankton abundance and taxa richness were both initially lower and increased significantly over time reflecting the effect of the disturbance caused by the deployment of the AquaMats® in the ponds and the consequent recovery. Polychaeta larvae, abundant during the 45 days, were overrun mostly by Calanoida nauplii, and to a lesser extent by Harpacticoida nauplii and Gastropoda veligers. These are larval stages of organisms that except for calanoid copepods are benthic. At the example of *Acartia clausi* the adult calanoid present in the ponds with AquaMats® (*Paracartia grani*) reproduce by shedding eggs that attach to substrates [17–19]. These eggs can be subitaneous or diapause but in both cases, they need light to hatch [20]. The presence of AquaMats® as vertical substrates leads to an increase in the areas where the eggs can be attached and where they remain exposed to light and ready to hatch, may explain the higher number of Calanoid nauplii.

5. Conclusions

Plankton production in ponds is very much sculptured by external nutrients added to the systems and therefore fertilization and maintaining the balance between different nutrients is extremely important to control the phytoplankton populations. The linkage between phytoplankton and zooplankton population in ponds is strong with zooplankton exerting control over the phytoplankton population and vice-versa.

The use of vertical substrates like AquaMats® seemed to be able to enhance plankton productivity by increasing the substrate area for periphyton fixation. Their presence favored the development of Dinoflagellates, mostly Gymnodiniales, which may be of some concern since some species of this group have been associated with toxic algal blooms. The main zooplankton taxonomic groups associated with the presence of AquaMats® were Calanoid and Harpacticoid copepodids and nauplii, veligers of gastropods and trocophora of polychaets. These are all small larval stages of organisms that are important as food for fish larvae during the first phases of development and therefore there is potential for the use of AquaMats® in mesocosms for rearing fish larvae in semi-intensive systems either for the quality of the farmed juveniles or to rear species with larval stages that only survive with natural food increasing aquaculture diversification.

Acknowledgements

Appendices and nomenclature

Appendix A. Mean abundance of phytoplanktonic taxa during the trial (cells L^{-1})

Planktonic species	N	Control	Aquamats
BACILLARIOPHYCEAE			
Cylindrotheca closterium	23	515 ± (934)	1,296 ± (3,940)
Leptocylindrus spp.	23	7 ± (16)	8 ± (20)
Licmophora sp.	23	1 ± (4)	4 ± (8)
Meuniera membranacea	23	41 ± (66)	17 ± (35)
Navicula spp.	23	114 ± (161)	48 ± (121)
Odontela spp.	23	10 ± (29)	18 ± (41)
Pleurosigma spp.	23	33 ± (33)	43 ± (54)
Rhizosolenia spp.	23	7 ± (20) *	60 ± (142) *
Striatella unipunctata	23	97 ± (362) *	1 ± (4) *
Surirella spp.	23	17 ± (21) **	7 ± (18) **
Thalassiosira spp.	23	0 ± (0)	8 ± (38)
Pennate diatoms n.i.	23	389 ± (381)	457 ± (578)
Diatoms n.i.	23	160 ± (142)	98 ± (124)
DINOPHYCEAE			
Dinophysis caudata	23	1 ± (4)	2 ± (6)
Dinophysis spp.	23	3 ± (9)	15 ± (39)
Gymnodinium catenatum	23	0 ± (0)	7 ± (26)
Gymnodinium impudicum/ G. sanguineum	23	44 ± (180)	35 ± (99)
Gymnodinium spp.	23	151 ± (307) *	577 ± (859) *
Ornithocercus spp.	23	6 ± (9)	5 ± (11)
Prorocentrum micans	23	33 ± (95)	137 ± (347)
Dinoflagellates n.i.	23	455 ± (1,472)	173 ± (219)
OTHER			
Cysts	23	24 ± (86)	32 ± (110)
Ciliates	23	0 ± (0)	1 ± (4)
Tintinnids	23	185 ± (394)	42 ± (70)
Phytoflagellates n.i.	23	47 ± (90) *	465 ± (934) *

*P > 0.05.
**P > 0.01.

Appendix B. Mean abundance of zooplankton taxa during the trial

	N	Control	AquaMats
		(# L-1)	(# L-1)
Polychaeta (larvae)	23	3.6 ± (5.3)	9.0 ± (13.0)
Gastropoda (veliger)	23	4.2 ± (4.8) *	1.7 ± (3.2) *
Bivalvia (veliger)	23	1.4 ± (1.1) **	0.6 ± (0.7) **
Acartia clausi (female)	23	3.0 ± (4.5) **	0.0 ± (0.0) **
Paracartia grani (female)	23	0.2 ± (0.3) **	0.9 ± (1.1) **
Acartia spp. (male)	23	2.0 ± (3.1) *	0.6 ± (0.8) *
Acartia spp. (copepodite)	23	1.4 ± (2.1)	0.8 ± (2.0)
Calanoida spp. (nauplii)	23	14.7 ± (17.8)	15.5 ± (33.2)
Calanoida spp. (egg)	23	1.0 ± (1.4)	0.8 ± (1.6)
Oithona spp. (copepodite)	23	0.1 ± (0.3)	0.0 ± (0.1)
Oithona spp. (nauplii)	23	1.2 ± (2.5) *	0.0 ± (0.1) *
Harpaticoida spp. (adults)	23	1.9 ± (1.6)	1.1 ± (1.9)
Harpaticoida spp. (copepodite)	23	0.5 ± (0.6)	0.6 ± (0.7)
Harpaticoida spp. (nauplii)	23	3.1 ± (7.0)	1.6 ± (2.4)
Cirripeda spp. (cypris)	23	0.9 ± (4.1)	0.1 ± (0.3)
Cirripeda spp. (nauplii)	23	0.1 ± (0.2)	0.2 ± (0.4)

*$P > 0.05$.
**$P > 0.01$.

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