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Impact of Global Warming on the Management of Mussel Fouling: Can the Use of Different Air Exposure Facilities Mitigate the Effects of Temperature? A Preliminary Experimental Trial in the Mar Piccolo of Taranto (Mediterranean, Ionian Sea)

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Abstract

The management of fouling through exposure of mussels to air has become risky due to rising temperatures, as it can negatively impact product quality and farm productivity. Since the early 2000s, during air exposure, mussel farmers of the Mar Piccolo have been using high-density polyethylene (HDPE) cloths to cover mussels and prevent their overheating, thus contributing to marine litter from husbandry practices. In this context the aim of the present study was to evaluate whether the use of alternative types of air exposure facilities (wooden, without and with hemp cloth vs. galvanized iron, without and with HDPE cloth) can impact mussel condition index (CI). Since the most damaged mussels during exposure to air are those in contact with galvanized iron structures, for each facility, it was evaluated if there were differences between the mussels in contact with galvanized iron/wood racks and those near the sea surface. Overall, the results showed that the CI of mussels cleaned on wooden racks, ranging from 11.4 ± 2.7 to 12.5 ± 2.7, did not differ significantly from that of mussels before air exposure (CI = 13.1 ± 2.3), except for those near the sea surface without cover (CI = 9.6 ± 2.6). In contrast, a significant decrease in CI was observed in mussels cleaned on galvanized iron racks, with the lowest values observed in covered mussels (CI = 8.2 ± 2.3).

Keywords: mussel farm; fouling management; sustainable air exposure facility

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1. Introduction

Mussel farming is a relevant sector of aquaculture, with the potential to meet the growing global demand for safety and sustainable food, as it is an efficient source of high-quality proteins with a low footprint compared to land-based livestock and even fish farming [1].

Mussels are filter-feeders, so they consume phytoplankton, organic detritus and bacteria, grow rapidly, sequester carbon by incorporating it into their shell, and increase biodiversity by providing habitats and food for other species, influencing nutrient cycling and improving water quality [2–4]; their cultivation does not require chemical treatments, antibiotics, or artificial feed and land or freshwater use. According to the European Market Observatory for Fisheries and Aquaculture Products [5], between 2011 and 2020, the world's mussel production increased by 7%, reaching 2.2 Mt in 2020, primarily from aquaculture. Contrary to the general trend observed worldwide, in the European Union (EU), although

mussel production is still significant (430,748 t), there was an overall decrease of 13% during the same period in almost all member states. The decline in EU mussel production is the result of multiple factors, primarily environmental, with diseases, spat depletion, harmful algal blooms, poor water quality, predation, pollution and climate change being the main causes [6,7].

In addition, other significant issues including high production costs versus low profitability, limited suitable farming sites, no innovation in the production process and regulatory obstacles have contributed to the stagnation of the EU production [6].

Even though Italy is still one of the largest producers of mussels in Europe, after Spain and France, it has experienced the highest decline (−36%) in production, going from 79,520 t in 2011 to 50,913 t in 2020 [5].

Mussel production along Italian coastal areas is dominated by the Mediterranean mussel *Mytilus galloprovincialis* [8], which, as well other bivalve molluscs, is particularly sensitive to rises in temperature. Several studies have shown that thermal stress can cause alterations of behaviour, metabolism, respiration rate, growth, reproduction, oxidative status and the immune system in *M. galloprovincialis* [9–14].

In experiments of long-term acclimation at increasing temperature, authors demonstrated that exposure of *M. galloprovincialis* for prolonged periods of time to temperatures around 26 °C, above their upper optimum thermal limit, can cause mussel mortality, probably due to the reduced capacity to filter and assimilate food and, consequently, to the depletion of energy reserves. At 30 °C mortality increases dramatically even after a short period of time [9,15–17].

Recently, De Marco et al. [18] demonstrated that, after 30 days of exposure at 28 °C, mussels produced less byssus filaments with reduced mechanical resistance, impairing the capacity of adhesion to substrate and consequently their survival.

Moreover, increased temperature can exacerbate the responses to other stressors, enhancing vulnerability of mussels to pollution [13,19,20] and diseases [21,22].

In recent years, mass mortality events of *M. galloprovincialis* related to marine heatwaves (extended periods of unusually high seawater temperatures exceeding the typical seasonal temperatures) have occurred in the Ionian and middle Adriatic (Mediterranean Sea) [23,24], suggesting that they are one of the main factors contributing the decline in mussel production in Italy, as well in the rest of the Mediterranean Sea.

Recent studies confirmed that the occurrence of recurrent extreme marine heatwaves along the Mediterranean coasts during the 2015–2019 period caused mass mortality events in invertebrates, including corals, sponges, bryozoans and mussels [25,26].

The increased frequency, duration and intensity of marine heatwaves expose mussels to temperatures exceeding their thermal tolerance limits more often and for longer periods, leading to significant physiological stress, and, in severe cases, death [27].

The Mar Piccolo of Taranto (Southern Italy, Ionian Sea) is a complex marine ecosystem, susceptible to both natural and anthropogenic stressors, where all the challenges that mussel farming is facing in the EU exist, making it a suitable site for the study of their interplay and the development of strategies for sustainable aquaculture. The basin is one of the most historically important sites for the production of *M. galloprovincialis* in the Mediterranean Sea, recognized for the extraordinary quality of its mussels [28]. In the last two decades a complex combination of environmental and economic factors, including industrial pollution, mismanagement of permits, licences and concessions, illegal phenomena and climate change, has led to the decline of this sector in Taranto [29,30].

The Mar Piccolo is included within the area of the Italian Site of National Interest (SIN) which needs urgent environmental remediation [31] due to the high contamination of water and sediment with heavy metals, hydrocarbons, and other pollutants, caused by

the presence of heavy industries (steelworks, oil refineries, cement plants), shipyards, and urban and agricultural runoff [32]. In July 2011, following the detection of dioxins and polychlorinated biphenyl dioxin-like substances (PCB—DL) exceeding the limits established by the European Commission regulation [33] in the mussels of the first inlet of the Mar Piccolo, the Apulia region adopted Regional Ordinance n. 188/2016 to temporarily ban their production, with the only possibility of collecting larvae and moving juvenile mussels (<3 cm) from it to the second inlet until they reached the market size. Since 2012, severe marine heatwaves have frequently occurred in Taranto Gulf [23,34–36], causing mass mortality events; the last episode in the summer of 2024 led to the near-total loss of both adults and spat, which is crucial for restocking and future production.

To mitigate the negative impacts of climate change, mussel farmers are adopting worldwide various strategies, which are part of a process described as "spontaneous adaption", generally developed and implemented at the local level, without significant external intervention or top-down planning [37].

During the entire cycle of production, mussels are periodically exposed to air, in order to reduce the fouling that negatively impacts their growth and market value [38].

The management of fouling through this practice in spring/summer, but also in autumn, has become a particularly risky processing phase due to rising temperatures. Since the early 2000s, farmers of Mar Piccolo have adopted a measure, similar to that of agriculture, by covering mussels with high-density polyethylene (HDPE) shade cloth fixed to drying racks, to prevent their overheating, which can negatively affect their quality. As HDPE cloths generally remain fixed until they are no longer usable, they undergo a degradation process due to mechanical abrasion, UV radiation, weathering, and improper disposal, releasing microplastics that contribute to marine litter from mussel farming practices [39].

In this context, the aim of the present study was to compare the impact of the use of two types of air exposure drying racks—conventional galvanized iron racks without and with HDPE cloths versus sustainable wooden racks without and with hemp cloths—on mussel condition index (CI). Since the most damaged mussels during air exposure are those in contact with iron racks, for each treatment it was evaluated if there were differences between the mussels in contact with iron/wood racks and those near the sea surface. Air temperature was also measured under the various air-exposure drying racks to confirm whether the use of a cover effectively mitigates the temperature.

2. Materials and Methods

2.1. Study Area

The Mar Piccolo of Taranto (Mediterranean, Ionian Sea) (Figure 1A,B) is a lagoonal semi-enclosed basin with an area of 21 km^2, divided in two sub-basins, the first and second inlet, which have a maximum depth of 13 and 10 m, respectively. Two channels, named Porta Napoli and Navigabile, connect the Mar Piccolo to a wider bay, the Mar Grande, that opens in the Gulf of Taranto. The hydrodynamics of the basin are influenced by the limited tidal range (30–40 cm), the reduced water exchange, especially in the second inlet, and the presence of small tributaries and approximately 34 submarine freshwater springs called "citri" that regulate salinity, temperature, currents and phytoplankton abundance [29,40], providing favourable conditions for mussel farming.

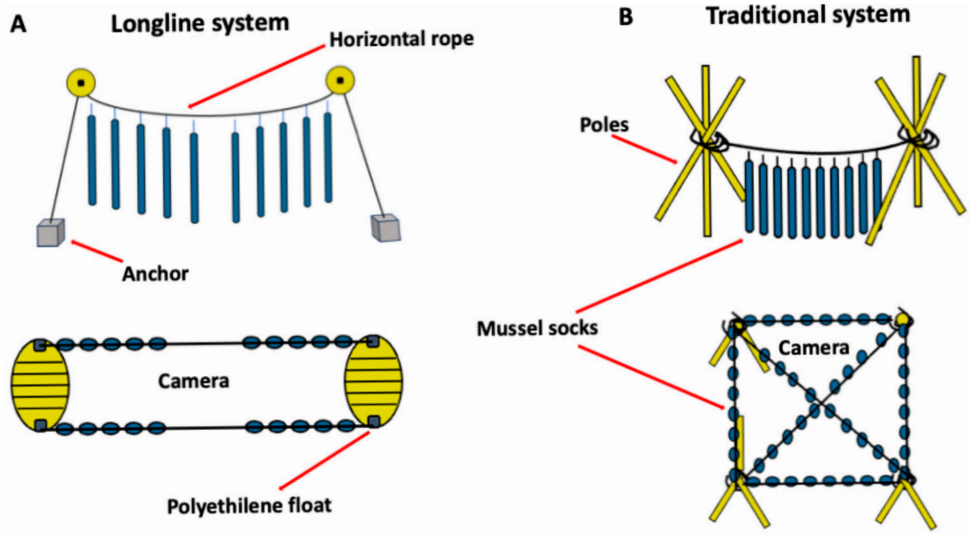

Figure 1. Scheme of a "camera" in the longline (**A**) and traditional system (**B**) of mussel farms in the Mar Piccolo of Taranto (Southern Italy). Above: frontal view; below: view from above.

2.2. Production Cycle in Mar Piccolo

The entire production cycle, lasting approximately 16–18 months, begins in November of each year with the submersion of spat collector ropes. Periodically, a total of three times, as the mussels grow, they undergo a grafting process which consists of delicately detaching them from the ropes and each other and then inserting them into socks, polystyrene tubular nets, of progressively larger diameter (60–80–100 mm). Mussel socks are suspended in series in seawater from horizontal ropes parallel to the water surface. Such ropes are fixed on poles driven into the bottom (traditional system) or on polyethylene floats held in place by anchors (longline system). In both systems, ropes delimit and/or diagonally cross a quadrilateral locally known as a "camera" (i.e., room), which is the basic unit of the traditional mussel farms in Taranto. Each room generally contains a total of 20 mussel socks (Figure 1) [34].

Throughout the entire production cycle, to effectively control the overgrowth of fouling on mussel shells, farmers expose mussel socks to the air for approximately 24 h, on average every 40–50 days. Mussel socks are hung like festoons at a height of approximately 1.50–1.70 m above sea level, on galvanized iron drying racks called "fusoli", once made of chestnut wood and/or pine, placed close to the room. This air exposure phase, locally called "sciorinatura", is lethal to many epibionts encrusting mussel shells, which do not survive to emersion for long, unlike mussels that survive the process by tightly closing their shells, thus preventing water loss.

2.3. Experimental Facilities

The experimental trial was conducted in a mussel farm located in the second inlet of the Mar Piccolo (Coordinates 40°28′13.81″ N, 17°18′6.61″ E) (Figure 2B,C) where, on the occasion of the Interreg Greece–Italy project Fish&Chips [41], a reconstruction of a traditional wooden drying rack was placed. The basic unit of a drying rack is also called a "camera" (i.e., room). On a section of the drying rack, for the length of two rooms, hemp shade cloths were positioned (Figure 2D). The cloths covered the drying rack at 360°. Similarly, on the galvanized iron drying rack, HDPE shade cloths were positioned, as mussel farmers in the Mar Piccolo have usually done for about twenty years, to limit the negative effects of intense sunlight on mussels, by providing shade during the air exposure (Figure 2E). The mesh structure and the density of both HDPE and hemp cloths ensured a

good shading rate and simultaneous UV protection and ventilation, crucial for preventing a greenhouse effect.

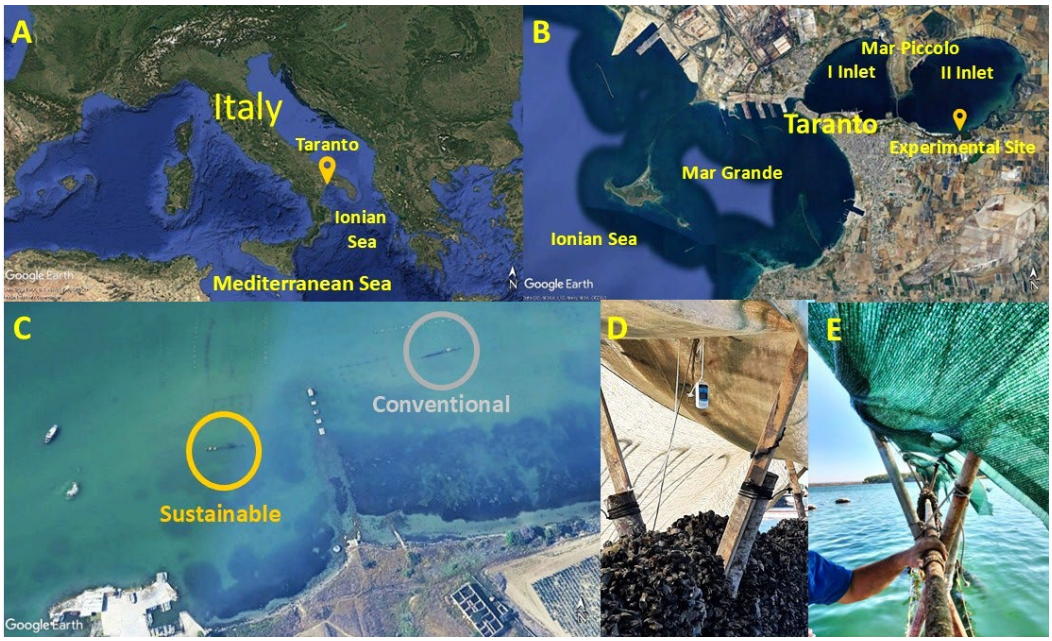

Figure 2. Study area (**A**,**B**) with location of the facilities (**C**); sustainable facility (**D**), conventional facility (**E**).

Finally, for the length of other two rooms, no covers were positioned both on wooden and galvanized iron drying racks, so that in total there were four experimental units. Between the galvanized iron rack and the wooden rack there was a distance of about 150 m.

To distinguish the four types of facilities, from here on, the wooden drying racks will be defined as "sustainable facility" without (S) and with cover (SC), while the galvanized zinc–iron one will be defined as "conventional facility" without (C) and with cover (CC).

A scheme of the conventional and the sustainable facilities is reported in Figure 3 to better illustrate the experimental trial.

The estimation of the overall length of the drying racks in the seas of Taranto (Mar Grande, Mar Piccolo I and II Inlet) was carried out by remote sensing using satellite Google Maps according to Caroppo et al. 2018 [42].

2.4. Experimental Trial

On 7 October 2022, mussel socks were retrieved from the experimental rooms, transferred to the boat's loading floor, and hung on each type of facility for the usual fouling management procedures.

To calculate CI of mussels before the various air exposure treatments, 5 individuals were randomly and gently detached from eight socks for a total of 40 individuals, taking care to preserve their byssus and minimize water loss. This sample, named Before (B), served as a control group to determine whether the CI of the treatment groups was affected by this processing phase.

Furthermore, since the most damaged individuals during air exposure are those resting on the horizontal galvanized iron pole (personal communication) (Figure 4), two treatments were assigned to each facility, to assess if there were differences between the CIs of mussels sampled from the sections of socks in contact with galvanized iron/wooden poles and those from the sections suspended above the sea surface, so that a total of eight treatments were performed (Table 1).

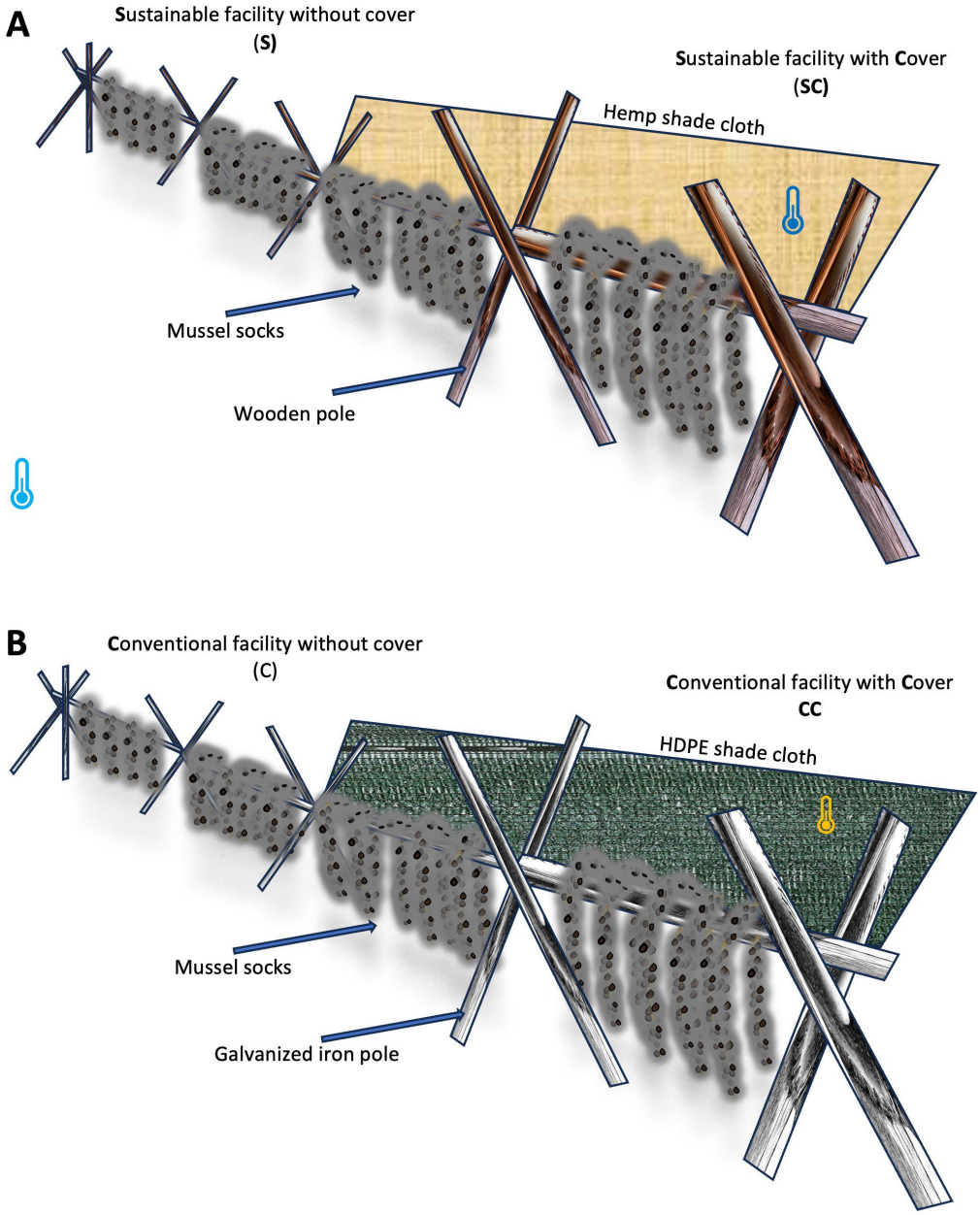

Figure 3. Scheme of the sustainable (**A**) and conventional facilities (**B**) with and without cover with hung mussel socks. The figure also shows where the thermometers were placed.

After 24 h of air exposure, 5 individuals per treatment were randomly sampled from eight socks (n = 40 per treatment) for a total of 320 mussels. All samples were transported in a cooler to the laboratory of the CNR Institute in Taranto, where they were stored in a refrigerator at 4 °C according to Noor et al. [43] to keep them alive and prevent them from drying until their analysis within a few hours. In the laboratory, after accurately cleaning mussels from epibionts, the following parameters were measured: Shell Length along the anterior–posterior axis (SL), by using an electronic calliper (0.1 mm accuracy), and Dry Flesh Weight (DFW) and Dry Shell Weight (DSW), by using a precision balance (0.01 g accuracy). CIs were calculated according to [44], after both the shells and the flesh were oven-dried for 48 h at 104 °C, using the following formula:

$$\mathrm{CI} = \frac{\mathrm{DFW}}{\mathrm{DSW}} \times 100$$

Figure 4. Mussel socks hung on a conventional facility. The damage caused by the previous air exposure phase in summer in the sections of socks that rested on the horizontal pole of the drying rack appears evident. The yellow dotting lines indicate the sections of socks from which the mussels were sampled.

Table 1. Experimental units and related treatments.

Experimental Units	Treatments	Abbreviation
Conventional facility without cover (C)	on pole (P) suspended (S)	CP CS
Conventional facility with cover (CC)	on pole (P) suspended (S)	CCP CCS
Sustainable facility without cover (S)	on pole (P) suspended (S)	SP SS
Sustainable facility with cover (SC)	on pole (P) suspended (S)	SCP SCS

During the air exposure, to evaluate the shading effectiveness of covers, air temperature outside the facilities, under the hemp cloth, and under the HDPE cloth was measured by using 3 digital thermometers (0.5 °C, accuracy) programmed for one measurement every half an hour. The thermometer was placed in a site outside the facilities equidistant from them to have a baseline air temperature measurement without the influence of the facility material itself, such as its specific heat or absorption properties, which could alter the local temperature. The baseline temperature served as a control against which it was possible to compare temperature values recorded under both types of covers.

2.5. Statistical Analysis

All results are presented as mean ± standard deviation (S.D.). The distribution normality and homogeneity of variance were tested through Shapiro–Wilk and Levene's tests, respectively. Since either assumption was met, data were analyzed with one-way

ANOVA, followed by Tukey's post hoc test to find significant variations ($p < 0.05$) among and between treatments. Analyses were performed with Past Version 4.17.

A three-way ANOVA was performed using the free online StatsCalculators software 2025 [45] to examine the effects of the three independent variables—facility (sustainable and conventional), cover (with or without), and mussel sock section (on pole or suspended)—and their interactions on CI.

3. Results

In Figure 5 we report the total lengths of drying racks in the Taranto seas measured by remote sensing. The overall length was found to be 5187.29 m.

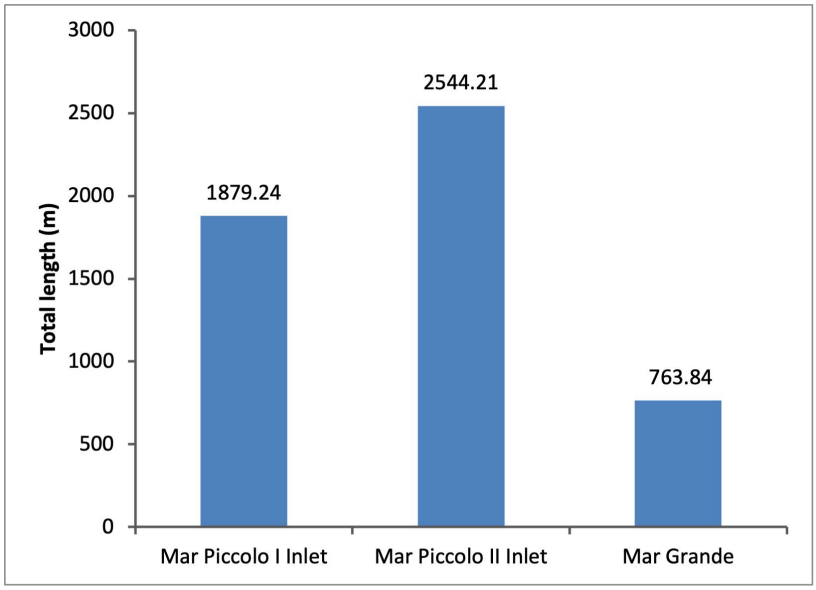

Figure 5. Total length expressed in metres of drying rack in the Mar Piccolo (first and second inlet) and Mar Grande of Taranto (Southern Italy).

Both hemp and HDPE cloths were effective in providing shade during the air exposure, mitigating temperatures, especially in the hottest hours, up to 2.6 and 3.5 °C, respectively. Air temperatures varied from 11.7 to 27.7 °C outside of the facilities, and from 11.7 to 24.2 °C and 12.6 to 25.1 under HDPE and hemp cloth, respectively (Table 2) (Figure 6).

Table 2. Mean (±S.D.), minimum and maximum temperatures during the air exposure.

		Mean ± S.D.	Minimum	Maximum
Air temperature (°C)	OUT	19.3 ± 5.4	11.7	27.7
	CC	18.1 ± 4.5	11.7	24.2
	SC	18.9 ± 4.5	12.6	25.1

Mussels used for the experiment measured 43.1 ± 3.8 mm and had an initial CI of 13.1 ± 2.3. The one-way ANOVA revealed significant differences in CI between the different treatments ($F = 18.61$, $p < 0.001$) (Table 3). After the air-cleaning phase a significant decrease in CI was observed in all mussels hanging on conventional facilities with values ranging from 8.2 ± 2.3 to 10.9 ± 2.9 (Figure 7). Surprisingly, the lowest values were observed in mussels of CCS and CCP treatments, covered by the HDPE shade cloth, despite its good shading capacity. In contrast, except for the mussels of SS treatment near the sea surface without cover, which showed a CI quite close to that found for CS treatment (ANOVA, $p > 0.05$), the other CIs of mussels cleaned on wooden racks did not differ significantly from that of mussels before air exposure (ANOVA, $p > 0.05$), with values that were between 12.5 ± 2.7 in mussels

of SCS and 11.4 ± 2.7 in mussels of SCP treatments (Figure 7), suggesting a greater effect of the material of the drying rack on CI, rather than the use of a cover. These findings were confirmed by three-way ANOVA that showed that only the facility variable individually affected CI ($F = 51.38$, $p < 0.001$), although a significant interaction occurred between facility and cover ($F = 36.12$, $p < 0.001$) and cover and mussel sock section ($F = 14.48$, $p < 0.001$) and between the three variables ($F = 4.80$, $p < 0.05$) (Table 4).

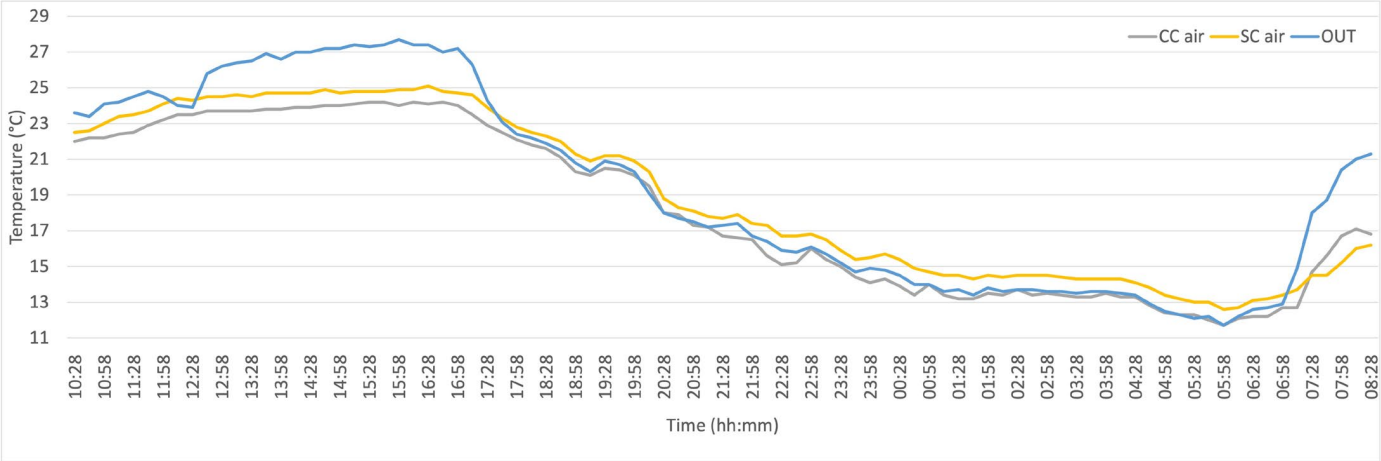

Figure 6. Graph of air temperatures registered during the 24 h air exposure of mussels. OUT: outside facilities; CC air and SC air: air temperature under conventional and sustainable facility with cover.

Table 3. One-way ANOVA results for condition index (CI) with sum of squares, degrees of freedom, F-values, and *p*-values. Significant effects are highlighted in bold.

	SS	df	Mean Squares	F	*p*-Value
Between groups:	0.0956281	8	0.0119535	18.61	**<0.001**
Within groups:	0.224137	349	0.0006422		
Total:	0.319765	367	0.00001		

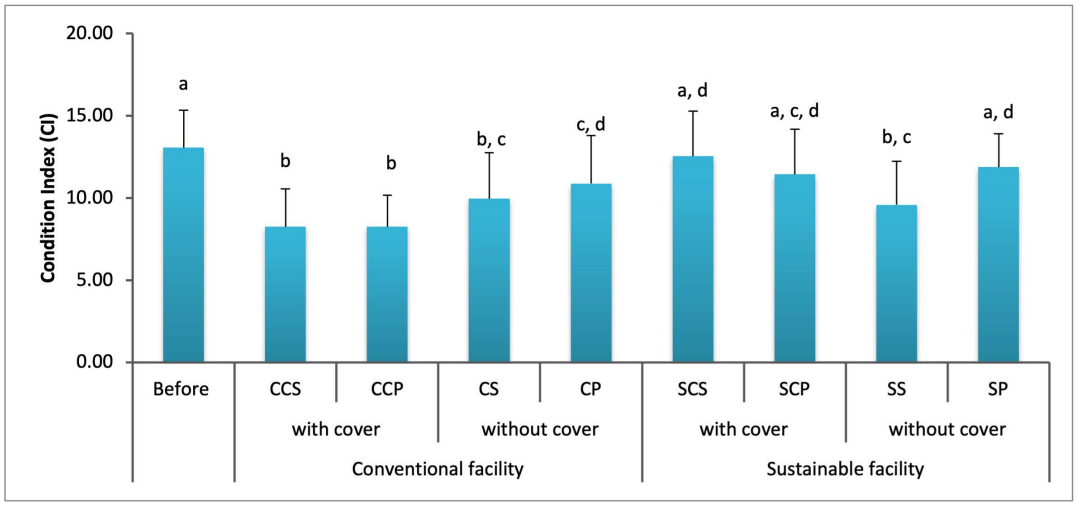

Figure 7. Condition index (CI) (±S.D.) before and after air exposure in the different treatments. Mussels suspended and on iron poles in the conventional facility with cover (CCS and CCP) and without cover (CS and CP); mussels suspended and on wooden poles in the sustainable facility with cover (SCS and SCP) and without cover (SS and SP). Bars with different letters indicate significant differences between treatments (Tukey test, $p < 0.05$).

Table 4. Three-way ANOVA results for effects of single variables and their interactions on condition index (CI) with sum of squares, degrees of freedom, F-values, and *p*-values. Significant effects are highlighted in bold.

Source	SS	df	F	*p*-Value
Facility	0.033	1	51.3841	**<0.001**
Cover	0.0016	1	2.4699	0.1171
Mussel sock section	0.0022	1	3.4283	0.065
Facility × Cover	0.0232	1	36.1235	**<0.001**
Facility × Mussel sock section	0	1	0.0509	0.8216
Cover × Mussel sock section	0.0093	1	14.4833	**<0.001**
Facility × Cover × Mussel sock section	0.0031	1	4.8041	**<0.05**
Residual	0.1999	311	-	-

4. Discussion

The practice of installing HDPE shade cloths to reduce intense sunlight and protect mussels from heat stress is well established among Taranto mussel farmers, so much so that exposure to the air is empirically considered impossible without adequate cover during the most climate-critical periods.

The length of the drying racks measured by remote sensing was consistent. Our findings are in line with those of Caroppo et al. [42], who found that the length of the drying racks has been almost stable since 1988, as they are fixed structures essential for the air exposure phase; for these reasons, wooden poles in mussel farms have been gradually replaced by galvanized iron ones to ensure greater resistance and durability in time, potentially contributing to localized metal pollution.

Given the considerable length of drying racks, the extensive use of the HDPE shade cloths to cover them contributes in a non-negligible way to plastic pollution. In fact, since HDPE shade cloths are resistant and low-cost, they are usually left fixed on the drying racks until they tear completely, releasing large amounts of plastic and, once they are no longer usable, they are almost always improperly disposed of on the shore (Figure 8).

Figure 8. HDPE shade cloth thrown away.

Overall, the CI after the air exposure, although not always significantly, decreased in all treatments. The current experiment shows a tendency rather than conclusive evidence.

To move from a trend to conclusive evidence, the experiment must be repeated using independent replicas of each facility to verify the results. CI is a key eco-physiological indicator of the health status of mussels, reflecting their nutritional status and ability to respond to different environmental pressures such as pollution, climate change, and food availability [43,46,47].

When exposed to air, *M. galloprovincialis*, differently from other intertidal bivalves that periodically gape valves, keeps their valves closed, minimizing water loss and the risk of desiccation. This condition determines the lack of oxygen and consequently the switch from aerobic to anaerobic metabolism, which can lead to the accumulation of byproducts and the reduction in overall physiological fitness [48]. While short periods of air exposure might not significantly alter the CI of *M. galloprovincialis*, extended or frequent air exposure, particularly at higher temperatures, can lead to increased oxidative stress and cellular damage generated by warming, affecting energy reserve [49].

In the present study, *M. galloprovincialis* was exposed to air for 24 h under different conditions for a single air exposure process. Although covering the drying racks determined a decrement of air temperature up to 2.6 and 3.5 °C, under hemp and HDPE cloth, respectively, such decrement was limited to a few hours. During the late spring and summer seasons, with the increase in temperature and the frequency of marine heatwaves, mussels are subjected to more intense and prolonged thermal stress, which could exceed their tolerance limits; thus, it should be verified whether the use of covers may be actually effective in protecting them from it during this period by keeping temperature below their thermal limits for a longer time than what occurred during this experiment.

Southern or lower-latitude populations of *M. galloprovincialis* are indeed living close to their tipping points of thermal tolerance limits (24–25 °C), at temperatures disrupting their optimal physiological processes. This can lead to physiological stress, metabolic impairment, and even mortality, especially during prolonged heatwaves [9,11,14,24].

Therefore, efficiently reducing the hours of air exposure to temperatures above the thermal limits of mussels during the summer season, thanks to the use of covers, could improve their thermal tolerance. In fact, repeated exposures to high temperatures, even if not immediately lethal, can negatively impact survival and physiological responses over time [50,51]. Furthermore, since the clumped structure of mussels in the socks, retaining water, creates a cooler microclimate, causing the internal temperature of the mussels to be lower than the air temperature [52], covering mussels during air exposure would further enhance this natural adaptation. This could be verified by measuring the temperature inside the mussel's valves to assess how their internal temperature responds to ambient changes [53].

Considering that, throughout the entire cycle of production, farmers expose mussels to air several times to manage fouling, a controlled long-term approach could favour an improvement in the heat tolerance of mussels, by potentially balancing the stresses associated with both elevated water temperatures and prolonged air exposure [54]. A long-term study across different farms and sites is also crucial to verify whether differences due to environmental variability (temperature, salinity, food availability), site-specific or season-dependent, influence not only CI, growth and survival, but also physiological and biochemical markers (e.g., byssal production, immune system impairment, oxidative stress, heat shock protein (HSP) gene expression, glycogen content) [9,11,13,14,18,55]. These indicators can provide an early warning of environmental stress before the condition index drops significantly, identifying the tipping point at which the damage becomes irreversible [55].

As regards the use of the sustainable facility, the results are encouraging, also considering that it was made from natural and biodegradable materials (wood and hemp) sourced

locally, which potentially not only reduce the environmental impact, but also promote sustainable economic development, by supporting local and non-local companies as well as preserving local traditions and skills.

5. Conclusions

The present study confirmed the empirical use of covers during exposure of mussels to the air by mollusc farmers in Taranto. However, this practice, which has been consolidated for at least twenty years, coincides with the massive use of plastic and gives rise to the question of how to make the relationships between marine research and production truly effective to manage adaptations to climate change from a sustainable perspective.

Based on our results, although preliminary, it seems that the use of different air exposure facilities to manage fouling could offer a potential mitigation strategy. To our knowledge this is the first attempt to evaluate if the use of different air exposure facilities could have positive repercussions on mussel production. Further research is essential to determine its feasibility and effectiveness by conducting a long-term study throughout the entire production cycle and in different mussel farms and sites, and to establish the optimal design, frequency, and duration of air-drying cycle conditions.

In this context it will also be essential to evaluate the costs and effectiveness of other biodegradable materials with prices lower than hemp cloth and more resistant and durable than wood. The results encourage us to continue building virtuous paths of integration between the ancient mollusc farming techniques and the modern needs of adaptation to climate change, with the aim of a plastic-free mollusc product.

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Institutional Review Board Statement: According to the Italian Legislative Decree 26/2014, which implemented Directive 2010/63/EU, ethical approval of research involving invertebrates should be waived. Informed consent was obtained from the owner of mussel farm.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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