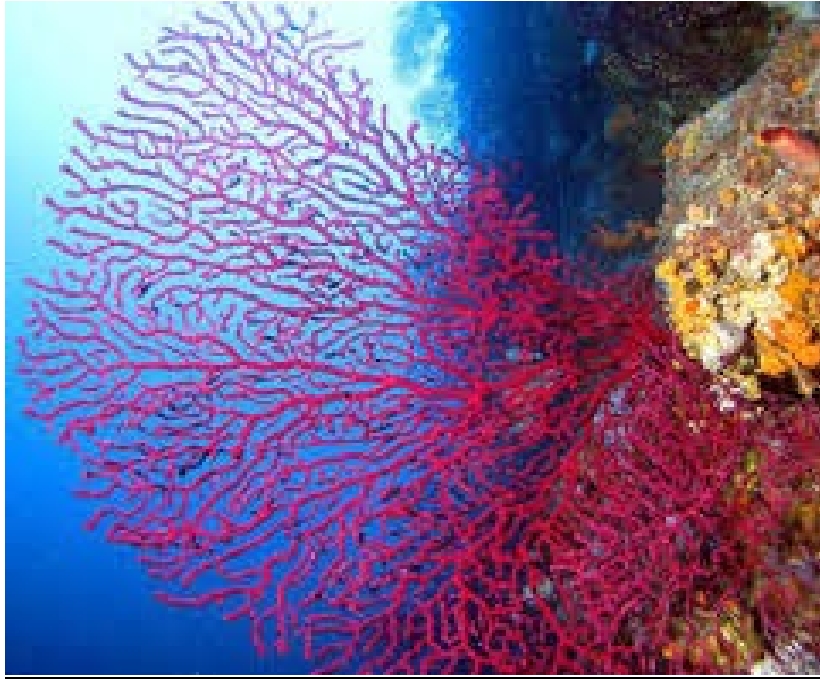


UNIVERSITY OF THE AEGEAN
DEPARTMENT OF ENVIRONMENT



Investigation of the sublethal effects of thermal stress on the reproductive output of the red gorgonian *Paramuricea clavata* and the role of sex on the response to thermal stress.

Dissertation thesis

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΙΓΑΙΟΥ
ΤΜΗΜΑ ΠΕΡΙΒΑΛΛΟΝΤΟΣ
ΣΧΟΛΗ ΠΕΡΙΒΑΛΛΟΝΤΟΣ



Διερεύνηση των προθανάτιων (sublethal) επιπτώσεων του θερμικού στρες στο αναπαραγωγικό αποτέλεσμα της κόκκινης γοργονίας *Paramuricea clavata* και η διαφορετική απόκριση ανάλογα με το φύλο.

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ΠΕΡΙΛΗΨΗ

Οι γοργονίες συγκαταλέγονται στα πιο κοινά είδη των κοραλλιογενών κοινοτήτων της Μεσογείου. Η κόκκινη γοργονία *Paramuricea clavata* θεωρείται από τα πιο αντιπροσωπευτικά είδη της Δυτικής Μεσογείου και παίζει σημαντικό ρόλο στη διατήρηση της βιομάζας και της δομικής πολυπλοκότητας των κοραλλιογενών κοινοτήτων. Σε ότι αφορά την αναπαραγωγή της *P. clavata*, πρόκειται για είδος γονοχωριστικό και η φυλετική αναλογία είναι συνήθως 1:1. Η γονιμοποίηση λαμβάνει χώρα στη επιφάνεια των θηλυκών ατόμων (surface brooding) ενώ σημαντικό ρόλο στον αναπαραγωγικό συγχρονισμό και στην απελευθέρωση γαμετών (αρσενικών και θηλυκών γονάδων) (synchronous spawning) παίζει η θερμοκρασία και ο σεληνιακός κύκλος. Σύμφωνα με πολλές μελέτες, έχει παρατηρηθεί ότι πολλά επεισόδια μαζικής θνησιμότητας της *P. clavata* σχετίζονται με περιστατικά θερμικών ανωμαλιών της στήλης του νερού. Βασικές παράμετροι στην εκτίμηση μιας επικείμενης διαταραχής αποτελούν τα ποσοστά τραυματισμού ή συνολικής νέκρωσης των αποικιών, ενώ οι επιπτώσεις στις βασικές φυσιολογικές λειτουργίες του οργανισμού, όπως αυτές που επηρεάζουν την αναπαραγωγή, είναι λιγότερο μελετημένες. Ελάχιστες είναι οι μελέτες που επικεντρώνονται στις προθανάτιες επιπτώσεις (sublethal effects) του θερμικού στρες στην αναπαραγωγική προσπάθεια του είδους. Σκοπός της συγκεκριμένης έρευνας είναι η μελέτη των επιπτώσεων του θερμικού στρες στην αναπαραγωγική προσπάθεια της *P. clavata* και τη διαφορετική απόκριση ανάλογα με το φύλο (αρσενικό-θηλυκό). Κατά το πειραματικό στάδιο ισάριθμες αρσενικές και θηλυκές αποικίες της *P. clavata* τοποθετήθηκαν σε ενυδρεία υπό κανονικές συνθήκες (17 C) και υπο συνθήκες θερμικού στρες (25C). Μετά το πέρας τριών εβδομάδων, οι αποικίες που επέζησαν εξετάστηκαν σε στερεοσκόπιο ώστε να αξιολογηθεί το αναπαραγωγικό τους αποτέλεσμα καθώς και οι πιθανές διαφοροποιήσεις ανάλογα με το φύλο. Οι παράμετροι που εξετάστηκαν ήταν η γονιμότητα των αποικιών, ο αριθμός και η διάμετρος των γονάδων ανά πολύποδα. Όλες οι παραπάνω μεταβλητές, παρουσίασαν στατιστικά σημαντική μείωση στις αποικίες που είχαν υποστεί θερμικό στρες σε σχέση με τις αποικίες που διαβίωσαν υπό κανονικές συνθήκες, ενώ παράλληλα παρατηρήθηκε ότι οι θηλυκές αποικίες επηρεάστηκαν περισσότερο από τις αρσενικές. Οι θηλυκές αποικίες υπό θερμικό στρες παρουσίασαν μείωση στη γονιμότητά τους κατά 89% σε σχέση με τις θηλυκές αποικίες υπό κανονικές συνθήκες, ενώ οι αντίστοιχες αρσενικές αποικίες παρουσίασαν μείωση της τάξης του 24%. Αντίστοιχα, ο αριθμός των θηλυκών γονάδων παρουσίασε μείωση κατά 98%, ενώ οι αρσενικές μειώθηκαν κατά 66%. Όσον αφορά το μέγεθος των γονάδων, η διάμετρος των θηλυκών μειώθηκε κατά 31% και η διάμετρος των αρσενικών κατά 62%. Τα αποτελέσματα της παρούσας έρευνας, υποστηρίζουν την υπόθεση ότι οι θηλυκές αποικίες επενδύουν περισσότερο στην αναπαραγωγή σε σχέση με τις αρσενικές, γεγονός το οποίο φαίνεται να τις καθιστά περισσότερο ευάλωτες σε μια επικείμενη αλλαγή όπως είναι η αυξημένη θερμοκρασία. Συνεπώς, οι θηλυκές αποικίες παρουσίασαν γενικά μεγαλύτερες μειώσεις στις περισσότερες μεταβλητές μέτρησης της γονιμότητας, γεγονός που σημαίνει ότι οι προθανάτιες επιπτώσεις είναι περισσότερο εμφανείς στα θηλυκά σε σχέση με τα αρσενικά. Συμπερασματικά, οι ενδεχόμενες αρνητικές επιπτώσεις της αυξημένης θερμοκρασίας (λόγω κλιματικής αλλαγής) στην αναπαραγωγή του είδους *P. clavata*, καθιστά επιτακτική την ανάγκη για περεταίρω διερεύνηση των επιπτώσεων στο είδος, καθώς επίσης και τη μέριμνα για μέτρα προστασίας που πρέπει να υιοθετηθούν.

ABSTRACT

Paramuricea clavata (Risso, 1826), is one of the most emblematic species in the NW Mediterranean Sea. Several mass mortality events have had lethal effects on the species while sublethal effects have also been observed due to thermal stress. We experimentally placed in aquaria male and female colonies of *P. clavata* under control (17°C) and thermal stress (25°C) conditions. After three weeks surviving colonies from both control and thermal treatments were examined to evaluate their reproductive output and potential differential responses exhibited by sexes. The three parameters examined were the fertility of the colonies, the number of gonads inside the polyps and the diameter of spermaries and oocytes. All three variables presented decreased values in the stressed colonies than in control ones, while at the same time, females were more impacted from thermal stress rather than males. Female stressed colonies showed a decrease of 89% in their fertility compared to control after being subjected to thermal stress while male colonies showed a decrease of 24%. Respectively for number of gonads, oocytes were reduced by 98% while spermaries by 66%. Additionally, the diameter of oocytes presented a reduction of 31% while spermaries were reduced by 62%. The results of the present study, support the hypothesis that females invest more in reproduction rather than males and for this reason they are more vulnerable to an imminent threat (such as the elevating temperature). As a consequence, the potential negative impact of positive temperature anomalies (related to climate change) on the reproduction of *P. clavata* underlines the importance for further investigation on the sublethal effects of the species and also for protection measures that have to be taken.

INTRODUCTION

Coralligenous assemblages, the unique calcareous formations of biogenic origin in the Mediterranean benthic environments is one of the most emblematic marine habitats in the Mediterranean Sea. They represent an important hotspot for biological diversity (harboring approximately 20% of Mediterranean species) and exhibit great structural complexity (Ballesteros, 2006), facts that make such communities comparable with coral reefs. (Margalef, 1985; Bellan-Santini et al., 1994). The dominant species of coralligenous seascapes are encrusting calcareous algae, sponges, cnidarians, bryozoans and tunicates (Ballesteros, 2006). Gorgonian corals (Anthozoa, Gorgonacea) are among the most common species of coralligenous assemblages (Peres & Picard, 1964) while at the same time the red gorgonian- *Paramuricea clavata* is one of the most representative species in the Western Mediterranean coralligenous assemblages (Weinberg, 1979; Gili & Coma, 1998), playing an important role in the maintenance of structural complexity and biomass of these habitats (Ballesteros, 2006).

P. clavata is a modular colonial marine invertebrate (Coma et al., 1995) which is consisted of a horny skeleton, made out of gorgonin (a complex protein) covered by a thin layer of cells, the coenenchyma and the polyps. It is widely distributed along the coasts of western Mediterranean (Carpine and Grashoff, 1975) and eastern Atlantic Ocean (Weinberg, 1994)

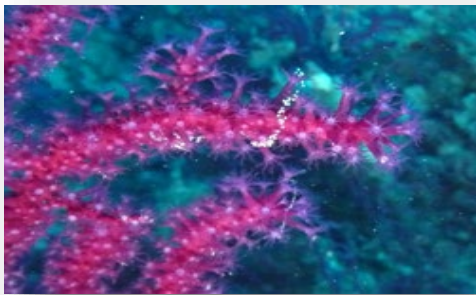


Fig. 1: Surface brooding of *P. clavata*.

and typically lives between the depth of 10-110m (Carpine and Grashoff, 1975). It is a filter feeder mostly fed on copepods, diatoms, dinoflagellates, ciliates and organic carbon suspended particles (Ribes, 1999b). *P. clavata* is a gonochoric species but without obvious sexual dimorphism. Sexual reproduction is the dominant reproductive process of the species as asexual reproduction is negligible (Coma et al., 1995a). The species generally exhibits 1:1 sex ratio

(Gori et al., 2007; Coma et al., 1995a). Sexual maturity is fully attained when the colony reaches the size of 20cm in height, while reproductive effort increases with the size of the colony (Coma et al., 1995b). *P. clavata* is characterised by spawning synchrony (every June in 2 to 3 separate episodes, lasting 1-8 days each). Then, female colonies retain their oocytes on their surface (through a mucus coating), where embryogenesis takes place (surface brooding), while male colonies release the sperms in the water column (Coma et al., 1995a). Shortly after embryogenesis, the planula larvae detaches from the surface of the maternal colony (Linares et al., 2008a) and after a short period of suspension in the water column, they settle on the substrate near the maternal colony (Coma et al., 1995a; Linares et al., 2008a). The main factor known to play an important role in the timing of spawning in gorgonians is temperature (Grigg, 1977) and lunar cycle (Brazeau & Lasker 1989,1990).

There is a general consensus that mass mortality events related to water temperature- related thermal anomalies due to climate warming, constitute a serious threat for coastal marine ecosystems (Harvell et al., 1999, 2002; Romano et al., 2000). The Mediterranean region is one of the fastest warming regions due to climate change (Bindoff et al., 2007; Burrows et al., 2011) and the rise of seawater temperature has caused several mass mortality events of benthic invertebrates (Garrabou et al., 2009; Kersting et al., 2013). Among the most affected species during these events were gorgonian octocorals and especially the red gorgonian *Paramuricea clavata* and the white gorgonian *Eunicella singularis* (Cerrano et al., 2000;

Linares et al., 2005; Coma et al., 2006; Coma et al., 2009; Garradou et al., 2009; Cupido et al., 2012). Given the fact that gorgonians are structurally important species within the Mediterranean hard- bottom communities, changes in the structure of their populations may lead to important community-level changes (Linares et al., 2007b,2008a; Cupido et al., 2012).

The most commonly used method to evaluate the effects of a disturbance upon a gorgonian population is through the direct estimation of the extend of colony injury or the proportion of colony mortality within a given population (Linares et al., 2005; Coma et al., 2006; Cupido et al., 2008; Huete- Stauffer et al., 2011). On the contrary, the sublethal physiological effects (including reproduction) posed by stressful conditions are harder to investigate and are therefore commonly ignored (Hughes & Connell, 1999; Coma et al.,2004; Linares et al., 2008). Most of the studies have focused on the assessment of direct (mortality) or delayed effects (partial mortality- extent of injuries to a colony's surface) of mass mortality events on gorgonian colonies (Linares et al., 2005; Coma et al., 2006; Cupido et al., 2008,2009; Huete- Stauffer et al., 2011). Only few studies have dealt with the sublethal effects of thermal stress on reproduction effort (Torrents, 2007; Linares et al., 2008a) and on the early life stages development (Kipson et al., 2012). Today, sublethal effects associated with elevated sea – water temperature conditions remain poorly studied. Information about the effects of mass mortality events on sexual reproduction is crucial due to the vital process of reproduction for the survival of a population (Coma et al., 1995a; Ribes et al., 2007; Linares et al., 2008).

The aim of this study is to examine the sublethal effects of thermal stress on the reproductive output of the red gorgonian *Paramuricea clavata* (Risso, 1826) and the differential response to thermal stress according to sex.

METHODOLOGY

Sampling

Sampling was carried out at the Marine Protected Area of Medes Islands (42°02'N, 3°13'E) in the Northwestern [NW] Mediterranean (Fig. 2). On the 18th of May 2013, a population of *P. clavata*, located between 20 and 25 m depth, was randomly sampled by SCUBA divers. Samples consisted of one small apical fragment per colony (about 5 cm in length). Gonadal mass and number are known to attain their peak in June while at the same time spawning episodes commonly occur also at the beginning of June (Coma et al., 1995). Consequently, we considered May as the most appropriate month for sampling. Overall 120 colonies were sampled, including 60 non- reproductive juvenile colonies (<10cm height) and 60 reproductive adult colonies (between 20 and 30cm height). Considering the sex ratio of the species (1:1) the number of the adult colonies was sufficient in order to obtain at least 10 male and 10 female colonies. Apical tips were transported in



Fig.2: Map of Spain with Medes Islands marked.

portable coolers from the collection site to the Experimental Aquarium Zone (ZAE) of the Institute of Marine Sciences in Barcelona within the same day. Upon arrival, one polyp per apical tip (hereafter referred to as “colony”), was dissected under a stereoscope, in order to determine the sex of each colony. The color of the gonads inside the polyps was the factor of classification. Males contain yellow spermaries while the oocytes are deep purple (almost black).

Experimental design

The experiment consisted of two aquarium settings: control and stress treatment (composed of three replicate tanks per each condition). Consequently, there was one tank for juveniles, one for males and one for females under control conditions and three for stress. To avoid intra-colony variability response, all colonies were divided into two parts, one was placed into control treatment while the other fragment was placed into stress treatment. Moreover, for control and stress treatment respectively we had 30 juvenile colony fragments inside the first tank, 30 male colony fragments inside the second tank and 30 female colony fragments inside the third tank. The colonies were acclimatized in the aquariums during five days at 16°C. Afterwards, the temperature was gradually raised to 25°C in the stress tanks, but it was left at 16°C in control tanks. The tanks were supplied with Mediterranean Sea water that was continuously pumped from 20 m depth into the experimental aquarium facilities of the Institute of Marine Sciences. Upon arrival to the facilities, the seawater was filtered before reaching the experimental tanks. Each tank had an inlet pipe for the supply of fresh seawater and an outlet pipe. Both pipes remained open so that the tanks functioned as an open system. In the stress treatment setting, seawater was heated in a buffer tank equipped with submersible resistance heaters and was regulated by temperature controllers (Aqua Medic T controller).

The experiment started on May 23rd (five days after the acclimatization of the gorgonians in the aquariums), which was considered as the “day 0” of the experiment, since it was the first day at 25°C for the stress fragments. After three weeks of thermal stress, samples for studying the reproductive output were collected from colonies without injuries in both stress and control treatment.

Reproductive output

After three weeks, surviving reproductive colonies were examined under a stereoscope to evaluate the effects of thermal stress on their reproductive output and the potential differential responses exhibited by colonies of different sex. In order to define reproductive output, three variables were used. a) Fertility, estimated as the proportion of fertile polyps (polyps that contained at least one gonad) to total number of dissected polyps, b) Number of gonads per polyp and c) Gonadal size based on the diameter of ten gonads within each polyp. In case of polyps that contained less than ten gonads, diameter was defined only for the existed gonads.

From each experimental treatment (control and stress), we finally examined 11 male and 11 female colonies (out of 60 adult colonies that were initially sampled). As a consequence 22 male fragments (11 stress and 11 control) and 22 females were examined. Overall, 440 polyps were dissected (ten polyps per each fragment), and the number and diameter of gonads mentioned was measured.

Statistical analyses

To test differences in fertility, number of gonads and diameter of gonads among treatments and sexes, we applied non-parametric U-Mann Whitney tests, since data did not follow normality (Shapiro- Wilk, $p < 0,01$). All statistical analyses were performed using the statistical software PAST3.

RESULTS

Effects of thermal stress on reproductive effort and gonadal development.

Exposure to thermal stress resulted in several aberrant oocytes and spermaries found in male and female colonies in comparison to those observed in control treatments (Fig.3). In addition, thermal stress negatively affected the proportion of fertile polyps, the number and the diameter of gonads in both sexes (Fig. 4 and 5). However, this effect was more marked for female than for male colonies.

In male colonies, fertility decreased from 100% in control to 76% in stressed colonies, showing a significant reduction of approximately 24% (Mann Whitney U;: $Z = -2,099$; $p = 0,036$) (Table 1, Fig. 4a). Additionally, there was a decrease in the number and diameter of the spermaries found in the male colonies under thermal stress (Table 1, Fig. 4b, c). The reduction of the number of gonads in male colonies under thermal stress was approximately 66% compared to the control colonies (Mann Whitney U;: $Z = -6,725$; $p < 0,001$, Fig. 4b), while the diameter of the gonads of the stressed males was reduced by approximately 62% compared to the control ones (Mann Whitney U;: $Z = -6,485$; $p < 0,001$, Fig. 4c).

In female colonies, the three reproductive parameters under study showed significant differences among treatments (Table 1, Fig.5). The fertility of females decreased from 97% to 8% in control and stress treatment respectively (Mann Whitney U;: $Z = -4,212$; $p < 0,001$, Fig. 5a). Female stressed colonies showed a reduction of 98% in the number of oocytes compared to the control ones (Mann Whitney U;: $Z = -13,04$; $p < 0,001$, Fig 5b). Moreover, a reduction of 31% in the diameter of the gonads in stressed females was observed (Mann Whitney U;: $Z = -12,614$; $p < 0,001$, Fig 5c).

Table 1: Summary of the results obtained from the thermal stress experiment.

Πίνακας 1: Σύνοψη των αποτελεσμάτων που παρατηρήθηκαν από το πείραμα του θερμικού στρες.

SEX	TREATMENT	FERTILITY(%)	NUMBER OF GONADS		DIAMETER OF GONADS	
		Mean	Mean	SD	Mean	SD
Male	Control	100	20,53	11,1	420,3	121,3
	Stress	76,36	13,58	8,6	260,9	101,4
Female	Control	97,27	20,01	8,9	438,6	67,7
	Stress	8,18	0,38	1,14	301,3	134

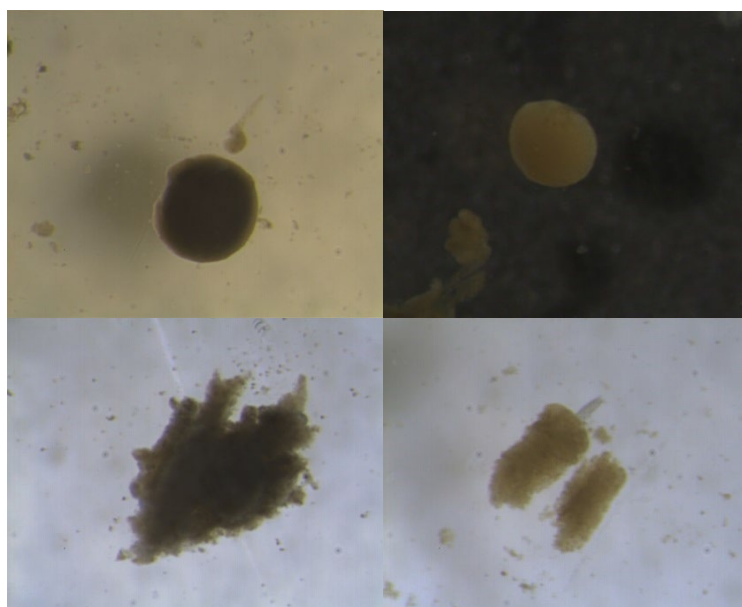


Figure 3: Regular form of oocytes (a) and spermatozoa (b) from control colonies. Aberrant forms observed in female (c) and male (d) colonies subjected to thermal stress.

Εικόνα 3: Κανονική μορφή ωαρίων (a) και αρσενικών γαμετών (b) από αποικίες υπό κανονικές συνθήκες. Μη φυσιολογικές μορφές που παρατηρήθηκαν σε θηλυκές (c) και αρσενικές (d) αποικίες οι οποίες είχαν υποστεί θερμικό στρες.

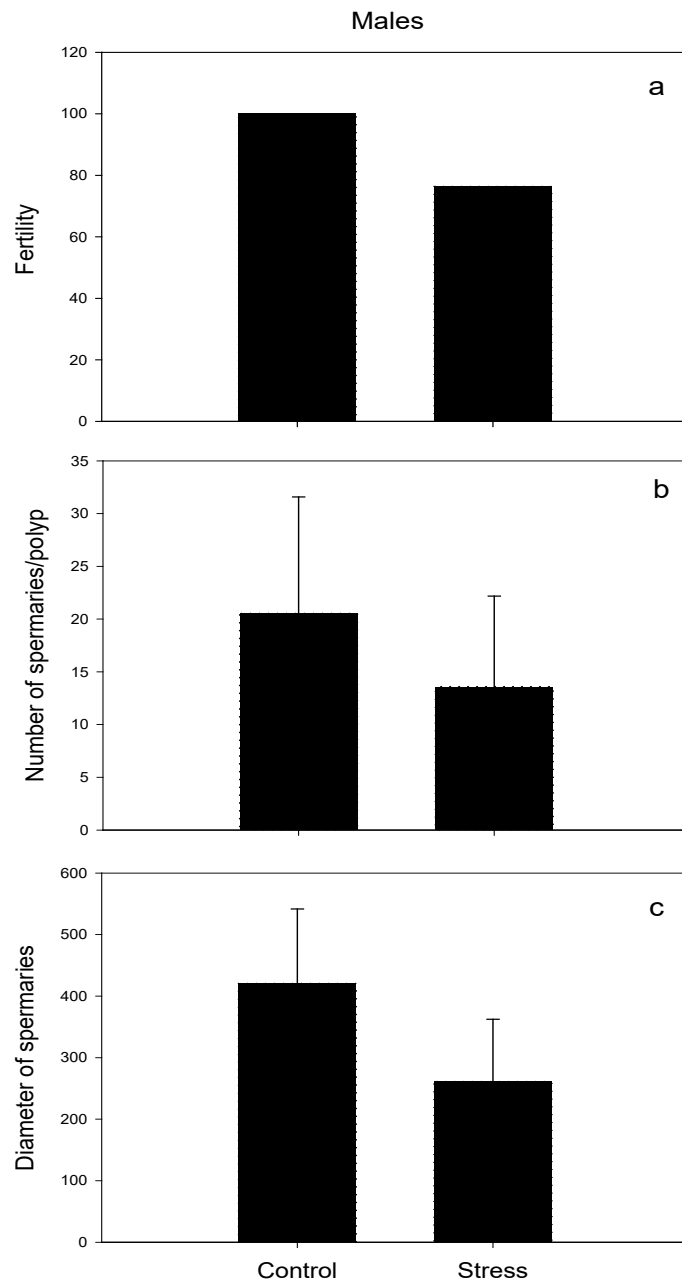


Figure 4: Reproductive parameters of male colonies under control and stress treatment. **a)** Mean fertility (% of polyps with spermaries). **b).** Mean number of spermaries per polyp. **c)** Mean diameter of spermaries. Whiskers represent standard deviation.

Εικόνα 4: Αναπαραγωγικές μεταβλητές των αρσενικών αποικιών υπό κανονικές συνθήκες και υπό συνθήκες στρες **a)** Μέση γονιμότητα (% των πολύποδων που περιείχαν σπέρματα). **b).** Μέσος αριθμός αρσενικών γαμετών ανα πολύποδα. **c)** Μέση διάμετρος των αρσενικών γαμετών . Whiskers represent standard deviation

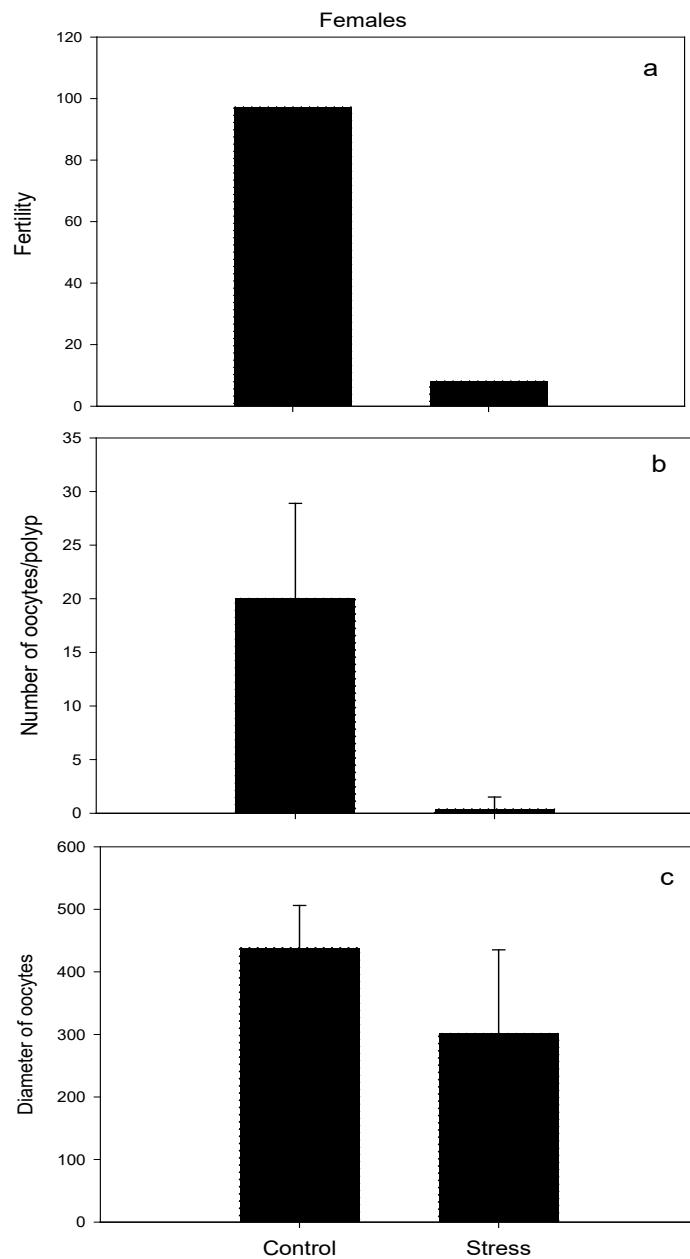


Figure 5: Reproductive parameters of female colonies under control and stress treatment. **a)** Mean fertility (% of polyps with oocytes). **b)** Mean number of oocytes per polyp. **c)** Mean diameter of oocytes. Whiskers represent standard deviation.

Εικόνα 5: Αναπαραγωγικές μεταβλητές των θηλυκών αποικιών υπό κανονικές συνθήκες και υπό συνθήκες στρες **a)** Μέση γονιμότητα (% των πολύποδων που περιείχαν ωάρια). **b).** Μέσος αριθμός θηλυκών γαμετών ανα πολύποδα. **c)** Μέση διάμετρος των θηλυκών γαμετών . Whiskers represent standard deviation

DISCUSSION

The results obtained in this study show that thermal stress leads to a general decrease in the reproductive effort of *Paramuricea clavata*. In both male and female colonies, all the reproductive parameters under study displayed significant declines (compared to control treatment), indicating that thermal stress causes sublethal effects. Previous studies dealing with the same species have also highlighted sublethal effects produced by thermal stress. Linares et al. (2007), in their study, showed that the 1999 mass mortality event (caused by elevated temperature) caused severe effects on reproduction of *P. clavata*. Moreover, thermal stress showed a negative effect on the embryos and larvae of *P. clavata*, resulting in abnormal embryonic development and reduced survivorship of the species (Kipson et al., 2012). Similarly, other works have also showed that elevated temperatures affect the embryonic coral development causing abnormalities (Bassim et al., 2002; Randal & Szmant, 2009b). Other studies related to the reproduction of corals, suggest that the level of the impact and the kind of species that are affected by the impact are the factors that determine the level of the effect on reproductive output (Szmant & Gassman, 1990; Michalec- Wagner & Willis, 2001; Baird & Marshall, 2002; Mendes & Wooley, 2002). Furthermore, Van Veghel & Bak (1994) underlined that mortality events are causing both short-term and long term effects on reproduction by the reduction of fertility and fecundity of coral populations and colonies.

Supplementary to the overall negative effect of thermal stress on the reproductive output of *P. clavata*, the present study takes into consideration the differential response to stress according to sex. The overall assumption was that females are more vulnerable to elevated temperatures than males.

According to the results, fertility was significantly more impacted in females rather than males. Linares et al. (2007) have also showed that fertility reduction in female colonies was greater than the reduction of male colonies. As Hayward & Gillooly (2011) have mentioned, there are clear differences between females and males in terms of energetic cost of gamete biomass production. In their study, regarding a broad diversity of species (mammals, birds, fishes, amphibians, reptiles and invertebrates), males invested 0,1% against 300% of females of the energy used for basal metabolism to gamete production. Moreover, the energetic cost of oocyte production was 3.5 orders of magnitude higher than the energetic cost of sperm production for the above species. Additionally, Hall & Hughes (1996), in their study about reef-building corals, state that egg production has a higher energetic cost than sperm production. As a consequence, we could assume that as females invest more in reproduction, their fertility could be more impacted from a thermal disturbance than male fertility.

The same pattern followed also the second variable of reproductive output which was the number of gonads. Gori et al. (2007) refer that a mean oocyte number per polyp (for *P. clavata*, on May 2003) was 11,6 while a mean number of spermaries per polyp was 24,3. In a corresponding study, Coma et al. (1995), refer that the mean oocyte number per polyp was 13 (for the whole reproductive cycle) while the mean spermarie number was 24 in April 1991 and 35 at the beginning of June (just before spawning). In the present study, the number of the oocytes was significantly more decreased than the number of spermaries in the stressed colonies. According to a study on the effects of the 1999 mass mortality event (Linares et al., 2007), female colonies showed a 73-75% reduction in oocyte production (after the event) while male colonies exhibited a reduction between 49 and 64% in spermarie production, suggesting that female colonies were more affected than male colonies (Linares et al., 2007). For many invertebrates, especially for the sessile ones, gonads are the storage for most of the energy that participates in reproduction (Leuzinger et al., 2003). Oogenesis represents a

greater part of this energy investment rather than spermarie production which does not influence remarkably the energetic balance of the organism (Hayward & Gillooly, 2011). Due to the above facts, it can be presumed that the more a colony invests in reproduction, the more vulnerable it can be to an imminent disturbance.

According to the results of the present study, the diameter of both spermaries and oocytes also decreased significantly. Gori et al. (2007) report that the mean diameter for male colonies of *P. clavata* (in May 2003) was 348 μm and 349 μm for female colonies. According to another study, mean diameter for male colonies during May 1991 was 258 μm and 313 μm for female colonies during May 1990 (Coma et al., 1995).

The general decrease observed in all the reproductive parameters in colonies under thermal stress, underline the long-term consequences of thermal stress for the future viability of the species. A reduced number of gonads can be directly translated in a lower number of embryos and larvae which could lead to an important recruitment failure in the following years. This study underlines the need to study the effects of thermal stress on reproductive performance of the species. In this sense, further investigation on the sublethal effects of thermal stress on structural species such as *P. clavata* will help us obtain a more holistic view of the impacts of climate change in corraligenous benthic communities.

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RESPONSE OF CORALLIGENOUS TO GLOBAL CHANGE: EVIDENCES FROM FIELD AND EXPERIMENTAL STUDIES IN GORGONIAN FORESTS

Abstract

*Global change is one of the major concerns for the conservation of the rich biodiversity of coralligenous assemblages. There is a strong likelihood of increasing frequencies of mass mortality events linked to global warming and the spread of invasive species in the Mediterranean Sea. Gorgonian forests, one of the most emblematic facies of coralligenous outcrops, are especially vulnerable to global change related disturbances. The presentation will focus on the study of the responses of gorgonians, mainly the red gorgonian *Paramuricea clavata*, to warming and exotic algae invasions from observational and experimental approaches in NW Mediterranean Sea. Long-term monitoring of recurrent warming-induced mortalities in marine protected areas such as Cabrera Archipelago and Columbretes Islands showed that warming may act as an important driver for long-term shifts in the bathymetrical distribution of gorgonian forests. Aquaria experiments and field surveys indicate that thermal stress may also have important sublethal effects on the timing of reproduction, the reproductive effort and the viability of early life stages of gorgonians. Additionally, manipulative experiments demonstrated that invasive algae, such as *Caulerpa racemosa* and *Womersleyella setacea*, have the capacity to reduce gorgonian recruitment and juvenile survival. The final aim of the presentation is to discuss the future consequences of global change on the persistence and recovery of gorgonian forests, in particular, and of coralligenous assemblages in general.*

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