http://dx.doi.org/10.32360/acmar.v57i2.92219
ISSN 0374-5686 e-ISSN 2526-7639
SCIENTIFIC NOTE

Arquivos de Ciências do Mar

ACUTE TOXICITY OF AMMONIA FOR SOFT CORAL Xenia umbellata *(Lamarck, 1916)*

Toxicidade aguda de amônia para o coral mole *Xenia umbellata* (Lamarck, 1916)

Giovanni Martins Busanello[1], Marco Shizuo Owatari[2], Ricardo Vieira Rodrigues[3], Mônica Yumi Tsuzuki[4], Caio Magnotti[1]

[1]Marine Fish Culture Laboratory – LAPMAR, Federal University of Santa Catarina, Aquaculture Department, 476 – CEP 88040-970 – Florianópolis – SC. E-mail: giovannimartinsbusanello@gmail.com
[2]Laboratory of Algae Culture – LCA, Aquaculture Department, Federal University of Santa Catarina (CCA, UFSC), Rodovia Admar Gonzaga 1346, CEP 88040-900 Florianópolis, SC, Brazil. E-mail: owatarimarco@hotmail.com
[3]Laboratory of Marine Fish Culture, Institute of Oceanography, Federal University of Rio Grande – FURG, Rua do Hotel, 02 – Bairro Cassino, CEP 916210-030, Rio Grande, RS, Brazil. E-mail: caio.magnotti@ufsc.br
[4]Fish and Marine Ornamentals Laboratory – LAPOM, Federal University of Santa Catarina, Aquaculture Department, 476 – CEP 88040-970 – Florianópolis, SC Brazil. E-mail: monica.tsuzuki@ufsc.br

ABSTRACT

*Coral reefs are important ecosystems on the planet and provide a wide variety of ecosystem services that are extremely important for the development and survival of several species, including humans. The lack of information and knowledge about the influence of abiotic parameters on the physiology of marine cnidarians with ornamental potential has hampered the cultivation of coral species on a large scale in aquaculture. The objective of this work was to determine the median lethal concentration after 96 h (LC_{50}^{96h}) of nonionized ammonia (NH_3-N) for the octocoral white pulse soft coral (*Xenia umbellata*) over a period of 96 h. Eighty colonies of* X. umbellata *coral were exposed to five different ranges of N-NH_3 (0.0, 0.92, 3.87, 5.95, 8.46 or 10.18 mg L^{-1}, all in triplicate. Tests were performed on a standard semistatic system with 100% daily water renewal. The LC_{50}^{96h} was estimated to be 0.28 mg NH_3-N L^{-1} (0.22~0.36 mg L^{-1}). The lethal concentration of ammonia decreased with increasing time. Furthermore, concentrations below 0.96 mg L^{-1} total ammonia (0.08 N-NH_3) are not lethal for this organism in an exposure period of 96 h.*

Keywords: *Aquaculture; Octocoral; Regenerative; White pulse soft coral.*

Received:26 September 2023
Accepted for publication:26 September 2024

RESUMO

Os recifes de corais são ecossistemas importantes do planeta, fornecendo uma grande variedade de serviços ecossistêmicos que são extremamente importantes para o desenvolvimento e sobrevivência de várias espécies, incluindo humanos. A falta de informação e conhecimento sobre a influência dos parâmetros abióticos na fisiologia dos cnidários marinhos com potencial ornamental tem dificultado o cultivo de espécies de corais em larga escala na aquicultura. O objetivo deste trabalho foi determinar a concentração letal mediana após 96 h (CL_{50}^{96h}) de amônia não ionizada (NH_3-N) para o octocoral Xênia pulsante (*Xenia umbellata*) em um período de 96 h. Para isso, 80 colônias de coral *X. umbellata* foram expostas a cinco diferentes concentrações de N-NH_3 (0,0; 0,92; 3,87; 5,95; 8,46; ou 10,18), todas em triplicata. Os testes foram realizados em sistema semiestático padrão com 100% de renovação diária de água nas unidades experimentais. A CL_{50}^{96h} foi estimada em 0,28 mg NH_3-N L^{-1} (0,22~0,36 mg L^{-1}). Concluiu-se que a concentração letal de amônia é menor com o aumento do tempo. Além disso, concentrações abaixo de 0,96 mg L^{-1} de amônia total (0,08 N-NH_3) não foram letais para este organismo em um período de exposição de 96 h.

Palavras-chave: Aquicultura; Octocoral; Regenerativo; Xênia pulsante.

INTRODUCTION

Coral reefs are important ecosystems on the planet and provide a wide variety of ecosystem services that are extremely important for the development and survival of several species, including humans (Connell, 1978; Hughes *et al*., 2003). The class Octocorallia consists exclusively of polypoid organisms belonging to the class Anthozoa, the largest class in the phylum Cnidaria (Haddad, 2006; Pérez *et al*., 2016). It is estimated that the subclass Octocorallia includes approximately 3000 known species, which are distributed in 46 families belonging to three major orders: Helioporacea, Pennatulacea, and Alcyonacea (Daly *et al*., 2007), in which the genus *Xenia* is found.

Xenia umbellata (Lamarck, 1816) is a soft coral species that resembles a mushroom and is characterized as an autotrophic species that has a reduced gastrovascular cavity and greater photosynthetic activity than other corals without pulsating movement (Schlichter *et al*., 1983; Reinicke, 1997; Kremien *et al*., 2013). Furthermore, it is a coral that multiplies very quickly (Benayahu, 1991; Daly *et al*., 2007) and is easy to manage, making it highly desirable to beginner aquarists (Kim *et al*., 2022).

In aquaculture, coral farming is a growing activity that can act as a regenerative tool and control the degradation and exploitation of coral reefs around the world (Pomeroy *et al*., 2006; Leal *et al*., 2016). However, coral aquaculture is still underdeveloped (Leal *et al*., 2016). Aquaculture can offer a sustainable alternative to produce these animals and supply the ornamental trade (Barton *et al*., 2017). Nevertheless, to make commercial cultivation of a given species viable, it is necessary to establish safe levels of some abiotic factors, such as nitrogenous compounds, which potentially limit the survival of aquaculture species (Boyd and Watten, 1989; Tomasso, 1994).

Ammonia reaches aquatic systems through complex biogeochemical interactions and is released into the environment by various anthropogenic activities. Despite the toxic properties of ammonia in water, it also plays a pivotal role in the biogeochemical cycle of nitrogen (N) and regulates the mechanisms of normal and abnormal physiology in aquatic

organisms (Constable *et al*. 2003; Edwards *et al*., 2023). Ammonia cycling between a cnidarian animal host and intracellular symbiotic algae is a key metabolic pathway for corals; for example, recycled nitrogen accounts for 90% of the nitrogen demand of zooxanthellae in the coral *Stylophora pistillata*, and nitrogen cycles occur at a rate of 0.13% per day in algae and 0.013% per day in animal tissue (Rahav *et al*., 1989). External ammonium concentrations equal to 0.6 mM can sustain the growth of zooxanthellae populations in the coral *Stylophora pistillata* (Grover *et al*., 2002). However, a concentration of 0.001 mmol L^{-1} of ammonia or nitrate can significantly increase the expulsion of symbiotic algae from *Acropora nobilis*, *Palythoa* sp. and *Alveopora verrilliana* (Zhu *et al*., 2004).

The threshold concentration of ammonia in aquaculture is still unknown for several potentially produced coral species. Interactions between aquaculture research and the environment have emerged as promising technologies to contribute to ecosystem sustainability. Therefore, to enable large-scale cultivation of *X. umbellata*, the present study aimed to estimate the lethal concentration ($LC_{50}^{96\,h}$) of nonionized ammonia for this soft coral.

MATERIAL AND METHODS

Experimental design

The experiment was carried out at the Laboratory of Marine Fish Culture (LAPMAR) of the Federal University of Santa Catarina (UFSC). For this purpose, 80 specimens of *Xenia umbellata* were obtained from a small local producer in the city of Florianópolis, Brazil (Figure 1). The animals were acclimatized for 10 days in a 20 L tank with water from the ocean collected at Mozambique beach Florianopolis, Brazil (27°34′02′′S, 48°25′44′′W). The samples were subsequently transferred to experimental units filled with artificial marine water obtained by mixing fresh water purified via reverse osmosis with the addition of the natural marine salt Coral Pro Salt (Red Sea, USA), which was equipped with constant aeration and a thermostat to maintain a constant temperature at 24 °C.

Figure 1 – Colonies of the octocoral *Xenia umbellata* acquired for the experiment

Water preparation

In a 200 L tank, 120 L of freshwater sterilized with ultraviolet light and deionized water by reverse osmosis and an electrical conductivity of 0.714 µS m-1 were prepared. Afterward, 4.453 kg of Coral Pro Salt (Red Sea, USA) was added and dissolved via a submersible pump to homogenize the water for two hours until the salts were completely dissolved, following the manufacturer's recommendations. The salt used was chosen because it comes from the Red Sea, a place where *X. umbellata*, the species used in the experiment, naturally occurs, and, according to the manufacturer, meets the basic requirements of the chemical parameters of the water necessary for the maintenance of the species.

The saltwater was divided into six 20 L reservoir tanks. One of the tanks did not receive ammonium chloride (NH_4Cl) addition, whereas the other tanks received NH_4Cl concentrations calculated on the basis of the molecular weight of this salt. Water samples from each of the reservoir tanks were subsequently analysed. Water prepared and stored without ammonia content was used to carry out the necessary dilution of the samples for analysis and for the control group. The analyses were carried out at the Water Quality Laboratory of the Mariculture Station Elpídio Beltrame/UFSC via irradiance spectrophotometry, and the NH_4Cl weights and concentrations are shown in Table 1.

Table 1 - Weight of ammonium chloride used, and concentrations obtained in treatments

Treatments	Weight (g)	Analyzed (mg L^{-1})
0	-	0,001
1	0,0595	0,92
2	0,1788	3,87
3	0,2969	5,95
4	0,4158	8,46
5	0,5346	10,18

Determination of the median lethal concentration (LC_{50})

Sixteen experimental units with a capacity of 2 L (useful 1.5 L) were used, with LED lighting from an Al® Hydra 52 HD luminaire (Aquaillumination, USA), a light density (PAR peak) of 225 µmol photons m^{-2} s^{-1} and an average PAR over an area of 107 µmol photons m^{-2} s^{-1}, which is specific for coral development. The temperature was maintained at 24 °C, and the photoperiod was 12 h. The colonies of five animals were randomly distributed in the experimental units with five different concentrations (mg L^{-1}) of N-NH_3 [0.92], [3.87], [5.95], [8.46], [10.18], and a control group [0].

The experiment was conducted for 96 h. In the first 12 h, observations were made every 30 min to monitor animal movement and mortality. After this period, these observations were performed every 24 h at the same time daily. Temperature and pH analyses of the experimental units were also carried out during this period. Twenty-four hours after the beginning of the experiment, the first water changes were made through siphoning, and 100% of the water in each experimental unit was renewed so that the ammonia concentration was maintained at the predetermined levels. During daily maintenance, in addition to water changes, dead animals in each treatment were removed and counted. Data collection and physical–chemical parameters of the water occurred throughout the experimental period and were carried out in the morning, always at 10 am.

Accumulated mortality data were used to calculate the median lethal concentration over 96 h ($LC_{50}^{96\ h}$) and their respective confidence intervals via the mathematical method Trimmed Spearman-Karber (Hamilton *et al*., 1977). Organisms that did not show pulsation and that shrivelled during daily maintenance, lost their physical integrity (i.e., lost parts of the body) and caused turbidity in the water were considered dead.

RESULTS

The physical–chemical parameters of the water did not significantly differ among the groups at 96 h (Table 2). The median lethal concentrations of total ammonia and unionized ammonia were estimated for *Xenia umbellata* (Table 3).

The species *Xenia umbellata* presented a mortality curve within expectations, and almost all the treatments resulted in 100% lethality within a period of up to 96 h, except for the treatment with the lowest concentration of ammonia [0.92] and the control group, which did not experience mortality (Figure 2).

Table 2 – Water quality variables during assay of lethal concentration (LC_{50}) of non-ionized ammonia for soft coral *Xenia umbellata*. (*) Manufacturer's reference values for Coral Pro Salt (Red Sea – USA)

Variables	Control	[0,92]	[3,87]	[5,95]	[8,46]	[10,18]
Dissolved oxygen (mg L^{-1})	7.12±0.51	6.22±0.85	6.02±0.55	6.92±0.31	6.26±0.7	6.92±0.47
temperature °C	23.9±0.21	24.1±0.1	23.8±0.25	23.9±0.17	23.9±0.32	24.0±0.2
Salinity (‰)	34	34	34	34	34	34
pH	8.3±0.4	8.7±0.2	8.2±0.1	8.7±0.3	8.2±0.1	8.3±0.2
Total alkalinity (mg $CaCO_3L^{-1}$) *	250	250	250	250	250	250
Calcium (mg L^{-1}) *	435 - 465	435 - 465	435 - 465	435 - 465	435 - 465	435 - 465
Magnesium (mg L^{-1}) *	1,310 – 1,390	1,310 – 1,390	1,310 – 1,390	1,310 – 1,390	1,310 – 1,390	1,310 – 1,390
Potassium (mg L^{-1}) *	375 - 405	375 - 405	375 - 405	375 - 405	375 - 405	375 - 405
Phosphate (mg L^{-1}) *	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03

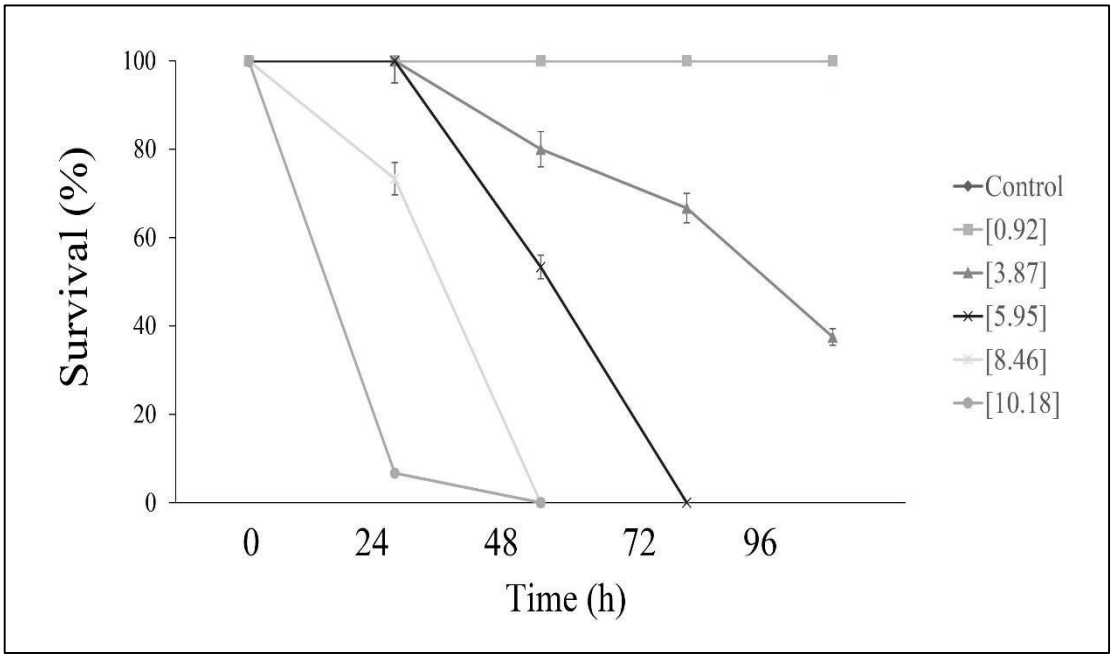
DISCUSSION

Ammonia is a chemical compound that originates mainly from the decomposition of biological residues and is toxic or lethal to animals, depending on the concentrations of $N\text{-}NH_3$ and the metabolic conditions of the animals (Randall and Tsui, 2002). Excess ammonia in the natural environment can harm coral reefs through eutrophication and degradation of water quality, with a consequent reduction in the photic zone that impairs the photosynthesis of symbiotic algae (zooxanthellae), which are essential for their survival (Constable *et al*., 2003; Hughes *et al*., 2003; Haas *et al*., 2009; Edwards *et al*., 2023). Currently, domestic and industrial effluents containing ammonia, originating from untreated or inadequately treated sewage, are a significant source of ammonia for marine environments (Edwards *et al*., 2023).

A concentration of 0.001 mmol L^{-1} ammonia or nitrate significantly increased the expulsion of zooxanthellae in *Acropora nobilis*, *Palythoa* sp. and *Alveopora verrilliana* (Zhu *et al*., 2004), whereas for the coral *Stylophora pistillata*, severe oxidative stress and a reduction in the aerobic

scope were observed when exposed to 3 μM NH_4^+ seawater enrichment combined with thermal stress (Marangoni *et al*., 2020).

Figure 2 – Survival of *Xenia umbellata* during acute exposure to ammonia for 96 h



According to Bassim and Sammarco (2003), increasing the seawater temperature in the presence of ammonia caused a significant decrease in the ciliary activity (motility) and larval settlement rate in a scleractinian coral (*Diploria strigosa*). On the other hand, Haas *et al*. (2009) described the negative impact of increased ammonia together with other inorganic compounds on the health of corals in the Red Sea, specifically on the deterioration of animal tissue, which was very similar to the findings of the present study; however, the direct impact of ammonia in coral cells was not detailed. A hypothesis for corals of the genus *Xenia*, as in other classes of Anthozoans, is that at high levels of inorganic nitrogen in water, zooxanthellae can retain more carbon for their own metabolism and growth, and consequently, less of this carbon is translocated to their host, causing coral mortality (Dubinsky and Jokiel, 1994).

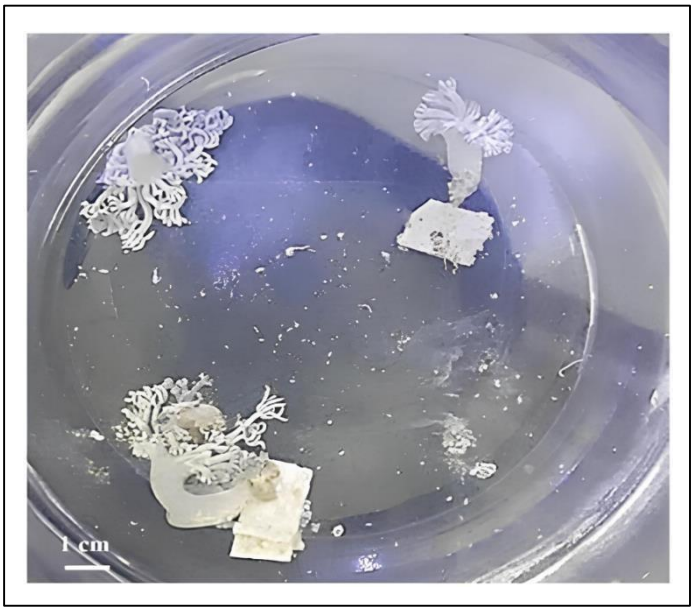


Figure 3 – Dead specimens of the coral *Xenia umbellata* after 72h in Treatment 3

The study of Octocorallia corals is incipient worldwide and became more popular in Brazil in the 1980s, with diving expeditions identifying native species of this group (Castro *et al*., 2010). The species of the present study is an Octocorallia nonnative to Brazil but is commonly found in the Brazilian marine ornamental market due to its relative rusticity, fast growth, and ease of management. The possibility of the proliferation of this species in Brazilian waters must be considered in the case of inadequate disposal of parts of colonies from domestic reef aquariums. This practice possibly led to the appearance of a similar species, popularly known as Xênia-azul (*Sansibia* sp.), described by Alderslade (2000) on the coast of Bahia; this species is also found on a tropical rocky reef in the southwest Atlantic, Brazil (Mantelatto *et al*., 2018).

Table 3 - Mean lethal concentrations of ammonia obtained by the Trimmed Spearman-Karber method according to Hamilton et al. (1977)

Time (h)	Total ammonia $N\text{-}NH_4+$	Confidence interval	Non-ionized ammonia $N\text{-}NH_3$	Confidence interval
24	8.81	8.18 - 9.50	0.77	0.71 - 0.82
48	4.9	3.95 - 6.10	0.42	0.34 - 0.53
72	3.74	3.02 - 4.63	0.32	0.26 - 0.40
96	3.3	2.61 - 4.18	0.28	0.22 - 0.36

Corals are examples of the richness and complexity of marine life, and the science developed in support of coral aquaculture can contribute to reducing the degradation of coral reefs around the world, supplying the ornamental, pharmaceutical and reef restoration industries (Leal *et al*., 2016).

On the basis of the present study, we conclude that the lethal concentration of ammonia decreases with increasing time and that the longer the exposure of the coral *X. umbellata* to ammonia is, the smaller the amount of ammonia necessary to intoxicate the animal. Furthermore, it was possible to conclude that concentrations below 0.96 mg L^{-1} total ammonia (0.08 $N\text{-}NH_3$) are not lethal for this organism in an exposure period of 96 h, since no mortality was observed in this group. Thus, the mean lethal concentration (LC_{50}) after 96 h of exposure to $N\text{-}NH_3$ was estimated to be 0.28 mg L^{-1}. These findings provide fundamental and important data on the toxic effects of ammonia on the coral *X. umbellata*. Some knowledge gaps were identified to support future research involving the cultivation of this species in aquaculture.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

G.M.B. – Conceptualization, Conducting the experiment, Investigation, Data curation. **M.S.O.** – Data analysis, Manuscript review, Final writing. **R.V.R**: Data analysis, manuscript review, final writing. **C.M.** – Methodology, Validation, Supervision, manuscript review.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data will be made available upon reasonable request.

ACKNOWLEDGEMENTS

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (grant code 001).

REFERENCES

Alderslade, P. (2000). Four new genera of soft corals (Coelenterata: Octocorallia), with notes on the classification of some established taxa. *Zoologische Mededelingen*, 74, 237-249.

Benayahu, Y. Reproduction and developmental pathways of Red Sea Xeniidae (Octocorallia, Alcyonacea). In: Williams, R. B. et al. (ed.). *Hydrobiologia. Belgium: Kluwer Academic Publishers*, 1991. p. 125-130.

Barton, J. A., Willis, B. L., & Hutson, K. S. (2017). Coral propagation: a review of techniques for ornamental trade and reef restoration. *Reviews in Aquaculture*, 9(3), 238-256. https://doi.org/10.1111/raq.12135

Bassim, K., & Sammarco, P. (2003). Effects of temperature and ammonium on larval development and survivorship in a scleractinian coral (*Diploria strigosa*). *Marine Biology*, 142, 241-252. https://doi.org/10.1007/s00227-002-0953-z

Boyd, C. E.; Watten, B. J. Aeration Systems in Aquaculture. *Reviews in Aquatic Sciences*, [s. l.], v. 1, n. 3, 1989. p. 425-472, 1989.

Castro, C. B., Medeiros, M. S., & Loiola, L. L. (2010). Octocorallia (Cnidaria: Anthozoa) from Brazilian reefs. *Journal of Natural History*, 44(13-14), 763-827. https://doi.org/10.1080/00222930903441160

Connell, J. H. (1978). Diversity in tropical rain forests and coral reefs: high diversity of trees and corals is maintained only in a nonequilibrium state. *Science*, 199(4335), 1302-1310. https://doi.org/10.1126/science.199.4335.1302

Constable, M., Charlton, M., Jensen, F., McDonald, K., Craig, G., & Taylor, K. W. (2003). An ecological risk assessment of ammonia in the aquatic environment. *Human and Ecological Risk Assessment*, 9(2), 527-548. https://doi.org/10.1080/713609921

Daly, M., Brugler, M. R., Cartwright, P., Collins, A. G., Dawson, M. N., Fautin, D. G., France, S. C., McFadden, C. S., Opresko, D. M., Rodriguez, E., Romano, S., Stake, J. (2007). The phylum Cnidaria: A review of phylogenetic patterns and diversity 300 years after Linnaeus. p. 127-182 in Zhang, Z-Q. and W.A. Shear (eds.), *Linnaeus Tercentenary: Progress in Invertebrate Taxonomy. Zootaxa* 1668: 1-766.

Dubinsky, Z., & Jokiel, P. L. (1994). Ratio of energy and nutrient fluxes regulates symbiosis between zooxanthellae and corals.

Edwards, T. M., Puglis, H. J., Kent, D. B., Durán, J. L., Bradshaw, L. M., & Farag, A. M. (2023). Ammonia and aquatic ecosystems–A review of global sources, biogeochemical cycling, and effects on fish. *Science of The Total Environment*, 167911. https://doi.org/10.1016/j.scitotenv.2023.167911

Grover, R., Maguer, J. F., Reynaud-Vaganay, S., & Ferrier-Pages, C. (2002). Uptake of ammonium by the scleractinian coral *Stylophora pistillata*: effect of feeding, light, and ammonium concentrations. *Limnology and oceanography*, 47(3), 782-790. https://doi.org/10.4319/lo.2002.47.3.0782

Haas, A., Al-Zibdah, M., & Wild, C. (2009). Effect of inorganic and organic nutrient addition on coral–algae assemblages from the Northern Red Sea. *Journal of Experimental Marine Biology and Ecology*, 380(1-2), 99-105. https://doi.org/10.1016/j.jembe.2009.09.005

Haddad, M. A. Cnidaria. In: Ribeiro-Costa, C. S.; Rocha, R. M. (ed.). *Invertebrados: manual de aulas práticas*. 2. ed. Ribeirão Preto: Holos, 2006. p. 26-53.

Hamilton, M. A., Russo, R. C., & Thurston, R. V. (1977). Trimmed Spearman-Karber method for estimating median lethal concentrations in toxicity bioassays. *Environmental Science & Technology*, 11(7), 714-719. https://doi.org/10.1021/es60130a004

Hughes, T. P., Baird, A. H., Bellwood, D. R., Card, M., Connolly, S. R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J. B. C., Kleypas, J., Lough, J. M., Marshall, P., Nyström, M., Palumbi, S. R., Pandolfi, J. M., Rosen, B., & Roughgarden, J. (2003). Climate change, human impacts, and the resilience of coral reefs. *Science*, 301(5635), 929-933. https://doi.org/10.1126/science.1085046

Kim, S., Wild, C., & Tilstra, A. (2022). Effective asexual propagation (fragmentation) method of the soft coral *Xenia umbellata*. https://dx.doi.org/10.17504/protocols.io.bsidnca6

Kremien, M., Shavit, U., Mass, T., & Genin, A. (2013). Benefit of pulsation in soft corals. *Proceedings of the National Academy of Sciences*, 110(22), 8978-8983. https://doi.org/10.1073/pnas.1301826110

Lamarck, M. C. (1816). Les Caracteres Generaux et Particuliers de ces Animaux, leur Distribution, leur Classes, leurs Familles, leurs Genres, et la Citation des Principales Especes qui s'y Rapportent. *Histoire Naturelle des Animaux sans Vertebres*, 2, 388-421.

Leal, M. C., Ferrier-Pagès, C., Petersen, D., & Osinga, R. (2016). Coral aquaculture: applying scientific knowledge to ex situ production. *Reviews in Aquaculture*, 8(2), 136-153. https://doi.org/10.1111/raq.12087

Marangoni, L. F. B., Ferrier-Pagès, C., Rottier, C., Bianchini, A., & Grover, R. (2020). Unravelling the different causes of nitrate and ammonium effects on coral bleaching. *Scientific Reports*, 10(1), 11975. https://doi.org/10.1038/s41598-020-68916-0

Mantelatto, M. C., da Silva, A. G., dos Santos Louzada, T., McFadden, C. S., & Creed, J. C. (2018). Invasion of aquarium origin soft corals on a tropical rocky reef in the southwest Atlantic, Brazil. *Marine Pollution Bulletin*, 130, 84-94. https://doi.org/10.1016/j.marpolbul.2018.03.014

Pérez, C.D., de Moura Neves, B., Cordeiro, R.T., Williams, G.C., Cairns, S.D. (2016). Diversity and Distribution of Octocorallia. In: Goffredo, S., Dubinsky, Z. (eds) *The Cnidaria, Past, Present and Future*. Springer, Cham. https://doi.org/10.1007/978-3-319-31305-4_8

Pomeroy, R. S., Parks, J. E., & Balboa, C. M. (2006). Farming the reef: is aquaculture a solution for reducing fishing pressure on coral reefs? *Marine Policy*, 30(2), 111-130. https://doi.org/10.1016/j.marpol.2004.09.001

Randall, D. J., & Tsui, T. K. N. (2002). Ammonia toxicity in fish. *Marine Pollution Bulletin*, 45(1-12), 17-23. https://doi.org/10.1016/S0025-326X(02)00227-8

Rahav, O., Dubinsky, Z., Achituv, Y., & Falkowski, P. G. (1989). Ammonium metabolism in the zooxanthellate coral, *Stylophora pistillata*. *Proceedings of the Royal Society of London. B. Biological Sciences*, 236(1284), 325-337. https://doi.org/10.1098/rspb.1989.0026

Reinicke, G. B. (1997). Xeniidae (Coelenterata: Octocorallia) of the Red Sea, with descriptions of six new species of *Xenia*. *Fauna of Saudi Arabia*, 16, 5-62.

Schlichter, D., Svoboda, A., & Kremer, B. P. (1983). Functional autotrophy of *Heteroxenia fuscescens* (Anthozoa: Alcyonaria): carbon assimilation and translocation of photosynthates from symbionts to host. Marine Biology, 78, 29-38. https://doi.org/10.1007/BF00392968.

Tomasso, J. R. (1994). Toxicity of nitrogenous wastes to aquaculture animals. *Reviews in Fisheries Science*, 2(4), 291-314. https://doi.org/10.1080/10641269409388560

Zhu, B., Wang, G., Huang, B., & Tseng, C. K. (2004). Effects of temperature, hypoxia, ammonia and nitrate on the bleaching among three coral species. *Chinese Science Bulletin*, 49, 1923-1928. https://doi.org/10.1007/BF03184283