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Marine Debris Undermines Herbivory in Coral-Algal Competition

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Abstract. Coral reefs are facing an emerging risk of coral-to-algae phase shift at global scale. Herbivory is known as the primary biological mechanism preventing phase shift. In contrast, marine debris has been recognized as an increasing threat to coral reef health. This paper examines whether these two factors are independent or synergistic from three aspects: marine debris impacts, the role of herbivory, and limited but growing evidence exploring interactions between them. The impact of marine debris on coral includes physical abrasion, chemical toxicity, and pathogen introduction. Microplastic ingestion has also been documented in fishes from seemingly unaffected reefs in remote areas. Herbivory has been found to influence the outcome of coral-algal competition through the timing of grazing relative to coral establishment and substrate availability, but this effect is highly variable depending on the spatial and temporal context of grazing activity and differs greatly among herbivore functional groups. Critically, herbivory itself can be disturbed by marine debris. These harms can take the form of both direct ingestion by scraping and browsing fish and behavioral avoidance of debris-covered substrate. This suggests that the effects of debris and herbivory loss may not be independent but instead potentiate. This paper proposes that they may produce a combined effect on coral-algal competition that may exceed what either factor would produce alone, although this compounded pathway has not yet been directly tested. These findings are crucial for reef management, as it may change conservation priorities from debris removal or herbivore protection alone to a combined effort.

Keywords: Marine debris, herbivory, coral-algal competition, phase shift, reef resilience

1. Introduction

Over the last 20 years, more and more evidence shows that marine debris is a growing threat to coral reef ecosystems worldwide [1-4]. However, existing studies on coral health usually focus on debris impact or herbivory effect individually, with relatively little work analyzing the interaction between the two factors. This is an important gap in the current understanding of coral reef ecology, as emerging evidence suggests marine debris may not simply act independently of herbivory but may actively damage it. Recently, evidence was presented indicating that plastic debris measurably decreases fish feeding pressure on reef substrate, implying that debris accumulation may disrupt the grazing mechanism, weakening the reefs' resistance to algal overgrowth [5]. If accurate, this would imply that marine debris and herbivory may not be separate threats but interacting stressors whose

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combined effect on coral-algal competition may exceed the impact of each factor individually. This is a hypothesis that this review develops but has not yet been directly tested. As global plastic production and reef degradation both continue to rise, determining whether or not debris and herbivory interact will be key to deciding which conservation strategy, debris removal, herbivore population protection, or a combination of both should be the priority for maintaining the health of the world's coral reef habitats.

By examining the independent effects of marine debris on coral health, the impact of herbivory on coral-algal competition, and the limited but growing evidence that these two factors interact directly across three bodies of evidence, this review hypothesizes that study of marine debris and herbivory separately may fail to accurately capture the combined impact of these stressors on coral reef resilience. This review also addresses knowledge gaps that must be resolved as coral reef managers respond to multiple stressors simultaneously and discusses potential underlying mechanisms behind the combined impacts. However, as few studies have conducted manipulations of both factors at the same time, the current available evidence for direct causation linking debris-driven herbivory loss to completed algal phase shifts remains mostly indirect, and the mechanisms and strength of their interaction are still not fully understood.

2. Marine debris as a direct stressor on coral reef ecosystems

Marine debris has been acknowledged by scientist in their recent literature as a widespread and independent stressor on coral reef ecosystems [3]. In a study on the effects of this stressor on corals, Nama et al. studied how marine debris affects coral tissue and other reef organisms. They found that physical abrasion, smothering, and chemical leaching associated with degrading plastics were damaging to corals and likely contribute significantly to their degradation [3].

Other than direct damage to corals, marine debris can also threaten reef ecosystems by participating in the food chain of fishes inhabiting them. According to Savoca et al., ingested plastic can be found in 386 species, including 210 of commercial importance [4]. Plastic ingestion has increased by approximately 2.4% per year for the last 10 years, revealing that debris exposure is a significant and growing pressure on marine fishes. More reef-focused investigation and more specific data are needed to determine if these impacts are also present in the coral-reef fish communities at the same magnitude.

Because macro-debris and microplastics pose different risks on coral organisms, it is necessary to discuss the mechanisms separately. Macro debris causes direct harm through abrasion of coral tissue and smothering of coral's habitat while microplastics create risks of ingestion and chronic chemical exposure. Huang et al. investigated microplastics in the coral reef fish populations in the Xisha Islands of the South China Sea, a site far from major populations [6]. Specifically, their study found microplastics in fifteen different coral reef fish species, with an average occurrence rate of 29.3%. These microplastics were primarily detected as tiny fibrous particles made of polyamide and polyethylene terephthalate. Contamination found in such a remote reef system implies that marine debris exposure affects not only localized but also extensive coral reefs.

Among different categories of macro-debris, the derelict fishing gear can cause particularly severe damages. A bibliometric analysis of literature on ghost fishing notes that derelict fishing gear can entangle, abrade, and smother coral colonies long after it is first discarded, and reviews strategies such as gear-marking and dedicated retrieval initiatives that might help reduce macro-debris buildup over time [7]. The nature of macro-debris differs from the more widespread and likely chronic effects of general litter or microplastics; macro-debris is likely to result in more acute and spatially concentrated impacts, potentially becoming more problematic over time as it catches

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additional debris passing by. This shows that not all types of marine debris causes the same level of risk to coral health, leading to the management hypothesis that gear-specific removal efforts could address a substantial portion of debris-related coral death compared to their share of total debris volume, though actual data on mortality and debris-volume would be needed to back this up. Overall, this review has highlighted three examples, including litter, microplastic ingestion and macro-debris, that indicate widespread exposure to different types of debris and provide a context within which debris may impact coral ecosystem functions such as herbivory.

3. Herbivory and coral-algal competitive dynamics

Before assessing the timing and extent of the impact of herbivory, it is important to understand how coral and algae compete. Under experimental conditions, algal turf suppresses coral photosynthesis by 8 to 29 percent within 24 hours of mere contact with algae through the release of allelopathic chemical compounds from the algal surface, without the effects of overgrowth or shading [8]. This effect was strongest during summer and negligible in winter, indicating that the competitive advantage algae hold over coral fluctuates temporally with sea temperature. Because of this chemical process, contact alone, not just overgrowth, is sufficient to harm coral tissue, and even small decreases in grazing pressure can allow algae to gain a foothold.

Some scholars further studied how herbivory affects the competitive dynamics between coral and algae. The work by Adam et al. highlighted that the order and timing of different species occupying the environment can result in different community structure [1]. Therefore, herbivories can be important for coral recovery after disturbances via complex priority effects. Notably, they also found that established juvenile corals can resist being overgrown by macroalgae without the presence of herbivores. This discovery reveals that the protective function of herbivory against coral decline is not always constant: its effectiveness depends on which organism becomes established first and the level of herbivory at the time when substrate becomes available for colonization. Such context-dependency is often absent from many previous models of herbivore-mediated resilience.

In addition to this temporal complexity, Wilson et al. discovered considerable site-to-site variation among herbivore grazing behavior even within the same species of parrotfish surveyed at different reef sites throughout the Caribbean [2]. Such results imply that herbivore abundance is not a sufficient predictor of actual herbivory rates on any particular reef, because grazing behavior itself varies by location. Together, these two studies indicate that herbivory's protective function in limiting algal overgrowth varies with environmental context, something that recent work is only beginning to quantify.

4. Marine debris as a disruptor of herbivory

Marine debris harms coral reef ecosystems in multiple ways, while herbivory protects corals from algal overgrowth in a context-dependent manner. A remaining critical question is whether debris also impairs the herbivory that reefs depend on. Cardozo-Ferreira et al. examined debris ingestion in three herbivorous reef fish species on the Brazilian coast, finding debris in the gut contents of 52.7% of all sampled fish [8, 9]. This coastal Brazilian dataset covers scraping and browsing functional groups with very different expected ingestion rates. Critically, there was considerable variation among feeding modes in ingestion rates: the scraping species showed ingestion rates of 74.6% and 95.7%, while a browsing species had a lower rate of 55.8%. This introduces yet another dimension of variation beyond what was discussed above: rather than only varying by location within a single functional group as Wilson et al. showed in parrotfish, debris is also unevenly distributed across

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different herbivore functional groups, with scrapers, an important functional group for facilitating coral settlement by removing algal turf, seemingly at the greatest risk. Beyond the rates of ingestion, debris lodged in the gut could reduce feeding efficiency by occupying gut space that would otherwise process algal material, although the actual physiological consequences of ingestion in these species were not tested in this study and are still unknown.

A second, behavioral mechanism operates alongside this direct ingestion pathway. Menezes et al. found that plastic debris present on reef substrate reduced fish feeding pressure even when fish rarely made direct physical contact with the debris itself, and that this avoidance was not diminished by the presence of biofilm on the plastic surface, which might otherwise be expected to attract grazing activity [5]. This suggests debris suppresses herbivory through two distinct, non-mutually exclusive pathways: ingestion-related risk, particularly among scraping species, whose physiological consequences remain undocumented, and behavioral avoidance of debris-affected substrate regardless of ingestion risk [5, 9].

When read alongside the herbivory literature discussed above, this interaction carries a specific implication. Debris alters ingestion risk unevenly across functional groups and suppresses feeding activity behaviorally [5, 9]. This may function as a disruption to top-down control analogous to what Adam et al. identify as decisive during the priority-effect window following coral disturbance [1]. Whether debris also contributed to the site-to-site behavioral variation documented by Wilson et al. is separate, more speculative possibility that has not been directly tested [2]. These findings indicate that marine debris would actively undermine the mechanism reefs depend on to resist algal overgrowth, particularly at the moments when that mechanism matters most. Experimental confirmation of this full pathway remains limited.

5. Management implications

These findings indicate that the management of marine debris and the conservation of herbivores are not separate priorities for reef management, but instead two interdependent components of the overall resilience of reef ecosystems. Nunes et al. found similar medium-high resilience scores in no-take and tourism-zoned reefs in the Tropical Southwestern Atlantic, in which herbivore biomass was the main positive indicator in both zone types. This suggested that it is the spatial management and compliance that possibly lead to these high resilience scores rather than the designation of a no-take area itself [10]. Given the evidence that debris negatively affects herbivore feeding activity, the paper recommends integrating debris removal and monitoring into existing resilience-based MPA frameworks, rather than administering it as an independent cleanup initiative [5, 9]. The following recommendations are proposals developed in this review rather than measures tested by the cited studies themselves. Firstly, debris removal efforts should be prioritized in areas known to be hotspots for scraping and browsing fish activity, since they have a relatively higher reported ingestion rate. Secondly, reef monitoring programs should monitor debris exposure per herbivore feeding group rather than total herbivore biomass, because the difference in species feeding mode may lead to different ingestion risk levels and behavioral responses. Lastly, future assessments of the effectiveness of MPAs on resilience should include debris density as a covariate along with herbivore biomass when evaluating resilience, in order to determine whether debris presence has a measurable impact on the protective effect that is usually credited solely to herbivore protection [2, 9]. This matches with other recommendations within the ghost-fishing literature for greater coordination of governance solutions like gear marking and retrieval programs to complement MPA management at a site level [7].

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Beyond the specific mechanisms addressed here, prioritizing any conservation intervention requires weighing ecological effectiveness against the practical constraints of funding and local capacity. Suggett et al. argue that sustainable reef restoration investment depends on integrating social and ecological priorities together, rather than optimizing purely ecological outcomes in isolation, since restoration and management efforts that ignore local community capacity and stakeholder priorities are less likely to be sustained over time [11]. Applied to the debris-herbivory interaction proposed here, this suggests that the specific combination of debris removal and herbivore protection recommended for a given reef should be adapted not only to which functional groups are locally at risk, but also to what local communities and managing authorities can realistically sustain over the long term, since an ecologically optimal intervention that lacks the resources or community buy-in to continue is unlikely to produce lasting resilience gains. On-the-ground implementation will therefore require adaptive adjustment for local reef conditions, as site-specific behavioral variability and resourcing prevent universal one-size-fits-all management prescriptions.

6. Conclusion

This paper set out to examine whether marine debris and herbivory act independently or interact in shaping coral-algal competition on coral reefs. The evidence gathered here indicates that marine debris causes direct, well-documented harm to coral tissue through physical abrasion, chemical exposure, pathogen transport, and, in the case of derelict fishing gear, acute structural damage, while separately, herbivory's protective role against algal overgrowth is context-dependent, varying with timing, location, and herbivore functional group rather than functioning as a constant safeguard. Most critically, marine debris can directly lower herbivory itself: herbivorous fish can ingest debris at distinct rates due to differences in feeding mode, and fish measurably reduce grazing activity around debris-covered substrate even without direct contact. Together, these findings suggest marine debris and herbivore loss should be understood as interacting stressors rather than independent threats, with a combined effect on reef resilience that this review proposes may exceed what either factor would produce alone.

These findings may be critical for coral reef management. If debris removal and herbivore protection are pursued as separate conservation priorities, management efforts may underestimate the benefit of addressing both simultaneously and may fail to identify reefs where debris is silently eroding the herbivory that management plans assume is protecting them. This paper has several limitations. There are few studies showing effects of marine debris on herbivory rates, and none of the studies we reviewed have measured debris exposure, herbivore functional-group activity, and resulting coral-algal outcomes together at the same sites. Thus, much of the causal chain proposed here, from debris exposure to reduced grazing to accelerated algal overgrowth, is therefore inferred by combining separate bodies of evidence instead of being confirmed through a single comprehensive study. Future studies could test this compound effect using multi-factor experimental designs in a manipulative field setting. Debris exposure, herbivory activity among functional groups, and coral and algae cover should all be measured and carefully evaluated.

References

[1] Adam, T. C., Holbrook, S. J., Burkepile, D. E., Speare, K. E., Brooks, A. J., Ladd, M. C., Shantz, A. A., Vega Thurber, R., & Schmitt, R. J. (2022). Priority effects in coral–macroalgae interactions can drive alternate community paths in the absence of top-down control. *Ecology, 103*(12), e3831. https://doi.org/10.1002/ecy.3831

DOI: 10.54254/2753-8818/2026.37438

[2] Wilson, M. W., Gaines, S. D., Stier, A. C., & Halpern, B. S. (2021). Variation in herbivore grazing behavior across Caribbean reef sites. *Marine Biology, 168*(4), 53. https://doi.org/10.1007/s00227-021-03844-9

[3] Nama, S., Shanmughan, A., Nayak, B. B., Bhushan, S., & Ramteke, K. (2023). Impacts of marine debris on coral reef ecosystem: A review for conservation and ecological monitoring of the coral reef ecosystem. *Marine Pollution Bulletin, 189*, 114755. https://doi.org/10.1016/j.marpolbul.2023.114755

[4] Savoca, M. S., McInturf, A. G., & Hazen, E. L. (2021). Plastic ingestion by marine fish is widespread and increasing. *Global Change Biology, 27*(10), 2188-2199. https://doi.org/10.1111/gcb.15533

[5] Menezes, M., Dias, J. D., & Longo, G. O. (2022). Plastic debris decreases fish feeding pressure on tropical reefs. *Marine Pollution Bulletin, 185*(Part A), 114330. https://doi.org/10.1016/j.marpolbul.2022.114330

[6] Huang, L., Li, Q., Li, H., Lin, L., Xu, X.-R., Yuan, X., Koongolla, J. B., & Li, H. (2023). Microplastic contamination in coral reef fishes and its potential risks in the remote Xisha areas of the South China Sea. *Marine Pollution Bulletin, 186*, 114399. https://doi.org/10.1016/j.marpolbul.2022.114399

[7] Wasave, S., Kamble, S., Kazi, T., Wasave, S., Sreekanth, G. B., & Sharma, A. (2025). A bibliometric review on ghost fishing: Impacts on marine environment and governing measures. *Marine Pollution Bulletin, 212*, 117604. https://doi.org/10.1016/j.marpolbul.2025.117604

[8] Altman-Kurosaki, N. T., Pratte, Z. A., Stewart, F. J., & Hay, M. E. (2025). Coral–algal competition: Allelopathy, temporal variance, and effects on coral microbiomes. *Coral Reefs, 44*(1), 49-62. https://doi.org/10.1007/s00338-024-02585-7

[9] Cardozo-Ferreira, G. C., Calazans, T. L., Benevides, L. J., Luiz, O. J., Ferreira, C. E. L., & Joyeux, J. C. (2021). Ecological traits influencing anthropogenic debris ingestion by herbivorous reef fishes. *Frontiers in Marine Science, 8*, 717435. https://doi.org/10.3389/fmars.2021.717435

[10] Nunes, V. F. C., Ferreira, M. T. O., Ferreira Junior, F., Amorim, M. B. B., Sampaio, C. L. S., & Pinto, T. K. (2022). Do marine protected areas protect shallow coral reef systems? A resilience-based management approach in Tropical Southwestern Atlantic reefs. *Journal of Coastal Conservation, 26*(6), 79. https://doi.org/10.1007/s11852-022-00930-y

[11] Suggett, D. J., Edwards, M., Cotton, D., Hein, M., & Camp, E. F. (2023). An integrative framework for sustainable coral reef restoration. *One Earth, 6*(6), 666-681. https://doi.org/10.1016/j.oneear.2023.05.007