The distribution of marine debris within a small *Zostera marina* meadow

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Abstract

Marine debris, which includes plastic debris and lost or abandoned fishing gear, has been negatively affecting coastal ecosystems for more than 50 years. We have been closely examining a seagrass ecosystem in Arikawa Bay, Nakadori Island, Nagasaki, Japan by collecting marine debris found within the seagrass meadow and in the barren sand surrounding the meadow. Over the course of the study period (2021 May to November), 117.2 $g \cdot m^{-2}$ of marine debris was collected, of which only 5.4% was collected from within the meadow. A multinomial analysis indicates that marine debris affects the coverage of seagrass and the probability of low coverage increases in the presence of marine debris. We hypothesize that the presence of marine debris is an additional factor that can lead to the degradation of seagrass ecosystems. We recommend that more research is needed to reveal the impacts of marine debris on seagrass ecosystems, given the sparsity of information regarding this environmental issue.

Keyword: Marine plastic/ Macrophyte/ Seagrass/ Coastal pollution /Marine litter/ Benthic ecosystems

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1. Introduction

Marine pollution can be roughly divided into three categories; radioactive pollution, chemical pollution, and pollution caused by the release of solid objects into the ocean; mostly plastics such as containers and fishing gear (Kennish 1997). Marine debris, such as plastic debris and lost or abandoned fishing gear remains a contemporary topic. However, it is relevant to note that the negative effects that marine debris causes in the marine ecosystem was pointed out more than 50 years ago. One of the first reports that suggested the negative effects of plastic debris in marine ecosystems was Carpenter and Smith (1972), which demonstrated that small plastic particles occurred in the Atlantic Ocean (i.e., Sargasso Sea) and suggested the potential harm to marine organisms. By the late 1970s, the wide- ranging dispersal of marine debris was reported in the Pacific and Antarctic Oceans, and studies described how entanglement and ingestion of plastics caused death in many marine mammals and birds (Merrel 1980, Slip and Burton 1991). Although the effect of marine debris, especially plastic debris, on megafauna has been the focus of many studies (e.g., Roman et al. 2021), lost and abandoned fishing gear has been shown to entangle benthic primary producers (Angiolillo and Fortibuoni 2020) and micro plastics are suggested to negatively affect the growth of microalgae (Gao et al. 2021). Indeed, microplastics have been found to accumulate in seagrass meadows (Sanchez-Vidal et al. 2021) and plastic debris accumulate within the coastal mangrove forests (Martin et al. 2019, Kesavan et al. 2021) and we are only just beginning to examine the impacts of these materials on marine benthic ecosystems.

Seagrass ecosystems are widespread coastal ecosystems that provide a wide variety of ecosystem services, such as carbon absorption, sediment stabilization, and fisheries production (Deyanova et al. 2017, Duarte et al. 2013, Unsworth et al. 2019). Along the coastal regions of Southeast Asia, seagrasses such as *Thalassia hemprichii* and *Cymodocea serrulata* and *C. rotundata* are abundant (Fortes et al. 2018). Further north, along the Ryukyu Archipelago (i.e., the islands extending from the southern tip of Kyushu Island to Yonaguni Island) seagrass taxa similar to those in Southeast Asia can be observed, although it remains the northern distributional limit for many taxa, especially *Enhalus acoroides*, *T. hemprichii*, *C. serrulata*, and *C. Rotundata* (Kuo et al. 2006). In the main islands of Japan, *Zostera marina* is the most frequently encountered species (Tanaka et al. 2009).

Throughout the world, seagrass ecosystems loss is accelerating (Waycot et al. 2009) with some species under the threat of extinction (Short et al. 2001). Although fine-scale maps of seagrass ecosystems in Southeast Asia are available (e.g., Fortes et al. 2018) information regarding the distribution of seagrasses in Japan remain vague at best (Tanaka et al. 2009). Nevertheless, the extent of seagrass (i.e., *Z. marina*) distribution in Japan is decreasing and the declines have been attributed to climate change as well as coastal water pollution (Terawaki et al. 2003). There is some progress in research regarding seagrass restoration in Japan; the management of environmental conditions, such as light and water quality and sand and water motion, are prerequisites for the expansion of seagrass meadows in Japan (Hiraoka et al. 2006).

Since May 2021, we have been investigating the effects of marine debris on the coverage of a small (ca. 1470 m^2) patch of seagrass (*Z. marina*) in Arikawa Bay, Nakadori Island, Nagasaki, Japan. We are interested in examining the negative effects of marine debris on seagrass ecosystems, since marine debris was hypothesized to increase stress and mortality of mangroves (Martin et al. 2019), and because southwestern Japan is a sink for a large quantity of marine debris that originates from the East China Sea (Lee et al. 2006, Kuroda et al. 2020). Although Sanchez-Vidal et al. (2021) show that seagrasses can trap marine debris, especially small plastic debris, and remove it from the water column, we hypothesized that through entrapment and removal of marine debris, seagrasses succumb to negative effects caused by entanglement, scouring and smothering. Therefore, as a first step into understanding the mechanisms that cause negative effects on seagrass ecology by marine debris, we examine the hypothesis that marine debris can influence the distribution of seagrasses in a well-defined coastal ecosystem.

2. Methodology

The study site is located in a small cove in Arikawa Bay, Nakadori Island, Nagasaki, Japan (32.9883°N, 129.1180°E). It is a small area well protected from wave energy by a seawall on its western edge. Surveys of marine debris and seagrass coverage were conducted once a month from 2021 May to November by skin-diving. Each monthly survey commenced by preparing 5 transects running north-south across the seagrass meadow during the first month (May) and increased to 11 transects thereafter. Each transects was 10 m apart during the first survey and 5 m apart thereafter. Photo quadrats were taken at 2 m intervals along each transect and the coverage of seagrass was given a rank of A to E, where A was for coverage estimated to range from 71% to 100%, B was for the range 41% to 70%, C was for the range 11 to 40%, D was for the range 1 to 11%, and E indicated no seagrass coverage (McKenzie, 2003). The result of this survey was modeled with a generalized additive model (GAM), assuming a multinomial distribution, and by applying a probit link-function. The response variable was the coverage rank and the predictors were the spatial coordinates of the quadrats.

Next, a survey independent of the transect surveys was conducted to assess the coverage of seagrass in the presence of marine debris. At most, five photo quadrats were taken in a haphazardly chosen location of the seagrass meadow, in areas of sand in the presence of marine debris, and in areas of the seagrass meadow in the presence of marine debris. The probability of seagrass coverage rank with respect to the type of marine debris was also analyzed assuming a multinomial distribution. In this case, the coverage rank was the response variable and type of marine debris was the predictor. The link-function was the probit function. The effect of the presence of marine debris on the probability of coverage rank was assessed using the difference in the expected log predictive probabilities (ELPD) of the model tested against the null model (Vehtari et al. 2017).

Finally, all observable marine debris were collected and classified into six categories: plastics, ropes and nets, metal debris, rubber debris, glass and ceramics, and textiles. Marine debris that was collected from the survey site were transported to the field lab, cleaned of organic matter, separated and dried prior to classification and measurement. Debris was measured to the nearest gram using an electronic scale and the density of marine debris found during the survey period is expressed with respect to the area of the seagrass meadow or sand.

All statistical analyses were done in R version 4.1.2 (R Core Team 2021) using Bayesian methods. A Student's t-distribution with 3 degrees-of-freedom, a location of 0, and a scale of 2.5, was used as the prior distribution for all parameters in the model. Four Markov chains were generated to produce at least 1000 effective samples. The chains and posterior distributions of all models were visually assessed.

3. Results

The total area of the survey site was 3740 m^2 and seagrass was detected in approximately 1470 m^2. The mean and standard deviation of spatial area for each coverage rank was, 35±19 m^2 for rank A, 110±34 m^2 for rank B, 216±97 m^2 for rank C, 664±158 m^2 for rank D, and 2534±484 m^2 for rank E. The multinomial GAM also indicated that the most likely rank to be observed at the study site was E and the next highest was D (Figure 1). Indeed, most of the seagrass were concentrated in the center of the survey site.

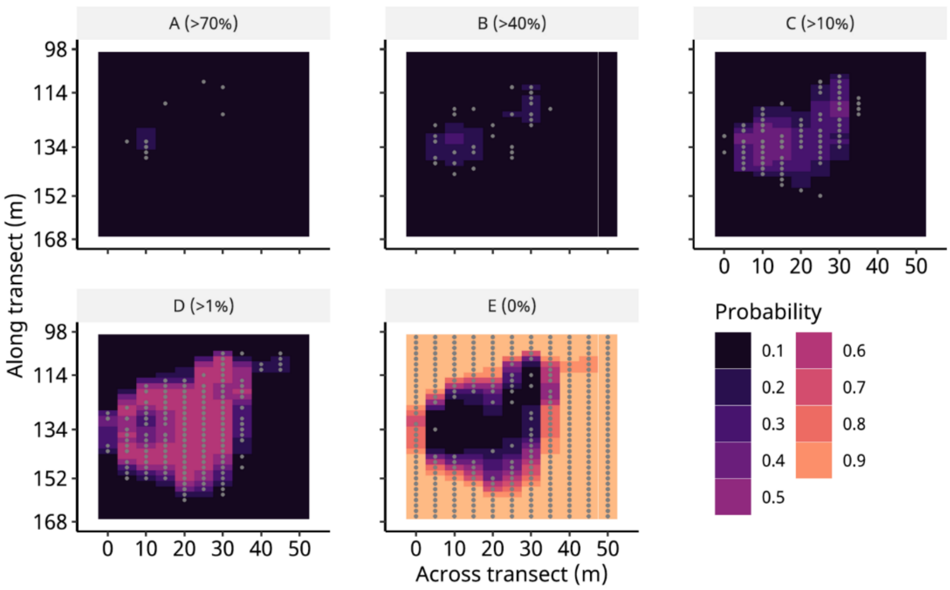

Figure 1. Multinomial model of seagrass coverage in a small *Zostera marina* meadow in Arikawa Bay, Nakadori Is., Nagasaki, Japan**.** Grey dots indicate a single quadrat with the appropriate coverage rank.

Over the survey period a total of 117.2 $g{\cdot}m^{-2}$ of marine debris was collected. A total of 110.7 $g{\cdot}m^{-2}$ was collected from the sand surrounding the seagrass meadow and only 6.5 $g{\cdot}m^{-2}$ was collected from within the meadow. Rope and nets associated with fishing gear was the most abundant type of marine debris (Figure 2) by mass. A total of 87.2 $g{\cdot}m^{-2}$ was collected from the study site, with the majority found in coverage rank E (i.e., sand). The next most abundant type of marine debris were glass and ceramics with a density of 10.1 $g{\cdot}m^{-2}$. Plastics debris, which includes plastic bags, plastic bottles, and large plastic fragments from household goods were the next most common type of debris in coverage rank E and the total density of plastics was 10.0 $g{\cdot}m^{-2}$. Metal debris, rubber debris, and discarded textiles were relatively less abundant by mass and ranged from 1.7 $g{\cdot}m^{-2}$ to 4.4 $g{\cdot}m^{-2}$

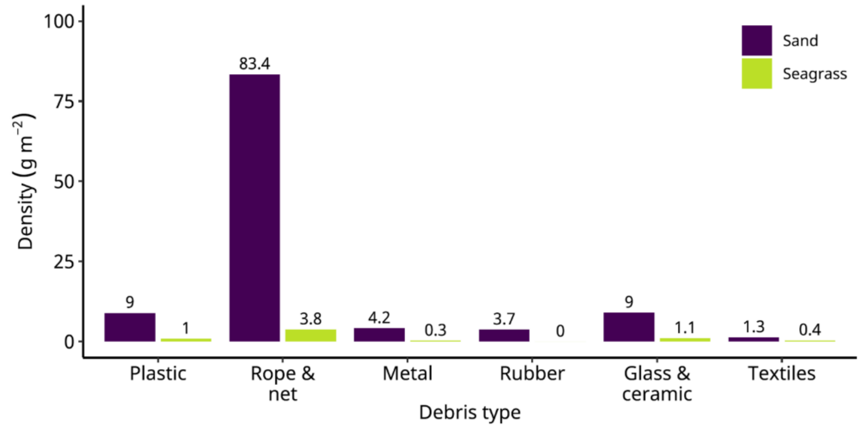

Figure 2. The total density of marine debris collected from the survey site during 2021 May to November.

A multinomial analysis of the transect-independent photo quadrat surveys revealed that at total of 133 pieces of debris were collected over the survey period (Figure 3A). Among which, plastics were the most common type of debris (71 items) while rope and nets (i.e., fisheries gear related debris) were the second most common (47 items). The model indicated that marine debris was an important factor that influenced coverage score (ΔELPD = -44.9±8.6) and that the probability of observing any type of marine debris was highest in coverage rank E (i.e., sand; Figure 3B). This contrasts with areas where no marine debris were observed, where coverage rank E occurred at relatively low probabilities.

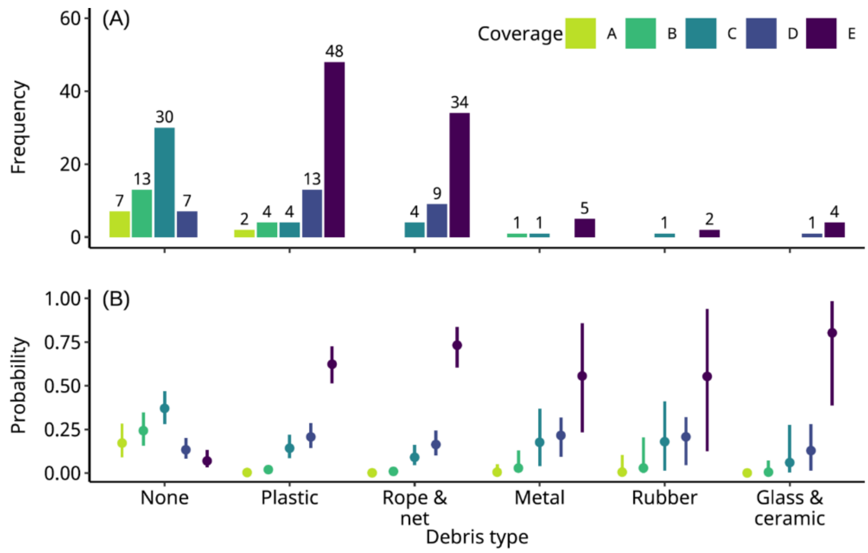

Figure 3. The (A) frequency of items observed in the survey site and (B) the multinomial model of the probability of coverage rank with respect to the presence of marine debris. None indicates no marine debris. The dots indicate the expected value and the vertical lines indicate the 95% highest density credible interval.

4. Discussion

The marine debris collected in and around the seagrass meadow of Arikawa Bay, Nagasaki, Japan was exclusively anthropogenic in origin. Approximately 86.1% of the collected marine debris by mass was plastic (i.e., plastic and rope and nets) or rubber, since the ropes and nets were all made of synthetic materials. It is difficult to compare our findings with past studies, since most studies of marine debris in coastal areas rely on the collection and identification of debris that are cast-up on shore (e.g., Fauziah et al. 2015) or focuses on the impact of microplastics on the benthos (e.g., Thushari et al. 2017). The frequency of plastics observed in the seagrass meadow in our study, were similar to that of an intertidal coastal area in False Bay, South Africa, where plastics accounted for 31% to 78% by mass (Weiderman et al. 2020). Plastics were also the most common type of marine debris trapped by mangrove forests along the coastal areas of the Arabian Gulf (Martin et al. 2019) and in the mangrove regions of Mumbai, India where 62% of the trapped marine debris were plastic (Kesavan et al. 2021).

Nets and rope were the most abundant marine debris by mass and generally occurred in the areas where seagrasses were not found (i.e., coverage rank E), ropes and nets were also the most abundant type of debris found in areas where seagrasses were present, however there was one order of magnitude less material within the meadow (Figure 2). Indeed, there was systematically less marine debris within the seagrass meadow when compared to the adjacent barren areas of sand. Therefore, unlike Sanchez-Vidal et al. (2021), where seagrasses were effective in trapping micro-size plastic particles, macro-plastic debris and any other large debris in general are unlikely to be able to penetrate the canopy of a seagrass meadow, since the hydrodynamic regime can abruptly change near the vicinity of the canopy (Inoue et al. 2019). Near the canopy, water motion is deflected and reduced by canopy drag, and can lead to the settlement of large objects prior to entering the canopy interior (Abdolahpour et al. 2018). We can only speculate that marine debris can also cause seagrass loss in our study site because of the lack of historical data on the extent of seagrass cover in Arikawa Bay prior to the deposition of marine debris. A long term study would be needed to elucidate the mechanisms through which marine debris affects the seagrass meadow at our study site. However, manipulative experiments and field studies elsewhere have demonstrated the negative impacts of plastics on the surface of seagrass bed through shading (Fitzpatrick and Kirkman, 1995), facilitate the spread of invasive species (Menicagli et al. 2021) or by altering biogeochemical processes when buried in the sediment (Green et al. 2015, Balestri et al. 2017). Nevertheless, our analysis indicates that in the presence of marine debris, the probability that seagrasses are present is low (Figure 2 and Figure 3). Here, we provide a few hypotheses that remain to be explored.

The presence of nets, ropes, and plastic bags may interfere with seagrass shoot expansion, rooting of new seedlings, and nutrient flux to and from the sediment by preventing the ingress of rhizoids into barrens sandy areas and preventing the flow of materials to and from the sediment surface. The mechanisms through which marine debris, especially that of plastic bags and nets, affect seagrass ecology can be inferred from the use of plastic films (i.e., plastic mulch) used by the agricultural industry. Plastic films are widely used in the agriculture industry to prevent the growth of weeds through a combination of smothering and blocking sunlight, increasing soil temperature, and providing soil stabilization (Sintim and Flury 2017). We hypothesize that plastic bags and other plastic debris in a seagrass meadow can likewise prevent material flux and interfere with rhizoid expansion. Indeed, *Z. marina* rhizoids were often observed at the edges of buried nets but were not detected within net masses during our study. The effect of smothering and shading by plastic debris is supported by evidence that plastic accumulation in the root zone of mangroves causes stress and negatively affects tree survival (van Bijsterveldt et al. 2021). Alternatively, the removal of marine debris on the surface and those buried in the sediments can lead to the recovery and facilitate the expansion of seagrasses.

Marine debris especially ropes and plastic bags can also cause entanglement. Entanglement can increase the drag experienced by individuals and elevate the risk of dislodgement and structural failure. Discarded and abandoned fishing debris was shown to negatively impact benthic animal and coral communities (Yoshikawa and Asoh 2004, Angiolillo and Fortibuoni 2020), leading to necrosis and breakage. Although we did not conduct experiments to directly assess the effects of smothering or entanglement on seagrasses, the high probability of a rank E coverage in the presence of marine debris supports our belief that large marine debris can lead to the degradation of seagrass ecosystems.

5. Conclusion

More than 60% of marine debris is plastic (World Economic Forum 2016) and the economic cost of marine plastics on ecosystem services is believed to range from 3300 to 33,000 USD ton^{-1}year^{-1} (Beaumont et al. 2019). Although research regarding the effect of microplastics on our ecosystems and the effects on marine debris on megafauna are increasing, very little is known about how plastics will affect the state of seagrass, mangrove, coral, and macroalgal ecosystems. Our study on the distribution of marine debris in a small seagrass meadow suggests that the accumulation of marine debris, especially persistent non-degradable plastics can be one factor in the degradation of these ecosystems.

We recommend that research regarding the impacts of marine debris on benthic ecosystems intensify and expand, so that we can continue to benefit from these important and productive coastal ecosystems.

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References

Abdolahpour, M., Ghisalberti, M., McMahon, K. and Lavery, P. S. 2018. The impact of flexibility on flow, turbulence, and vertical mixing in coastal canopies. Limnology and Oceanography (63), 2777–2792.

Aleksandarov, B. G., Minicheva, G. G., Strikalenko, T. V. 2002. Ecological aspects of artificial reef construction using scrap tires. Russian Journal of Marine Biology (28), 120–126.

Angiolillo, M. & Fortibuoni, T. 2020. Impacts of marine litter on Mediterranean reef systems: From shallow to deep waters. Frontiers in Marine Science (7), 581966.

Balestri, E., Menicagli, V., Vallerini, F., Lardicci, C. 2017. Biodegradable plastic bags oon the seafloor: A future threat for seagrass meadows? Science of the Total Environment (605-606), 755-763.

Beaumont, N.J., Aanesen, M., Austen, M.C., Börger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K., Pascoe, C., Wyles, K.J., 2019. Global ecological, social and economic impacts of marine plastic. Marine Pollution Bulletin (142), 189–195.

van Bijsterveldt, C. E. J., van Wesenbeeck, B. K., Ramadhani, S., Raven, O. V., van Gool, F. E., Pribadi, R., Bouma, T. J. 2021. Does plastic waste kill mangroves? A field experiment to assess the impact of macro plastics on mangrove growth, stress response and survival. Science of The Total Environment (756), 142826.

Carpenter, E., & Smith, K. 1972. Plastics on the Sargasso Sea surface. Science (175), 1240-1241.

Deyanova, D., Gullström, M., Lyimo, L.D., Dahl, M., Hamisi, M.I., Mtolera, M. S. P., & Björk, M. 2017. Contribution of seagrass plants to CO_2 capture in a tropical seagrass meadow under experimental disturbance. PLOS ONE (12), e0181386.

Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I. & Marba, N. 2013. The role of coastal plant communities for climate change mitigation and adaptation. Nature Climate Change (3), 961–968.

Fitzpatrick, J. & Kirkman, H. 1995. Effects of prolonged shading stress on growth and survival of seagrass *Posidonia australis* in Jervis Bay, New South Wales, Australia. Marine Ecology Progress Series (127), 279-289.

Fauziah, S.H., Liyana, I.A., & Agamuthu, P. 2015. Plastic debris in the coastal environment: The invincible threat? Abundance of buried plastic debris on Malaysian beaches. Waste Management & Research (33), 812–821.

Fortes, M. D., Ooi, J. L. S., Tan, Y.-M., Prathep, A., Bujang, J. Si., & Yaakub, S. M. 2018. Seagrass in Southeast Asia: a review of status and knowledge gaps, and a road map for conservation. Botanica Marina (61), 269-288.

Green, D. S., Boots, B., Blockley, D. J., Rocha, C., Thompson, R. 2015. Impacts of discarded plastic bags on marine assemblages and ecosystem functioning. Environmental Science and Technology (49), 5380-5389.

Gao, G., Zhao, X., Jin, P., Gao, K., & Beardall, J. 2021. Current understanding and challenges for aquatic primary producers in a world with rising micro- and nano-plastic levels. Journal of Hazardous Materials (406), 124685.

Hiraoka, K., Sugimoto, K., Miura, H., Terawaki, T., & Okada, M. 2006. Study on eelgrass (*Zostera marina* L.) bed restoration based on literatures and field experiment. Environmental Science (19), 241-248. in Japanese.

Inoue, Y., Terada R., Belleza, D. F. C., Nishihara G. N. 2020. Effect of water velocity on the physiology of a collapsing *Sargassum siliquastrum* canopy under a controlled environment. Phycological Research (68), 313-322.

Kennish, M. J. 1997. Practical Handbook of Estuarine and Marine Pollution. CRC Press, Bota Raton. pp. 554.

Kesavan, S., Xaiver, K. A. M., Deshmukhe, G., Jaiswar, A. K., Bhusan, S., Shukla, S. P. 2021. Anthropogenic pressure on mangrove ecosystems: Quantification and source identification of surficial and trapped debris. Science of the Total Environment (794), 148677.

Kuroda, M., Ichida, K., Tokai, T., Miyamoto, Y., Imai, K., Yagi, M., Yamanaka, Y., Mituhashi, T. 2020. The current state of marine debris on the seafloor in offshore area around Japan. Marine Pollution Bulletin (161), 111670.

Lee, D.-I., Cho, H.-S., Jeong, S.-B. 2006. Distribution characteristics of marine litter on the sea bed of the East China Sea and the South Sea of Korea. Estuarine, Coastal and Shelf Science (70), 187-194.

Martin, C., Almahasheer, H., Duarte, C. M. 2019. Mangrove forests as traps for marine litter. Environmental Pollution (247), 499-508.

McKenzie, L. J. 2003. Guidelines for the rapid assessment and mapping of tropical seagrass habitats. (QFS, NFC, Cairns), 46 pp.

Menicagli, V., Balestri, E., Vallerini, F., De Battisti, D., Lardicci, C. 2021. Plastics and sedimentation foster the spread of non-native macroalga on seagrass meadows. Science of the Total Environment (757), 143812.

Merrell, T. 1980. Accumulation of plastic litter on beaches of Amchitka Island, Alaska. Marine Environmental Research (3), 171-184.

Roman, L., Schuyler, Q.,Wilcox, C., & Hardesty, B. D. 2021. Plastic pollution is killing marine megafauna, but how do we prioritize policies to reduce mortality? Conservation Letters (14), e12781.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sanchez-Vidal, A., Canals, M., de Haan, W.P., Romero, J., & Veny, M. 2021. Seagrasses provide a novel ecosystem service by trapping marine plastics. Scientific Reports (11), 254.

Sintim, H. Y. & Flury, M. 2017. Is biodegradable plastic mulch the solution to agriculture's plastic problem? Environmental Science & Technology (51), 1068-1069.

Slip, D., & Burton, H. 1991. Accumulation of fishing debris, plastic litter, and other artefacts, on Heard and Macquarie Islands in the Southern Ocean. Environmental Conservation (18), 249-254.

Tanaka, N., Aida, S., Akaike, S., Aramaki, H., Chiyukubo, T., Chow, S., Fujii, A., Fujiwara, M., Ikeuchi, H., Ishii, M., Ishikawa, R., Ito, H., Kudo, T., Muraoka, D., Nagahama, T., Nambu, T., Okumura, H., Oshino, A., Saigusa, M., Shimizu, Y., Suwa, T., Suzuki, K., Takeda, K., Tanada, N., Tanimoto, T., Tsuda, F., Urabe, S., Yatsuya, K., Yoshida, G., Yoshimatsu, T., Yoshimitsu, S., Yoshimura, K., Morita, K., Saitoh, K.. 2009. Distribution of Zostera species in Japan. I. *Zostera marina* L. (Zosteraceae). Bulletin of the National Museum of Nature and Science. Series B (35), 23-40.

Terawaki, T., Yoshikawa, K., Yoshida, G., Uchimura, M., Iseki, K. 2003. Ecology and restoration techniques for *Sargassum* beds in the Seto Inland Sea, Japan. Marine Pollution Bulletin (47), 198-201.

Thushari, G. G. N., Senevirathna, J. D. M., Yakupitiyage, A., & Chavanich, S. 2017. Effects of microplastics on sessile invertebrates in the eastern coast of Thailand: An approach to coastal zone conservation. Marine Pollution Bulletin (124), 349–355.

Unsworth, R. K. F., Nordlund, L. M. & Cullen-Unsworth, L. C. 2019. Seagrass meadows support global fisheries production. Conservation Letters (12), e12566.

Vehtari, A., Gelman, A., and Gabry, J. 2017. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Statistics and Computing (27), 1413–1432.

Weideman, E. A., Perold, V., Omardien, A., Smyth, L. K., Ryan, P. G. 2020. Quantifying temporal trends in anthropogenic litter in a rocky intertidal habitat. Marine Pollution Bulletin (160), 111543.

World Economic Forum, 2016. Ellen MacArthur Foundation and McKinsey & Company, The New Plastics Economy - Rethinking the Future of Plastics.

Yoshikawa, T. & Asoh, K. 2004. Entanglement of monofilament fishing lines and coral death. Biological Conservation, (117), 557-560.