Sustainable Manufacturing and Environmental Pollution

Biodolomer®Ocean

Material Development, Testing and Pilots

Prepared by Tim Coles

21 December 2023

The GAIA Biomaterials Project, implemented by GAIA Biomaterials AB and Catchgreen in partnership with Kompost-it, FishSA, and Alnet, has been awarded a UK International Development grant in order to replacing harmful polyethylene fishing nets with biodegradable nets in an innovative application of Biodolomer®Ocean, a polybutylene succinate (PBS) based biodegradable polymer.

The grant has been made via the Sustainable Manufacturing and Environmental Pollution (SMEP) Programme. The SMEP Programme is funded by UK International Development from the UK Government and is implemented in partnership with the UN Trade and Development (UNCTAD) providing technical support. The grant has been awarded until [Month, Year].

UK International Development

Partnership | Progress | Prosperity

SMEP is funded by UK International Development Finance and is implemented in partnership with UN Trade and Development (UNCTAD), who provide Technical Assistance to the programme.

catchgreen Powered by Biodolomer®

Purpose of this report

Catchgreen, in partnership with GAIA Biomaterials, has developed the PBS-based, biodegradable polymer Biodolomer® Ocean. This polymer is being trialed, as a spun rope, as a replacement for traditional nylon & HDPE fishing gear in order to reduce the negative impacts of ALDFG or "ghost fishing" by creating gear that will be metabolized into harmless biomass at its end-of-life.

Polybutylene succinate (PBS) has been shown to biodegrade into water and carbon in multiple environments, including compost and marine sludge/sediment. This occurs in a two-step process whereby hydrolysis on the surface removes monomers/oligomers, which are then metabolized in a reaction catalyzed by the naturally occurring enzyme PBSase.

Previous research into PBS-based fishing gear has shown degradation after approximately 24 months and some loss in fishing efficiency for some applications after heavy use. Catchgreen is focused on overcoming these efficiency losses through selective replacement of net parts with Biodolomer® Ocean to retain efficiency, application-tailored formulas, and exploring fishery sectors we believe the current product will be well-suited to.

Lab testing of Biodolomer® Ocean is currently underway with SINTEF in Norway. Although these have only been running for 6 months, preliminary results are promising and indicate early stages of degradation and small losses in tensile strength. Extensive further testing is planned and will determine exactly how, and how quickly Biodolomer® Ocean degrades, in different marine environments. Similar compounds have shown a usable life span of 2 years and an ultimate degradation rate strongly influenced by local environmental factors. Data from the further tests in real ocean conditions is crucial to determining the suitability and potential changes that may need to be made to our formula for future commercial production of Biodolomer® Ocean.

Pilot projects are underway to see how Biodolomer® Ocean performs in various applications. Many partners have come on board to trial this project across varied industries. We are confident that variations of the current version of Biodolomer® Ocean perform well in its pilots in kelp & seaweed farming, coral restoration, and modified gill nets, opening up large markets. We hope that future grades will be suitable for other mode advanced applications including trawl & full gill nets. Due to the complex nature and high-performance requirements of these nets, further refinement may be required to create a grade with greater strength.

A large-scale production run is scheduled for early 2024 to make Biodolomer® Ocean available for more piloting, the most ambitious of which is a trawl net for use in South Africa.

Table of Contents

Figures

BACKGROUND

Catchgreen is working in partnership with GAIA Biomaterials, a leading biopolymer producer, in the development of a material that can replicate or exceed the performance of traditional plastic fishing gear, whilst being able to biodegrade or compost at the end of its usable lifespan – or when lost at sea. The benefits of such a material would be numerous, including the reduction of plastic pollution as macro-, meso- or microplastics, elimination of ”ghost nets/fishing”, and enhanced marine ecosystem and food supply resilience in line with global SDGs and the EU Mission: Restore our Oceans and Waters. This mission seeks to reduce plastic litter by 50% and microplastics by 30% by 2030 and has been a leading light for our project.

However, achieving this grail of marine sustainability is a complex and demanding task, requiring extensive research, development, and testing. GAIA is currently trialing a polymer called Biodolomer® Ocean, which uses a PBS-base that can be broken down by hydrolysis & a naturally occurring enzyme found in certain microbes, including those in marine sediment. Trials to determine the suitability of Biodolomer® Ocean for fishing gear have yielded positive results, however, these trials are ongoing and more time and testing is required before the long-term efficacy and suitability of the new polymer can be accurately assessed. The fishing industry is diverse and the gear varies, with different material requirements in disparate regions for dissimilar applications. Current applications in the trial phase include gillnets (head and lead lines), seaweed & kelp farm infrastructure, coral restoration, lobster traps, and trawl nets. We are most confident that our current grade is suitable for many of these applications, and that future grades tailored for performance in other applications are not far off.

This report will lays out how Biodolomer® Ocean was developed, its expected performance in a variety of settings, and the processes behind Biodolomer® Ocean's eventual decomposition.

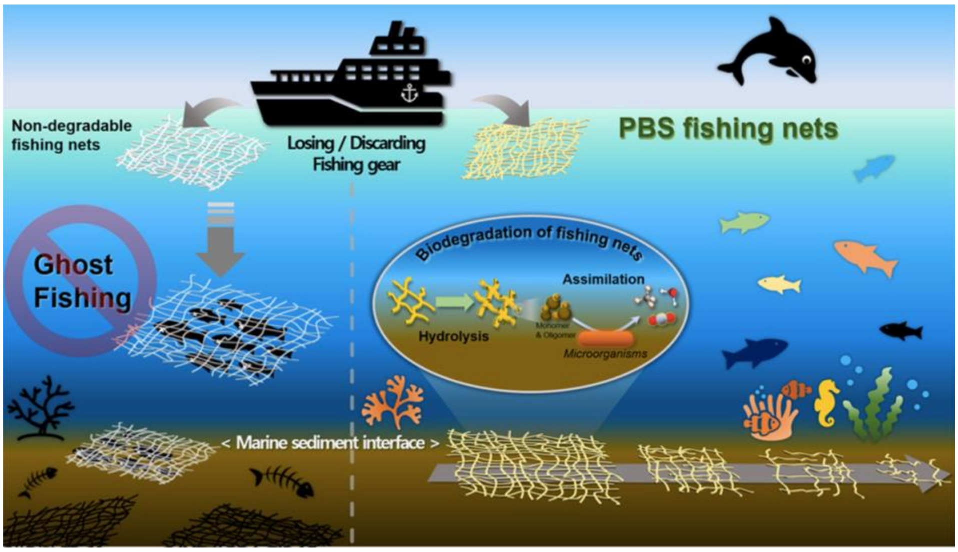


Figure 1. The process of decomposition of biodegradable fishing nets

Image Source: Kim et al., 2023

THE ROAD TO BIODOLOMER® OCEAN

GAIA BioMaterials, founded in 2015 by famous Swedish inventor Åke Rosén, has a plant in Helsingborg where it has its research labs, produces products, and creates its unique Biodolomer® Granules. Working together with Catchgreen, R&D Manager Konrad Rosen and his team at GAIA have developed an alternative to polyamide that is aimed at replacing conventional polluting plastics in marine applications. Polyamides (HDPE or Nylon 6,6 in this case) are traditionally used in the manufacturing of fishing gear due to their useful properties – high strength, flexibility, resilience, and toughness. Our proposed alternative, better material would need to emulate these properties, be manufactured and processed in a similar way in existing machines, perform in harsh environments for up to three years, and biodegrade in the ocean if lost or in compost if recovered at end-of-life. Using a unique mix of biodegradable polymers, calcium carbonate (from limestone), sugar cane, and vegetable oils Konrad and his team have created a biodegradable polymer that may be a viable alternative, as well as eliminating the formation of microplastics during use, reducing energy consumption during manufacturing and leaning on bio-based ingredients.

Traditional Biodolomer® consists of three main groups. Binders such as PBAT, PLA or PBS form the bulk of the material and define base properties. Fillers, here talc and CaCO3, may detract from, or in this case *enhance* the properties of the binder whilst lowering overall cost. Additives such as antistatics are used to enhance, add or remove certain qualities based on the intended use.

Konrad and his team have been working on a recipe that allows for durability during use *and* planned degradation if lost at sea or during the end-of-life phase – a juggling act of the highest degree. Building on the proven success of biodegradable Biodolomer® but optimizing for this application was never going to be easy, and required a rethink of the binder better suited to this environment. PBS was selected as the binder and was copolymerized with PBAT (polybutylene adipate terephthalate), another biodegradable polymer similar to fossil-based polyethylene, with good flexibility and resilience.

WHY PBS?

Polybutylene succinate (PBS) is a promising aliphatic polymer that can naturally biodegrade through various routes, including digestion by microbes found in the ocean . This polymer has a balanced range of properties well-suited to this application, notably thermal stability, flexibility and ductility, as well as good processability across a wide range of temperatures. Physical properties of PBS can be markedly varied by the content & type of co-polymers, the key tool that allows us to tailor our material to the application. By changing the size and bonds formed during crystallization process the resultant material properties are changed. Copolymerization of PBS generally increases elongation at breakage and impact strength but decreases tensile strength, as well as decreasing thermal properties. Concentration of comonomers is generally kept below 15-20% mol to maintain stable PBS qualities in the final product. PBS is also marginally denser than conventional polymers, which means that products (nets) derived from PBS will sink – removing their ghost fishing potential and delivering them to microbe-rich ocean sediment.

Although industrial production currently relies on synthesis from fossil resources, PBS can be produced from renewable monomer sources such as corn and sugarcane, and producers worldwide are moving towards making this economically viable. When this becomes reality, PBS will be an important polymer in the fight against reliance on fossil resources and pollution as a plastic that is both biodegradable and bio-based.

Results from the RISE test indicated that the 900643-5 blend had potential but also revealed some shortcomings. The relatively high concentration of PBAT lowered overall crystallinity potential and meant that stable spinning only occurred in a relatively small temperature window. These qualities of the material are undesired as the material is destined for industrial production and manufacturers may be unable to accurately replicate the effective temperatures. A second test was run in November 2022 at the Primo filament extrusion line with 900463-5, as this facility better replicates industrial manufacturing conditions. Although it was possible to spin and create strong filaments with this grade, some problems related to production temperature and the overall stretchability of the

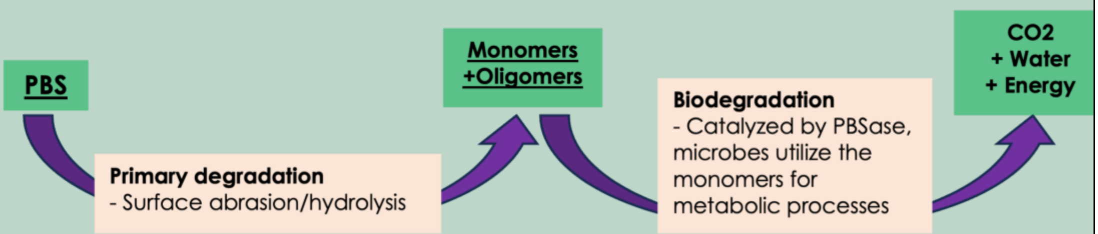
Two subtly different versions of Biodolomer® Ocean have been produced in Green and Orange for manufacturing trials at Alnet in South Africa in June 2023. The manufacturing trials at Alnet were a success, with 9 runs across two different die sizes with slight changes to the production variables, including temperature, pressure, and filters. The manufacturing trials yielded valuable data about not only the filament but also the processing.

Two new grades have subsequently been developed and are scheduled for manufacturing trials in February 2024. A final grade for scale-up in 2024 is ever nearer, and although we are overjoyed with the great strides Konrad and the team at GAIA have made in bringing us the results we have we are, as always, looking forward and improving. Further development is planned before production scales, mainly focused on increasing toughness, stress, and flaw sensitivity by adding a polymeric chain extender to react with the chain ends of the PBS and increase the melt viscosity.

BIODEGRADATION OF PBS

PBS (and other environmentally degradable plastics) are broken down initially by mechanical wear/hydrolysis that causes lower molecular species (monomers and oligomers) to be shed from the surface of the PBS. The inside of the material maintains its crystallinity and strength whilst the surface changes at a rate determined by the crystallinity and hydrophobicity of the polymer, and environmental conditions – abrasion, temperature & UV exposure are known to increase this rate. These lower molecular species shed from the surface are then broken down into CO2 and water by microorganisms and an enzyme found in nature, PBSase. There are a few strains of microorganisms able to do this, and they occur naturally in the environments in which PBS is destined to be broken down within. The hydrolysable ester bond found in the main chain is susceptible to microbial attack, although the rate at which this happens varies greatly depending on the total composition of the polymer (varied by addition of copolymers) and the environment. Soil, compost or marine sediment all have far higher concentrations of these microorganisms, and PBSase, than seawater, so the bulk of the degradation process may be limited whilst a PBS-based polymer is in use, and accelerated when it reaches sediment.

Numerous studies (Kunioka et al, 2009 and others) on the biodegradation of PBS *powder* (high surface area) in compost at high temperature (around 60 degrees Celsius) have shown very quick degradation rates, up to 80% in fewer than 80 days, however it must be noted that these is ideal degradation conditions and not representative of our use case. Suffice to say, it is certainly not a “forever plastic”! Other studies using different forms of PBS (pellets and films) demonstrated lower rates but all found evidence of decomposition (Huang et al, 2018, amongst others). There is a large body of prior research that has demonstrated the safe, albeit slower decomposition of PBS in marine environments too, much of it focused on the potential to use in fishing gear. A study run in Korea recently showed that PBS fishing gear on the seawater sediment surface was converted into CO2 by 27.3% over 180 days (Kim et al, 2023), with the primary degradation occurring through surface abrasion and the products being metabolically utilized thereafter by microorganisms, chiefly from the *Rhodococcus* genus. This is particularly promising as it may be indicative of the biodegradation process requiring the initial abrasion to begin, which bodes well for the potential retention of strength whilst in use – before becoming ALDFG. It is also interesting as other studies identified *Vibrio ruber* and other members of the Gazogenes clade as the vibrios chiefly responsible for biodegradation/the production of PBSase, although this capability is being found in more and more microbial life as studies on PBS broaden. Chemical degradation by hydrolysis in pure water at 25°C has hardly any effect on pure PBS, which was shown to have almost constant bending strength even after 1500 hours immersion (Kanemura et al, 2012). Current estimates sit at around the two year mark for the use cycle for PBS or PBSAT nets, with two separate studies in Korea and Portugal finding similar results (Kim et al, 2016). The degree to which hydrolysis can affect the PBS is very dependent on the water temperature and crystallinity of the polymer, thus differing environments, production temperatures and copolymers will greatly affect the overall lifespan. The presence of fillers in the PBS also has a significant effect on the speed of biodegradation, with studies showing an increase in the rate when PBS is paired with biobased or natural fillers (Platnieks et al, 2020).



OUR LAB TESTING

Although we have strong science on the breakdown of PBS in nature, we are not working with a pure PBS and every additional copolymer or additive will have some effect on the rate and method of degradation. Whilst we know our plastic can and will biodegrade, questions regarding it's useful lifespan and rate of degradation are still to be answered precisely, and this will take time. Four different grades are currently being tested for degradation and loss of tensile properties with SINTEF in Norway, using different analytical tools such as respirometric analysis, thermal desorption pyrolysis GC-MS (TD/pyrGC-MS), Scanning Electron Microscopy (SEM)/optical microscopy, differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR), potentially X-ray photoelectron spectroscopy (XPS), tensile strength (mechanical) testing, and analysis of microbial community composition (16S rRNA amplicon sequencing). As the project has only been running for 18 months (with testing of the material for 6 months) we do not yet have conclusive results across all the proposed analytical tools, but we have seen some loss of surface material and a small reduction in tensile strength in material tested in the lab for 6 months. FTIR testing indicates that this primary degradation likely occurred as a result of the removal of lower molecular species from the surface as predicted, potentially due to hydrolysis. This is indicated by a shift in the carbonyl peaks from $1715cm^{-1}$ to $1711cm^{-1}$ in some of our grades. The surface roughness has also increased slightly in at least two of the samples. This may be indicative of biodegradation, in line with previous research (Kim et al) that demonstrated slow biodegradation of a PBS-PBAT blend in cold seawater.

The ongoing Pyrolysis GC-MS analysis can be supplemented with GC-MS/LC-MS analysis for quantification of specific degradation of the different components in the test material over time (primary degradation) and used for extrapolation of degradation beyond the test period. By combining respirometric and chemical analyses, it would then be possible to study both primary (component-specific) and ultimate (BOD/conversion to CO2 and water) biodegradation of the material to be tested. SINTEF will also look to examine the microbial communities that form – and change - on the material over time, analyse the water-soluble components and microplastic formation (toxicity) and look at accelerated weathering cases by including UV, temperature and humidity in their studies. These tests will be essential to determining the how and why of Biodolomer®'s biodegradation, the length of the use period, and the time taken to fully biodegrade after this – key information that will guide our development of future grades, and allow us to accurately predict applications for which our current grades will work.

A proposed experimental setup to be deployed across multiple sites to determine the rate of degradation of our nets/material whilst recording potentially contributing environmental factors.

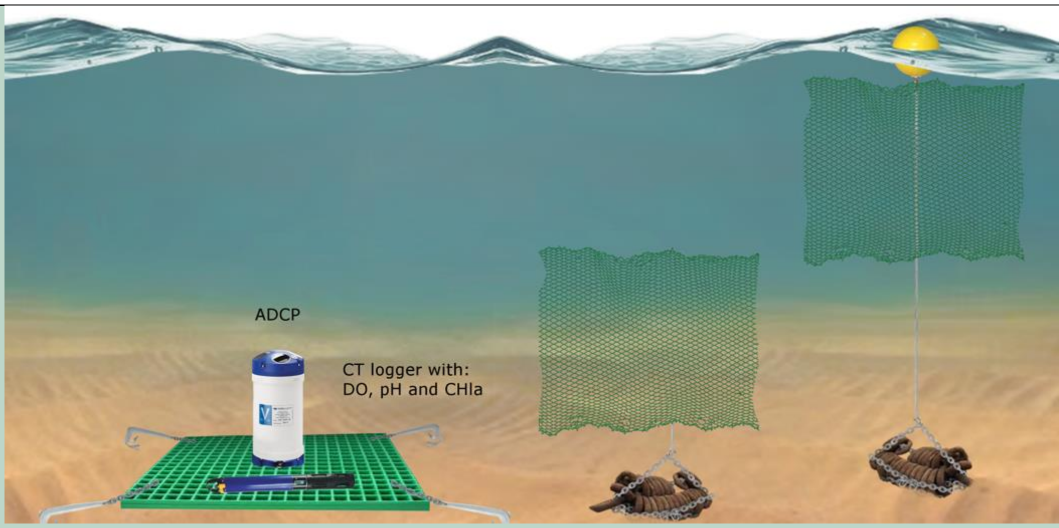


Figure 2. Proposed experimental setup

Source: CLS, Southern Africa

1 Proposed Ocean Biodegradability testing

While the SINTEF tests are conducted under lab conditions, our products are destined for life at sea. Therefore, a further experiment has been devised, in which the nets will be anchored to the seafloor in various locations worldwide and monitored over 24 months, for catch efficiency, entanglement of non-target species (ghost fishing), strength, durability, and degradation. This will enable us to confirm our assumptions that these nets, sunk to the ocean floor, will have a low impact on marine life both whilst they are intact and as they degrade into non-toxic biomass. These tests will take place in South Africa, Kenya, Norway, and Britain and require commercial dive teams and the cooperation of local marine research institutes.

It is also certain that the degradation rate of Biodolomer® Ocean will vary by location, application, and environment so along with lab and open-water testing we have undertaken to do real-world application tests in as many use cases as possible through our pilot projects. Factors to consider here will be abrasion, UV exposure, water temperature, exposure to sediment or other microorganism-rich settings, and most importantly stress and wear from use in the given application – increases in any of which will probably increase the degradation rate. The crucial fact will be whether this significantly alters the mechanical properties in a short timeframe, in which case additives that increase durability or otherwise maintain durability will be added to later grades.

Although conventional nylon nets are too durable for our collective good, it is a mistake to think they are immune to degradation, particularly whilst in use. Previous studies that have compared PBSAT nets with nylon have found that they both suffer reductions in tensile strength and elongation at break, particularly after heavy use. A study focused on the Norwegian gill net fishery (Grimaldo et al., 2018) demonstrated only a 5% difference in tensile strength loss between nylon and biodegradable nets after a long season. Although the knots of the biodegradable net did suffer somewhat higher rates of light damage overall they demonstrated almost identical numbers of broken and badly damaged knots, indicating that nylon is perhaps not as invincible as we may believe. The same study did register a significant (26.6% and 22.5%) reduction in overall catch for the biodegradable gillnets across cod and saithe, and although the cause of this is not completely clear it is thought to be a factor of the tensile strength reduction. Our product aims to address these issues by redesigning the gear in such a way that biodegradable ropes are used for headlines and other crucial net parts, but keeping the catching area in nylon – thus if the net is lost it will lose its shape & ghost fishing ability but **no fishing efficiency is lost** whilst it is in use, and the biodegradable ropes are in place and whole. Through our pilots, we hope to prove this concept further.

A recent study looking at the replacement of conventional gear with biodegradable alternatives suggested that this replacement, even if new gear had lower efficiencies, is already economically viable and would pay dividends in the future as the effects of ghost gear are mitigated, as the fishers would likely not see immediate results (nylon ghost fishing gear can last for many decades in the ocean) they would need to be incentivized and financially supported through the transition period (Drakeford et al, 2023). Our proposal to replace only certain parts in some nets/applications means that we can remove ghost fishing potential far more quickly than with a conventional net whilst maintaining efficiency, a win-win situation for fishers and the environment.

Other studies, such as one on the Korean croaker fishery (Kim, S. et al, 2016) and one on the snow crab fishery demonstrated no significant difference in catches and even showed the biodegradable nets catching fewer smaller/undersize individuals and bycatch, which would be positive for fishers (and fish!) that may have to return these, dead or alive, to the ocean. It is hypothesized that the reason for this may be the slight increases in stiffness of the biodegradable nets, but further study is needed.

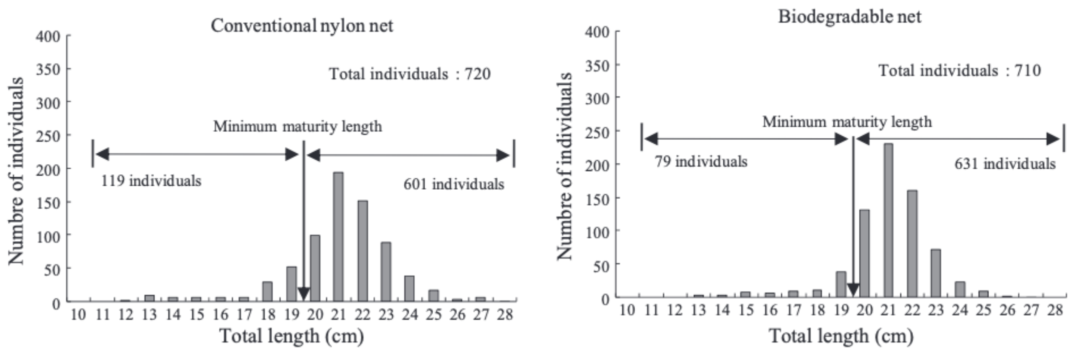


Figure 3. Comparison and catch composition for Korean croaker fishery

Source: Kim et al., 2016

PILOT PROJECTS

Catchgreen has partnered with stakeholders across the board to develop, learn, and provide viable alternatives to the “forever plastics” currently in use. These pilots will yield performance, durability, and composting data (the first of their kind in Africa) to assess the suitability of Biodolomer® Ocean within each fishing sector and location. Based on the data, future grades will be tailored to meet the requirements for each application if necessary. Below is a brief outline of our partners, the applications we are testing for, and preliminary results where available. For projects not already provided with rope/material, the later grade chosen for production at Alnet in early 2024 may be provided if we believe this shall perform better.

2 Kenya Marine Fisheries Research Institute (KFMRI)

A range of different projects are currently running in partnership with local government and communities.

2.1 Gillnets

Gillnets represent an important study area as they play a large role in commercial and artisanal fisheries worldwide - and often become deadly ghost nets. Previous studies in North Atlantic, Danish, and Korean fisheries have shown that fully biodegradable gill nets exhibit somewhat lower catch efficiency, so we have remedied this through redesign and selective replacement of gillnet sections. We have provided our product (3000m of 1.5mm & 2mm twine) to fishermen from the Kuruwitu Beach Management Unit (BMU) to modify gillnets to include Biodolmer® Ocean in specific areas of importance, and for easier recovery. These will be tested for fishing performance and durability over a year. So far, 6 nets have been modified and fishing trials alongside traditional nets have begun, although the data is not yet in. At the end of their usable life, these nets will be composted for a year to simulate the end-of-life process for recovered gear. Response from fishers has been generally positive, as they feel Biodolomer Ocean replicates the normal HDPR, however, they have raised concerns about the texture and fraying. These problems may be solved by tweaking our formula for less friction, slowing down the spinning of ropes & burning ends during net manufacturing.

2.2 Seaweed farming

Seaweed farming creates a livelihood for many people in impoverished coastal areas, particularly women. This economic activity can be key to their upliftment, empowerment, and development, although traditional HDPE ropes used contribute to local and marine pollution when lost or at the end of their usable life. Catchgreen has provided 5000m of 8mm Biodolomer® Ocean rope to 5 female farmers of the Kibuyuni BMU to trial alongside HDPE in their seaweed farms. Data for the growth rate and dry biomass is recorded bi-weekly for a year to provide performance information, and the ropes will be used until they break to provide data on their longevity. Initial results suggest that the seaweed takes well to our ropes, potentially due to the slightly rougher texture that may prove advantageous for this application. Some setbacks were experienced regarding the initial tying of seaweed fragments to the rope. This was attributed to a looser twist of the rope during manufacturing, a problem easily remedied. Another concern was the higher density of the ropes which made the manual handling more difficult. This may be overcome by reducing the thickness to 6mm. For this application, we are almost certain our current grade will be sufficient to replace existing ropes without sacrificing performance.

2.3 Coral Restoration

Coral restoration plays an important role in remediating degraded marine environments, restoring biodiversity and marine life and increasing resilience. The current process involves a time-consuming and expensive growth and transplant step which may be avoided when using our ropes. Biodolomer® Ocean will also biodegrade into CO2 and CaCO3 – key building blocks for coral formation! Our 8mm rope has been provided to the Wasini BMU for piloting, where coral fragments are attached directly onto the rope before it is pegged into the seafloor in degraded areas. Each pilot covers 500m^2 and is being monitored monthly for growth rates, material biodegradation, survival rates and biodiversity over a year. Preliminary results indicate that the coral has taken well to the rope, and feedback from the researchers suggests that the loose twist made it easier to attach fragments. It was noted that the rope did far more easily than HDPE, but this is another application for which we believe the current grade is more than sufficient.

A parallel project in French Polynesia run by the NGO **Coral Gardeners** is seeking to replicate this experiment in their local ecosystem, monitoring similar indicators whilst using 900m of three-strand Biodolomer® Ocean. This project includes regular strength tests of the ropes to evaluate the lifetime pf the ropes.

3 Kelp farming

Kelp farming is an important and rapidly growing aquaculture sector that can contribute to agar, livestock, and marine feed production. In partnership with a kelp farm in South Africa, the project aims to expand our knowledge and potential customer base by piloting the replacement of traditional, harmful plastic ropes with Biodolomer® Ocean. The project has been allocated 220m of three-strand 16mm rope, for use in hatchery cultivation of kelp sporophytes and subsequent out-planting. Performance indicators in both phases will be recorded, as will durability over time. This industry is gaining traction worldwide for its numerous environmental and health benefits, and if Biodolomer® Ocean can be marketed as a viable, sustainable alternative to conventional rope the rewards may be significant. We believe the current grade will satisfy all the requirements for this application and can't wait to get the results in!

4 Lobster cages

Lobster traps have a high chance of becoming ALDFG and can continue ghost fishing for many years – if they do not biodegrade. Regulation has been steadily introduced across countries where these traps are used to ensure they do not remain functional for years after being lost, and should this regulation and voluntary adoption continue this represents an exciting market for Catchgreen expansion. A commercial lobster company in South Africa will pilot the use of biodegradable rope for use in the traps and markers and will monitor the performance of these traps against their conventional traps for performance and durability. We expect the current grade to do well here and believe we may be close to breaking into this multimillion-dollar market.

5 Trawl fishing

Trawl nets are an incredibly important but complex area of study for the adoption of Biodolomer® products. The size of the worldwide industry, the financial position of the companies and the outsize contribution to microplastics created through abrasion mean that these nets are ripe for replacement with biodegradable options – should we prove their viability. Trials will be run in which nets consisting wholly or partly of Biodolomer® Ocean will be trawled in deep water fishing along the Cape Coast alongside HDPE nets to allow for data on performance and durability to be captured. Variables in question will include catch composition, weight & efficiency, damage & loss, biodegradation, and potential increases in drag due to the marginally heavier weight of our product. These nets are large and complex and may require a specific Biodolomer® Ocean grade refined for the strength and density characteristics required. It is possible that only the replacement of certain sections of the net is viable at this point, but even replacing the "sacrificial" dolly ropes or the net belly would yield significant microplastic & harm reduction.

ONWARDS AND UPWARDS

We believe that our current grade shall prove successful in coral restoration, kelp & seaweed farming, and lobster trap applications and will work towards proving this, and breaking into the market. We hope that we will find similarly positive results in both trawl and gill net applications but as the requirements here are far more complex than those of the before-mentioned industries we believe there may be a need for further refinement or the creation of grades specific to these industries. We will also need the data from the various analyses provided by further SINTEF testing to make sure Biodolomer® Ocean is both safe and durable enough for its planned applications. Although there is, unfortunately, no silver bullet for marine plastic pollution we believe we have made massive strides towards providing the fishing industry a brilliant alternative to conventional materials that wreak havoc on our shared oceans. We are incredibly proud of how far Catchgreen has come in this pursuit, the partnerships, relationships, and projects we've nurtured and grown along the way, and, of course, the brilliance of the team at GAIA in delivering the foundation from which we shall build. However, we are far from finished. We will have new, better grades for large-scale production in 2024, hard data from our pilots and testing with SINTEF to guide and tailor the development of our new polymers, expanded partnerships in the public and private sectors, and, as always, a passionate team dedicated to tackling the specter of ocean waste.

RECOMMENDED CITATION

Lorem ipsum Lorem ipsum Lorem ipsum Lorem

BIBLIOGRAPHY

Aliotta, L., Seggiani, M., Lazzeri, A., Gigante, V., & Cinelli, P. (2022). A brief review of poly (butylene succinate)(PBS) and its main copolymers: synthesis, blends, composites, biodegradability, and applications. *Polymers*, *14*(4), 844.

Drakeford, B. M., Forse, A., & Failler, P. (2023). The economic impacts of introducing biodegradable fishing gear as a ghost fishing mitigation in the English Channel static gear fishery. *Marine Pollution Bulletin*, *192*, 114918

Grimaldo, E., Herrmann, B., Vollstad, J., Su, B., Moe Føre, H., Larsen, R. B., & Tatone, I. (2018). Fishing efficiency of biodegradable PBSAT gillnets and conventional nylon gillnets used in Norwegian cod (Gadus morhua) and saithe (Pollachius virens) fisheries. *ICES Journal of Marine Science*, *75*(6), 2245-2256.

Huang, Z.; Qian, L.; Yin, Q.; Yu, N.; Liu, T.; Tian, D. Biodegradability studies of poly(butylene succinate) composites filled with sugarcane rind fiber. Polym. Test. 2018, 66, 319–326.

Kanemura, C.; Nakashima, S.; Hotta, A. Mechanical properties and chemical structures of biodegradable poly(butylene-succinate)

for material reprocessing. Polym. Degrad. Stab. 2012, 97, 972–980.

Kim, S., Kim, P., Lim, J., An, H. and Suuronen, P. (2016), Use of biodegradable driftnets to prevent ghost fishing: physical properties and fishing performance for yellow croaker. Anim Conserv, 19: 309-319. https://doi.org/10.1111/acv.12256

Kim, Y., Park A., Jung, S., Yun, H., Choi, K., Heo., Jin, H., Heo, G., Jin, H., Park, S. and Kwak, H (2023), Biodegradation behavior of polybutylene succinate (PBS) fishing gear in marine sedimentary environments for gear fishing prevention, Polymer Degradation and Stability, Vol 216.

Kunioka, M.; Ninomiya, F.; Funabashi, M. Biodegradation of poly(butylene succinate) powder in a controlled compost at 58 °C evaluated by naturally-occurring carbon 14 amounts in evolved CO2 based on the ISO 14855-2 method. Int. J. Mol. Sci. 2009, 10, 4267–4283.

Platnieks, O.; Barkane, A.; Ijudina, N.; Gaidukova, G.; Thakur, V.K.; Gaidukovs, S. Sustainable tetra pak recycled cellulose/poly(butylene succinate) based woody-like composites for a circular economy. J. Clean. Prod. 2020, 270, 122321

Xu, B.-H. Guo, Poly(butylene succinate) and its copolymers: Research, development and

industrialization, Biotechnol. J. 5 (2010) 1149–1163.

Zhao, J. H., Wang, X. Q., Zeng, J., Yang, G., Shi, F. H., & Yan, Q. (2005). Biodegradation of poly (butylene succinate) in compost. *Journal of Applied Polymer Science*, *97*(6), 2273-2278.

DISCLAIMER

This is an output of research funded by the Sustainable Manufacturing and Environmental Pollution (SMEP) Programme. UK International Development, from the UK Government, and UN Trade and Development (UNCTAD) provide financial and technical support for SMEP. The views expressed and information contained in this document (including any maps and their respective borders) are not necessarily those of or endorsed by the UK government, UNCTAD or the entities managing the delivery of SMEP, which can accept no responsibility or liability for such views, completeness, or accuracy of the information or any reliance placed on them.

UK International Development

Partnership | Progress | Prosperity

SMEP is funded by UK International Development Finance and is implemented in partnership with UN Trade and Development (UNCTAD), who provide Technical Assistance to the programme.

catchgreen

Powered by Biodolomer®