BETTER ALTERNATIVES 3.0

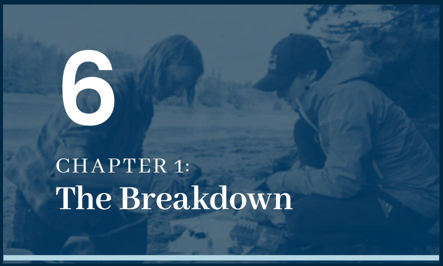
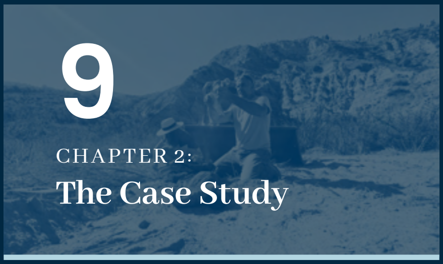
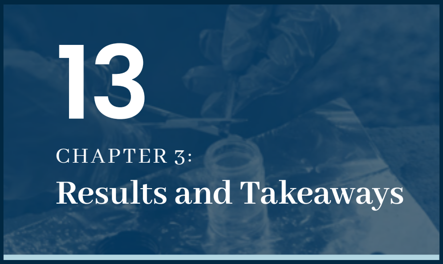
A CASE STUDY ON BIOPLASTIC PRODUCTS AND PACKAGING

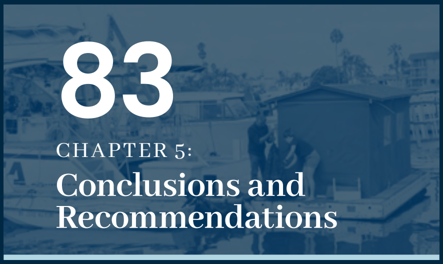
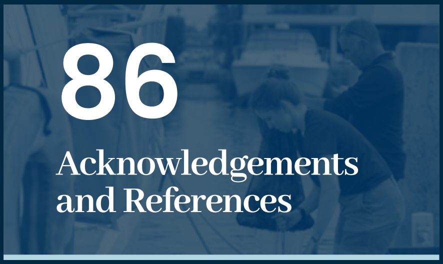
November 2023

5 GYRES
SCIENCE TO SOLUTIONS

CONTENTS




EXECUTIVE SUMMARY

As the world recognizes the need to transition away from fossil fuel-based plastic products and packaging, promising research continues to emerge around novel biomaterials, offering a potential solution to the environmental harm caused by plastics.

However, biomaterials are far from uniform in their characteristics, environmental fate, and impact. Due to a lack of vetting, scientific research (in realistic environmental scenations), and challenges surrounding end-of-life management, many have observed confusion and disagreements over the role biomaterials should play. In this study, we aim to provide greater transparency, providing details on emerging materials, their real-world behavior in the environment, and considerations that should be made before the widespread adoption of bioplastics in all sectors of society. Through five chapters, we aim to provide greater clarity, context, and scientific results to help inform decision making:

Chapter 1: The Breakdown

We first lay the groundwork for understanding bioplastics. This chapter provides a fundamental understanding, definitions, and some of the environmental backlash from certain bioplastics that were introduced over a decade ago.

Chapter 2: The Case Study

In our second chapter, we outline the objectives and methodology. Our primary aim is to assess how 22 products and packaging behave in real-world environmental conditions. We seek to provide stakeholders with essential scientific data to inform product design and end-of-life scenarios. To achieve this, we conducted tests in six environments across Florida, California, and Maine, representing various ecological conditions. Items in the environment were retrieved at intervals over 64 weeks.

Chapter 3: Results and Key Takeaways

In chapter three, we present various factors influencing the fate of bioplastic items in environmental conditions, shedding light on their persistence. Results indicated that product thickness and polymer type impacted environmental performance. Notably, items exhibited longer persistence in terrestrial environments due to reduced moisture and microbial activity compared to marine settings. Within product categories like straws, thin films, and utensils, we observed differing rates of fragmentation. Traditional plastics like polyethylene and polystyrene displayed remarkable persistence even after 64 weeks. Surprisingly, some bioplastic items demonstrated similar persistence to paper and bamboo alternatives, challenging assumptions about reasonable alternatives. Thickness and design also affected degradation rates, with thinner items decomposing more quickly. Blends with other polymers can also impact degradation. This chapter highlights the complex interplay of factors shaping environmental fate of bioplastics, providing insights for future research and product design in this quickly evolving industry.

Chapter 4: Bioplastics, a Solution or Pollution?

Our fourth chapter helps provide context to where bioplastics may play a role in solutions, as long as the material and design are applied correctly, and the materials are managed properly at their end of life. We outline stakeholder concerns and considerations that must be made before widespread adoption. Transparency, responsible labeling, and informed decision-making emerge as imperative themes.

Chapter 5: Conclusions and Recommendations

Bioplastics present a valuable area of exploration when it comes to developing new materials, though they are not a silver bullet solution to a complex issue. To harness their potential, stakeholders must prioritize truth in advertising, strengthen waste management practices, and foster responsible practices through fair legislation. While bioplastics may not offer a universal solution, they hold value in specific sectors of society. Further research is crucial to comprehensively understand their environmental impacts (e.g., from composites and additives) and degradation processes. Additionally, designing bioplastics with end-of-life scenarios in mind will align materials with appropriate disposal or recycling methods.

PREFACE

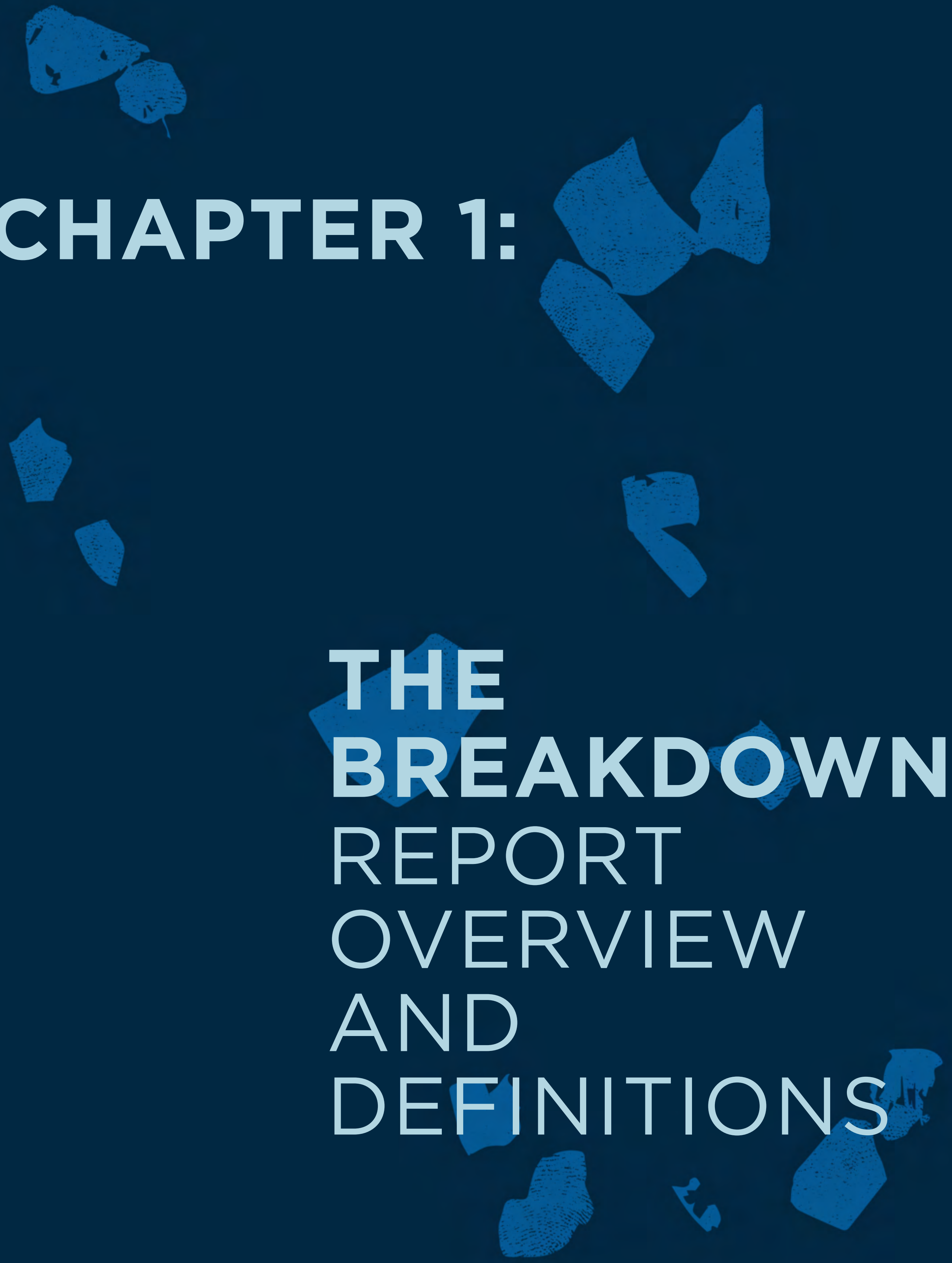
> Science and technology revolutionize our lives, but memory, tradition and myth frame our response.
>
> **ARTHUR M. SCHLESINGER**

We aim to be the Honest Broker; to be as objective as possible and give the public and policymakers a full understanding of the scope of possible actions they could take. We do not take sides, but lean in toward what serves decision makers. The intent is to support them in making the best possible choices based on all available alternatives and the scientific evidence that validates them.

We've recognized the challenging role policymakers play in attempting to reduce the harm from plastic packaging and products. The array of conflicting descriptions and definitions of material properties is highly problematic, confusing both to legislators and consumers. What do labels like "compostable" vs. "biodegradable" truly mean? Missing from these conversations is an evidence-based critique of how these materials and their forms behave in different environments over time. In the case study described here, we ask a simple question: "How do biodegradable polymers, formed into different types of products and packaging, react to six different natural environments?" We aim to communicate our findings to multi-stakeholders with a clear, concise, image-driven report that errs on the side of brevity.

We follow up our description of the study with a description of the key findings, and point out some of the challenges from stakeholders in choosing the appropriate bioplastic applications and policy frameworks. We also acknowledge that to answer key questions about the best applications for bioplastics in the consumer products space, there are additional research questions that must be answered, particularly around the potential toxicological impact of bioplastic additives. Debate is encouraged – we invite a diversity of opinions, as long as we argue from the same foundation of knowledge.

Photo by Markus Spiske on Unsplash



CHAPTER 1:

THE BREAKDOWN- REPORT OVERVIEW AND DEFINITIONS

Truth in Advertising

Bioplastics are an emerging area of research and innovation, especially as societies recognize the need to find alternatives to fossil-based plastics. Discrepancies in bioplastic design and marketing promises, however, have created confusion, making adoption and new innovation challenging. What is needed is better truth in advertising. Science can tell an accurate story about the lifecycle of these novel materials as packaging, post-consumer raw materials, or pollution. Scientific research can level the playing field.

We have seen in earlier years how a lack of shared knowledge can affect public confidence, industry communication, and the policy landscape. More than a decade ago, PLA (polylactic acid) was understood to be a compostable replacement for many types of plastic products and packaging. The discrepancy between what stakeholders were led to believe, and how PLA actually performed in home and industrial compost settings triggered a backlash. This generated public confusion and mistrust around PLA biodegradability and the meaning of compostability (see Box 1 for definitions). Consequently, there is a pressing need to establish truth in advertising for emerging bioplastics, and ensure that systems are robust enough to handle new material designs as replacements to conventional plastics.

This report addresses several important questions concerning the degradation of bioplastics in natural environments, both marine and terrestrial. We investigate the rates of fragmentation for bioplastics in six environments. We also examine the impact of product and packaging variables on fragmentation, including polymer type, thickness, and surface area. Furthermore, it is essential to consider the desired time scales for degradation, as different applications may require varying rates of breakdown, and how this may be in conflict with the performance characteristics required for many items (e.g., shelf life, water barriers). Lastly, we explore the expectations and perspectives of various stakeholders, including consumers, municipal waste management systems, manufacturers, and leaders in the plastic pollution movement to ensure that the findings of this research align with needs for decision makers.

While this report delves into how material design and environment play important roles in the fate of bioplastics in the environment, it is important to acknowledge that certain factors remain beyond its scope. Toxicity and biodegradation, for example, fall outside the purview of this study. We outline areas for future research to investigate the fate and effects of bioplastics and any associated additives. Nevertheless, Better Alternatives 3.0 offers insights into fragmentation rates of novel bioplastics and provides stakeholders with truth in advertising to better understand whether these materials contribute to advancing solutions.

BOX 1

Biodegradable vs. Compostable

In the realm of new materials such as biopolymers, the terms “biodegradable” and “compostable” are distinct, and bear critical differences. While all compostable items are inherently biodegradable, not all biodegradable substances are necessarily compostable, or break down in the environment. Here, we define these terms, which are essential for accurate labeling to ensure responsible waste management and foster informed consumer choices.

BIODEGRADABLE

The term “biodegradable” may often have technical accuracy, but can be problematic. “Biodegradation” refers to microorganisms consuming organic carbon in a material. It is not incorrect to refer to certified compostable products as “biodegradable.” However, “biodegradable” can be a misleading or confusing term for end-of-life behavior due to its lack of specificity (e.g., timeframe and environment). Several U.S. states have banned the term “biodegradable” in sales and marketing language for single-use products and packaging.

BIOPLASTICS (BIOBASED PLASTICS, BIOBASED POLYMERS)

Items that are made from “bioplastics” are produced from renewable biomass sources (e.g., vegetable fats, corn starch, straw, sawdust, and recycled food waste). Bioplastics are polymers chemically or biologically synthesized from biomass monomers, such as polyesters (e.g., polyhydroxyalkanoates (PHAs) and polylactic acid (PLA)). Bioplastics may or may not be biodegradable or compostable.

COMPOSTABLE

“Compostable” often refers to ASTM and other compostability standards when describing end of life attributes. ASTM D6400 and ASTM D6868 refer to method-specified degradation within 180 days. Consistently using “compostable” instead of “biodegradable” on products and marketing materials will aid consumers in distinguishing between legitimate compostable products and non-compostable alternatives, promoting contamination-free organics streams in composting facilities.

BIOPOLYMERS

Biopolymers are natural polymers produced by the cells of living organisms. Biopolymers are a distinct category of bioplastics. Biopolymers are biologically produced (by microbes and plants) from carbon sources (e.g., sugars and lipids), forming polymers (e.g., cellulose, PHAs).

CHAPTER 2:

THE CASE STUDY

Objectives and Outcomes

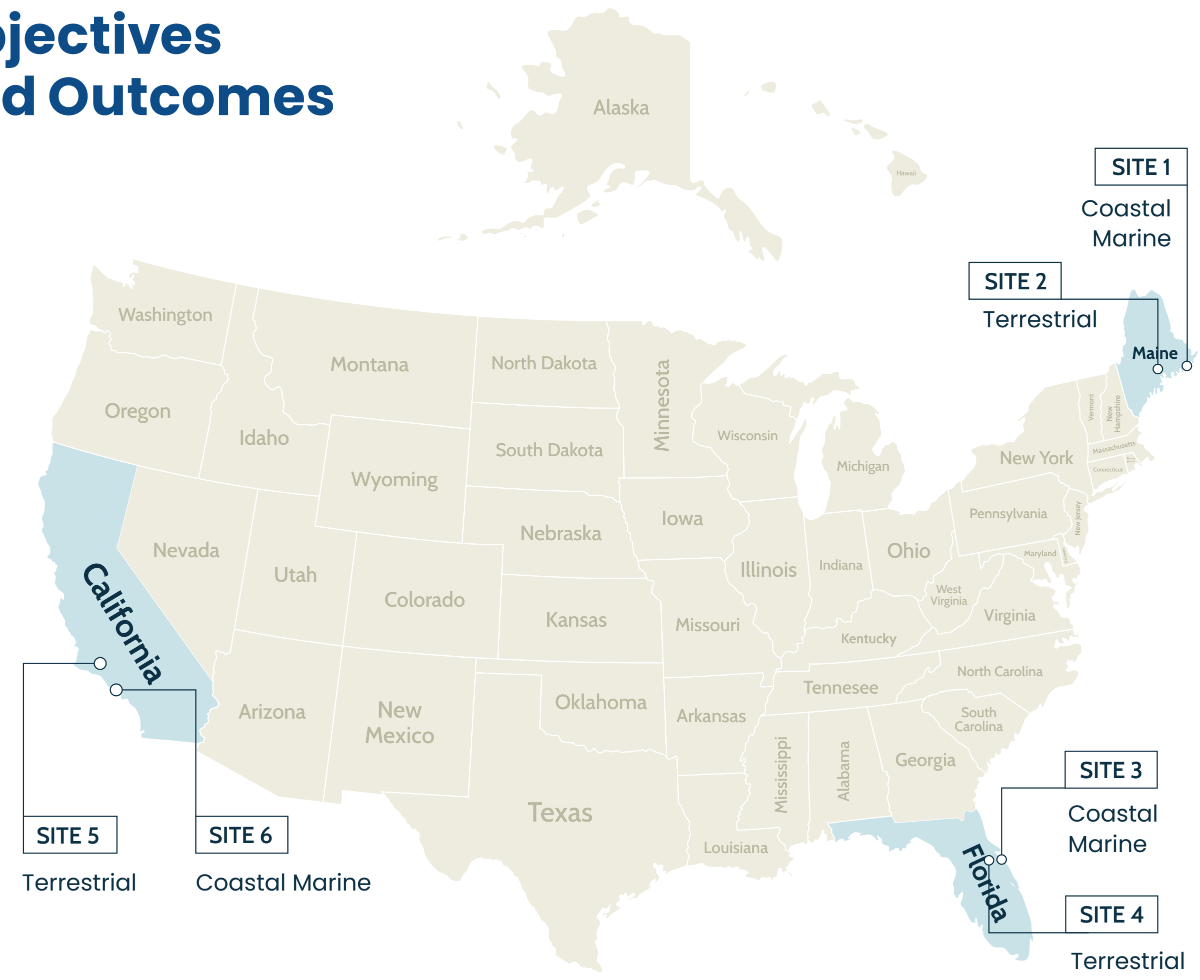


Figure 1. Six study sites in three states, Florida, California and Maine, were evaluated, representing diverse ecological environments for testing.

The main objectives of this study are to evaluate the fate of bioplastic products and packaging under realistic environmental conditions, and to vet marketing claims. The key outcome is scientific data, to provide stakeholders with end-of-life scenarios that can inform product design.

We tested six environments – two each in Florida, California, and Maine – representing realistic terrestrial and marine environmental conditions (Figure 1). At each site, we placed six unique sets of 22 different items in the environment. Sets of items were retrieved at 2, 4, 8, 16, 32, and 64 weeks (Figure 2). Each set of items contained 22 different items, and each item had 3 replicates (n = 3) (Figure 3). Upon retrieval, individual items were cleaned, dried, weighed, and photographed (Figure 4). For detailed methods, see Appendix 1.

Figure 2. Each large black mesh bag contained three sets of the same 22 items (n = 3). There was one bag for each location and for each time period, totaling 36 bags deployed in the field.

A TRIPLICATE SET OF **22** PRODUCTS x **6** SITES x **6** TIME INTERVALS = **2376** ITEMS

MARINE SITES

TERRESTRIAL SITES

A	Film, PLA
B	Film, PE (Control)
C	Film, Bio-based PBS Resin
D	Film, PHA
E	Film, PHA/PLA Laminate with Metal Barrier
F	Film, Extruded PLA/PHA
G	Pen, PHB
H	Utensil, PHA
I	Utensil, PLA
J	Utensil, Bamboo
K	Utensil, PE (Control)
L	Bottle, PHA
M	Bottle Cap, PHA
N	Straw, PHA
O	Straw, Paper
P	Straw, PHB
Q	Straw, PLA
R	Straw, PE (Control)
S	Bag, Compostable Starch-based Resin
T	Bag, PBAT/PLA
U	Tampon Applicator, PHA
V	Baby Wipe, PHA

Figure 3. A total of 22 products were evaluated in this study. At the terrestrial sites, black mesh bags were buried. At the marine sites, black mesh bags were placed in milk crates, which were weighed down with bricks.

RECOVER

CLEAN

WEIGH

Figure 4. After recovery from the environment, items were cleaned, dried, and weighed to measure fragmentation.

Measuring Fragmentation vs. Biodegradation

Two different methods to measure biodegradation include physical methods (e.g., mass loss, as in our study) and respirometric methods (e.g., CO2 release and oxygen demand). Respirometric methods provide a full picture of biodegradation, as they are the only methods to validate that the final step in biodegradation, mineralization, has occurred. If a piece of packaging fragments, i,e., breaks apart into thousands of unseen smaller pieces, this does not mean it is biodegradable and microbes will consume it. Respirometric methods are normally the focus of biodegradation standards, but are not possible for a field study. In this study we measured fragmentation, and did not measure CO2 flux to validate biodegradation.

Blends of non-biodegradable plastics with bioplastics may fragment as bioplastic degrades, but the remaining plastic particles will persist in the environment. Chemical additives in plastic (e.g., plasticizers, UV stabilizers) often oxidize, leaving the remaining plastic polymer brittle and vulnerable to fragmentation by mechanical forces. The polymer is still there, just in smaller pieces. It is important not to confuse fragmentation with biodegradation. However, pitting or peeling on the surface of biodegradable plastic products usually does indicate microbial activity and biodegradation. In our study, items either stayed whole or fragmented into smaller pieces, and we photographed each one for all fragments that could be recovered by visual inspection, typically larger than 200 µm.

CHAPTER 3:

RESULTS AND KEY TAKEAWAYS

Results

Here, we present an in-depth look at the environmental persistence of 22 items. To give an understanding of the performance of each item, we've dedicated a two-page spread of photographs to each item, documenting its degradation over 64 weeks in six study sites. The percent degradation is summarized in a plot for each item, illustrating the average difference in mass from day zero. Combined, the photographs and plots illustrate how these items performed across different environments.

Following the detailed look at each item, this section culminates in comparing specific item types (e.g., straws, utensils, and thin film). By examining the performance of items within each product category, we aim to offer insights into their relative persistence.

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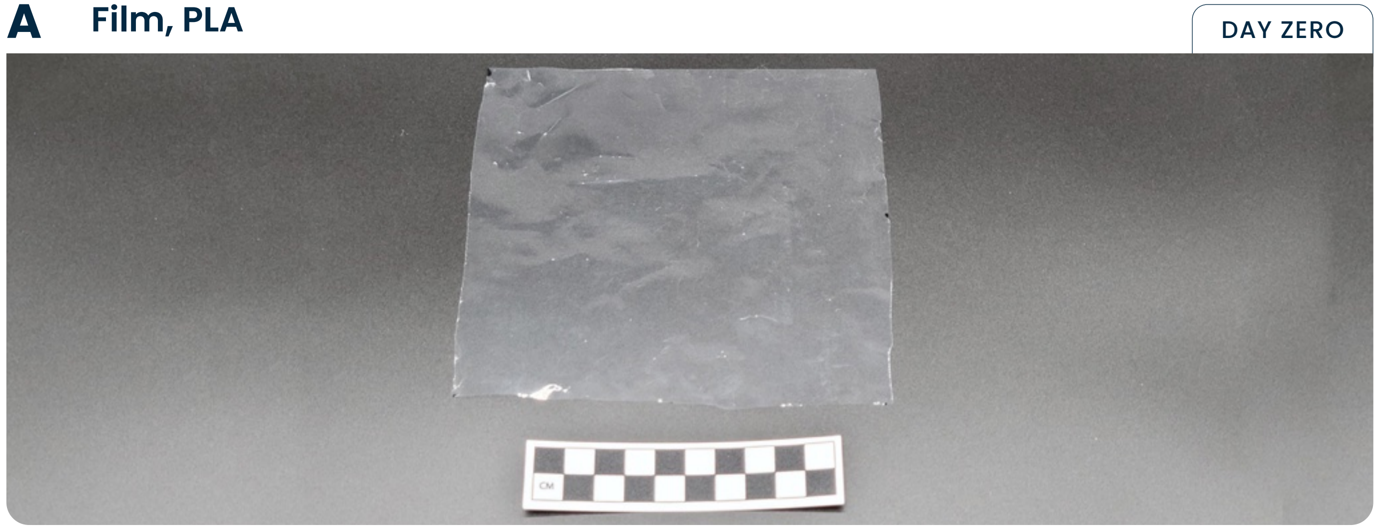
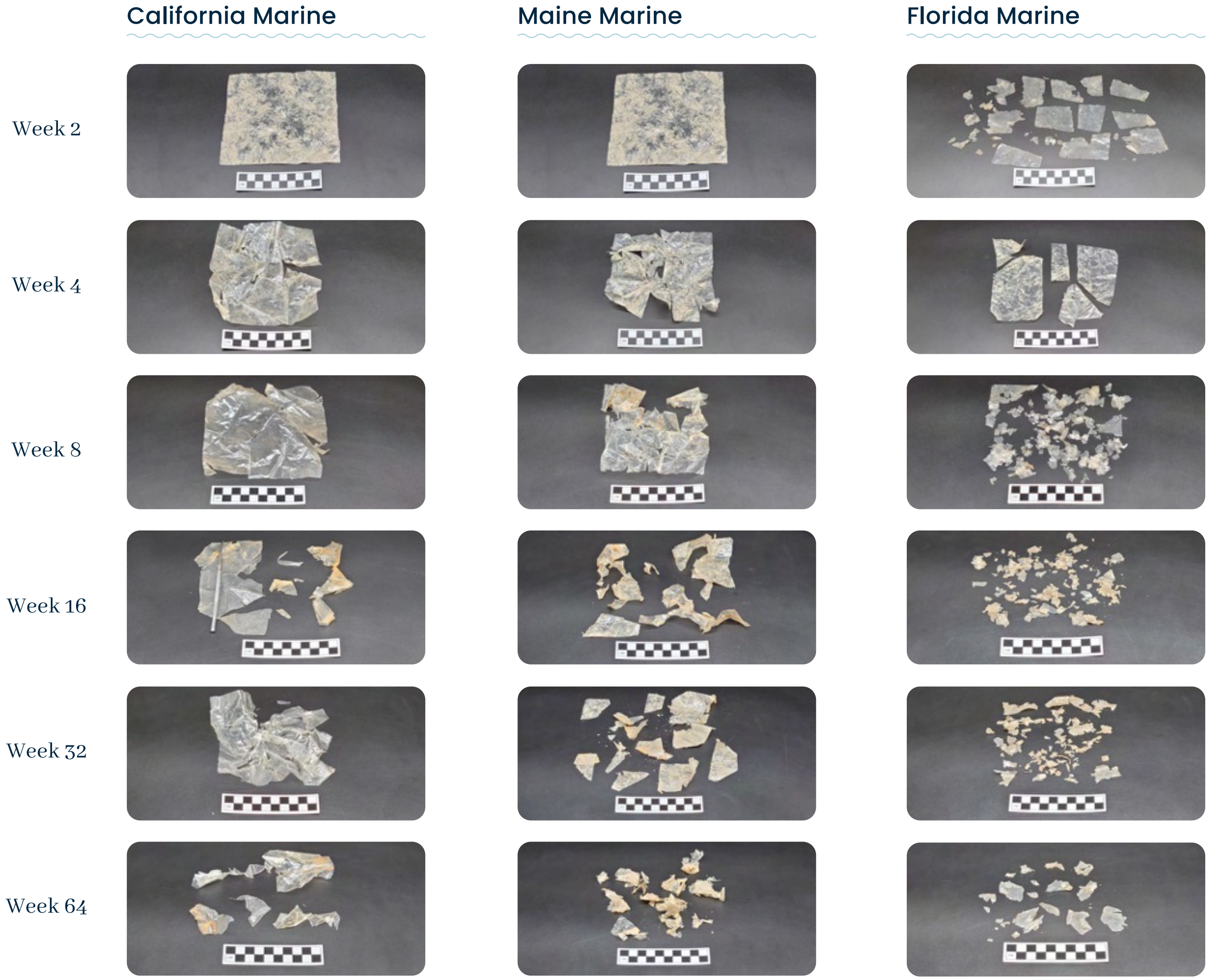
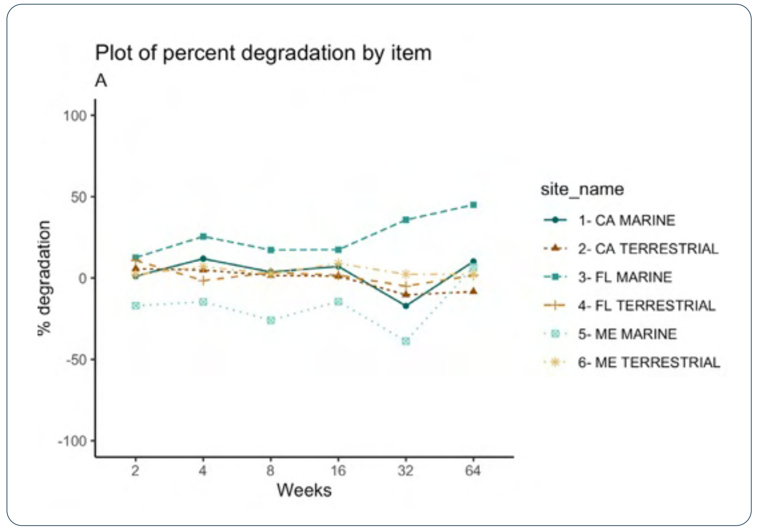
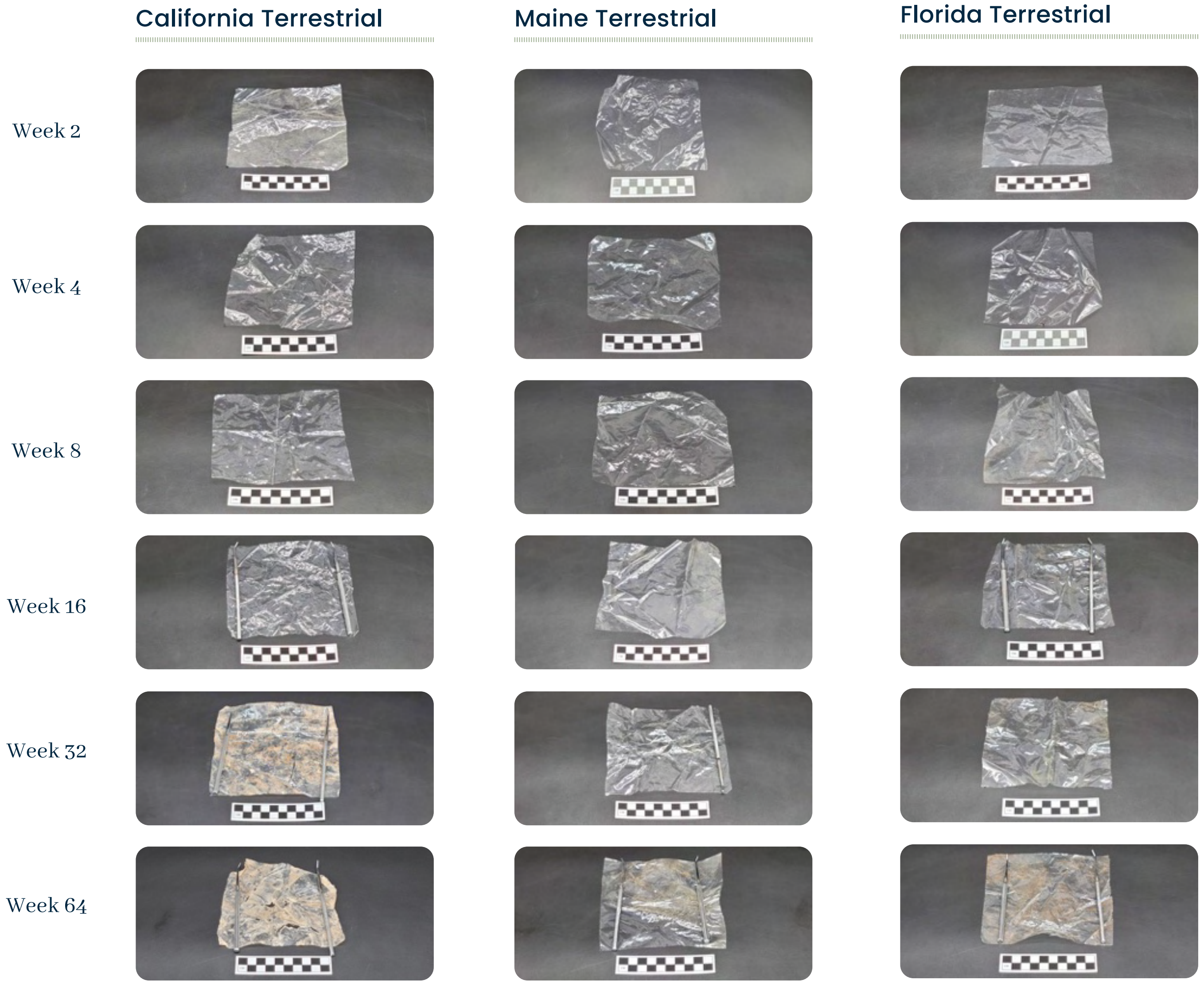




A Film, PLA

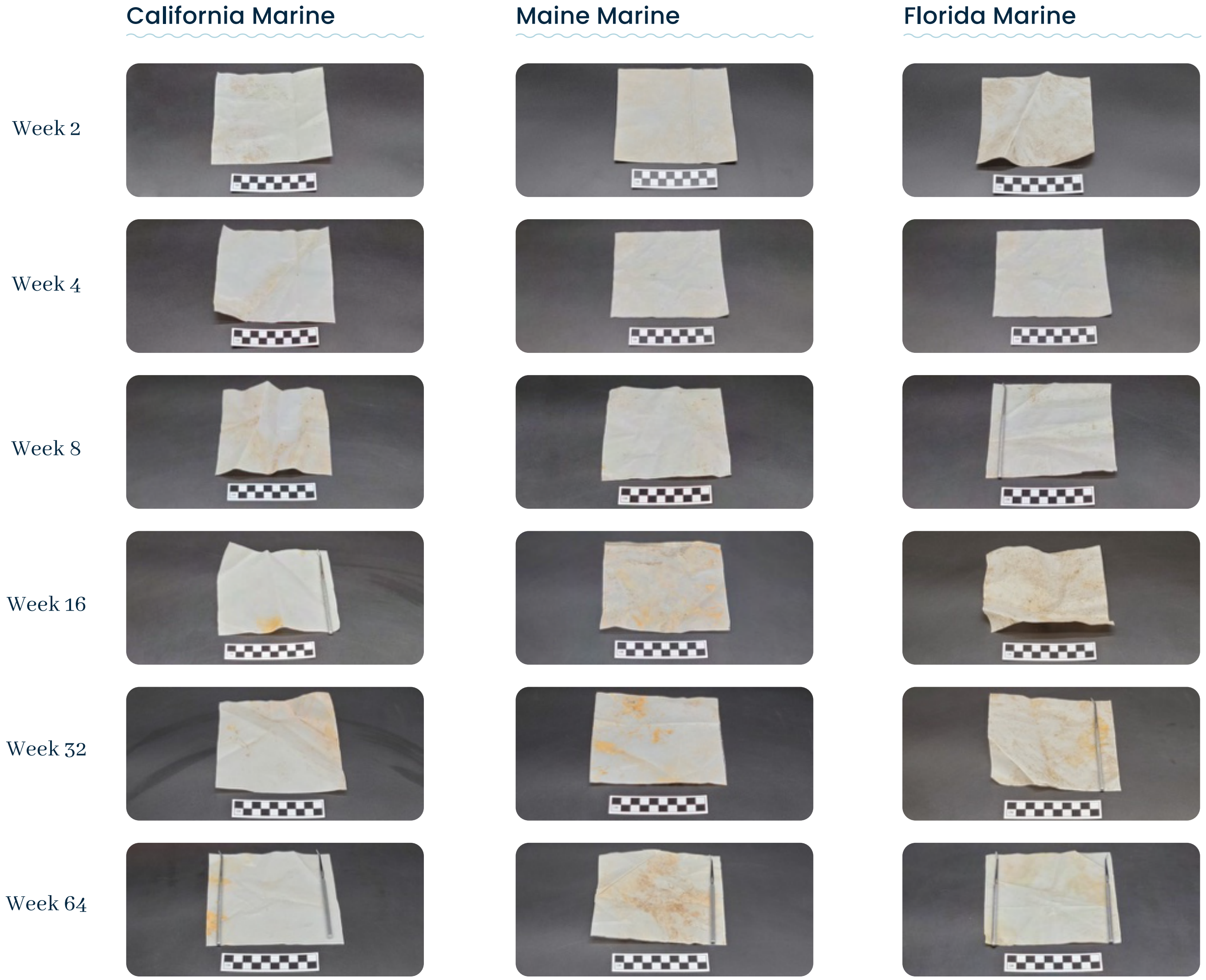
The PLA film exhibited slower fragmentation compared to PHA. It started to show degradation at the Florida marine site after 4 weeks, although some replicates persisted for 64 weeks. The fragmentation time appears to be slightly slower than the bio-based PBS resin. Minimal to no fragmentation was observed at the California and Maine marine sites, and there was no fragmentation at terrestrial sites.





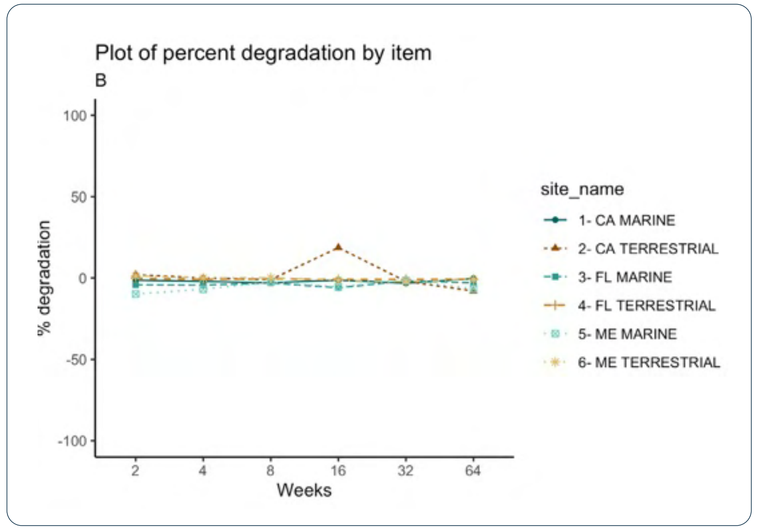
B Film, PE (Control)

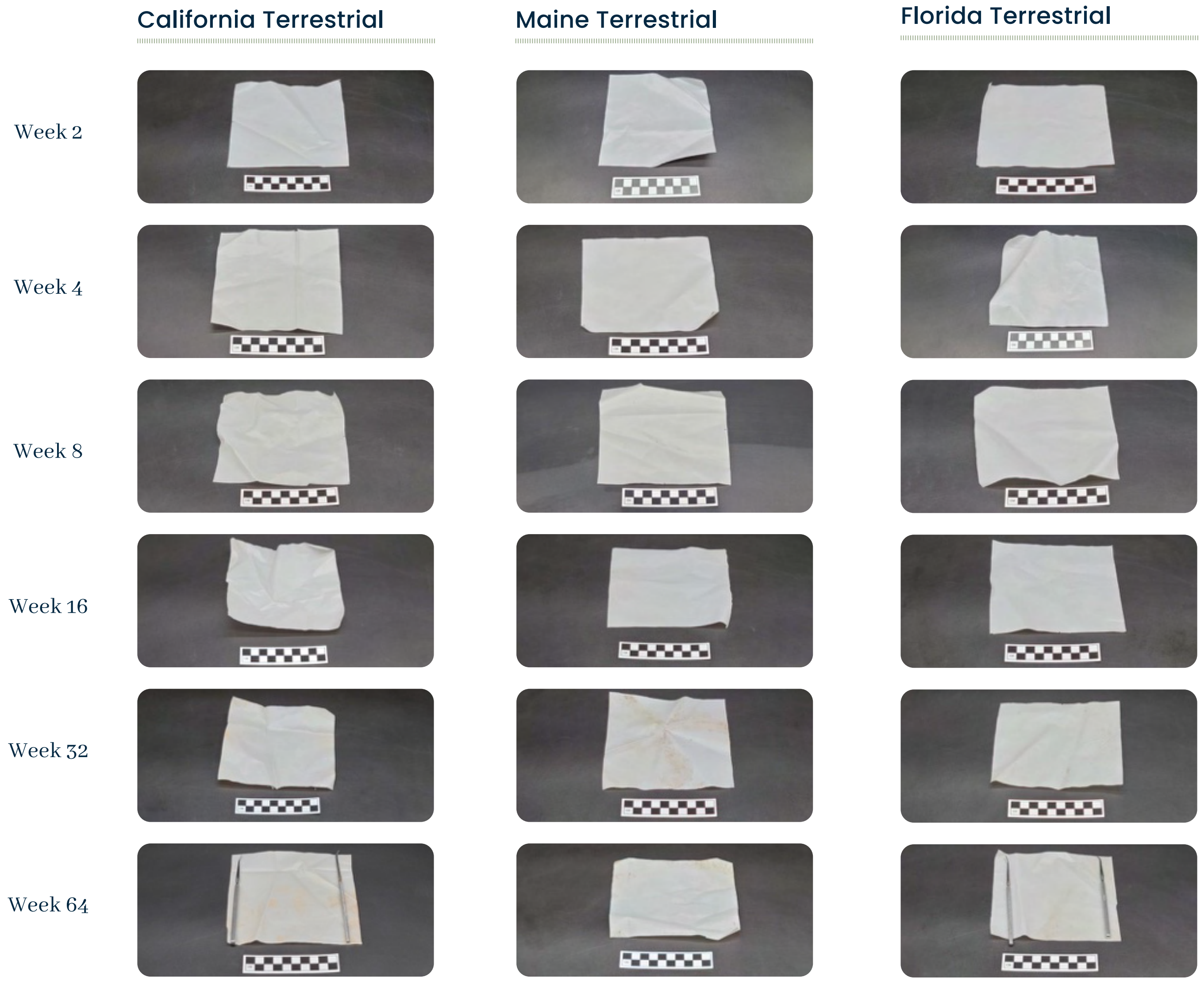
DAY ZERO



B Film, PE (Control)

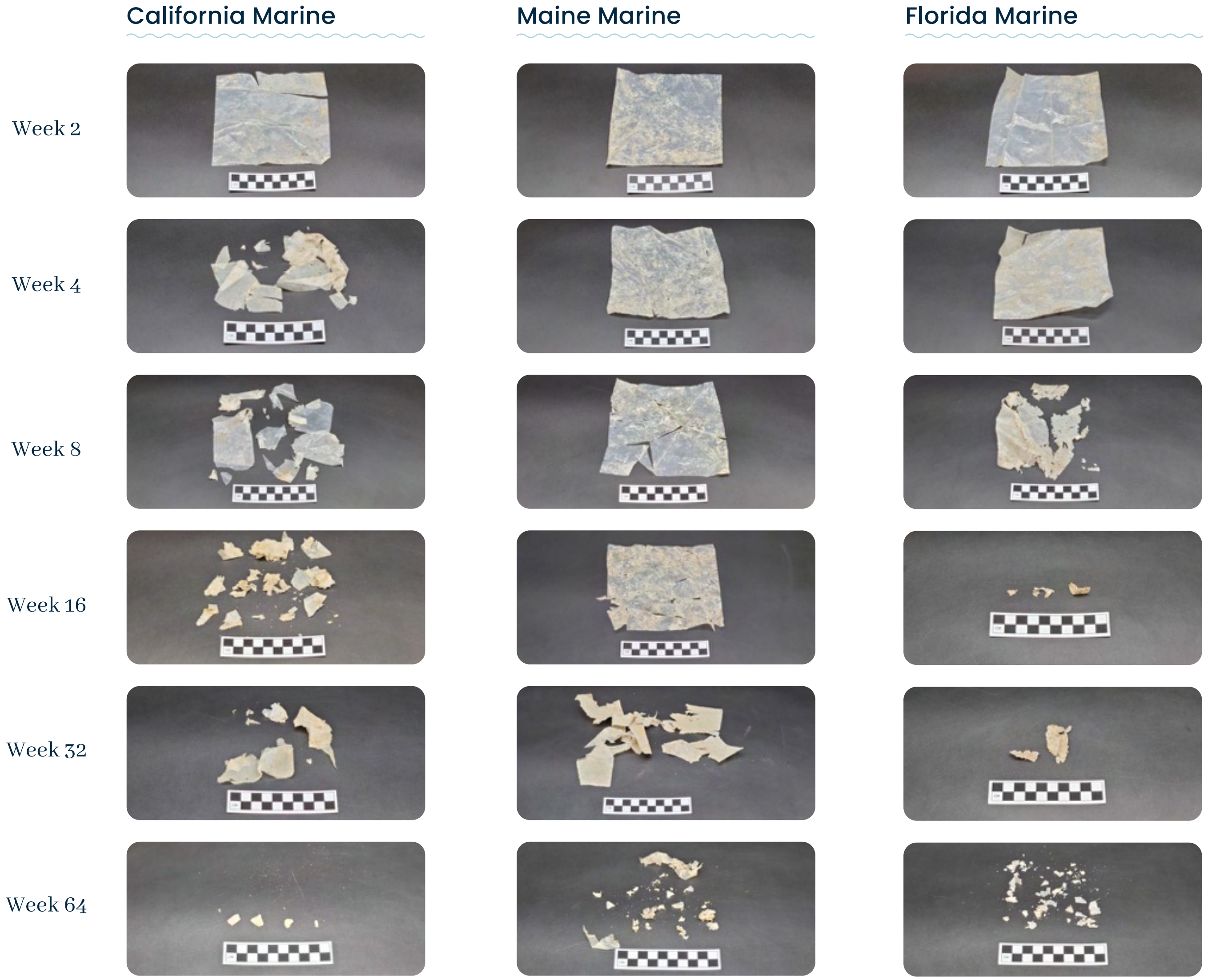
The PE film did not degrade at any of the tested sites. There was no change in mass observed over time in any of the environments. This is a persistent item in all environments tested.





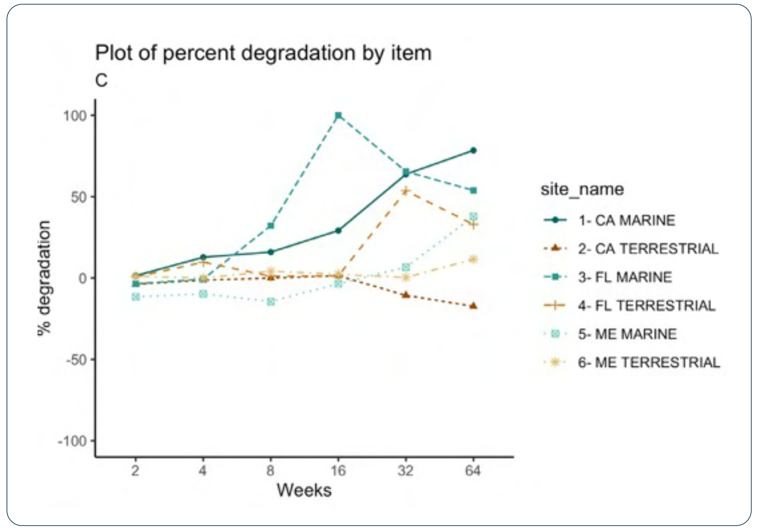
C Film, Bio-based PBS Resin

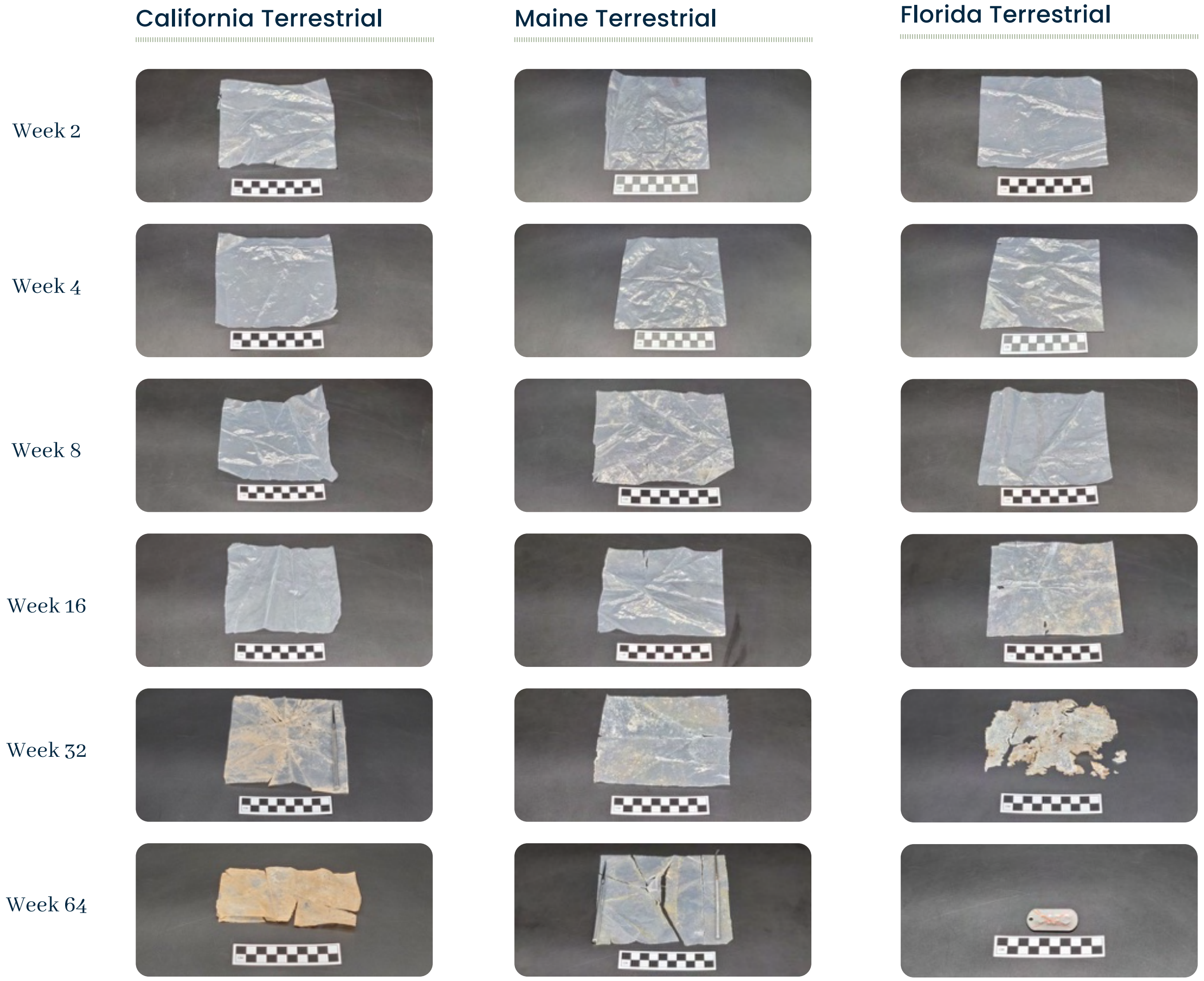
DAY ZERO



C Film, Bio-based PBS Resin

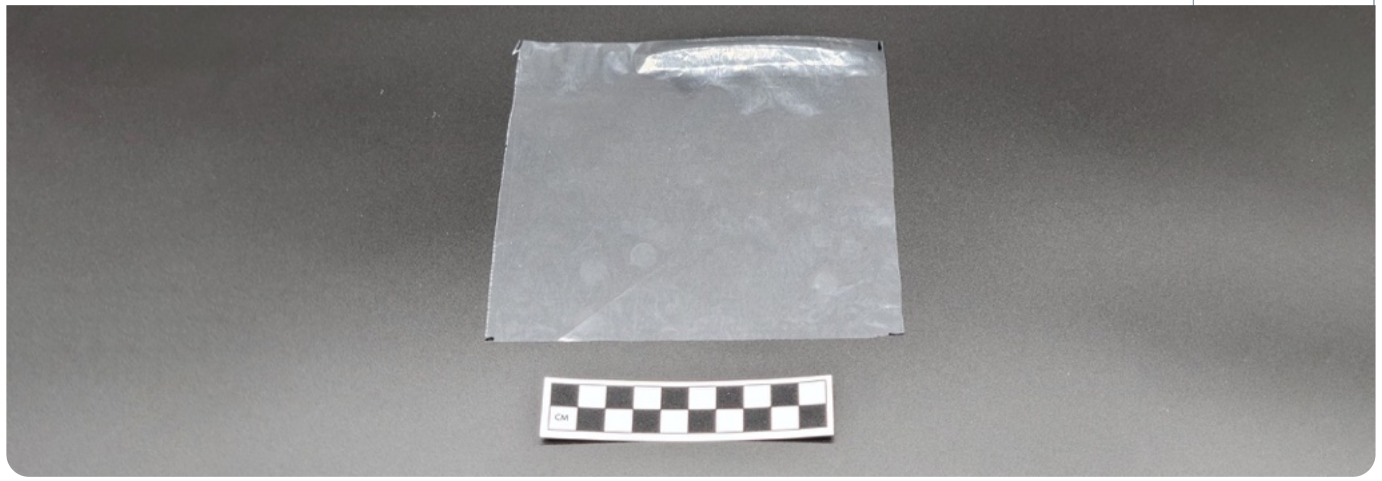
This film showed slower fragmentation compared to PHA but faster than PLA. It exhibited degradation at all the marine sites after 32 weeks and some degradation at terrestrial sites, with a 40-50% loss in mass at the Florida terrestrial site after 32 and 64 weeks.

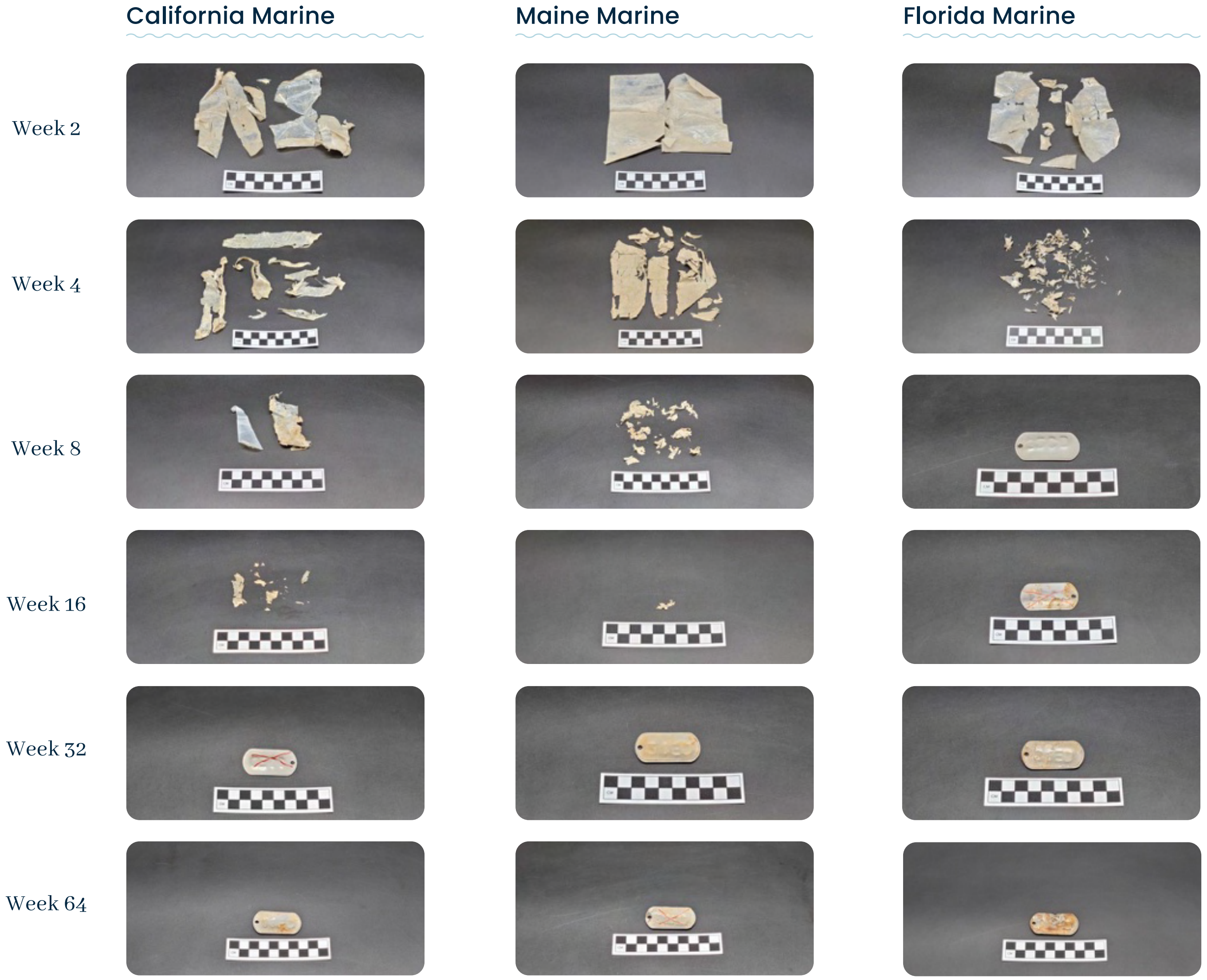




D Film, PHA

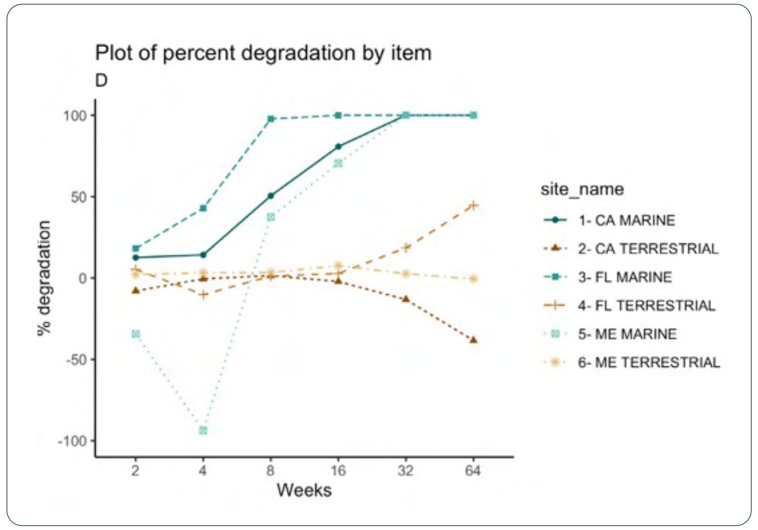
DAY ZERO

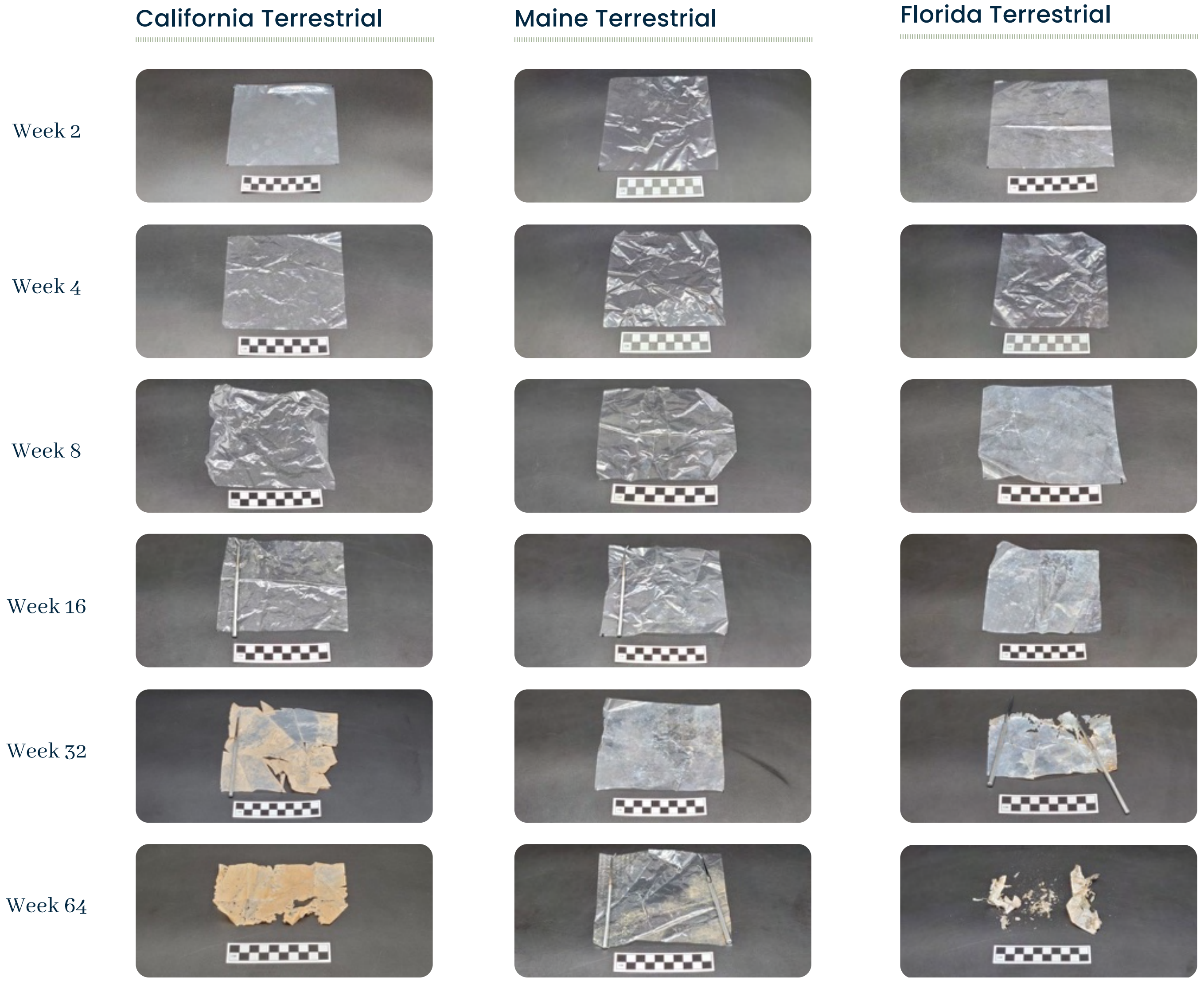




D Film, PHA

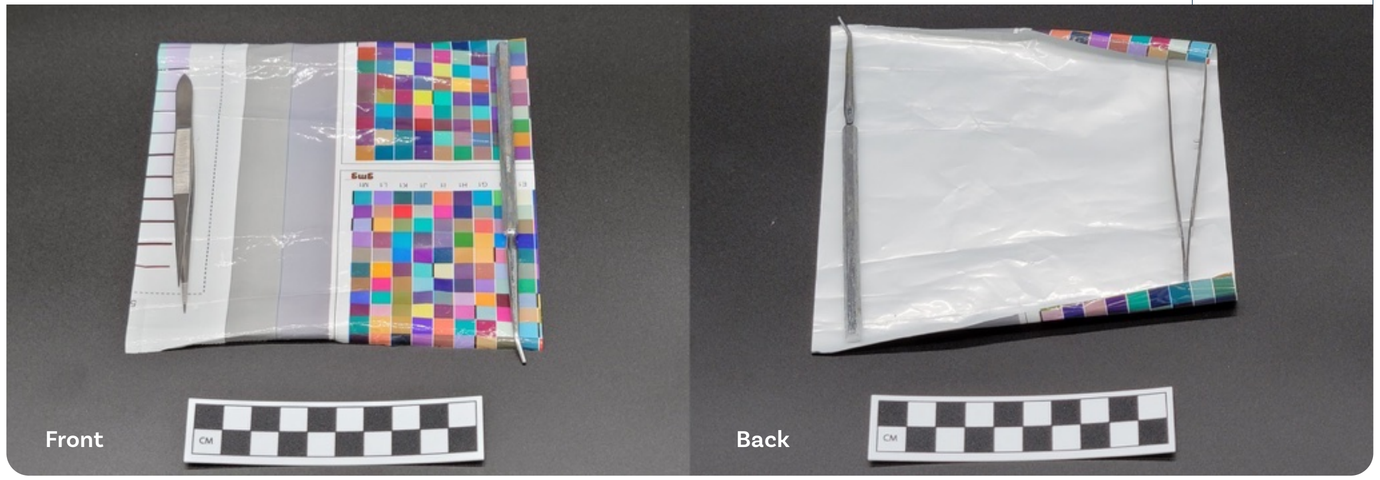
The PHA film had the fastest fragmentation among all films. It was not detected at the Florida marine site after 8 weeks and at the Maine and California marine sites after 32 weeks. Some degradation was observed at the Florida terrestrial site, but it still retained an average of 50% mass after 64 weeks.

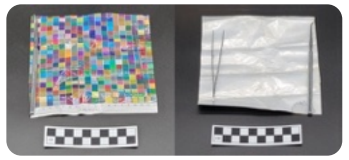
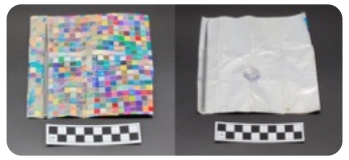
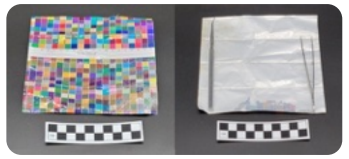
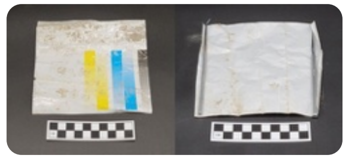
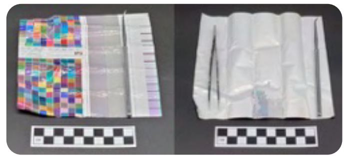
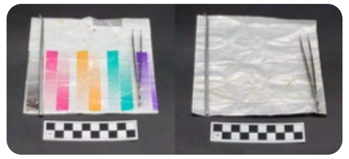
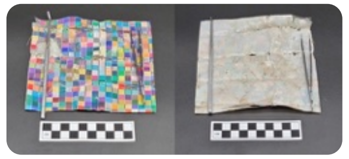




E Film, PHA/PLA Laminate with Metal Barrier

DAY ZERO



	California Marine	Maine Marine	Florida Marine
Week 2			
Week 4			
Week 8			
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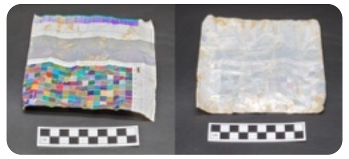
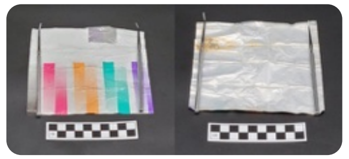
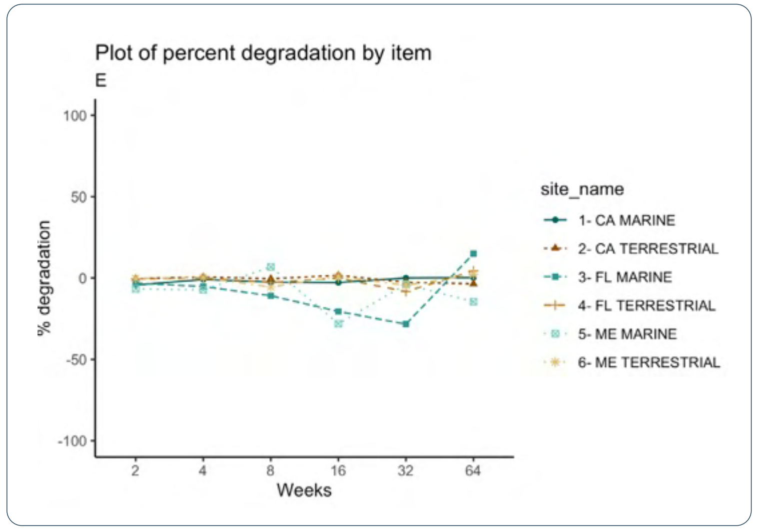
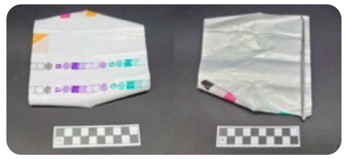
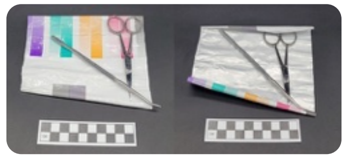
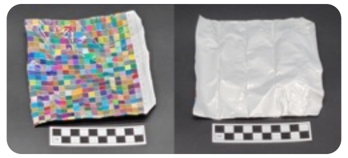
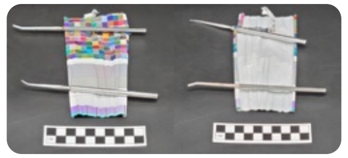
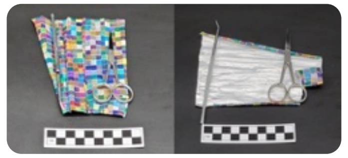
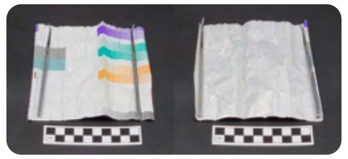
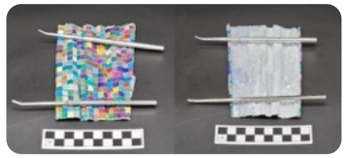
Week 32			
Week 64			

E Film, PHA/PLA Laminate with Metal Barrier

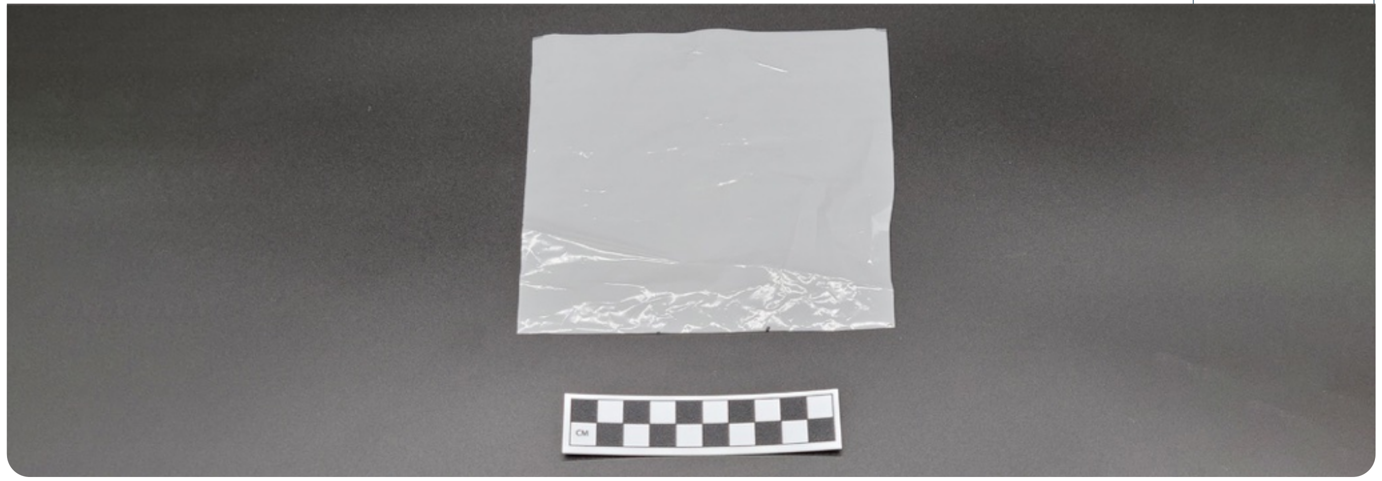
The presence of a metal barrier slowed down the degradation of this film. It was the most persistent film item along with the PE film. The composition of multi-layer packaging can slow degradation times.

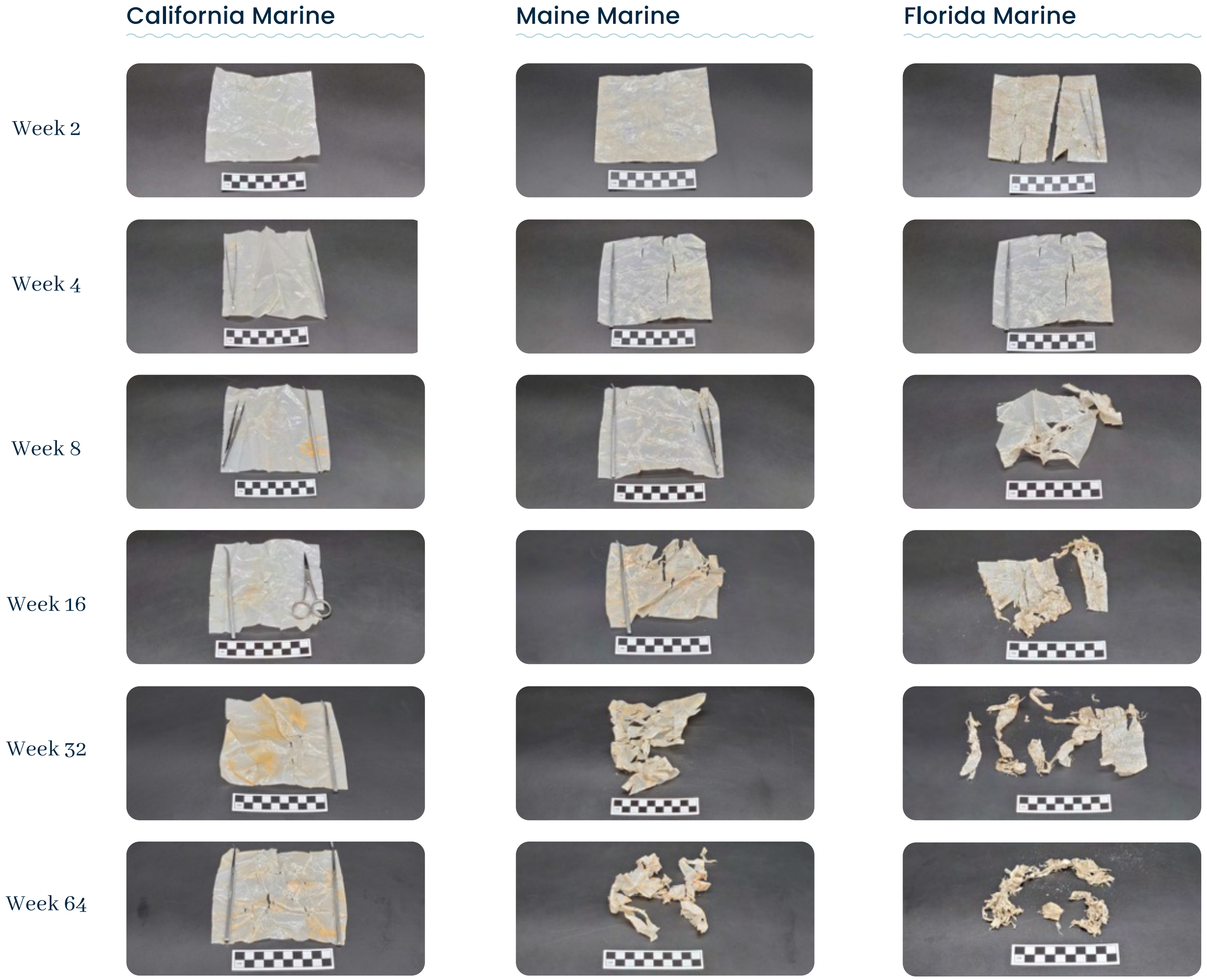


	California Terrestrial	Maine Terrestrial	Florida Terrestrial
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

F Film, Extruded PLA/PHA

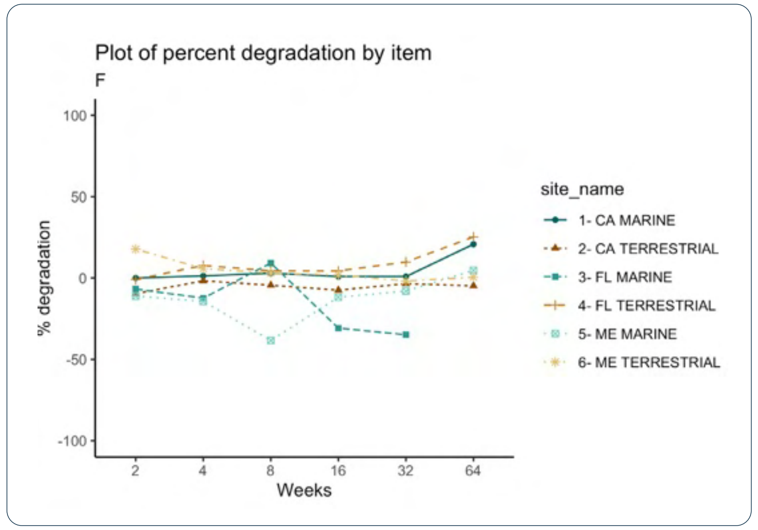
DAY ZERO

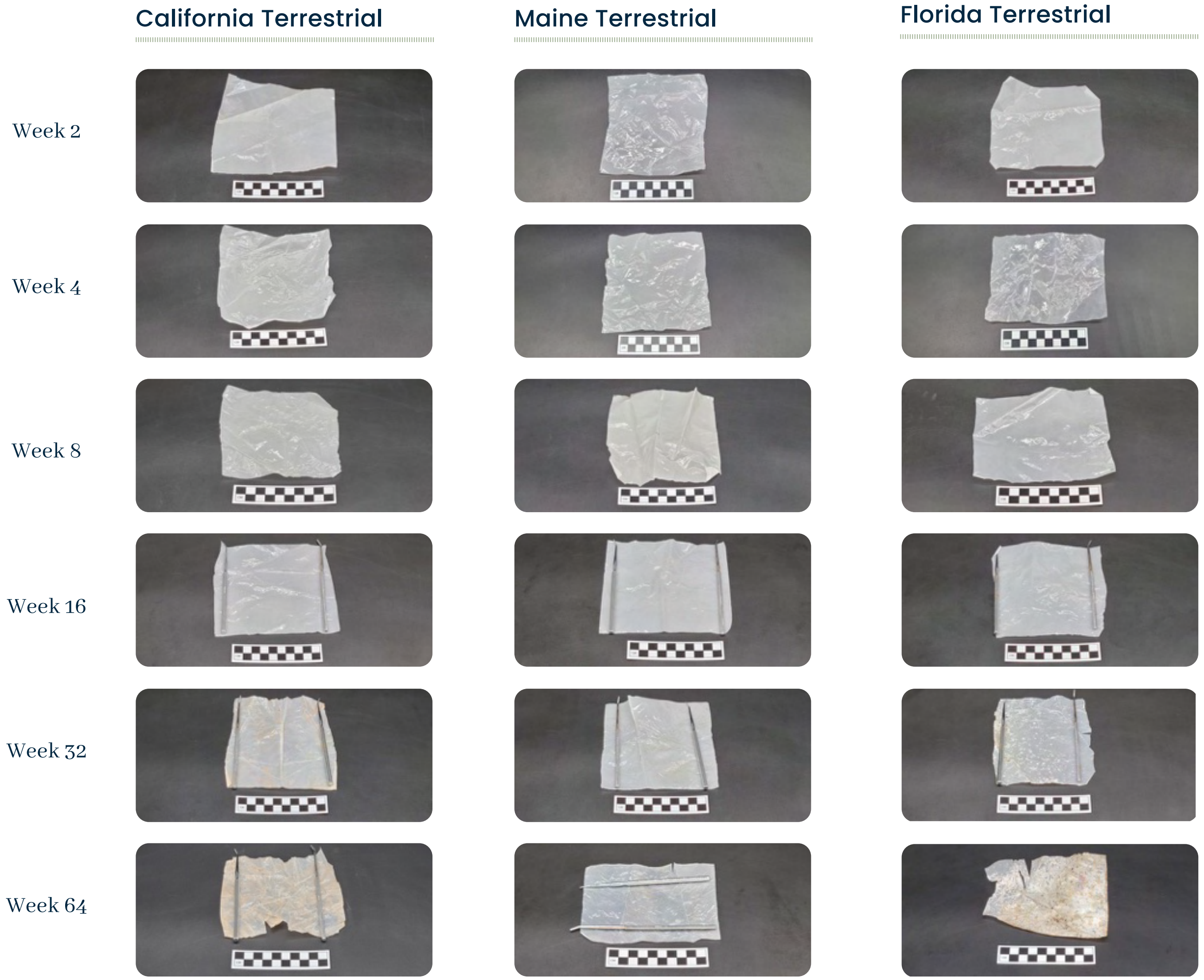




F Film, Extruded PLA/PHA

This film exhibited minor fragmentation, and exhibited slower degradation compared to PLA and PHA films. It is unclear whether the blend of polymers caused slower fragmentation.





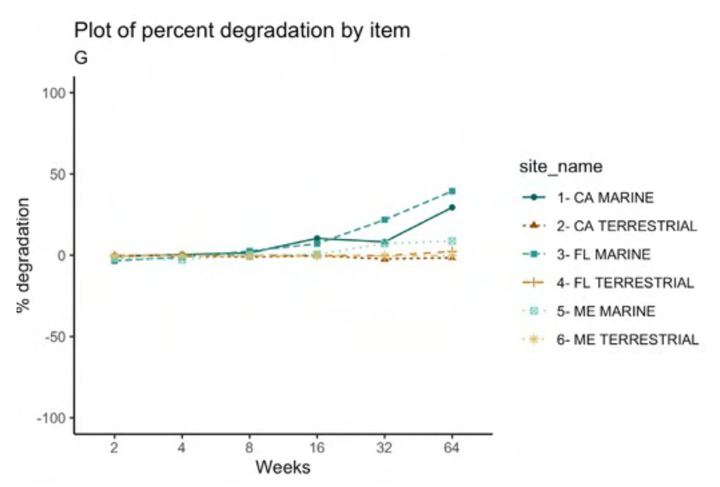
G Pen, PHB

DAY ZERO

	California Marine	Maine Marine	Florida Marine
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

G Pen, PHB

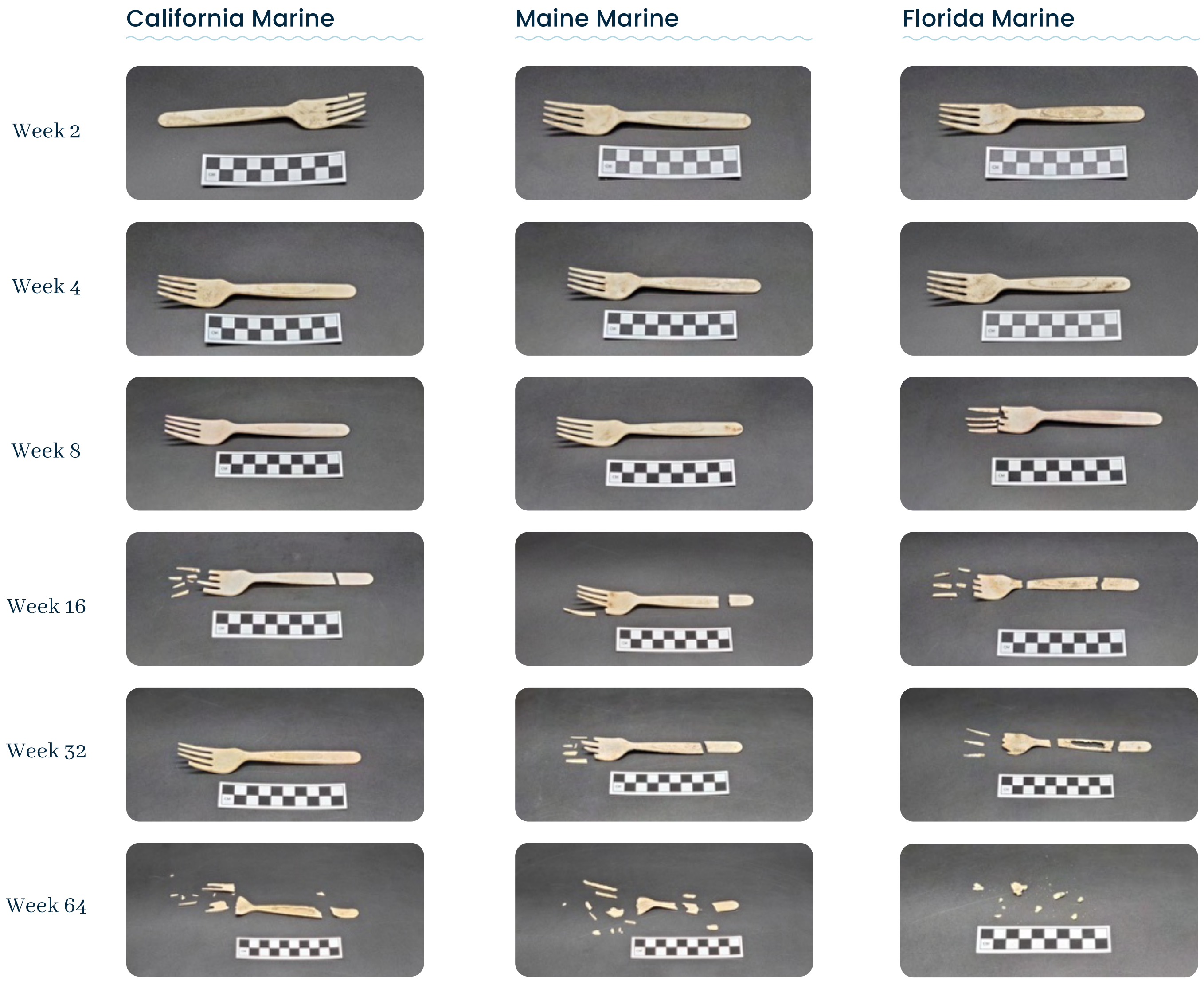
The PHB pen showed some degradation at marine sites, with the fastest fragmentation observed at the Florida site, with an average of approximately 40% mass loss. Of the marine sites, it was slowest at the Maine marine site (<10% average mass loss). Little to no degradation was observed at terrestrial sites. Its thickness likely contributed to its persistence.



	California Terrestrial	Maine Terrestrial	Florida Terrestrial
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

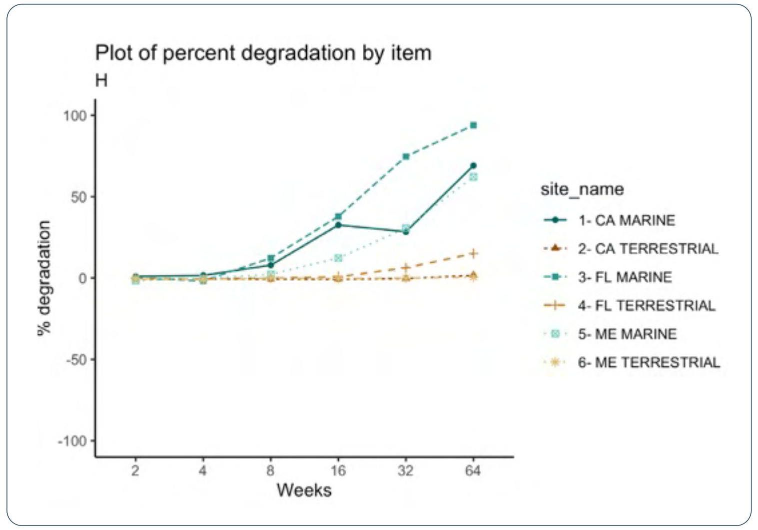
H Utensil, PHA

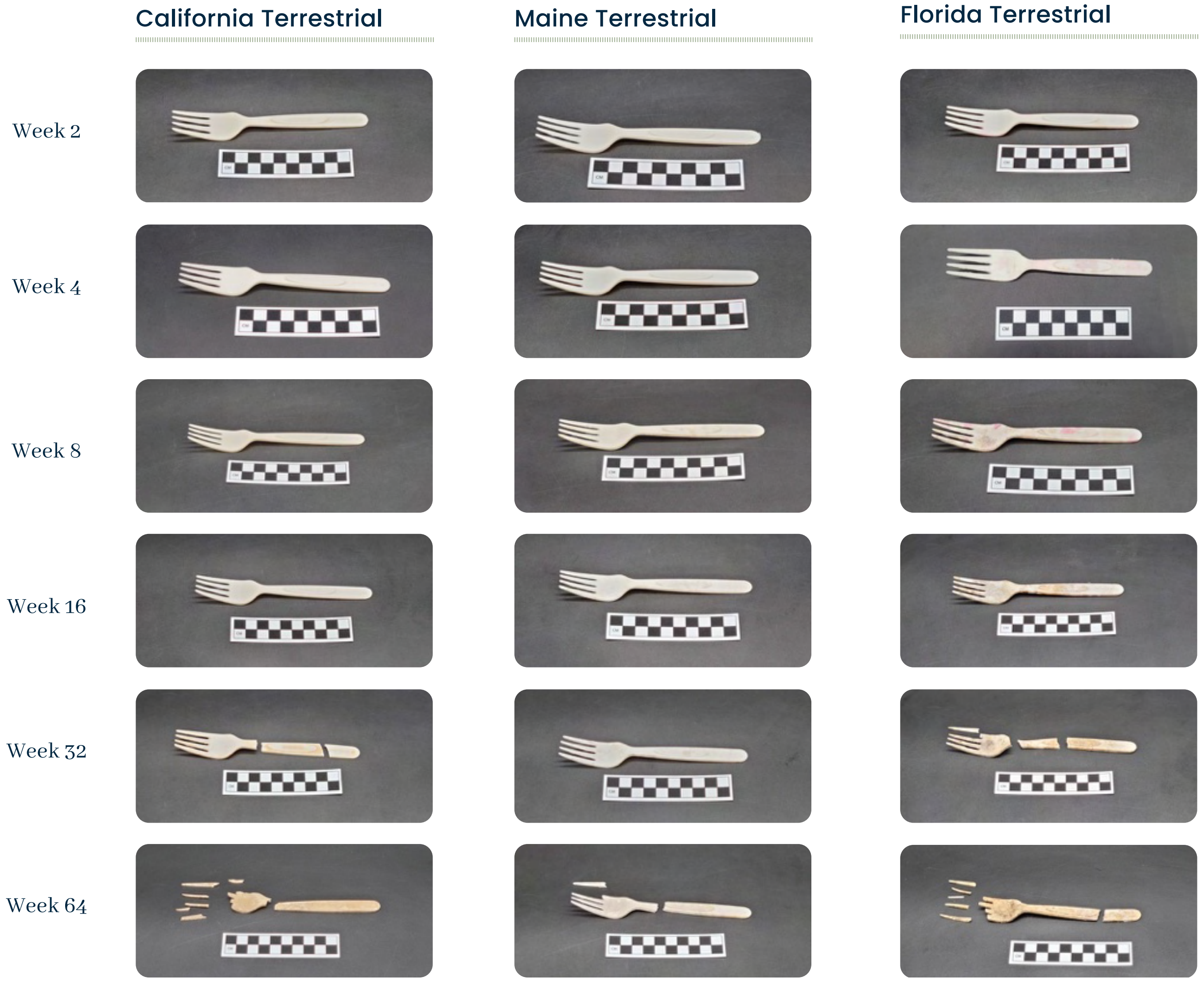
DAY ZERO



H Utensil, PHA

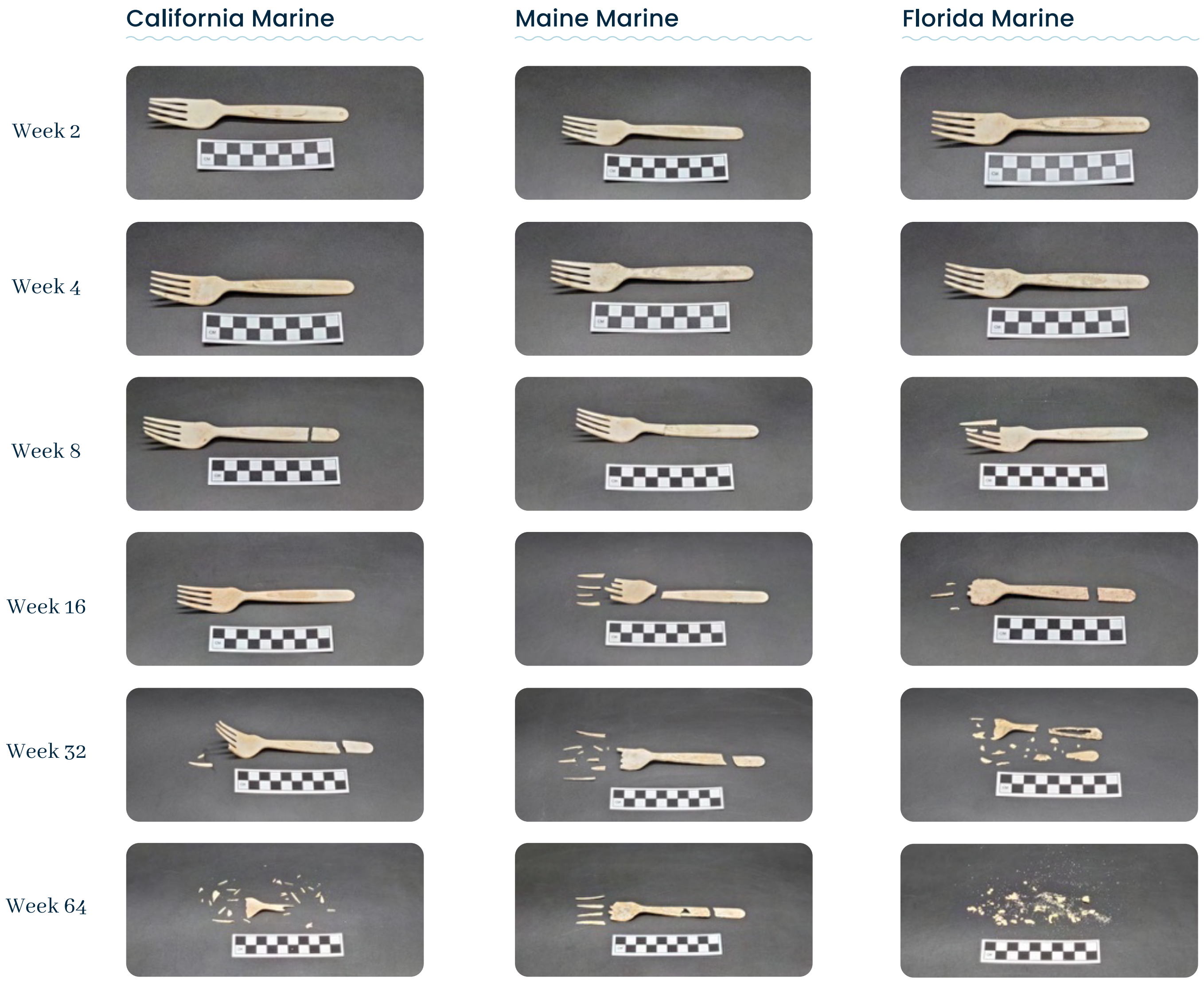
The PHA utensil fragmented quickly, similar to the PLA utensil. It showed the fastest fragmentation at the Florida marine site, although some small fragments remained.





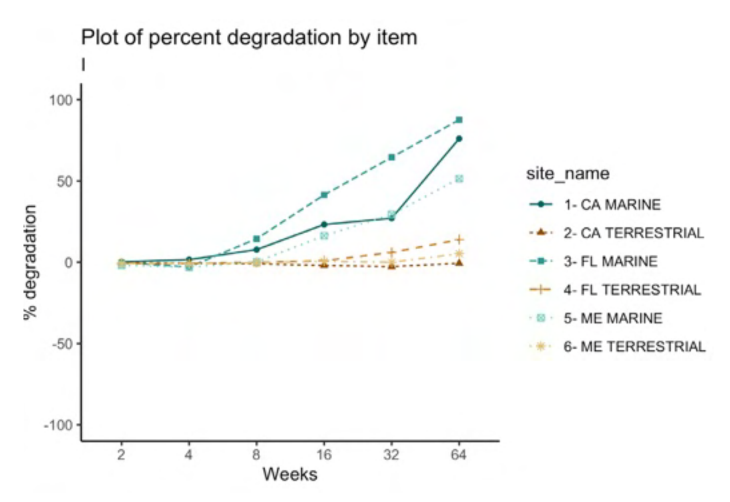
Utensil, PLA

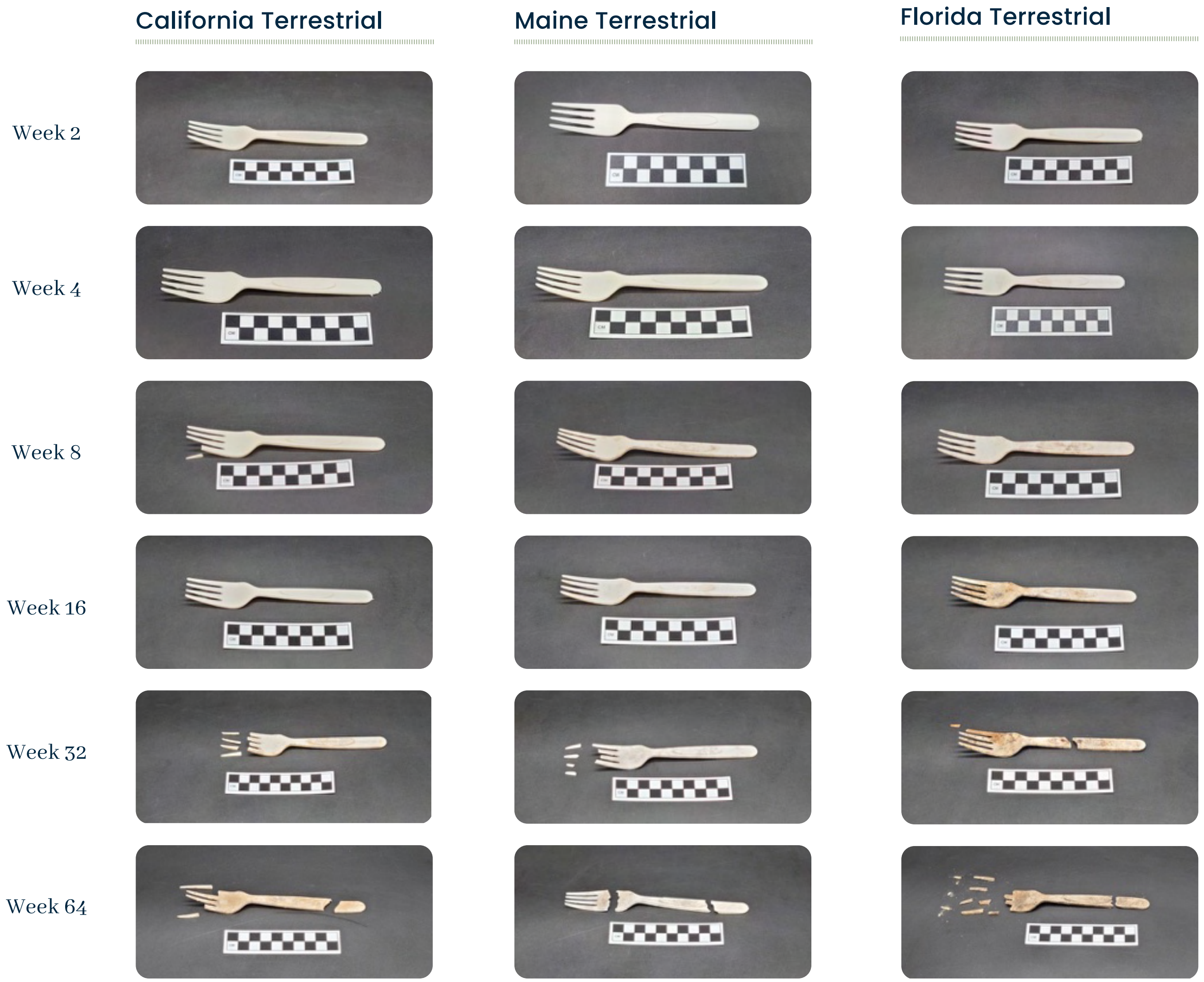

DAY ZERO



Utensil, PLA

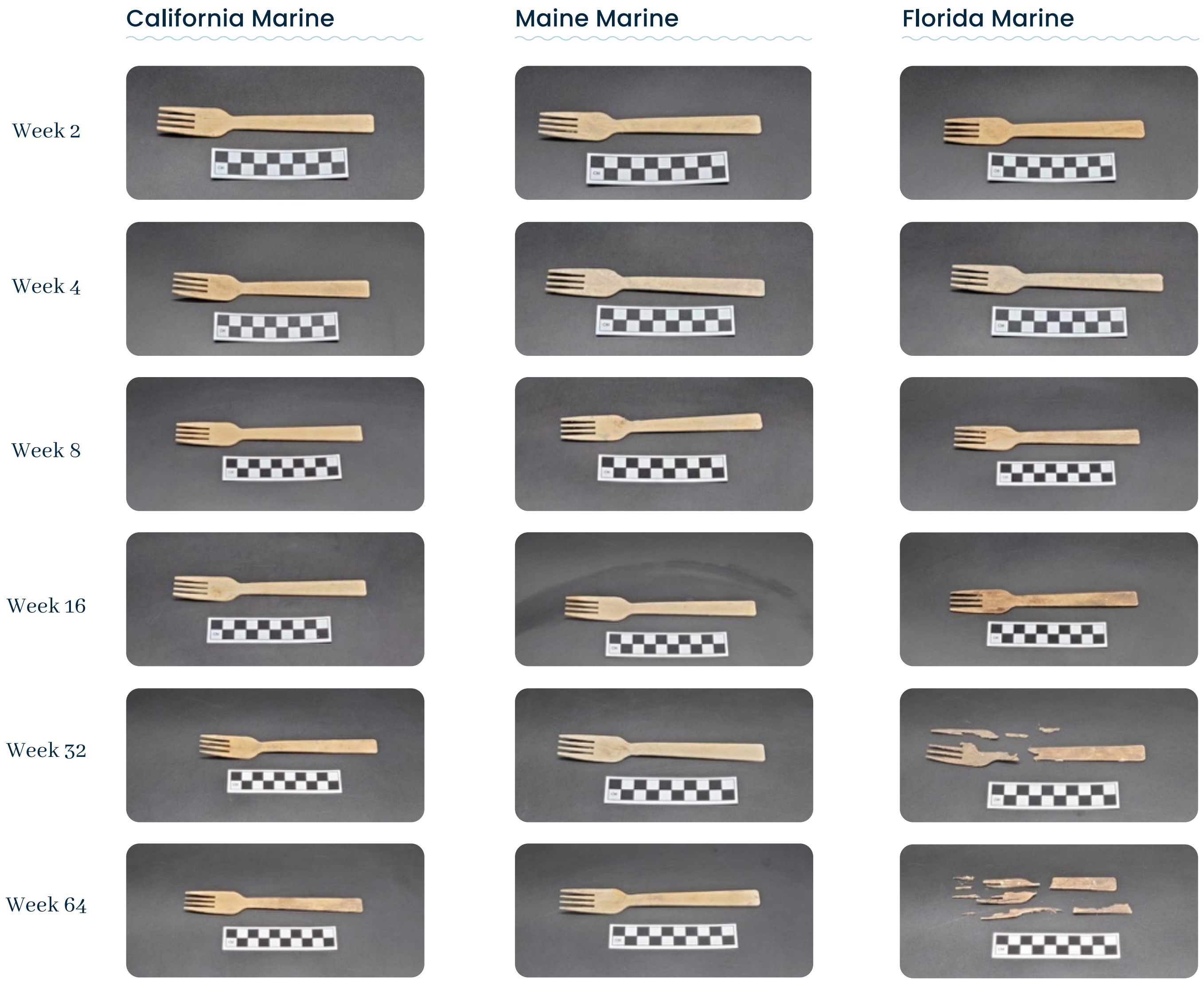
The PLA utensil fragmented similarly to the PHA utensil, with the fastest fragmentation at the Florida marine site. Similar to the PHA utensil, some small fragments remained, even at the Florida marine site.





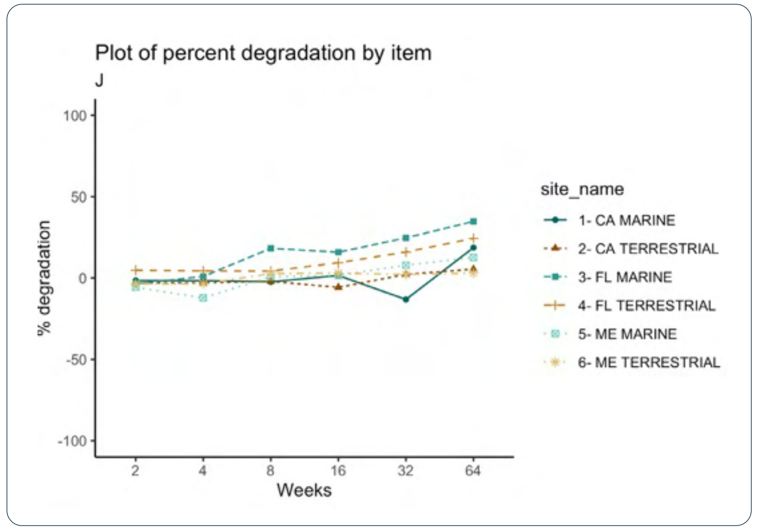
J Utensil, Bamboo

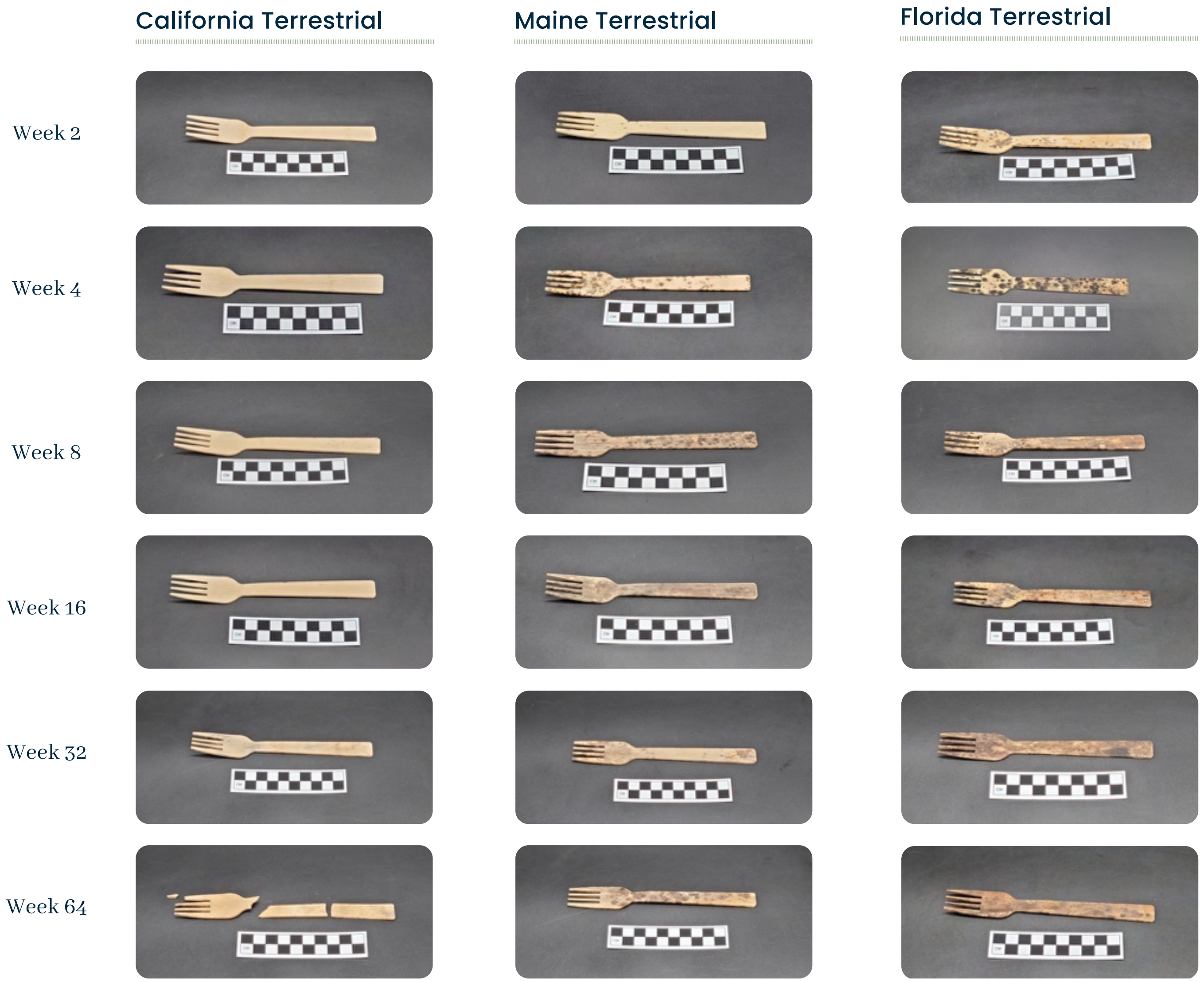
DAY ZERO



J Utensil, Bamboo

The bamboo utensil persisted longer than PHA and PLA utensils. Similar to the biodegradable plastics, the bamboo utensil exhibited the fastest degradation at the Florida marine site and the second fastest at the California terrestrial site.





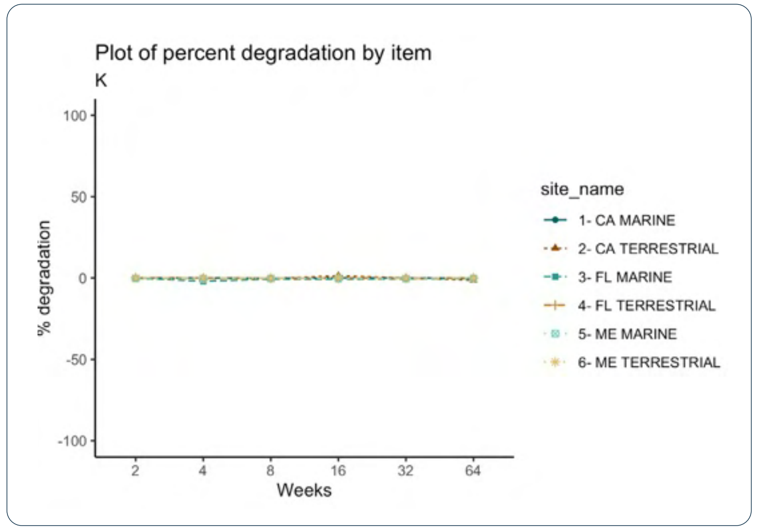
K Utensil, PE (Control)

DAY ZERO

	California Marine	Maine Marine	Florida Marine
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

K Utensil, PE (Control)

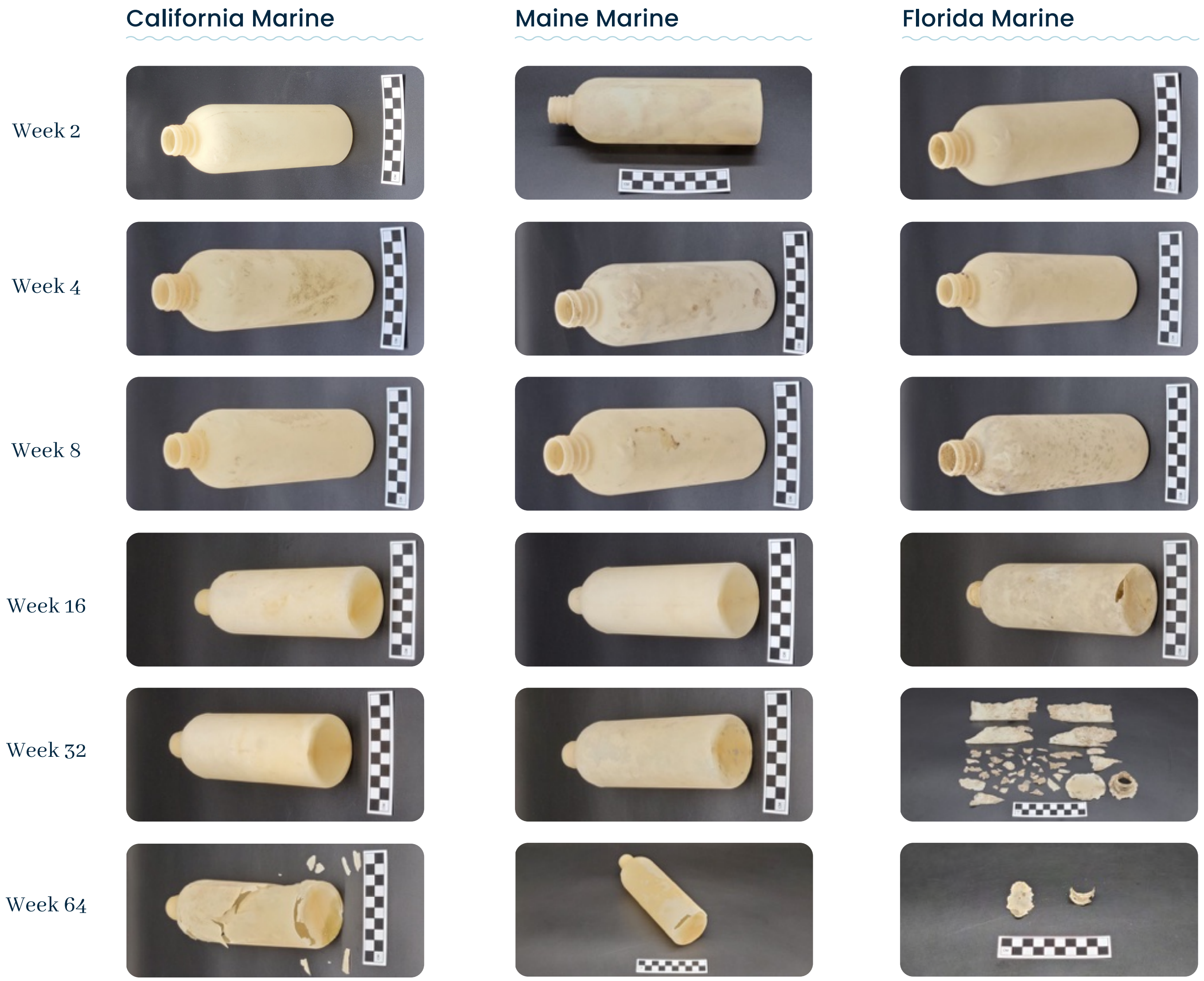
The PE utensil remained unchanged across all sites and environments. This is a persistent item in all environments tested.



	California Terrestrial	Maine Terrestrial	Florida Terrestrial
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

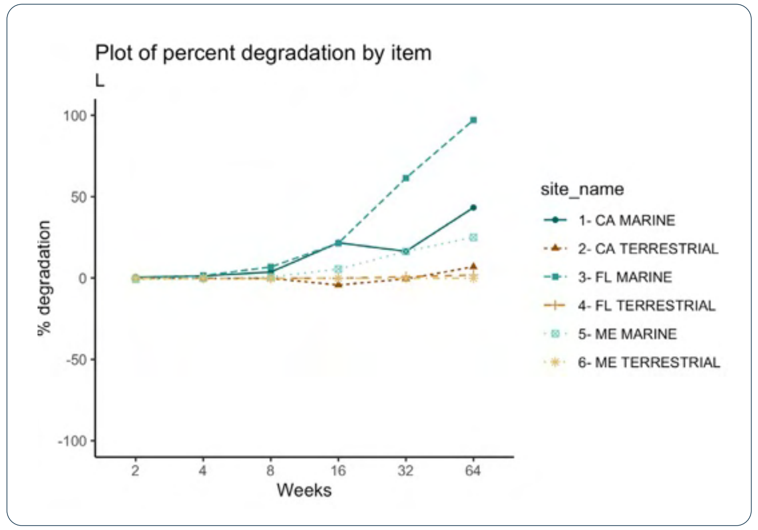
L Bottle, PHA

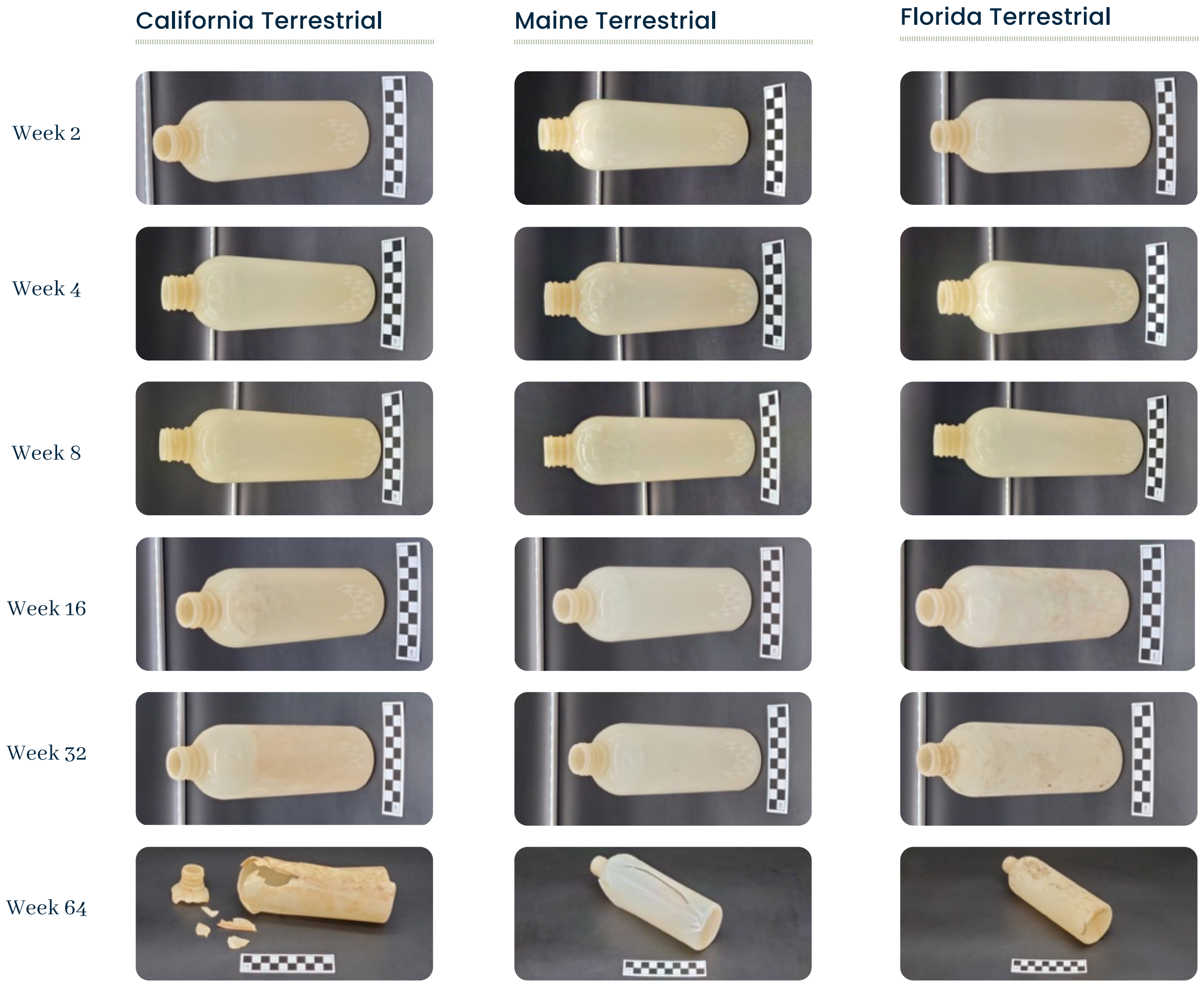
DAY ZERO



L Bottle, PHA

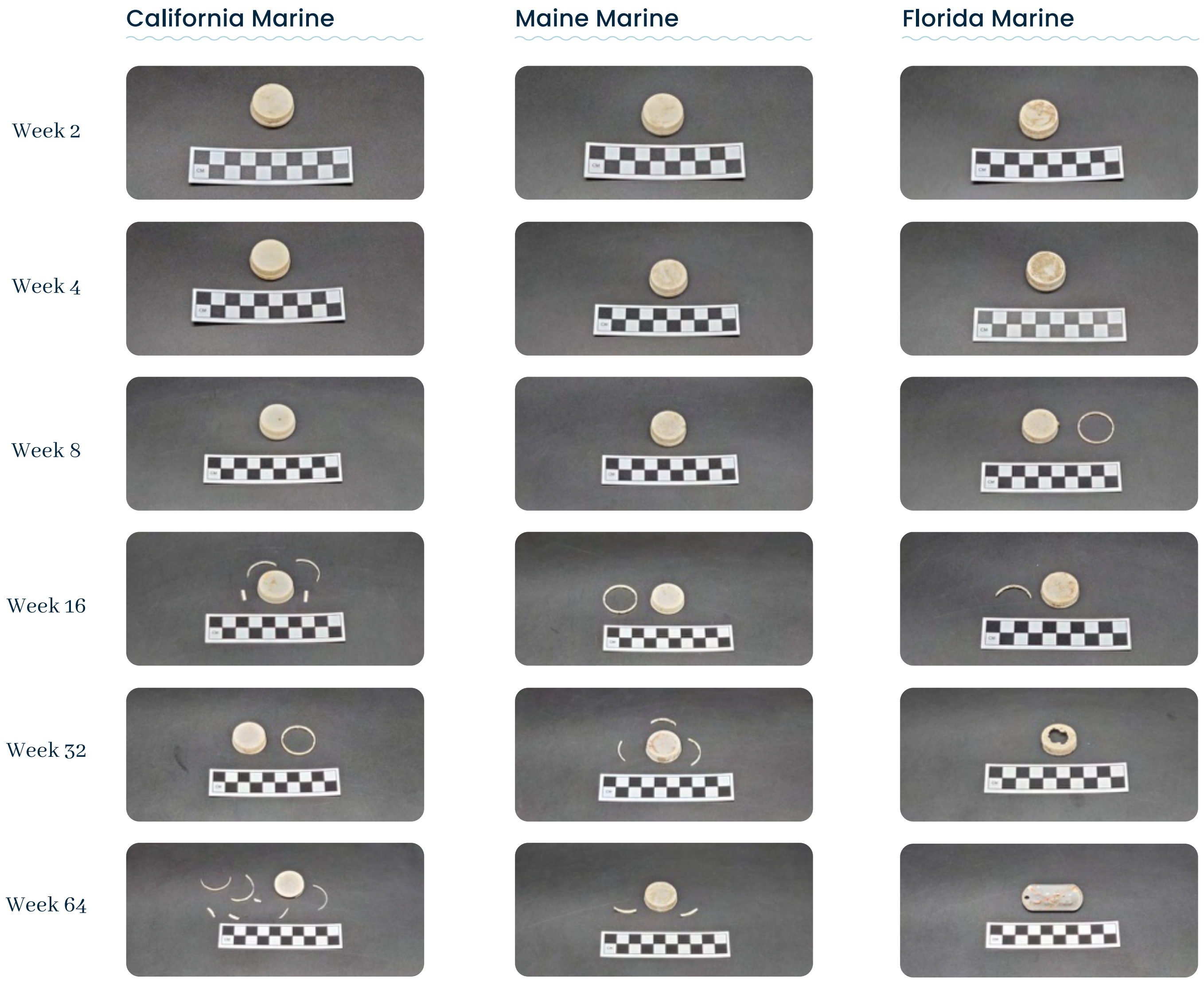
The PHA bottle exhibited similar degradation behavior to the PHA bottle cap, with slightly slower degradation compared to the bottle cap.





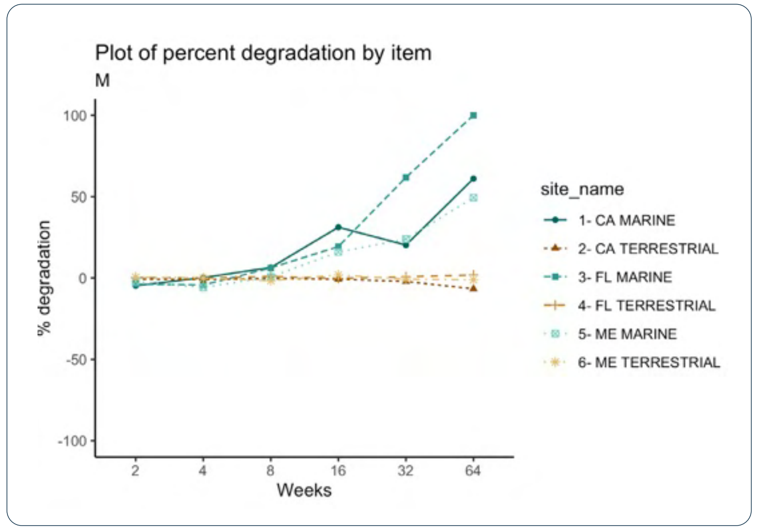
M Bottle Cap, PHA

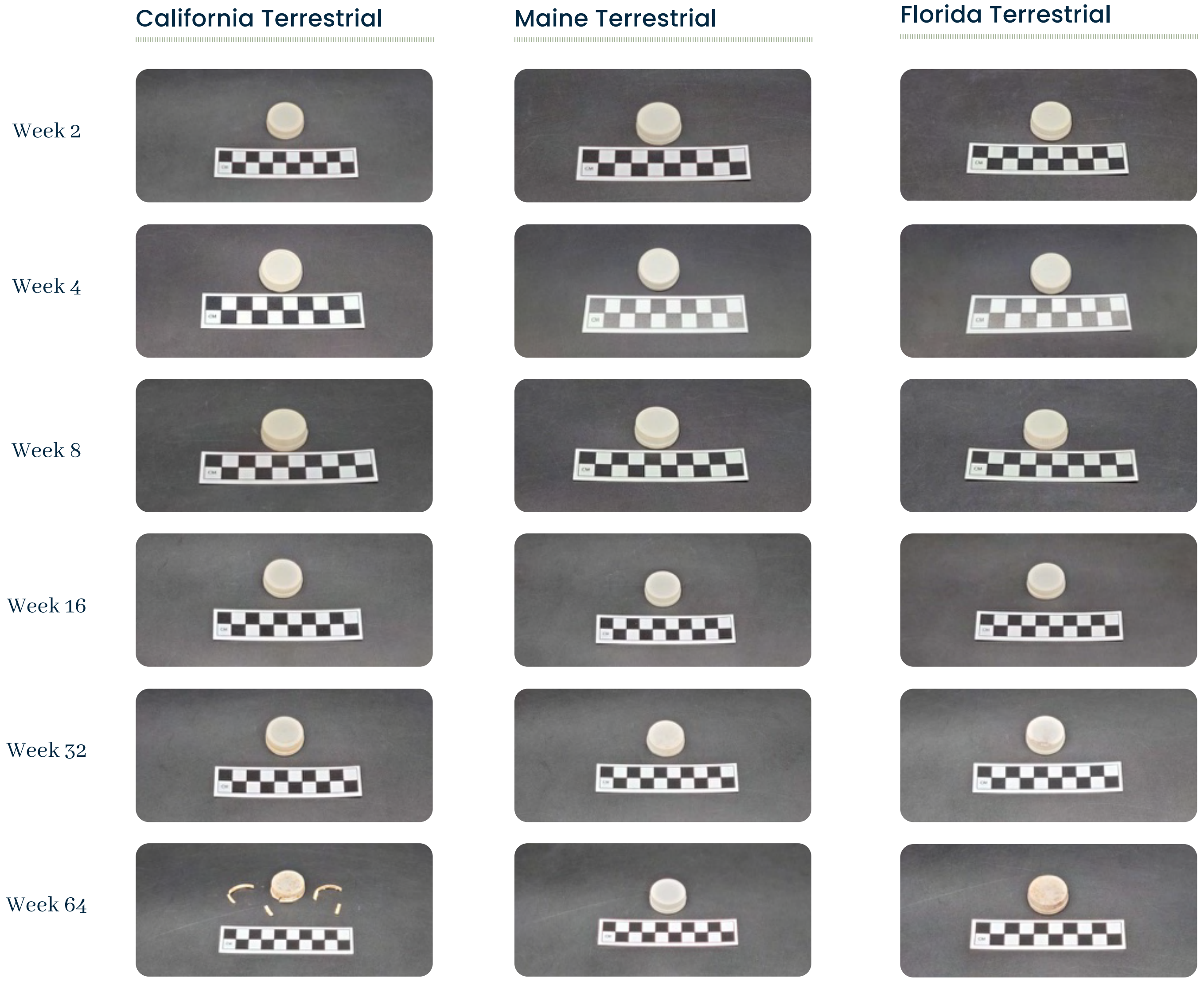
DAY ZERO



M Bottle Cap, PHA

The PHA bottle cap showed similar degradation behavior to the PHA bottle, with slightly quicker degradation compared to the bottle.



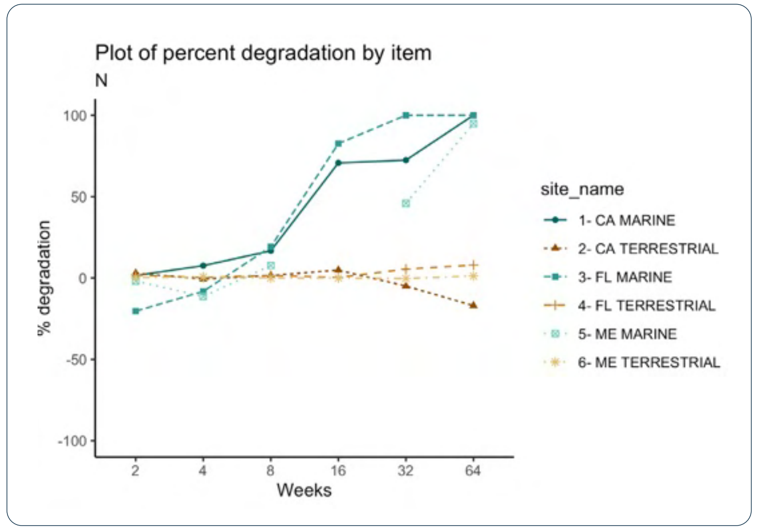


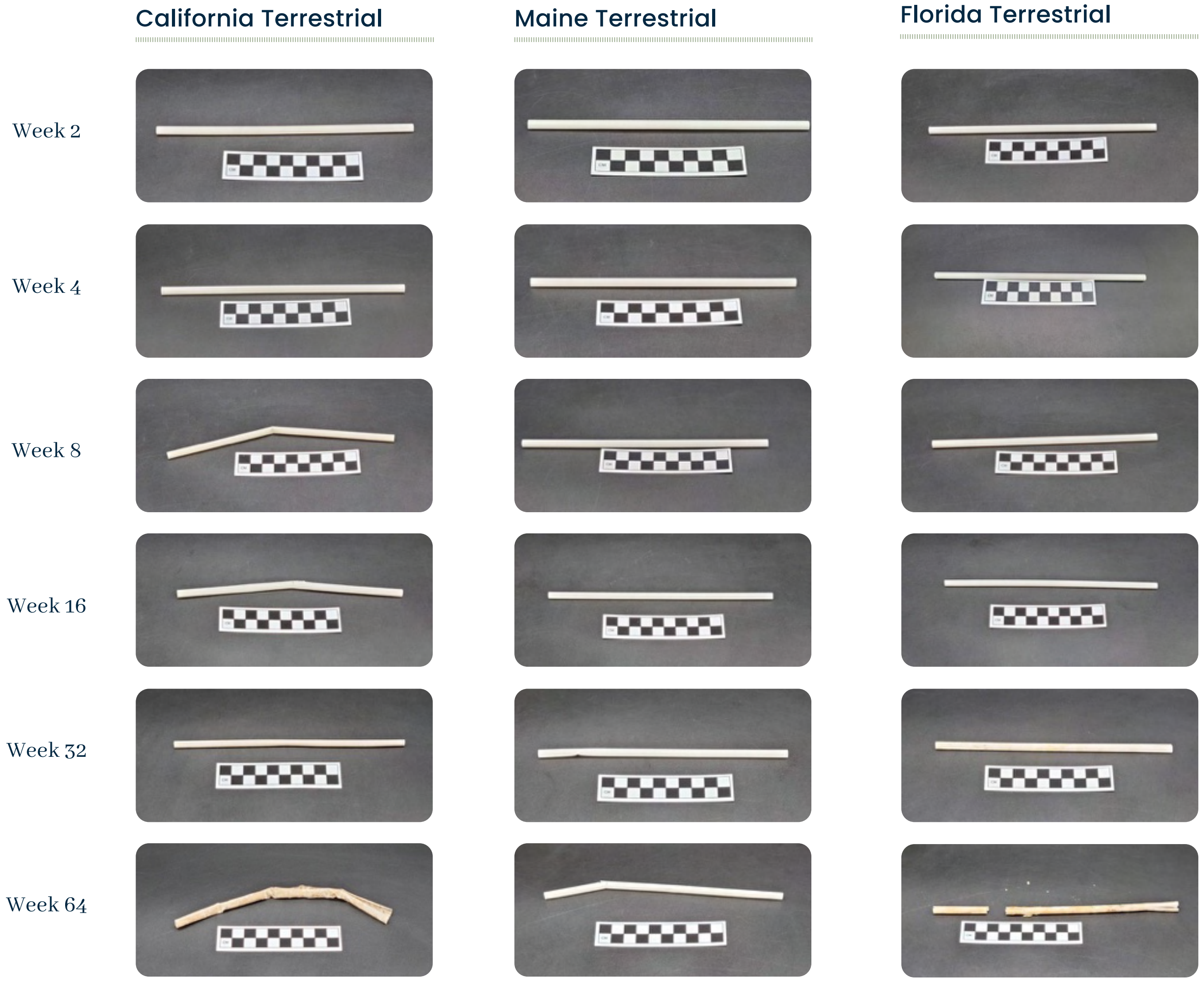
N Straw, PHA

DAY ZERO

N Straw, PHA

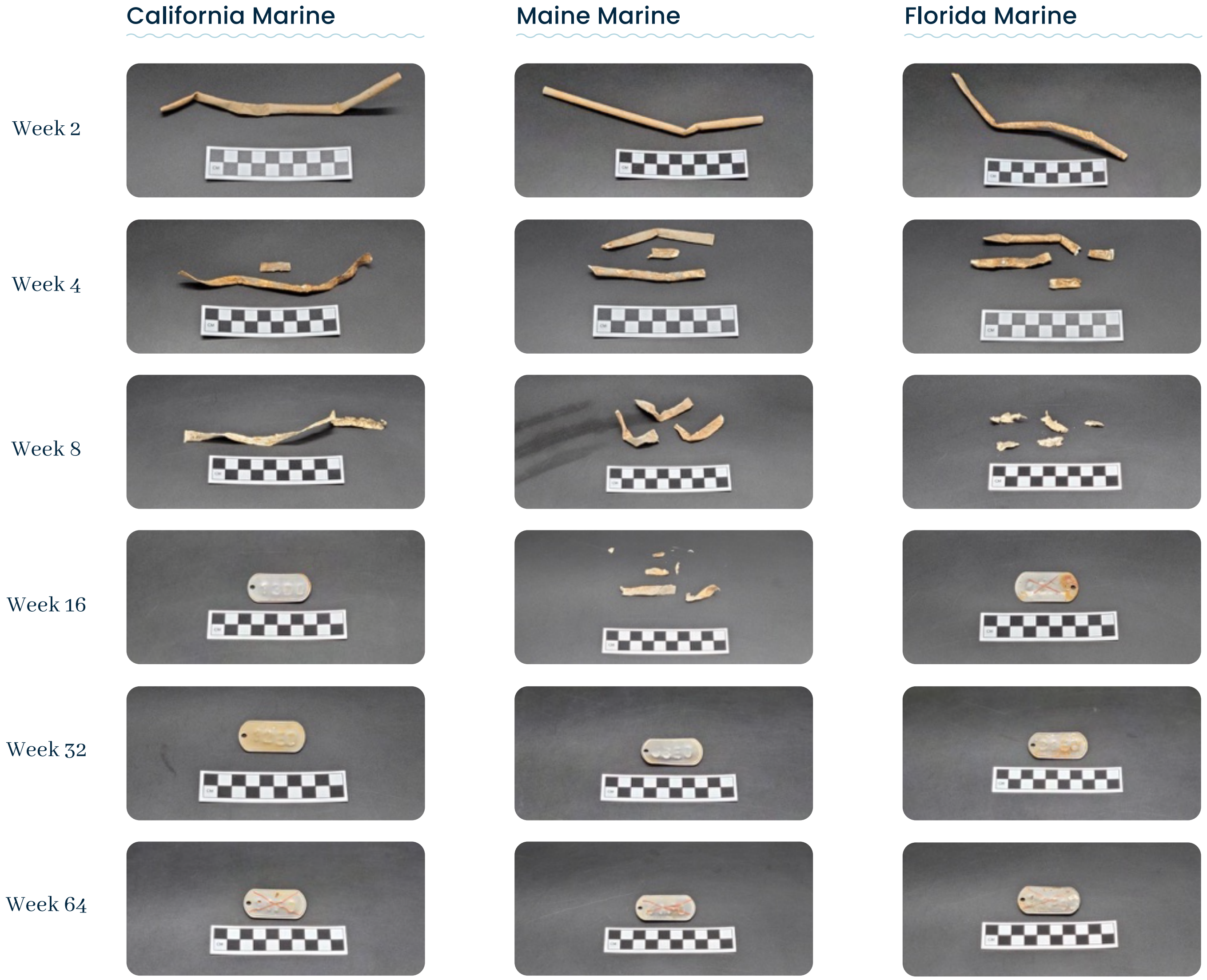
The PHA straw exhibited slower degradation compared to PHB and paper straws. It fully degraded at the Florida marine site after 32 weeks, and was fully degraded at all marine sites after 64 weeks. However, the PHA straw showed limited to no degradation at terrestrial sites. Its degradation times were similar to PLA straws.





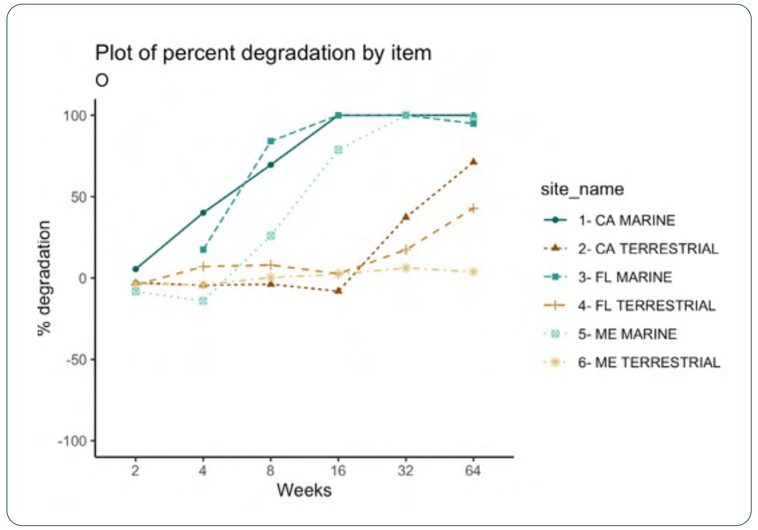
O Straw, Paper

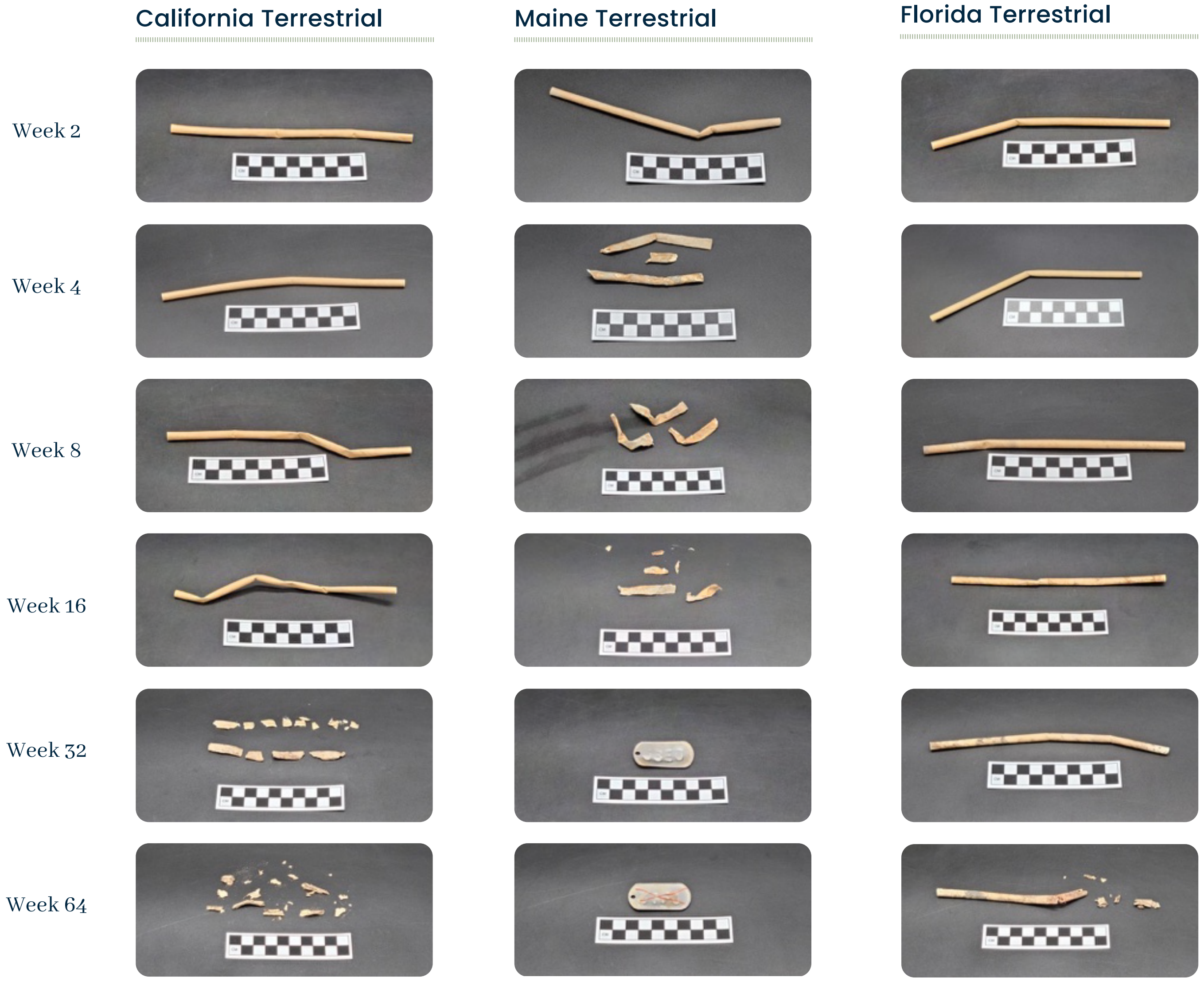
DAY ZERO



O Straw, Paper

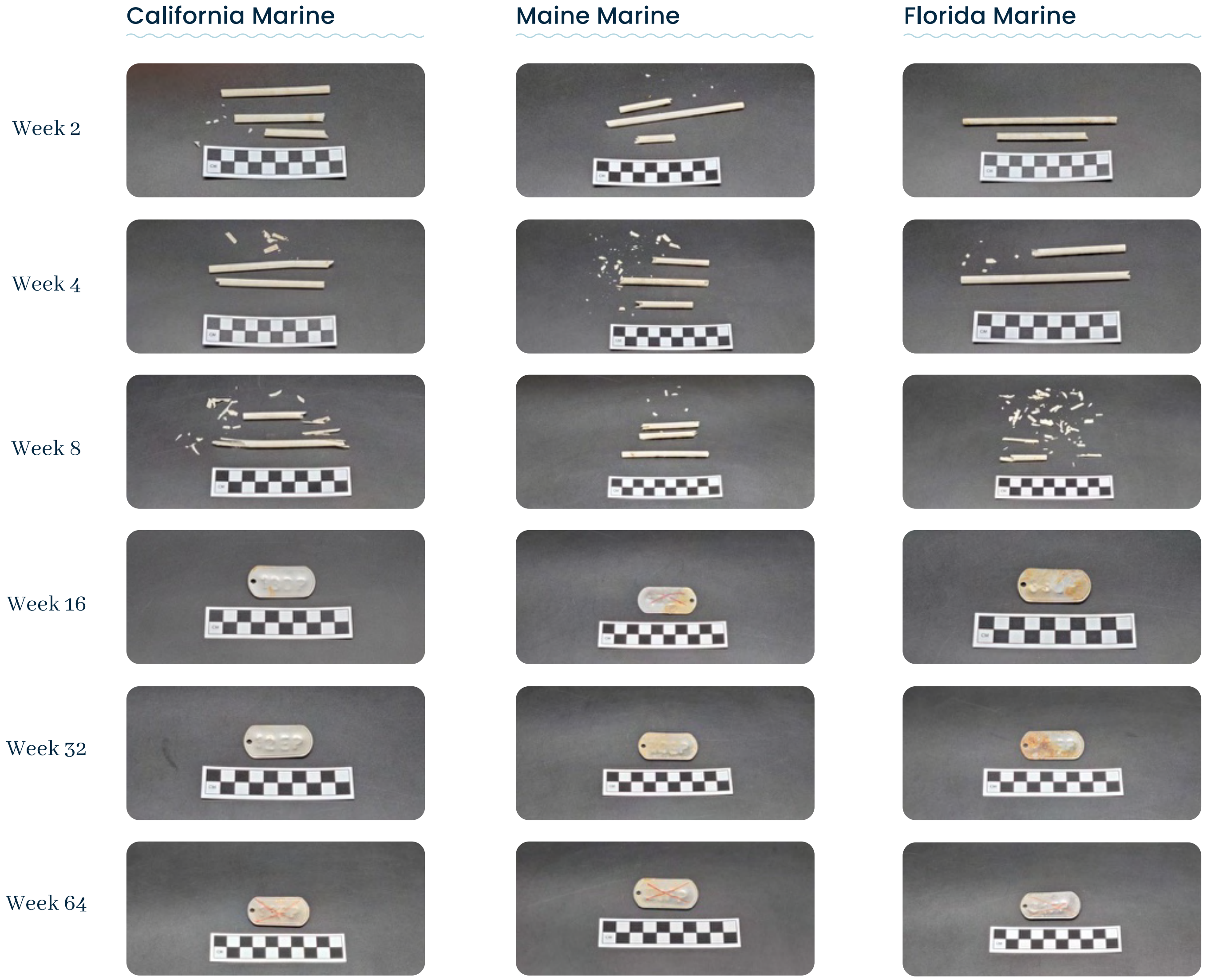
The PLA straw exhibited slower degradation than PHB and paper straws. It fully degraded at the Florida marine site after 32 weeks, and at all marine sites after 64 weeks. Limited to no degradation was observed at terrestrial sites, with similar degradation times to PHA straws.





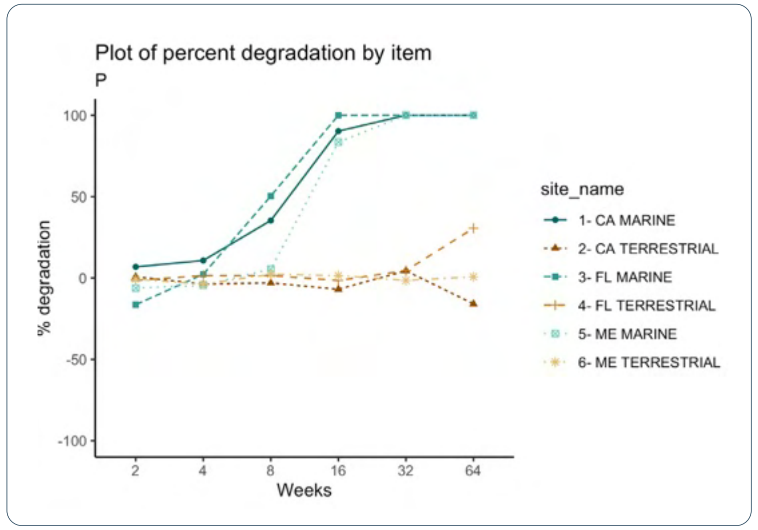
P Straw, PHB

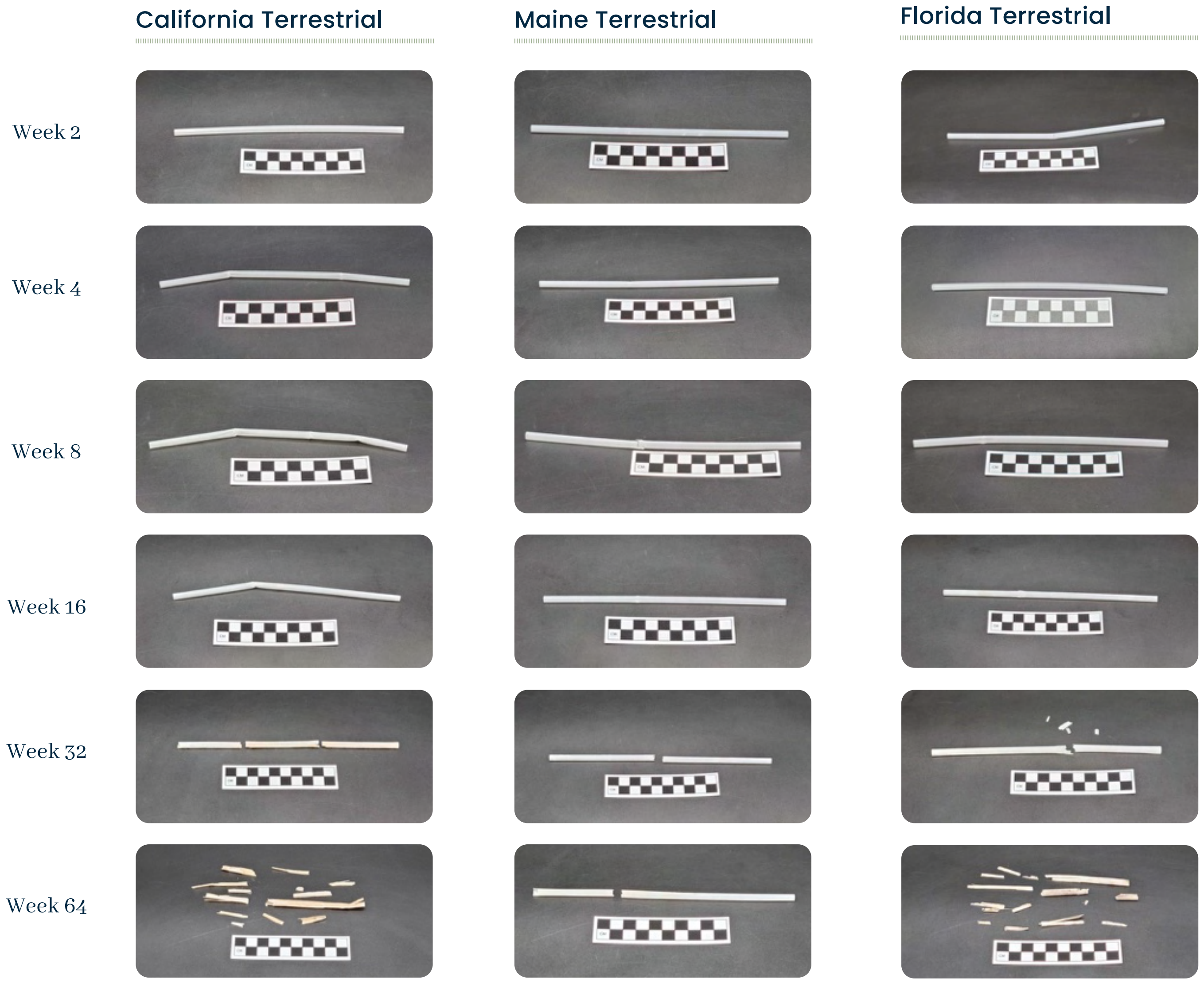
DAY ZERO



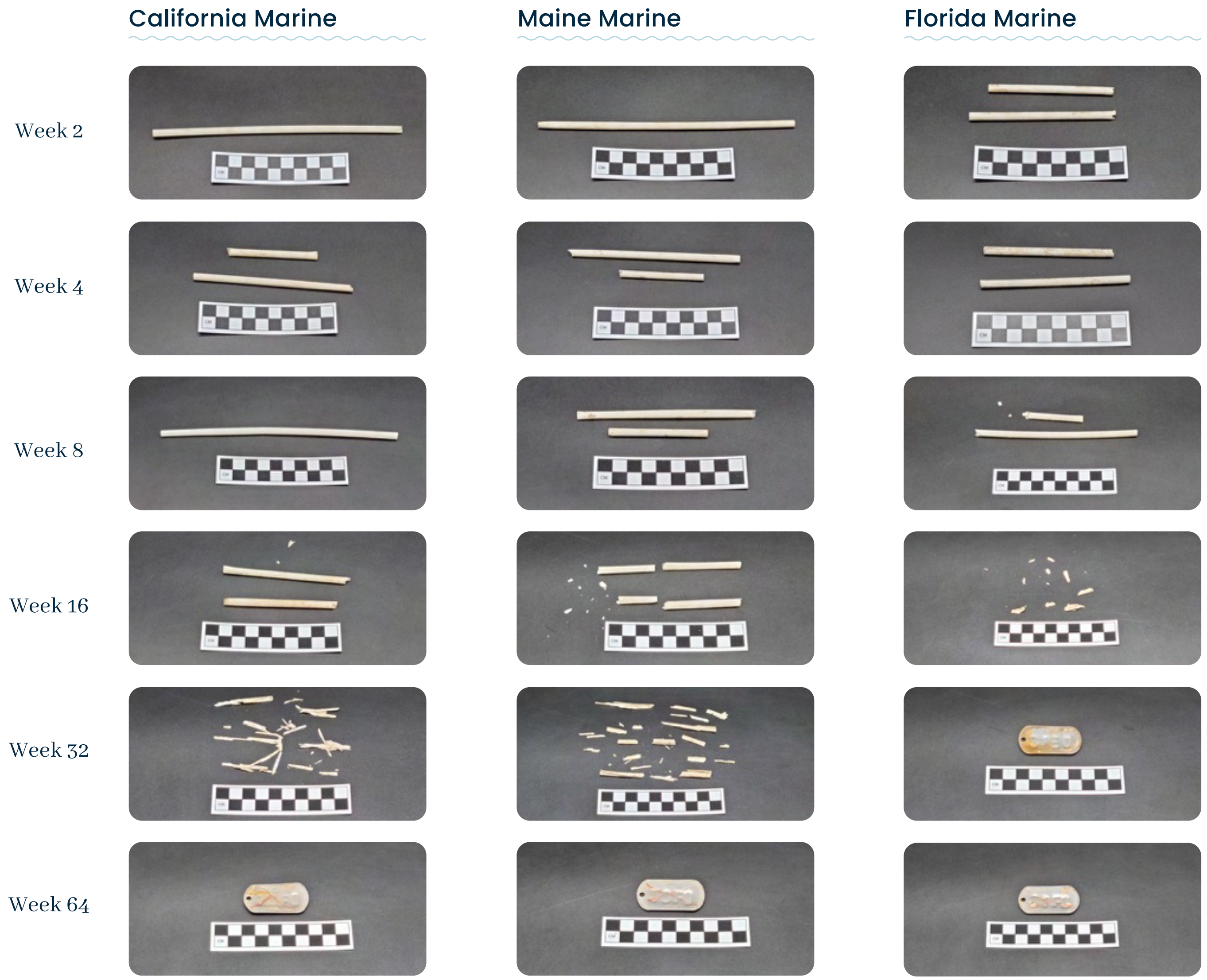
P Straw, PHB

The PHB straw had the fastest fragmentation among straws, almost fully degrading at all marine sites after 16 weeks. It was not detected at 32 and 64 weeks at marine sites. Some signs of mass loss were observed at the Florida terrestrial site after 64 weeks. Of the straws, only the PHB and paper straws exhibited degradation at terrestrial sites.



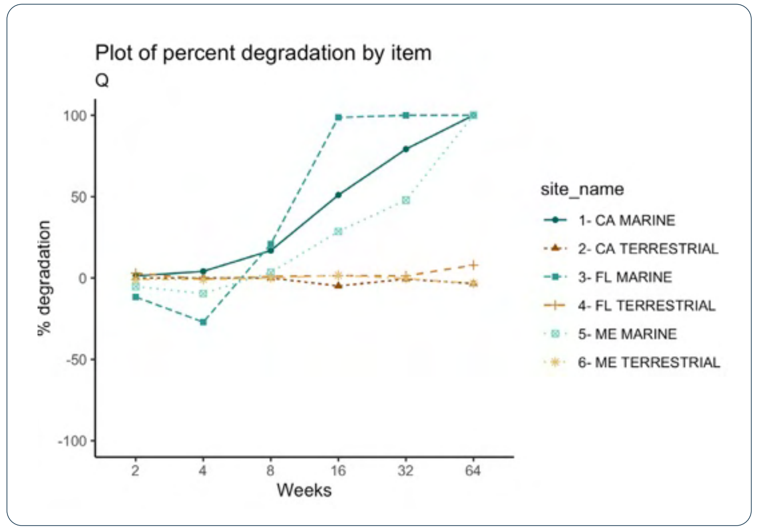


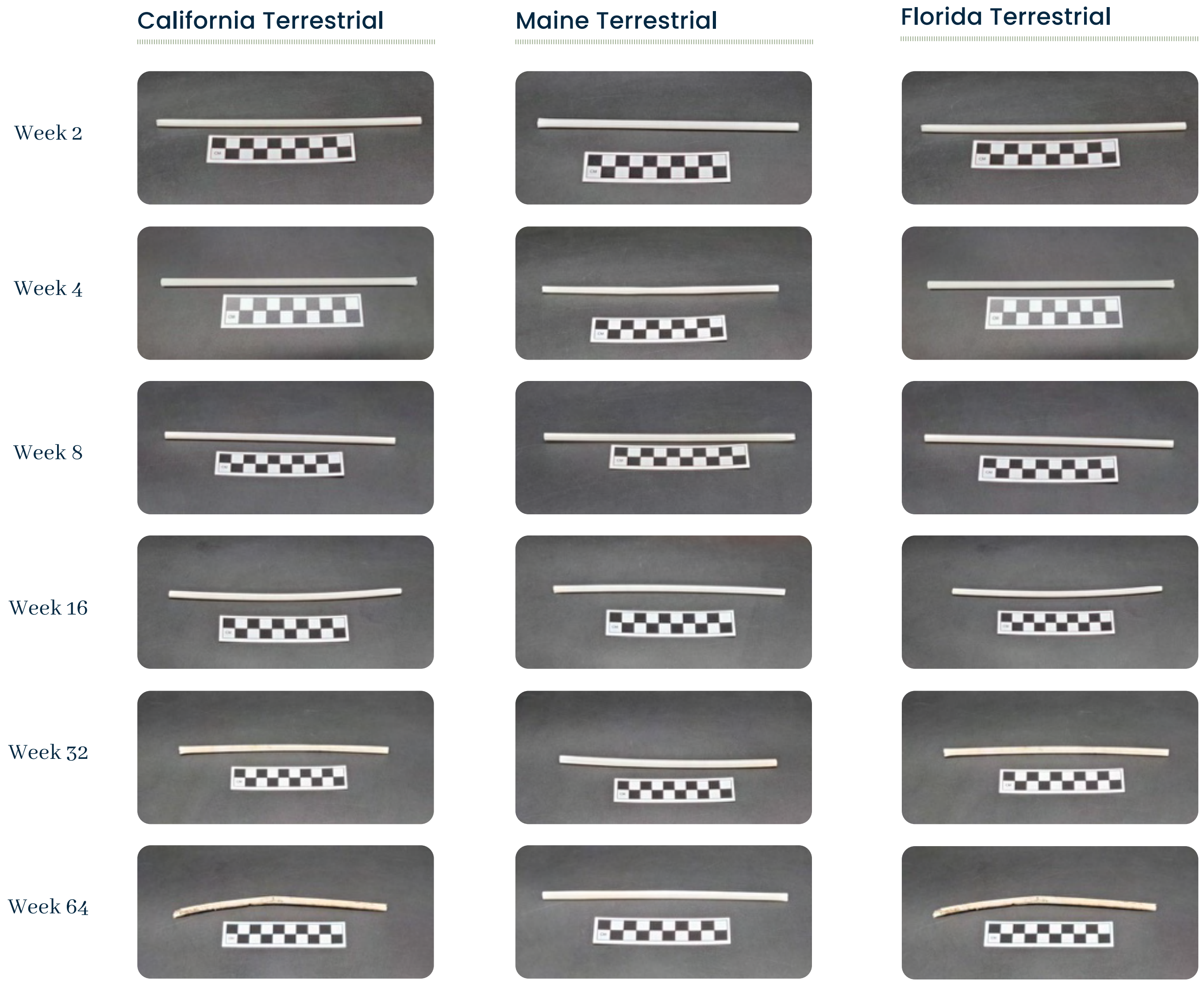
Q Straw, PLA



Q Straw, PLA

The PLA straw exhibited slower degradation than PHB and paper straws. It fully degraded at the Florida marine site after 16 weeks, and at all marine sites after 64 weeks. Limited to no degradation was observed at terrestrial sites, with similar degradation times to PHA straws. We observed 100% mass loss for the PLA straw at 16 weeks, compared to 32 weeks for the PHA straw.





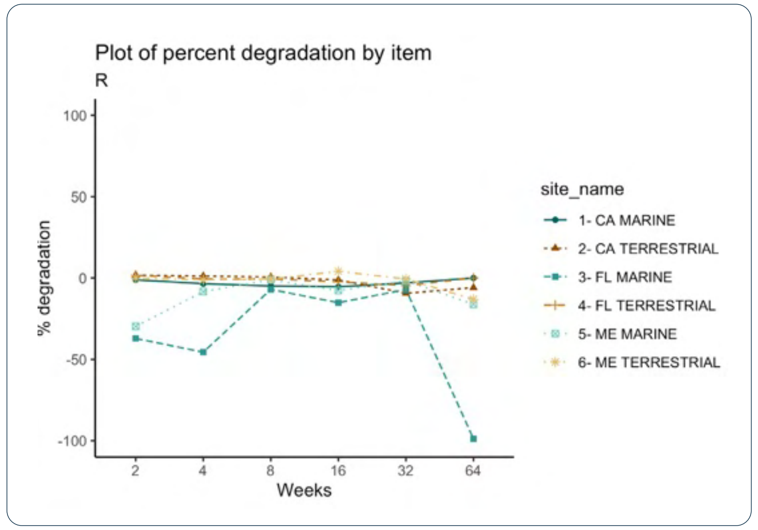
R Straw, PE (Control)

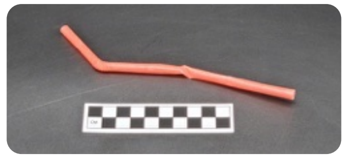
DAY ZERO

	California Marine	Maine Marine	Florida Marine
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

R Straw, PE (Control)

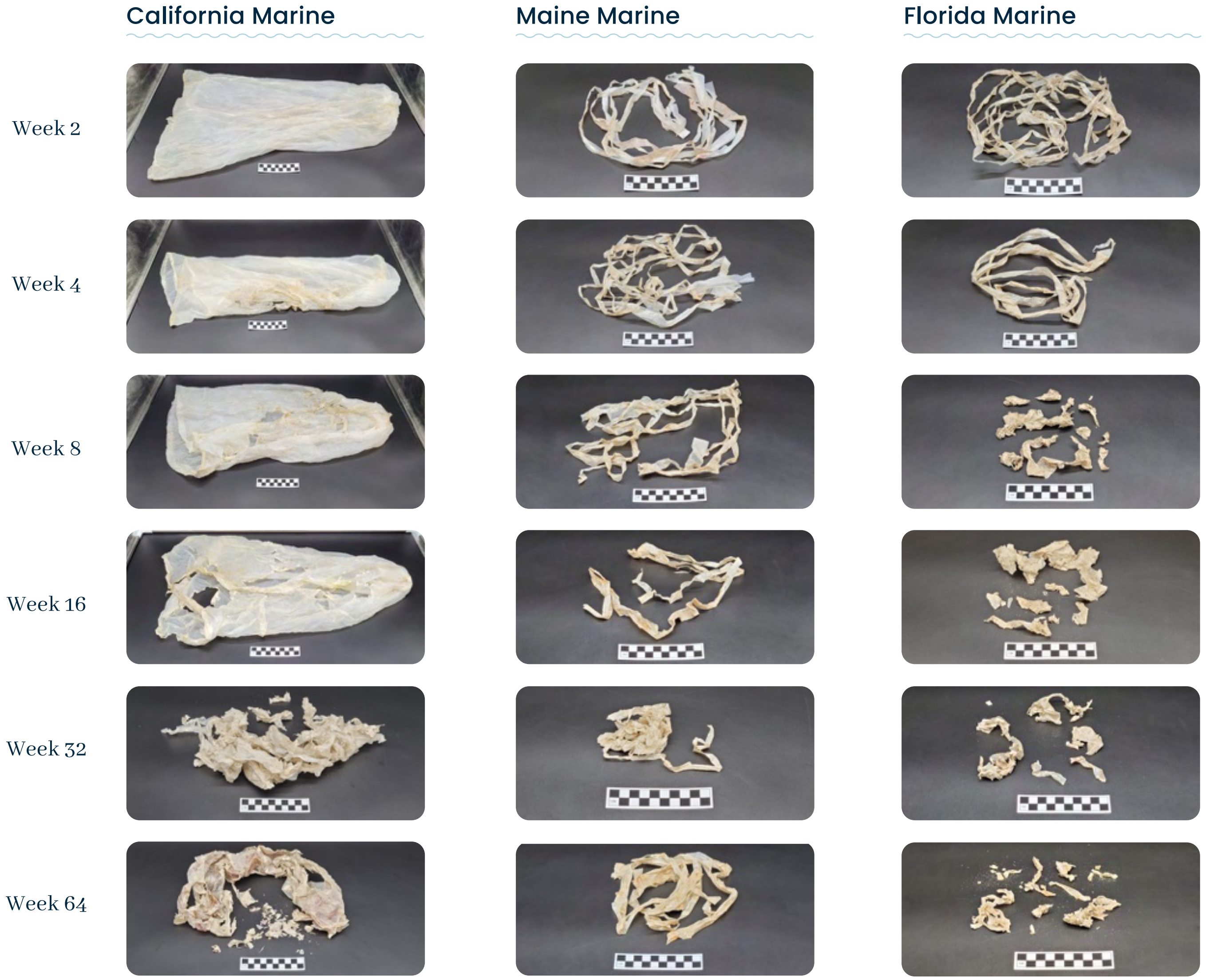
The PE straw remained unchanged across all sites and environments, exhibiting persistence of this item.



	California Terrestrial	Maine Terrestrial	Florida Terrestrial
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

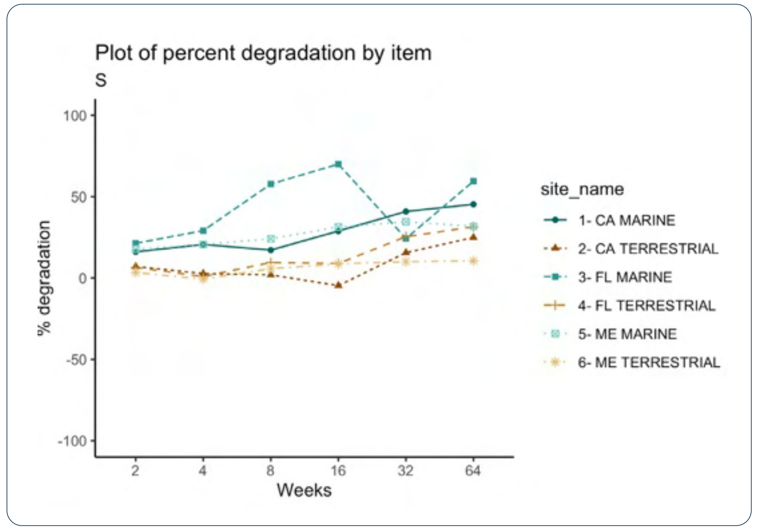
S Bag, Compostable Starch-based Resin

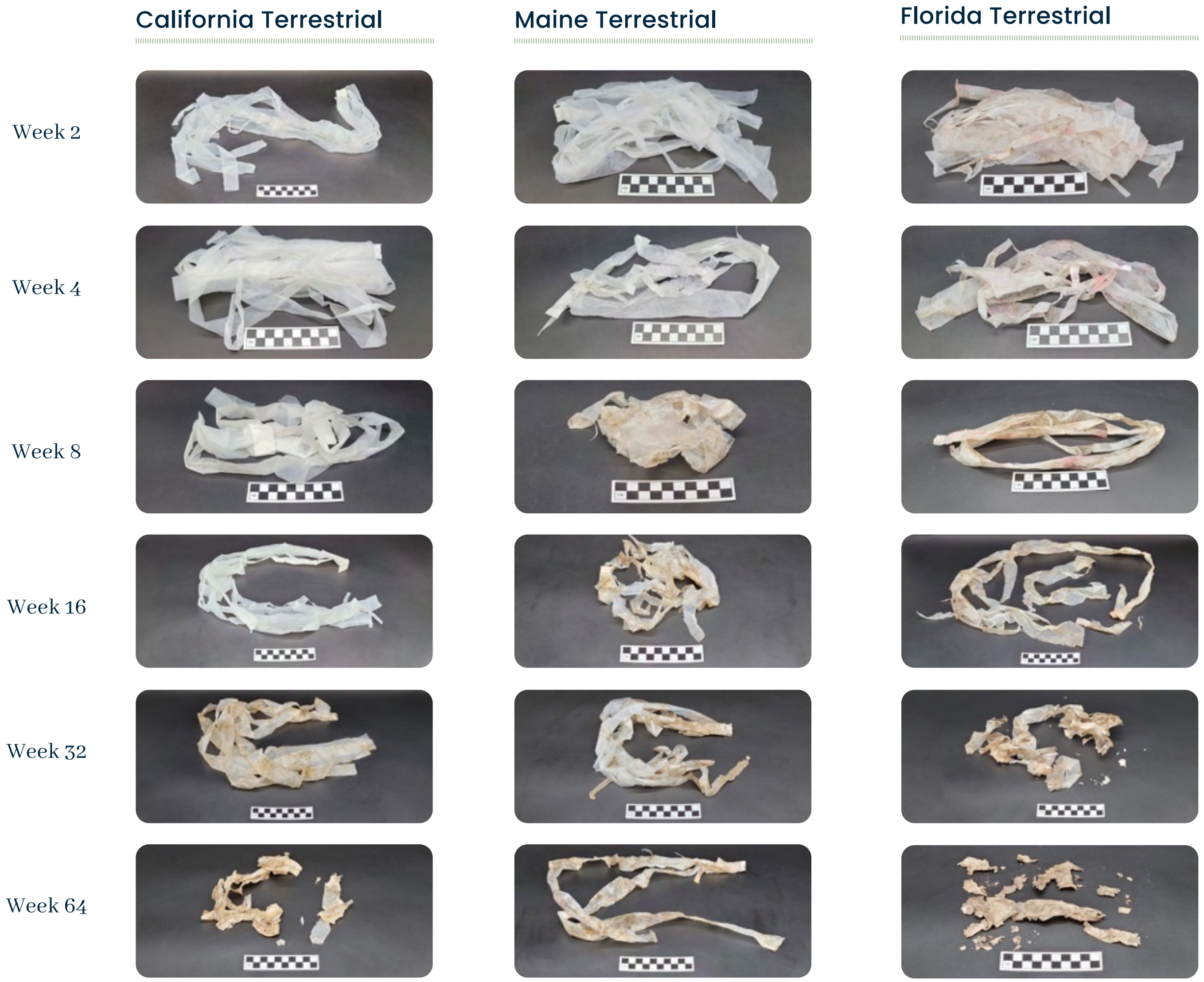
DAY ZERO



S Bag, Compostable Starch-based Resin

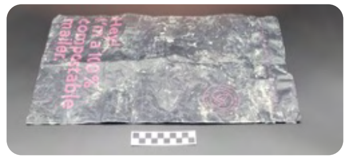
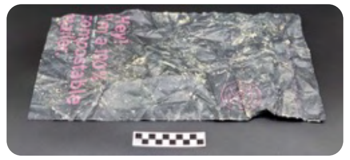
The compostable starch-based resin bag showed some degradation at marine sites, with inconsistent mass changes over time. It lost approximately 50% mass at the Florida marine site after 64 weeks, with slower fragmentation at the California and Maine marine sites.





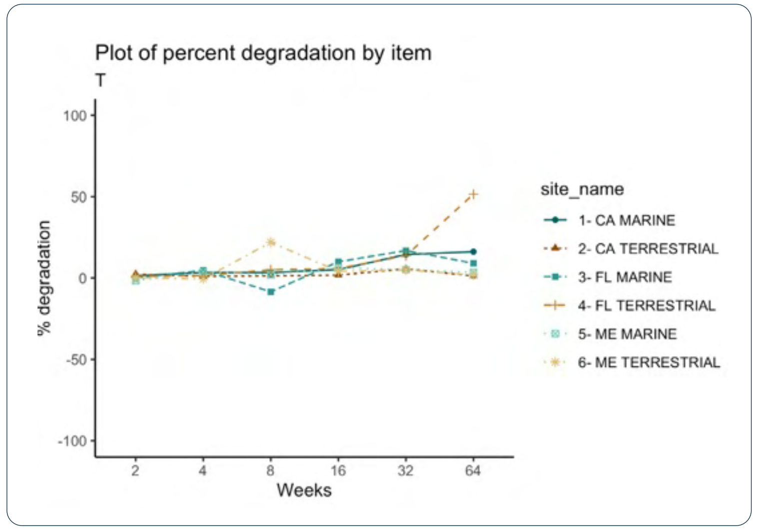
T Bag, PBAT/PLA

DAY ZERO

	California Marine	Maine Marine	Florida Marine
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

T Bag, PBAT/PLA

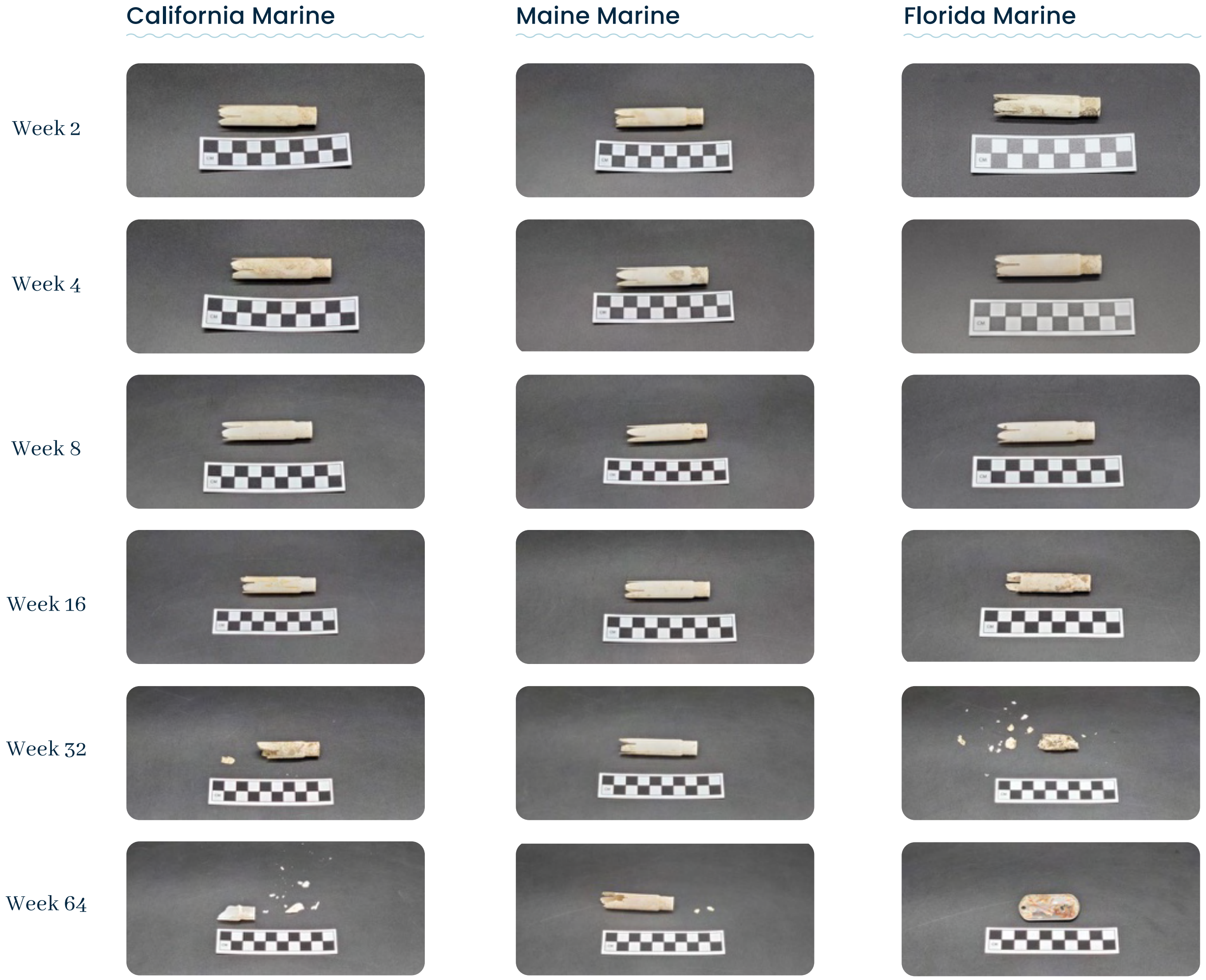
The PBAT-PLA bag labeled compostable persisted throughout the study in all environments. Notably, the greatest mass loss occurred at the Florida terrestrial site, with an average of 50% mass loss after 4 weeks.



	California Terrestrial	Maine Terrestrial	Florida Terrestrial
Week 2			
Week 4			
Week 8			
Week 16			
Week 32			
Week 64			

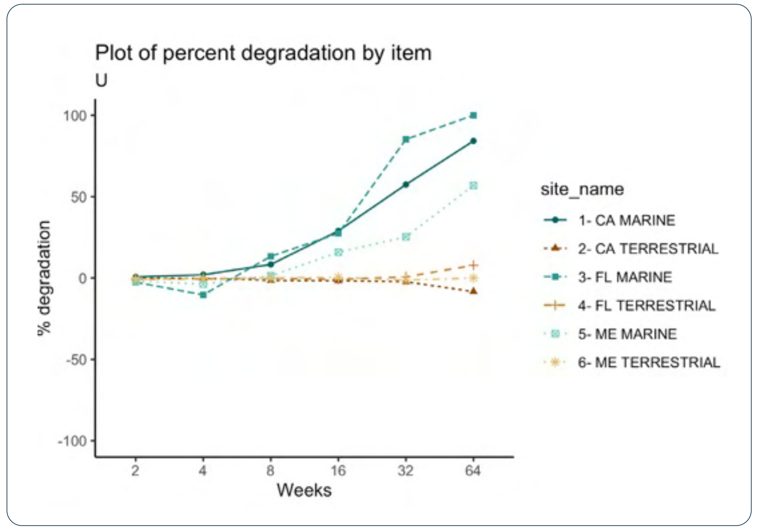
U Tampon Applicator, PHA

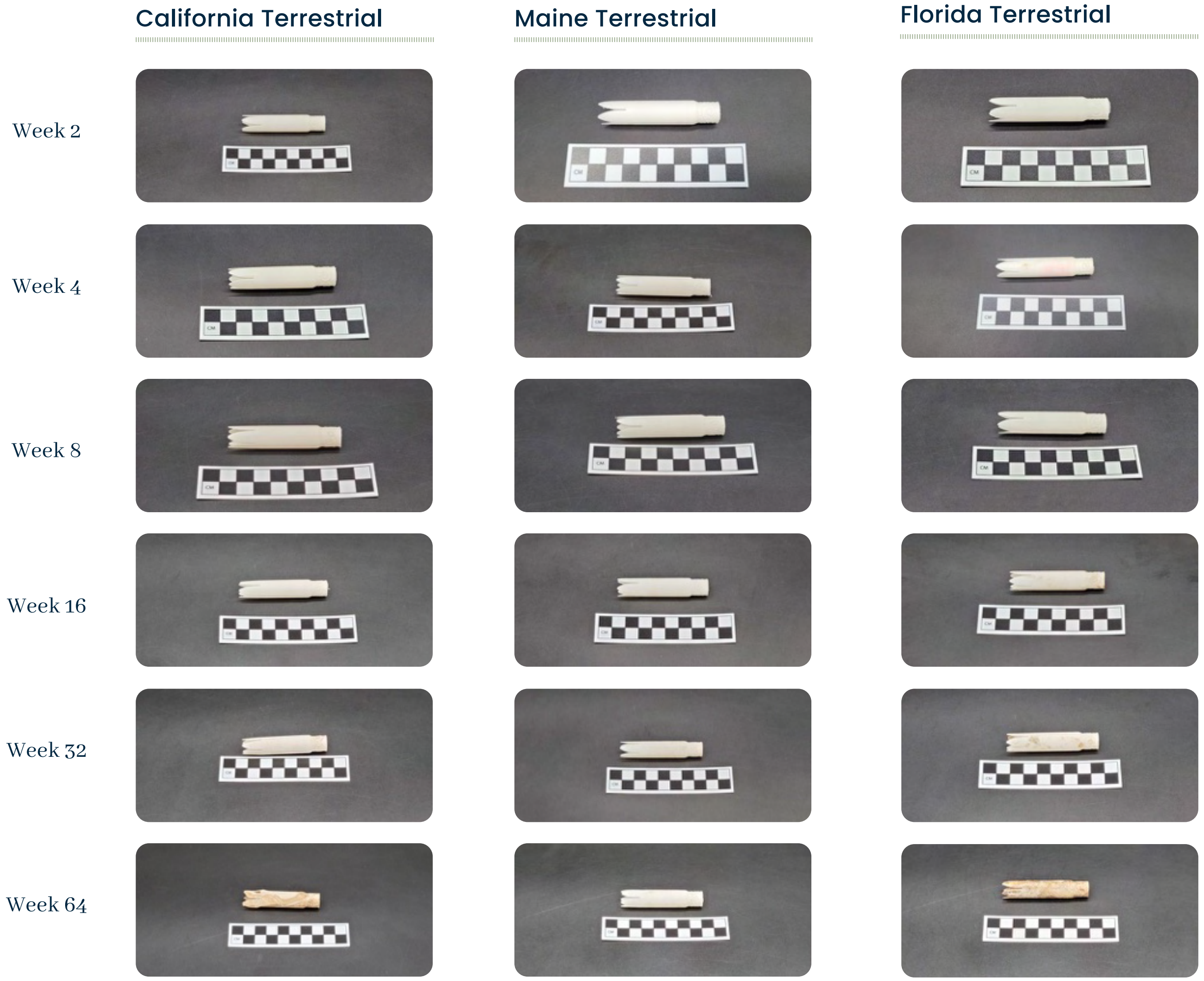
DAY ZERO



U Tampon Applicator, PHA

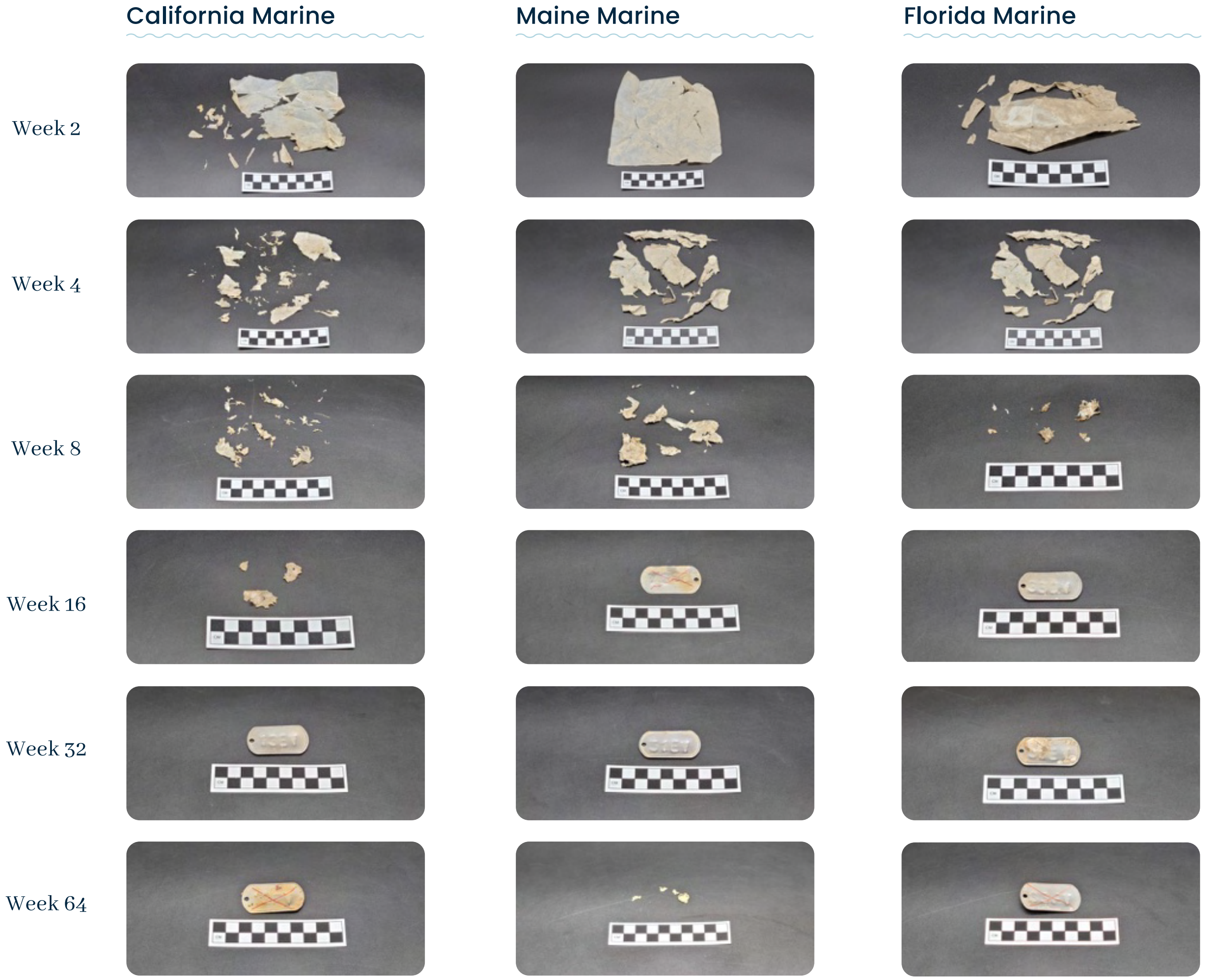
The PHA tampon applicator showed some degradation at marine sites, with the fastest fragmentation at the Florida marine site. It was undetected at the Florida marine site after 64 weeks, but exhibited limited degradation at terrestrial sites. Fragmentation was faster than the PHB pen. The thickness of this item likely slowed fragmentation at the marine sites compared to thinner PHA items.





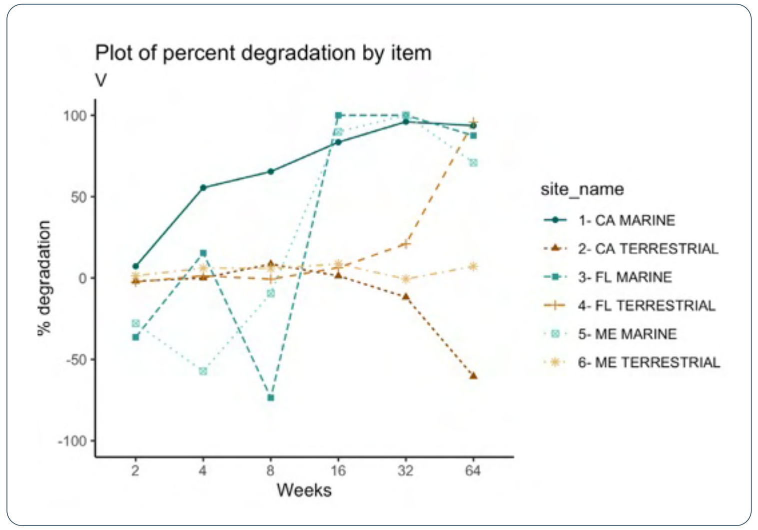
V Baby Wipe, PHA

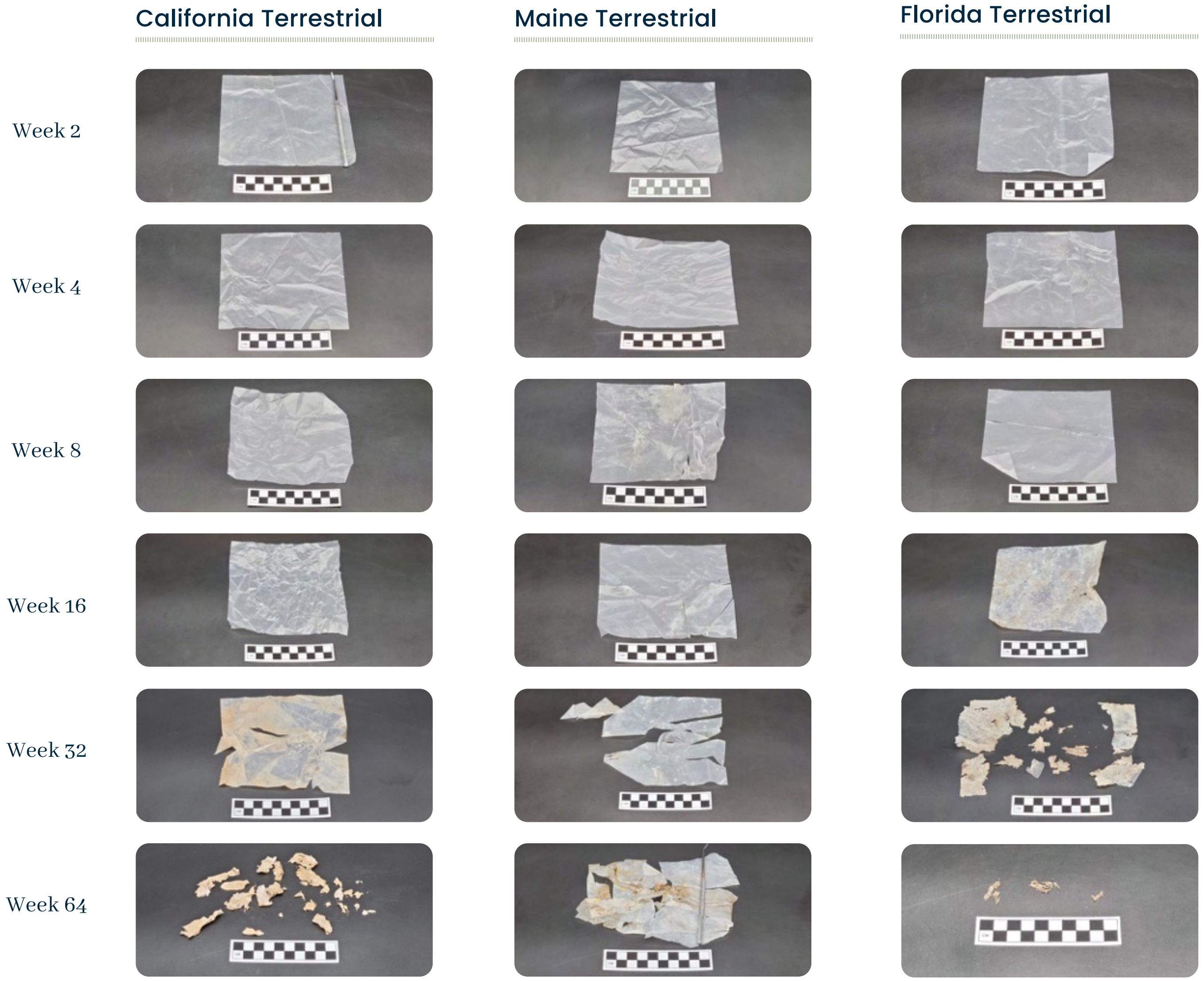
DAY ZERO



V Baby Wipe, PHA

The PHA baby wipe exhibited similar degradation rates to the PHA thin film, showing relatively quick degradation in all marine environments, with almost complete mass loss at 16 weeks. In the Florida site it was almost completely degraded at 64 weeks. Like all other samples, our methods may have missed the smallest fragments. These wipes in particular fragment into thin fibers that because of their shape could more readily escape the mesh bag (200um).





Results

Within a product category (e.g., straws, thin films, and utensils), items exhibited different rates of fragmentation. Overall, we found that traditional plastics, like polyethylene (PE) and polystyrene (PS), were persistent in all environments. These plastic items were practically unchanged after 64 weeks in the environment. We also found that the persistence of the paper straw and bamboo fork were similar to some of the items made from biopolymers, which may contradict some stakeholder assumptions about reasonable alternatives based on degradation rates. Here, we compare item performance, and use the California marine setting to illustrate that polymer type impacts degradation.

FILMS

We tested seven types of thin film. Thin film made from PHA, PBS, and PLA showed signs of degradation after 16 weeks in the California marine environment. The PHA film was over 75% fragmented at 16 weeks and was the only film to show fragmentation past the point of recognition at 32 weeks. Following the PHA film, the PBS film showed the second quickest fragmentation.

Three film samples with blended materials, PHA-PLA, PHA-PLA with a metal barrier, and PBAT-PLA, were resistant to fragmentation. The polyethylene (PE) film showed no observable signs of fragmentation.

- **Thin film fragmentation fastest for PHA, PBS, and PLA. PHA blended with PLA persisted longer than PHA, PBS, and PLA alone.**
- **PHA and PLA with metal barrier was the most persistent.**
- **PBAT-PLA bag labeled compostable was persistent throughout the study in all environments.**

PLA

PE

PBS

PHA

PHA-PLA WITH METAL BARRIER

PBAT-PLA

PHA-PLA

STRAWS

We tested five types of straws. Results after 16 weeks in the California marine environment are shown here. The paper straw fragmented quickly; at 8 weeks the straw lost approximately 75% of its initial weight. By comparison, the three bioplastic straws lost 25-50% their initial weight in the same timeframe.

At 16 weeks, the PHB straw was the only bioplastic straw to fragment past the point of recognition. The PHA straw showed slightly greater fragmentation compared to the PLA straw at 16 weeks. The PE straw was largely intact.

- **Straw fragmentation fastest for the paper straw.**
- **PHB the fastest bioplastic to fragment (PHA and PLA were similar).**

PHA

PLA

PHB

PAPER

PE

UTENSILS

Utensils persisted much longer than straws, likely due to thickness. The amount of exposed surface area plays a significant role in degradation rates due to a higher contact with microbial activity.

In the California marine environment, at 64 weeks all items were still visible. The PHA and PLA forks were the most fragmented, while the bamboo fork was only beginning to show signs of fragmentation. The same trend was observed at all marine sites. This observation may be counterintuitive to many stakeholders who consider cellulosic materials (wood or paper) to be better alternatives, in terms of environmental persistence. Lastly, the polystyrene (PS) fork showed no observable signs of degradation.

- **Utensil fragmentation fastest for PLA and PHA.**
- **Bamboo utensil persisted longer than PHA and PLA.**
- **PS utensil unchanged.**

PHA

PLA

BAMBOO

PS

Factors that Influence Bioplastic Fragmentation

ENVIRONMENT

- Moisture is key to microbial communities. Marine environments had greater fragmentation than terrestrial environments.
- Temperature matters. Cooler climates slow microbial activity. The cooler Maine setting slowed fragmentation of some items.
- Anoxic environments, like deeply buried mud and sediment that lacks oxygen, have fewer microbial communities and slower fragmentation rates.

As expected, the fragmentation rates varied across the six environments. The most striking differences were between marine and terrestrial environments; we observed greater fragmentation at all the marine sites compared to terrestrial environments. The dry California setting exhibited the slowest fragmentation overall. Thus, a product may be advertised as biodegradable, but under what conditions?

Temperature, moisture, exposure to sunlight (UV), and microbial communities are all factors that matter. A product that is 100% PHA may be expected to fragment into smaller particles, but this may be slowed in some environmental conditions. For example, environments with low oxygen, like some samples buried in wet mud in Maine, likely slow or prevent fragmentation.

Test certifications can be misleading. While our sites mimicked real environmental loss of products and packaging lost to the environment, testing certifications on biodegradability rarely include temperatures and moisture variability regimes. Certifications that an item is “marine degradable” or “degradable in soil” are not representative of all conditions and should be avoided to limit confusion. Nature is full of variability. Such certifications can be misleading to consumers that may think a degradability rating applies to deserts, forests, and marshlands equally, or that marine degradability applies to lakes and rivers, as well as oceans in warm and cold-water conditions.

THICKNESS

- Thin films and straws appeared to fragment fastest.
- Thick utensils, as well as a PHA bottle and PHA pen, fragmented slowly.
- Future product and packaging should consider designs that increase surface area, such as hollow or honeycombed replacement for thick pieces.

As with environmental conditions, thickness and design also had significant impacts on fragmentation rates. Only the PHA film, some straws (PHA, PHB, PLA, and paper), and PHA baby wipes fragmented beyond visual observation at all three marine sites. The PHA bottle, PHA bottle cap, and PHA tampon applicator fragmented beyond recognition only in the Florida marine site. Only one item fragmented beyond observation for terrestrial sites, the PHA baby wipes at the Florida terrestrial site. In all other cases, objects either stayed whole or fragmented into smaller observable pieces. We observed thin items (e.g., film and straws) decomposed more quickly than thicker items (e.g., cutlery and bottles). Overall, the thicker the item, the longer it remained intact.

Future products and packaging design will likely rely on innovations to decrease thickness and increase surface area for PHA, PHB, and PLA items. For example, a honeycomb structure could replace solid cutlery handles to reduce overall thickness and increase the surface area for microbes to act (Figure 5).

Figure 5. Meats and cheeses have challenging packaging replacements. A biodegradable material with a honeycomb design can be an alternative.

Photo by EasyPak

BLENDS AND LAMINATES

- Metal barrier to PBAT and a PLA blend inhibited fragmentation
- Blends of PE and biodegradable plastics might improve product performance, but impact fragmentation, biodegradation, and the release of additives into the environment

A product that is 100% PHA is expected to fragment into smaller particles. This may, however, be impacted with the addition of synthetic chemicals, and blends with other non-biodegradable plastics, like polyethylene or polypropylene. Blends are often used to help overcome some of the limitations of pure bioplastics. For example, pure PLA is limited in its use in food packaging due to its poor toughness and low impact resistance. To overcome these technical challenges, PLA is blended with other polymers. Similarly, PHB in its pure form is quite brittle, but blending with other polymers can enable better mechanical properties. Although we observed blends with PE to have slow fragmentation rates, blends of PHA with other biodegradable polymers generally demonstrate better biodegradability than pure PHA (Soroudi and Jakubowicz 2013).

Products may contain various types of biodegradable biopolymers and bioplastics, which makes third party certifications critical to making clear and well vetted marketing claims.

Recommendations for Future Research

The bioplastic industry is moving quickly, from material chemistry to packaging design, with the performance of varied polymers and their blends driving innovation. Yet many products and packaging lack testing to evaluate their fate in varied environments and waste management streams. More research is needed to evaluate the fate of these new novel packaging materials and designs.

TEST CONSUMER-READY PRODUCTS AND PACKAGING, NOT PROTOTYPES.

Biomaterials in their raw form (e.g., 100% PHA) may perform in a certain way, but we cannot expect those materials to perform in the same way once product manufacturing takes place, adding in additional chemicals and blends. Future work should evaluate commercially available PHA, PHB, and PBAT products and packaging items that contain realistic mixtures of chemical additives (e.g., plasticizers, colorants), and blends of polymers. Blends of different polymers may increase packaging performance but could significantly change end of life characteristics.

TEST INNOVATIVE REPLACEMENTS FOR THICK, SOLID ITEMS.

Degradation slows down considerably with solid parts, but could design elements – e.g., a honeycomb or foamed interiors – increase degradation without losing strength? Increasing the surface area of a product and allowing microbes to get inside thick items more easily will speed up degradation. Lightweighting an item without compromising performance would have the added benefit of reducing material costs. There are two questions here to consider: 1) how do new designs impact product performance and 2) are new designs able to decrease degradation times?

CHAPTER 4:

BIOPLASTICS, A SOLUTION OR POLLUTION?

> “
>
> Zero Waste: The conservation of all resources by means of responsible production, consumption, reuse, and recovery of all products, packaging, and materials without burning them and with no discharges to land, water, or air that threaten the environment or human health.
>
> **ZERO WASTE INTERNATIONAL ALLIANCE**

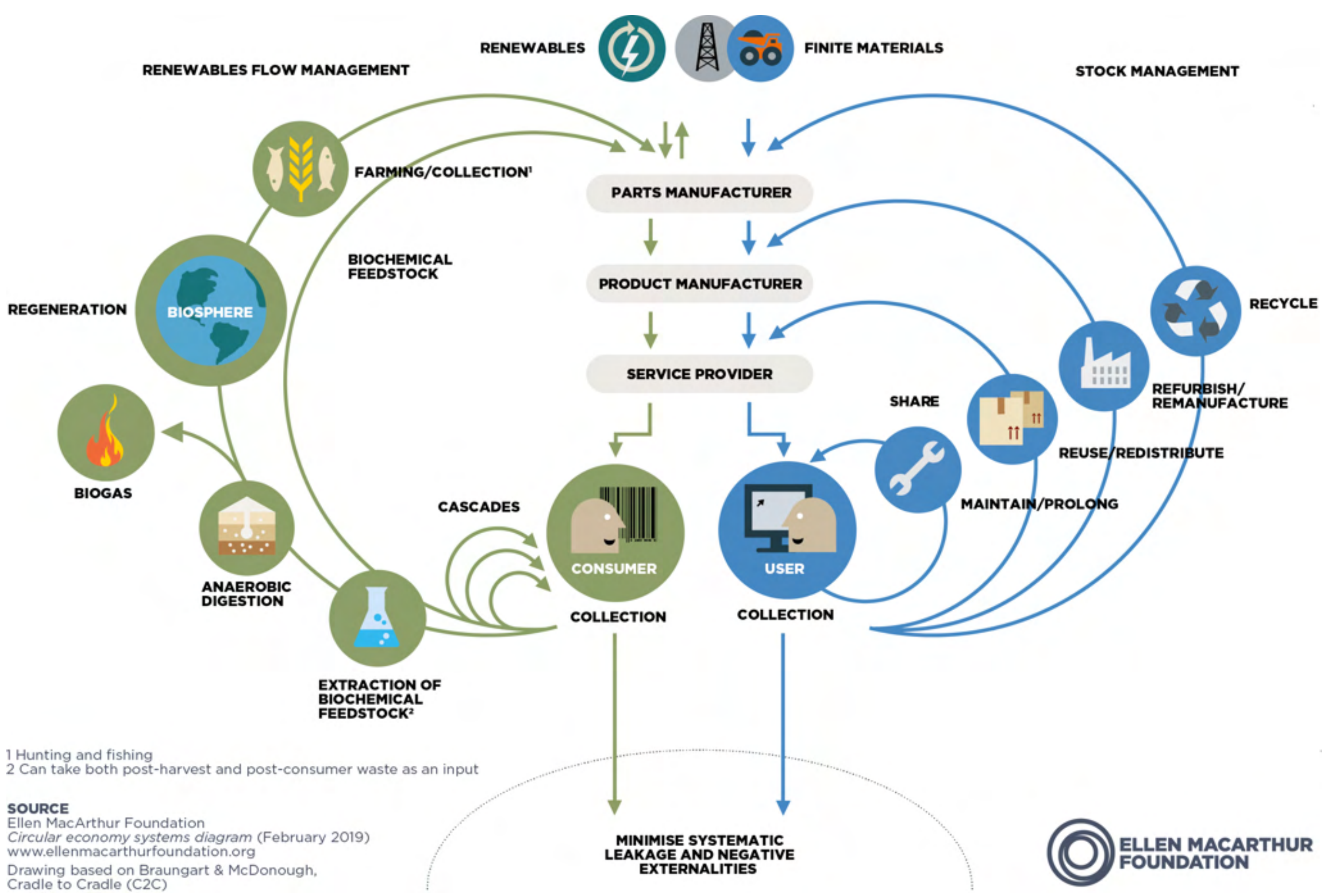
Bioplastics are part of the solution to the plastic crisis, but only if the right material and right design are applied correctly to the right problem. In the zero waste hierarchy, biodegradable items are designed for the biological cycle, with composting historically considered to be the primary end of life scenario. However, things have changed.

There are two holy grails: packaging performance and rapid degradation. Is it possible to have both? Product and packaging producers are working to meet market demand for materials that perform like conventional plastics, but without the legacy of harm science has revealed. To improve packaging performance, additives and blends are employed to increase shelf-life, create a vapor barrier, or prevent degradation or deformation. But as we’ve seen, these improved performance properties often come at the cost of end of life degradation.

A “compostable” label for all bioplastics is no longer realistic because of the variety of additives and blends, especially when they are proprietary and their chemistry undisclosed. With the emergence of diverse biodegradable materials with varied properties, we are now blurring the lines between biological and technical materials (Figure 6). Careful consideration of the full lifecycle of products and packaging, from extraction and production, to end of life – is required.

Bioplastics, a Biological or Technical Material?

The circular economy system diagram, also known as the butterfly diagram, encompasses the flow of human-made materials in a circular economy (Figure 6). Materials are divided into two groups, 1) the biological cycle and 2) the technical cycle. In the biological cycle, renewable materials break down into nutrients. In the technical cycle, finite materials remain in circulation through reuse, repair, refurbishing, and recycling. The goal is to achieve true circularity with no products or materials in the linear economy, which ends in incineration, landfill, or pollution lost from the system. Where do bioplastics fit?



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

Figure 6. Circular economy butterfly diagram for biological and technical materials (Ellen MacArthur Foundation, 2019).

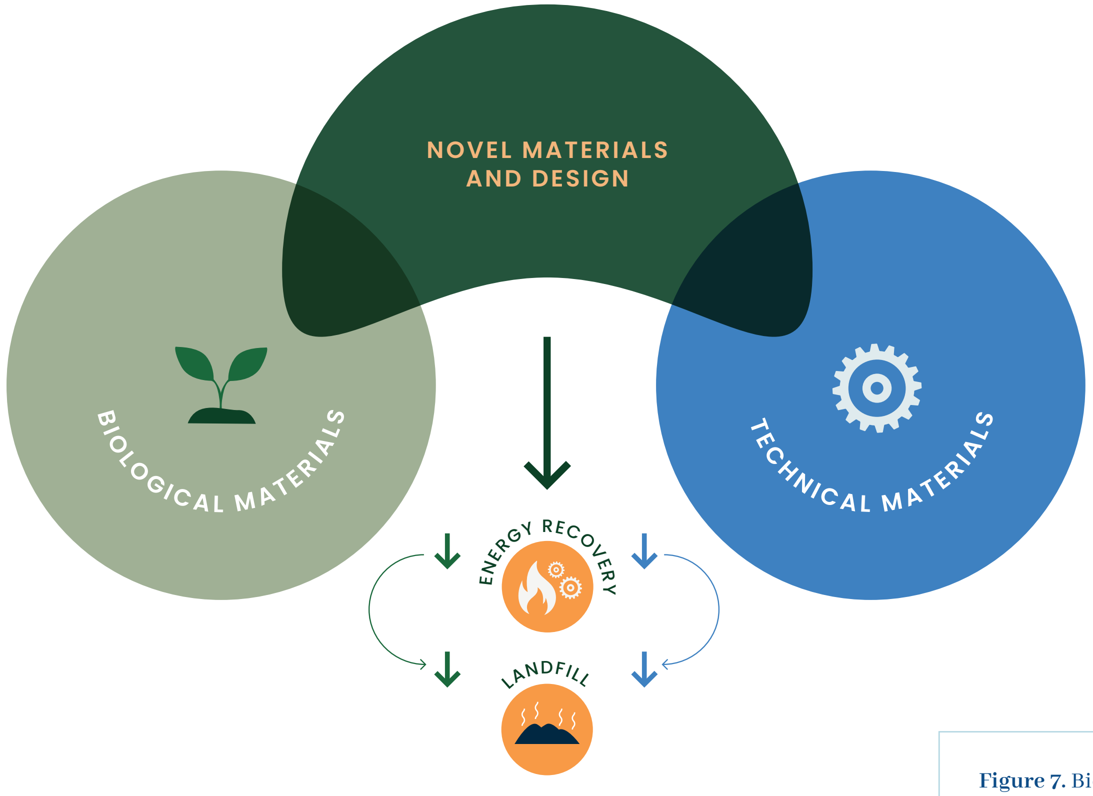


Figure 7. Biodegradable plastics can be considered biological or technical materials based on chemistry and design.

Bioplastics encompass a diverse set of materials with a wide range of properties. Degradation rates vary depending on the environmental conditions and design (e.g., polymer type, shape, and thickness). Although bioplastics can be made from renewable materials, they also exhibit characteristics of technical materials. As a result, it is no longer appropriate to categorize a bioplastic or biopolymer solely within a biological or technical cycle based on the primary polymer in a product (Figure 7). Unless the entire suite of chemistry is disclosed and the design of the product or packaging exhibits relatively rapid degradation in all environments (such as the performance of biopolymer straws and utensils compared to similar paper and bamboo items).

Our case study revealed a wide range in bioplastic degradation rates. We found that a thick fork handle can last 64 weeks (over one year) in the Florida coastal marsh, whereas a thin film can fragment beyond recognition in less than 16 weeks in the same environment. Considering the needs of compost facilities and municipalities responsible for managing litter, the persistence of certain thicker packaging materials can pose challenges. Policymakers face the crucial task of determining whether a bioplastic utensil should be classified as a technical material, a biological material, disposed of in a landfill, or even restricted from production.

Stakeholder Questions and Concerns

REUSE VS. SINGLE-USE?

Bioplastics are not functional replacements for the majority of single-use, throw away products.

The ideal packaging material would be biodegradable in all environments, including compost facilities, soil, and water. In our study, several forms of packaging exhibited fragmentation timelines comparable to natural materials. However, the challenge lies in distinguishing these novel materials from synthetic polymers once they enter waste management systems. As more composting facilities emerge and face increasing volumes of materials, the need for fast and reliable composting rates, without contamination from additives or synthetic polymers, becomes paramount. Unfortunately, certain types of bioplastic materials and packaging designs have not performed as expected, and contamination is a commonly cited issue.

On a positive note, the refill and reuse economy is growing worldwide, with the exploration of business models centered around refill and packaging-free product delivery. These innovative approaches are being actively tested and implemented to reduce packaging waste and promote a shift in consumption patterns.

IMPACTS AND LIMITATIONS OF REUSABLE PACKAGING MATERIALS

Reusing packaging surpasses single-use options across most, if not all, metrics of environmental impact. However, selecting the appropriate materials for reusable packaging can be a complex task, as different materials exhibit various environmental impacts and functional limitations. For example, stainless steel and glass have limitations in their applications, including their fate at an item's end of life. Furthermore, it's essential to recognize that reusable packaging and foodware services operate within circular systems, unlike disposable packaging that follows a linear (and often more simplistic) approach. The design and implementation of these systems can yield significantly different outcomes.

In this context, the overall functioning and environmental benefits environmental performance of the system holds greater significance than the specific materials chosen. While materials like glass, aluminum, stainless steel, and durable plastics (primarily polypropylene) dominate the current landscape of reusable packaging and foodware, it is crucial to consider the system as a whole. Each material may have its specific set of advantages and disadvantages, and materials should be chosen that are specific to the application.

By focusing on the holistic approach, we can ensure that the design and operation of reusable packaging systems are optimized to achieve the best environmental outcomes.

THE ROLE OF BIOMATERIALS IN REUSABLE PACKAGING

The use of bioplastics in reusable items deserves further attention. If bioplastics items (e.g., bioplastic cups at events) can be reused and washed, then bioplastics could replace many traditional plastics in reusables, and would have the added benefit of entering composting systems at their end of life, where facilities accept them.

In general, we should prioritize materials that have longer lifespans and minimal environmental impact, while also considering the well-being of communities located near extraction, production, and disposal facilities. However, we understand that businesses have unique requirements and considerations, and there is no universal solution that fits all scenarios.

Conventional plastics are often favored for various applications due to its affordability[1], lightweight nature, and functional properties. In such cases, if plastic is necessary, it is preferable to use bio-based materials, sourced from agricultural waste or other bio feedstocks, rather than from fossil fuels. This choice reduces the overall environmental impact throughout the lifecycle and typically involves the utilization of safer chemistry.

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[1] in part, due to fossil fuel subsidies and unaccounted negative externalities

THE LIMITATIONS OF REUSE

While reusable packaging and foodware are suitable for many applications and require supportive policies and business practices to encourage their widespread adoption, there are still situations where single-use materials will be necessary. One example where single-use may still be necessary is plastic film and shrink-wrap used for certain prepared food products.

Minimizing the use of plastic film is generally recommended, although there are currently instances where alternative materials do not currently provide the desired product protection or customer experience. For items like meat, customers are accustomed to visually assessing freshness, and shrink-wrapped film offers superior protection against pathogens and leaks compared to other available materials.

BOX 2

A Use for Bioplastics in Single-Use?

In cases where reusable packaging is not the optimal choice, our focus should be on utilizing single-use materials that meet the following criteria:

1. Possess the best environmental profile as determined by life-cycle analysis.
2. Employ safer chemistry in their production and composition.
3. Have established infrastructure for effective collection, processing, and utilization in either technical (e.g., recycling) or biological (e.g., composting) waste management streams.

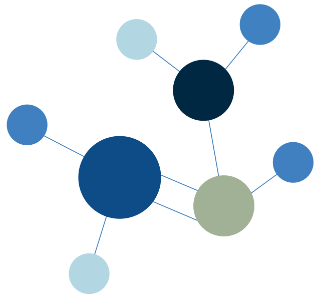
By prioritizing materials that meet these criteria, we can minimize the environmental impact of single-use applications where reusable packaging is not the most viable option. Vetted certification to verify marketing claims (e.g., biobased content, compostability, and toxicity) can be helpful to ensure these criteria are met.

TRANSPARENCY AROUND ADDITIVES

Stakeholders need full disclosure of the chemistry of packaging. Policymakers and product manufacturers need transparency around the chemicals in packaging to make informed decisions around environmental and public health, material design, and end of life scenarios. However, the chemistry behind packaging is often undisclosed or proprietary. This has created information barriers that make packaging innovation challenging, and also leads to divisions within advocacy groups working to protect the public from toxic chemical exposure. In September 2023, the United Nations Environment Programme (UNEP) released the zero draft text for a Global Plastics Treaty, which includes provisions that would require producers and importers to disclose information on the chemical composition for plastics. We have ingredient lists for our food, so why not have them for our packaging and products?

Final products and packaging often contain a complex mixture of chemical additives, including UV stabilizers, plasticizers, dyes, and other polymers. Negative effects from bioplastics such as PLA and PHA have been observed in laboratory experiments (Zimmermann et al., 2020; Wang et al 2023), although it is unknown whether these negative effects are from the polymer, the additive chemicals, or a combination of the two. Even if bioplastic polymers are non-toxic, bioplastics can still be harmful if they have chemical additives (e.g., PFAS, see Box 3) non-degradable polymers (e.g., petroleum-based plastic, or polymers such as bio-PET), in composite materials. Furthermore, the rapid fragmentation and biodegradation of bioplastic polymers can intensify the release of additives, plasticizers, and potentially harmful chemicals into the environment.

BOX 3



Forever Chemicals

Some additives, like per- and polyfluoralkyl substances (PFASs) are a family of greaseproof, waterproof, and non-stick industrial compounds used in hundreds of consumer products, including food packaging (e.g., a paper application coated with biopolymer). These chemicals bioaccumulate in the bodies of almost everyone worldwide, and have been linked to a slew of serious health problems (EWG). Many states are now regulating and/or eliminating PFAS in consumer products and packaging. Although many states require disclosure, there is still a patchwork of bans on PFAS. The EPA has recommended product labeling that disclose PFAS in household items. Currently the FDA does not require consumer food package labeling to disclose PFAS, but is working with companies to voluntarily discontinue its use.

A Way Forward: Truth in Advertising

Consumers deserve truthful information – “Truth in Advertising” – about our purchases, whether we are families shopping at grocery stores, school districts procuring cafeteria supplies, or city councils implementing recycling programs. Currently in the U.S., there are discrepancies between states and even cities that make this information extremely confusing. On the one hand, there are federal guidelines published through the Federal Trade Commission (FTC) for terms like recyclable, degradable, and compostable used in advertising. On the other hand, individual states and local jurisdictions have their own guidelines and regulatory policies. This can leave people confused; they either give up or “wish cycle,” adding items to waste streams in hopes that the materials will be recycled or composted. Even if in reality, those items are not accepted.

Many states, like California, have taken steps to address truth in advertising, implementing relevant environmental laws since the early 1990s. In recent years, the focus has shifted from simply assessing whether a material can technically be recycled or composted to evaluating whether it will actually be recycled into new products or composted. In other words, a material is only deemed recyclable or compostable if it will genuinely undergo the recycling or composting process when placed in the appropriate bin by consumers. It is important to recognize that what is technically possible does not necessarily align with economic feasibility or practical reality (See Box 4).

BOX 4

Truth in Advertising and Labeling: Guiding Consumers to More Informed Choices

Labels play a crucial role in providing consumers with information about products and packaging. However, some labeling systems have limitations in conveying comprehensive information. For instance, the commonly known chasing arrows symbol, which bears a numbering system, only identifies a limited set of seven polymers, despite the existence of over 100 different polymers in use. Furthermore, this symbol is recognized by many consumers as an indication of recyclability, when in reality it only designates the polymer type. To help consumers make better choices, initiatives like How2Recycle have emerged. How2Recycle is a program that involves over 150 member companies placing specific labels on packaging. These labels inform consumers about accurate recycling methods and direct them to find municipality-specific recycling information if needed. This program aims to enhance recycling practices and improve consumer awareness.

In terms of compostability or biodegradability labeling, regulations vary across different jurisdictions. In California, policymakers enacted specific legislation to regulate such claims. In 2004, SB 1749 was passed, prohibiting the labeling of plastic bags as “compostable,” “biodegradable,” or “degradable” unless they met the relevant ASTM standard. In 2008, AB 1972 expanded these restrictions to include all plastic food and beverage packaging, allowing only certain claims that met specified standards. Subsequently, in 2020, AB 2287 further limited the use of certain terms related to biodegradability.

While these measures targeted companies that engaged in “greenwashing” traditional plastics, concerns remained among California’s composting industry and local agencies. They expressed worries about the potential for contamination and the impact on compost sales even with ASTM compliance. In response, Assembly Member Ting introduced AB 1201 in 2021, which marked a significant legislative effort in California to restrict compostability claims and address these concerns.

Other U.S. states have also implemented their own bills to address “Truth in Advertising.” In 2020, Washington passed HB 1569 prohibiting the labeling of most plastic products with terms like “degradable,” “decomposable,” “oxo-degradable,” or “biodegradable.” Minnesota and Maryland passed similar bills. In Oregon, a coalition of composting companies collectively rejected biodegradable plastics, including PLA, from municipal green waste due to inconsistencies between corporate claims about packaging degradation and product labeling in composting environments. These state-level actions reflect the recognition that federal legislation may be insufficient and aim to strike a balance between encouraging the development of better alternatives to traditional disposables, supporting local composting efforts, and ensuring transparency for consumers.

The Right Fit: Finding the Right Sector Requires Knowing End of Life Scenarios

Prevention measures and upstream solutions are crucial to reduce plastic emissions to the environment. But there are instances where it is exceptionally challenging to eliminate leakage, which may vary by sector of use in society (Figure 8). For example, the extensive use of plastics in agriculture for mulches, which often leave behind pieces that are tilled into the soil, leads to microplastic fragments entering the environment. Additionally, in the fishing industry, plastic gear such as nets and traps lost at sea or sometimes intentionally discarded, constitute the majority of ocean plastic pollution. Biodegradable materials may help eliminate the harm from entanglement and accumulation of microplastics in the marine environment. They may serve as alternatives in these cases where high leakage occurs.

Understanding which sectors biodegradable materials can be applied requires careful consideration of their full lifecycle, including fate and effects if they are lost to the environment. There are many markets where biodegradable materials fit, due to documented low recovery rates and contamination, or a demonstrated need for degradation (Table 1).

Figure 8. Plastic is used in diverse sectors of society. Here we present 17 sectors of plastic use in society, and each may have applications for bioplastics (Erdle and Eriksen 2023).

Table 1. Biodegradable materials are viable replacements for conventional plastics in many sectors.

①	Textiles	Non-woven fabrics (wipes, tea bags)
②	Tires	Replace tires[1]
③	Hospital and Medical	Tissue scaffolds, drug delivery, etc...[2]
④	Fishing Gear	Fasteners on oyster bags and crab pots
		Fish traps and oyster pots
⑤	Home Décor, Furnishings, and Goods	Dog poop bags
⑥	Shipping and Transportation	Bubble wrap, mailers, labels, adhesive tape
		Thin film for pallet wrap
		Coated paper: coatings on paper & cardboard
⑦	Hygiene and Cosmetics	Non-woven fabrics (wipes)
		Fillers in cosmetics
		Containers, tubes, etc...[3]
⑧	Toys, Sports, and Recreation	Beach toys[4]
		Festival toys and trinkets (Mardi Gras beads)
⑨	Construction	Insulation that is cut, often creating fragments of microplastics
⑩	Smoking Materials	Filter replacement[5]
		Thin film wrap over product boxes
⑪	Events, Travel, and Hospitality	Packaging for soaps and other hotel in-room items
⑫	Agriculture	Mulch film
		Planter pots, underlying fabric used in landscaping
		Organic waste mgt. (Biobag bin liners)
		Food labels/stickers
⑬	Food Service and Packaging	Thin film applications (meats and cheeses, chip and candies)
		FFS (form and seal) applications, such as yogurt lids and containers
		Rigid food packaging (clear salad bins)
		Single use (thin: straws)
		Single use (thick: plates, utensils, cold cups, utensils)
		Non-woven applications (tea bags/Infusions)
		Paper coatings for food service and storage, labels on packaging
⑭	Electronics	3D printer filament[6]
⑮	Primary Microplastics	Abrasive media used in paint stripping
⑯	Durable Goods	
⑰	Appliances and Machinery	

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1 https://www.bioplasticsmagazine.com/en/news/meldungen/20200617_Tyres.php
2 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8875380/
3 https://www.bioplasticsmagazine.com/en/news/meldungen/20230824_CJ_Riman.php
4 http://www.zoeborganic.com/
5 https://www.greenbutts.com/
6 https://beyondplastic.com/collections/pha-3d-printer-filament

When it comes to replacing synthetic polymers, there are four qualities that largely determine the right use for biodegradable plastics:

1. **Chemistry:** Is it degradable in its entirety over an acceptable time frame, and non-toxic, including all additives, plasticizers, inks, etc.?
2. **Design:** Does the design impede or improve biodegradation (laminates, coatings, volume/surface area ratio)?
3. **Need:** Is there an overwhelming societal need for this innovation?
4. **EOL Sorting:** Does the infrastructure exist to accommodate the novel product?

Certain product uses already align with the existing infrastructure and are regarded as viable solutions, exemplified by BioBags (see Box 5). However, in other sectors of use in society, the adoption of bioplastics may result in increased pollution, particularly through contamination of current recycling and composting systems.

BOX 5

Case study: BioBag Exceptions

Many municipalities accept BioBags in their compost facilities, yet reject nearly all other forms of biodegradable plastics. This is because BioBags fulfill a need, can be easily sorted, and the combination of chemistry and design enables this material to fit in a biological cycle. Four considerations drive the BioBag exception:

a. **Chemistry:** Their chemical composition is biodegradable according to ASTM standards and there are no harmful additives.
b. **Design:** As a thin film by design, the product is more accessible to microbes and therefore is more readily degraded in certain environmental or compost conditions.
c. **Need:** There is a need for a waterproof container that allows households to collect table scraps and transport them to the green bin.
d. **EOL Sorting:** The design of BioBags address sorting concerns waste managers and composting facilities might have, because BioBags are easy to identify by color (light green) and shape (film).

What is the End of Life for Bioplastics?

Waste Management and Industrial Composting Challenges

Given the complexities around biomaterials, coupled with the challenges in a largely disposable culture, we need to carefully think through the entire lifecycle when introducing bioplastics into the marketplace, from production to collection, disposal, recycling, and remanufacturing. When these steps are not planned out, issues arise (see Box 4).

End of life (EOL) sorting scenarios may differ depending on the sector and use. EOL should be considered in the design of all products and packaging.

COMPOSTING SYSTEMS

Curbside composting is progressively diverting residential food waste away from landfills. Nevertheless, the inclusion of bioplastics in composting systems can lead to contamination, depending on the specific items and the facility type. Accepting bioplastics runs the risk of synthetic polymer contamination due to the existing challenges in distinguishing between compostable and non-compostable items.

RECYCLING SYSTEMS

Bioplastics often enter recycling or trash if not properly labeled. Bioplastics are rarely recovered once they enter recycling systems, which are designed only for specific types of plastic packaging that can be easily sorted and hold market value. As we strive towards reduction and reuse, recycling should be considered as a transitional strategy.

Identifying Bioplastics at EOL

Product labeling requirements are currently a challenge faced in the U.S. Composters and producers have suggested product labeling based on colors, for example bright yellow or green, and no other packaging can be that color. Washington state has striping or specific colors to help identify compostable products from non-compostable. However, Washington has not banned the colors or patterns in other uses.

BOX 6

Case Study: Oregon Composters

The State of Oregon's Department of Environmental Quality released a report titled "Compostable" to shed light on such problems. One notable example involves the advertisement of PLA (polylactic acid) packaging and other biodegradable materials as compostable, allowing them to enter the green waste stream alongside yard clippings and food waste. These materials, however, failed to live up to their marketing claims. The degradation properties of PLA, combined with the thickness of the products, led to inadequate degradation, contaminating the compost and eroding public trust around alternative materials. Ultimately this can result in widespread rejection.

A Message from Composters Serving Oregon:

Why We Don't Want Compostable Packaging and Serviceware

Photo by Gabriel Jimenez on Unsplash

> “We need to focus on recycling organic wastes, such as food and yard trimmings, into high-quality compost products that can be used with confidence to restore soils and conserve resources. Compostable packaging doesn’t help us to achieve these goals.”
>
> COMPOSTERS SERVING OREGON

A nine point list from Oregon Composters:

1. It does not always compost
2. It introduces contamination
3. It hurts resale quality
4. The composters cannot sell to organic farmers
5. It may impact human health and environmental health
6. It increases compost operators’ costs and makes our jobs harder
7. Just because something can be composted does not mean that it is necessarily better for the environment
8. In some cases, the benefits of recycling surpass those of composting
9. Good intentions are not being realized

Better truth in advertising, informed by real data about material degradation in various environments, with different sizes, thickness, and shapes, could have potentially prevented the justified backlash from industrial composting facilities.

CHAPTER 5:

CONCLUSIONS AND RECOMMENDATIONS

Bioplastics must be placed in the context of existing initiatives to reduce waste, and best available scientific information. Although bioplastics are not a silver bullet that will "solve" the plastic pollution crisis, they offer potential in mitigating the harm caused by traditional petrochemical plastics. We present several recommendations to improve bioplastics implementation and success:

1

Truth in Advertising:

Stakeholders should receive science-based evidence, including documented environmental impacts, to make informed decisions about biomaterials. Producers and brands must uphold truth in advertising, avoiding greenwashing and false claims.

2

Bioplastics and Waste Reduction:

Introducing bioplastics alone will not solve waste management issues if they hinder reuse systems or contaminate existing recycling and composting processes. Regulations are necessary to prevent misleading claims and promote responsible practices.

3

Bioplastics in Transition to Reuse:

While bioplastics are not a standalone solution to the waste problem, they can play a vital role in developing sustainable alternatives to single-use plastics. Some products, such as thin films for meat packaging or agricultural mulch, are challenging for reuse systems or recycling, making novel materials like bioplastics relevant in specific use cases, such as home composting, festival packaging, and municipalities that accept bioplastics.

4

Degradation and Environmental Impacts:

Our study observed the degradation of bioplastics, but it is important to note that claiming complete biodegradability and environmental benignity requires thorough testing. The fate and impacts of bioplastics, additives, synthetic polymers, intermediate degradation products, and microplastics should be further investigated in terrestrial and marine ecosystems.

5

Future Research:

Further research is needed to understand the degradation processes of novel biomaterials and their behavior in real-life environmental conditions. Laboratory testing under favorable conditions should be complemented by testing materials in actual environmental settings to evaluate persistence, performance, and effects from leachates.

6

Design Principles:

End of life scenarios must be considered in the design of novel materials. Depending on the application, materials should be designed for either biological or technical material flows, aligning with appropriate disposal or recycling methods.

By adopting these recommendations, we can help build a responsible use of bioplastics, reduce waste, and ensure the continued development of novel materials.

Acknowledgements

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We would like to thank Danimer Scientific, New Light Technologies, Kimberly-Clark Corporation, The Ocean Foundation, SENSE Foundation Brussels, Preserve, and RWDC Industries for the contribution of funds and/or materials to support the research portion of this project. Thank you to Sean Reif and Abby Barrows who assisted in the laboratory and fieldwork, and to Indian River State College for donating lab space for all sample analysis. We would also like to recognize the following individuals who helped contribute expertise and thought leadership to this report: Matt Prindeville, Neil Edgar, Nick Lapis, Rhodes Yepsen, Michael Doshi, Lynn Hoffman, and Alex Truelove.

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Appendix 1

METHODS

To evaluate the performance of a range of products, we obtained 22 different products made from PHA (polyhydroxyalkanoate), PHB (polyhydroxybutyrate), PLA (polylactic acid), and starch-based resins, as well as non-bioplastic items for comparison (e.g., PE (polyethylene), bamboo, and paper). Items were all donated, and some items were prototypes. We included sites on land and in the ocean, totaling six sites: 1) Florida terrestrial, 2) Florida marine, 3) California terrestrial, 4) California marine, 5) Maine terrestrial, and 6) Maine marine.

At each site, we placed six sets of the 22 products in the environment, either buried in the ground or submerged in water. Each item was pre-weighed, placed in a fine-mesh (200 µm) nylon bag labeled with a metal tag, and added to a large-mesh (5 mm) nylon bag. For the marine sites, each large-mesh nylon bag was placed in a HDPE milk crate, weighted with bricks to keep it on the bottom. For the terrestrial sites, the large-mesh bags were buried in approximately 15cm of soil (Figure A1). These scenarios mimicked burial in the marine sediment, and roadsides, both common environments where plastic items are found. The items were left untouched until recovered. Items were recovered, weighed, and photographed at 1 week, 2 weeks, 4 weeks, 8 weeks, 16 weeks, 32 weeks, and 64 weeks.

To validate the polymer composition, we used µ-FTIR to determine the chemical id for all 22 products. The raw spectra are available for download.

Figure A1. Terrestrial site in California. A total of 6 bags were placed in each site.

LIMITATIONS

We evaluated all fragments larger than 200 µm (0.2mm). A limitation of this work is that we only measured fragments down to this size limit and did not evaluate the mechanisms of degradation. Thus, we did not directly measure biodegradation or mineralization of items, but instead evaluated the remaining fragments larger than 200 µm at each time interval.

Another limitation is the lack of control in a field study. There are seasonal variations from year to year, like drought, excessive rainfall, or unexpected storms. There can also be vandalism or tampering from wildlife. Wildlife interactions with samples can be unexpected, like the few crabs that nibbled on one of our PHA bottles in the Florida marine environment. Despite these risks to the study, overall, we experienced no major mishaps that could alter the observed outcomes and gained valuable information from the environmental realism in our study.

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