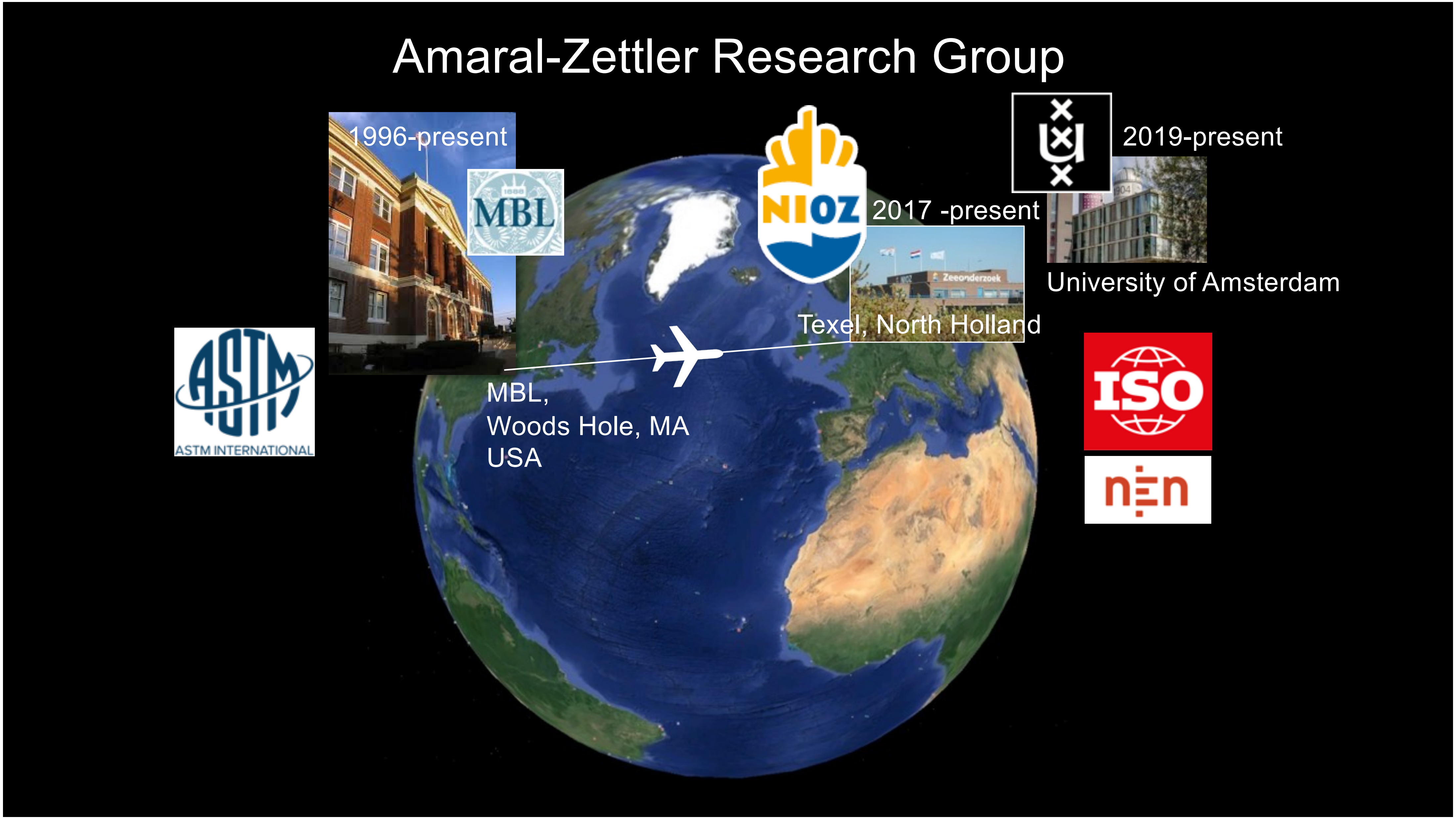
Biodegradation Studies and Experiments for Materials in the Marine Environment Series

Part 2: Status of Current ASTM / ISO Standards, Specifications and Research Studies in the Marine Environment

Prof. dr. Linda Amaral-Zettler
Research Leader
NIOZ Royal Netherlands Institute for Sea Research


Amaral-Zettler Research Group
1996-present
MBL
MBL,
Woods Hole, MA
USA
ASTM INTERNATIONAL
NIOZ
2017 -present
Texel, North Holland
2019-present
University of Amsterdam
ISO
nen

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Science & Environment

Ocean plastic a 'planetary crisis' - UN

By Roger Harrabin
BBC environment analyst, Nairobi

9 hours ago | Science & Environment

Share

Plastic waste has a variety of detrimental effects on the environment

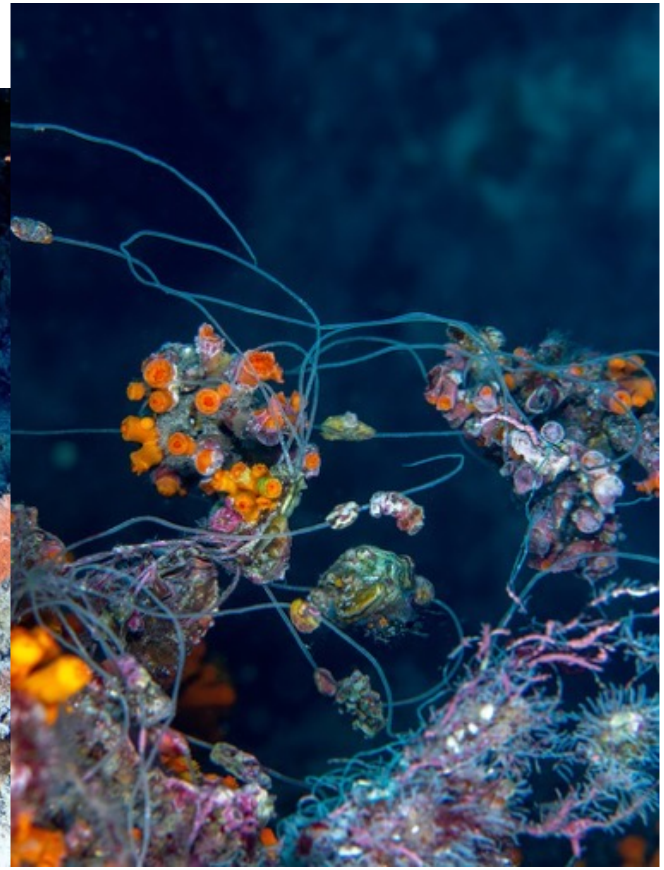
Life in the seas risks irreparable damage from a rising tide of plastic waste, the UN oceans chief has warned.

nature NEWS | 12 July 2023

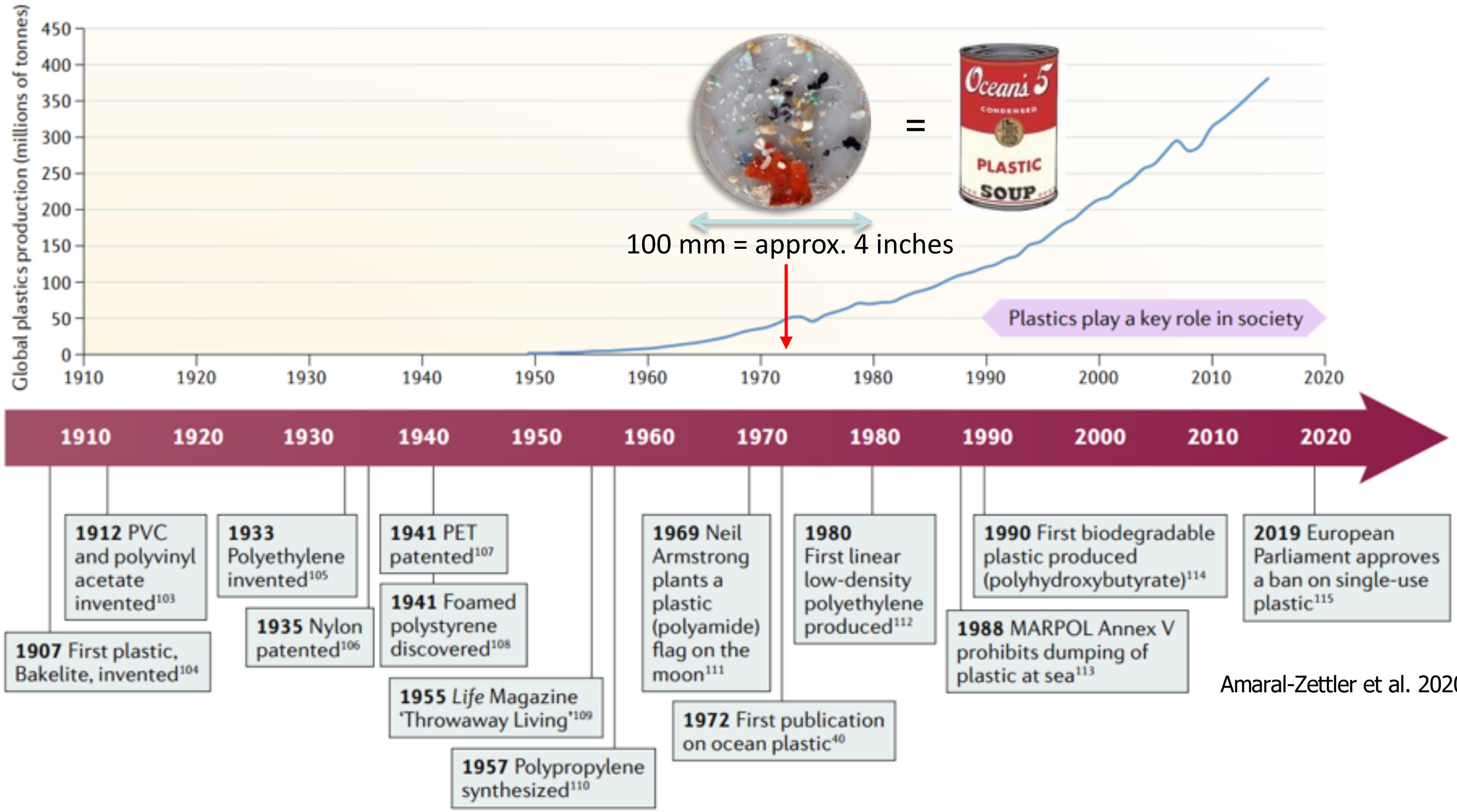
Striking images show plastic litter in the world's most remote coral reefs

Fishing nets, packaging and other debris threaten wildlife in some of the ocean's deepest reef ecosystems.

Katharine Sanderson



Plastics Timeline



Amaral-Zettler et al. 2020, Nat. Rev. Microbiol.

Approximately 10 million tonnes per year enters ocean

(Jambeck et al. 2015, Science)

June 2011

Scientific American

MARINE BIOLOGY

The Smallest Hitchhikers

Marine microbes may hold the key to the ocean's disappearing plastic

naturenews

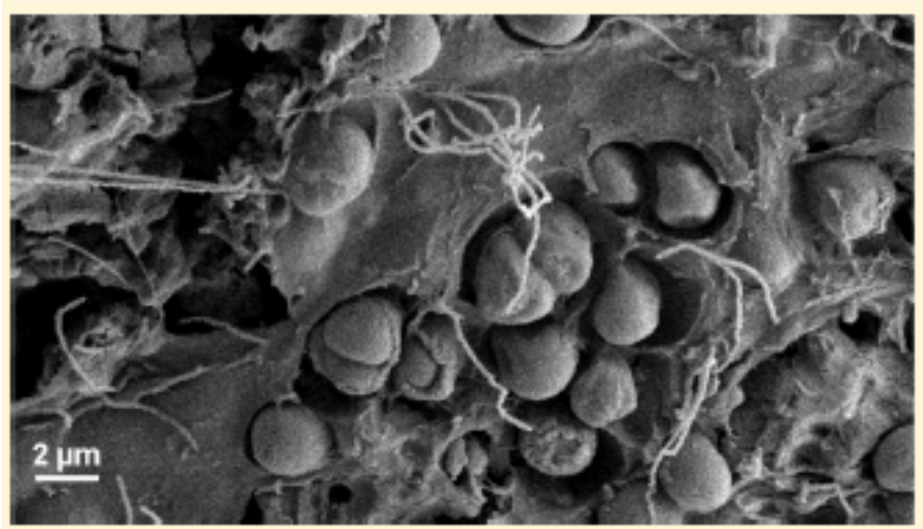
nature news home | news archive | specials | opinion | features | news blog | natur

Published online 28 March 2011 | Nature | doi:10.1038/news.2011.191

News

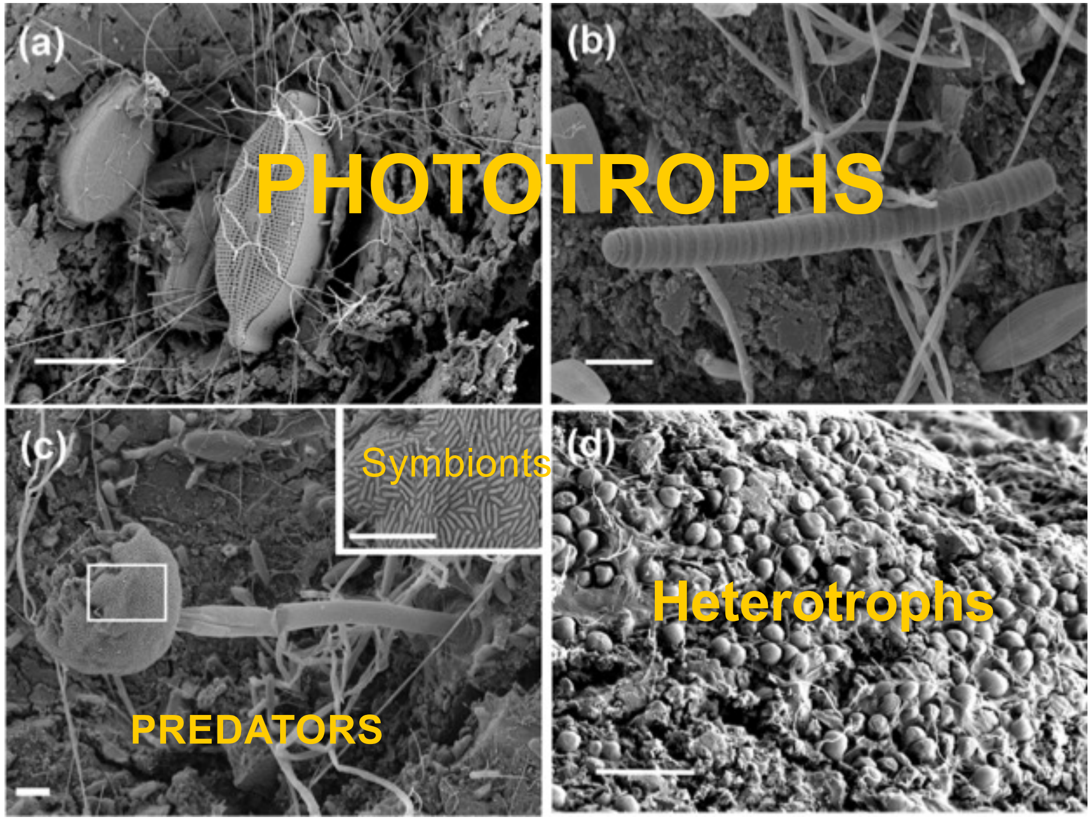
Marine microbes digest plastic

A 'little world' eating ocean garbage might be a mixed blessing.



Microbial Communities on Plastic Marine Debris: The “Plastisphere”

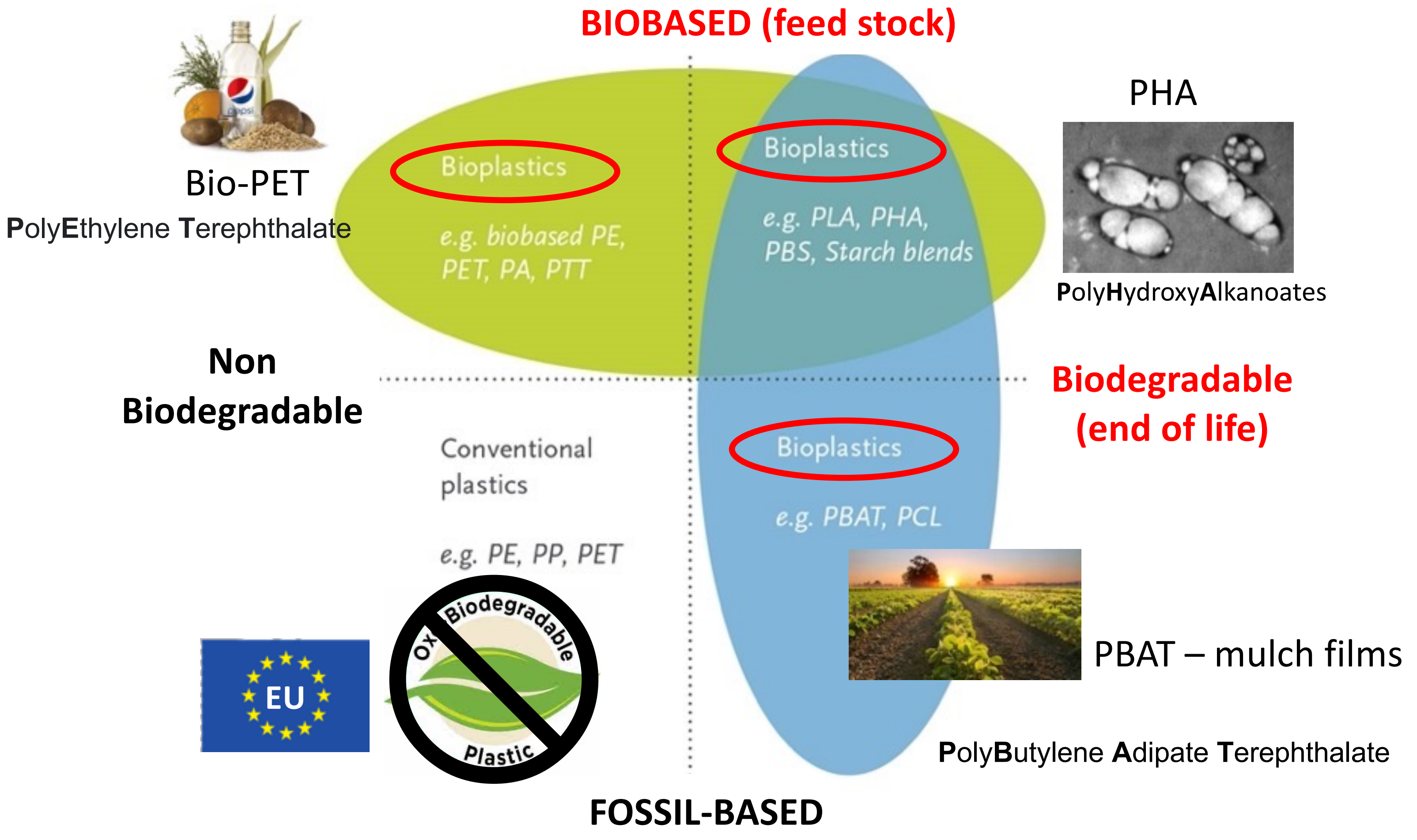
“Like the biosphere (the thin film of life around the surface of planet Earth), the Plastisphere represents ***a little world of life that exists on the surface of plastic particles****”*



All scale bars = 10 μm

Zettler, Mincer, Amaral-Zettler 2013

A Bioplastics Solution?



Sources: https://www.european-bioplastics.org/bioplastics/materials/; https://www.plasticstoday.com/pepsi-launch-100-bio-based-pet-bottle; https://plastics-rubber.basf.com/global/en/performance_polymers/sustainability.html
biobasedpress.eu; plastivision.org

Biodegradation in the Marine Environment

Plastic biodegradation is the extensive conversion of polymer carbon to CO_2 (under oxic conditions) or CO_2 and CH_4 (under anoxic conditions), and new microbial biomass, over a specific timeframe.

SAPEA Evidence Report 8, 2020

Motivation and Funding that fueled initial Biodegradation Testing & Research

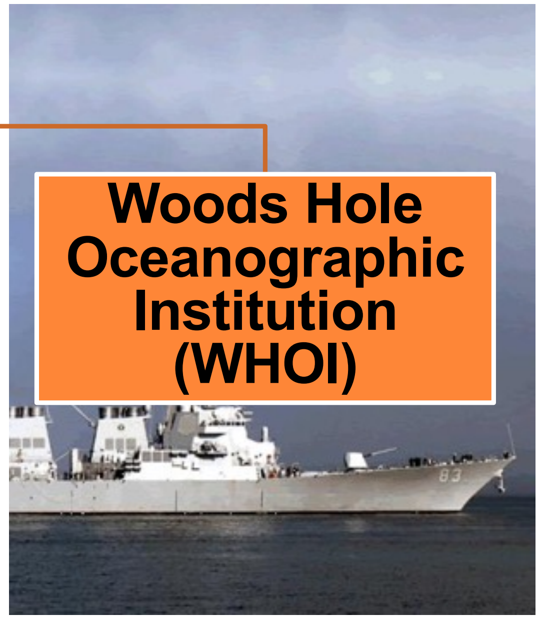
Jo Ann Ratto

Carl Wirsen

Biodegradable Polymer Testing and Research

U.S. Navy WRAPS Waste Afloat Protects the Sea

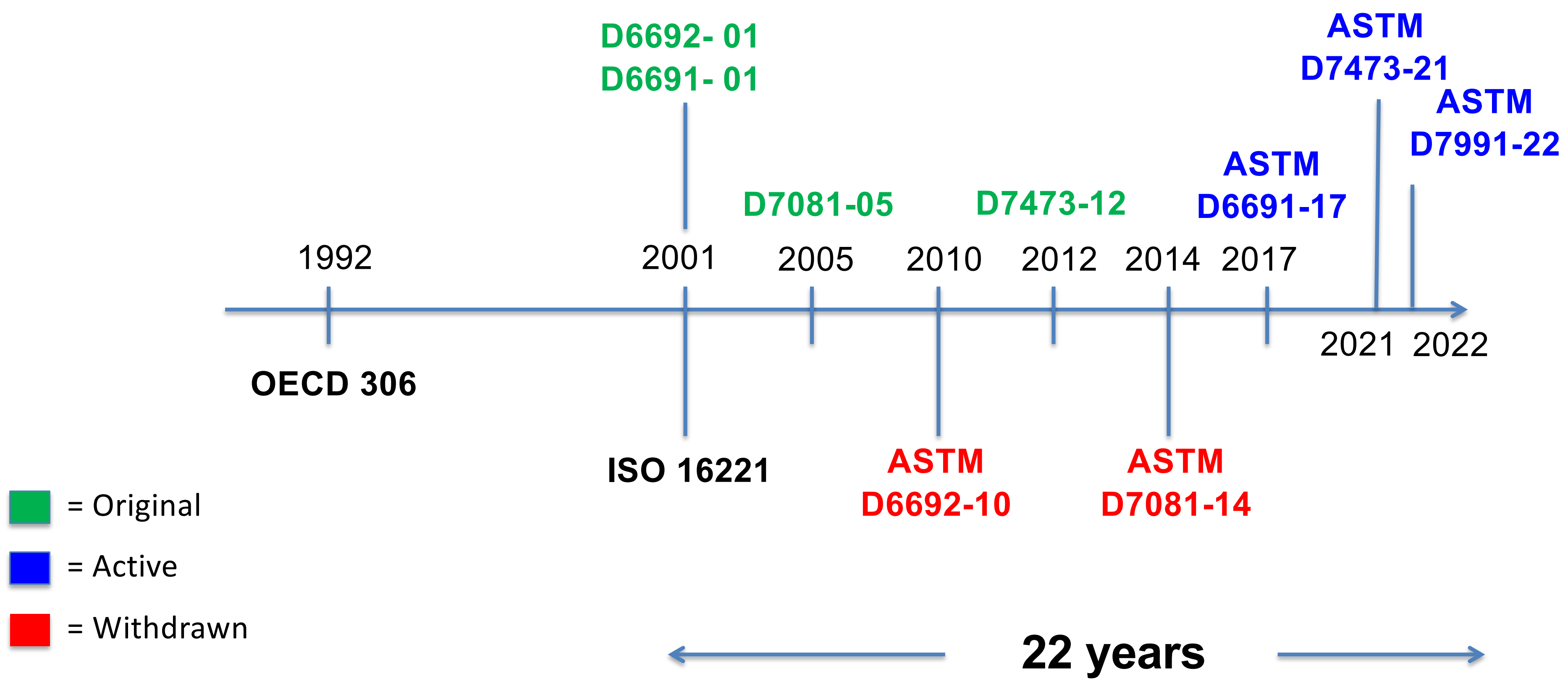
U.S. Army



Woods Hole Oceanographic Institution (WHOI)

Courtesy of Jo Ann Ratto

A Timeline of Biodegradation Methods in the Marine Environment



ASTM Standards Terminology

1. Standard Practice [**practice, n**— a definitive set of instructions for performing one or more specific operations that does not produce a test result – ASTM Bluebook April, 2016]

2. Standard test method [**test method, n**— a definitive procedure that produces a test result -- ASTM Bluebook April, 2016]

3. Specification [**specification, n**— an explicit set of requirements to be satisfied by a material, product, system, or service – ASTM Bluebook, April 2016]

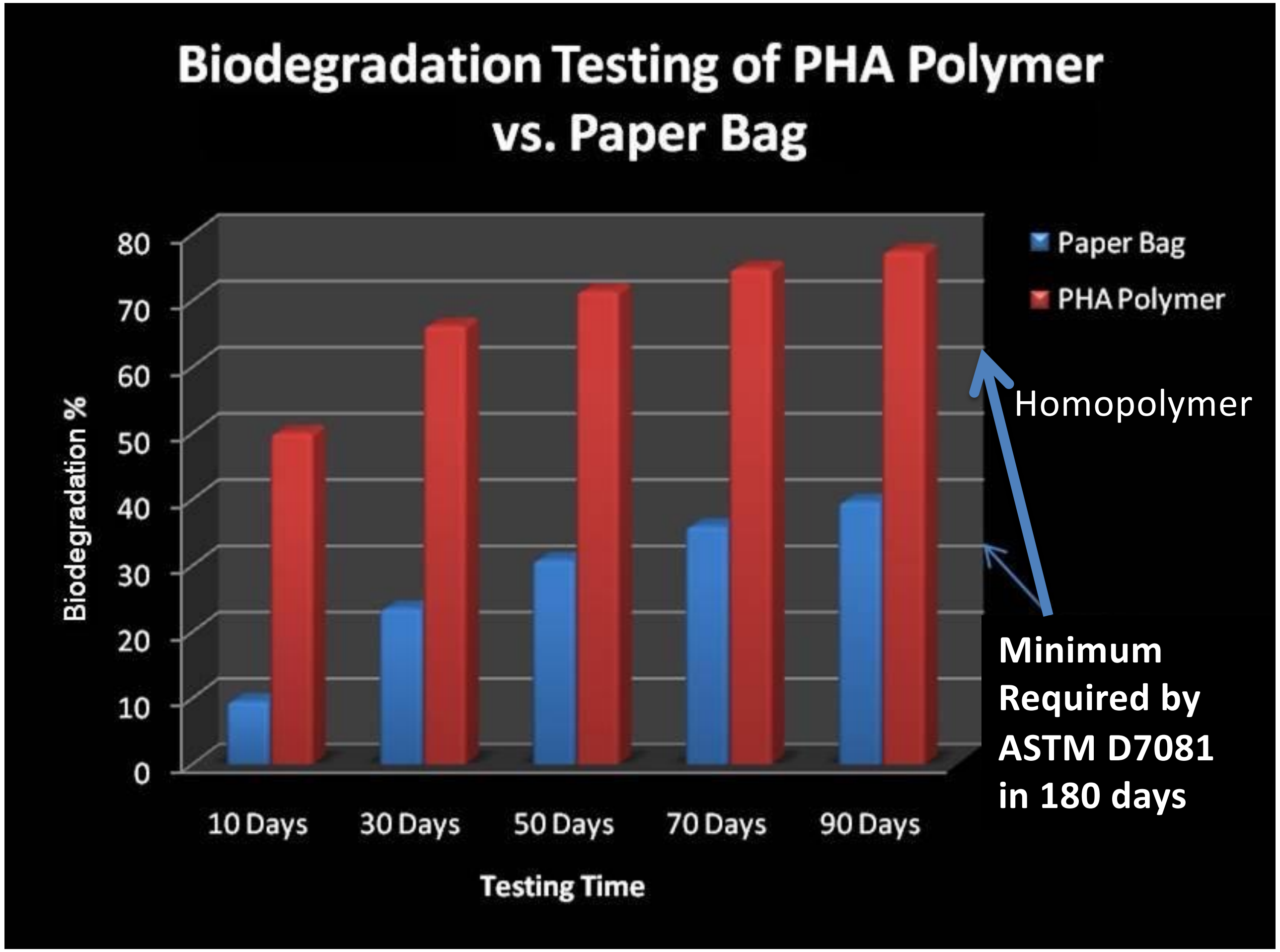
- Tier I – Standard methods in laboratory
  - Respirometry methods
  - **ASTM D6691**
    - Standard **Test Method** for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum

- Tier II – Confirmatory in Marine Environment
  - Incubation methods / Weight loss as a function of time
    - Static Laboratory
    - Dynamic Aquarium
      - **ASTM D7473** - **Test Method** For Weight Attrition of Plastic Materials in the Marine Environment by Open System Aquarium Incubations

- Tier III – Confirmatory in Marine Environment
  - Incubation methods / Weight loss as function of time
    - Coastal Studies
    - Deep Sea Moorings

Standard Specification D7081 (pass/fail criterion):

Polymer vs. Kraft Paper (Tier I)



Slide courtesy of Jo Ann Ratto

Specification for Non-Floating Biodegradable Products in the Aquatic Environment – Replacement for **D7081**

ASTM INTERNATIONAL

ASTM International Collaboration Area

Current Collaboration Area | 75797 - WK75797 - Non-Floating Biodegrad...

75797 - WK75797 - Non-Floating Biodegradable Products in the Marine Environment

Collaboration Area | Drafts | Polls | Discussions | Files

Overview | Members | History

WK75797 - Non-Floating Biodegradable Products in the Marine Environment

Group Creation Date: 02/08/2021
WorkItem Creation Date: 02/08/2021
Ballot Target Date: 12/2023
Work Item Status: Proposed
Status: Draft Withdrawn

Work Item Description

There is an industry need for a standardized approach to demonstrate product conformance for biodegradability in a marine environment. Currently, with no active ASTM specification standard, state and organizations are developing their own methods or prohibiting the use of terminology that implies biodegradation in a marine environment. The need to reestablish a specification standard in this area, with a cooperative industry approach, is critical. Users will include, academia, testing labs, government and industry manufacturing.

Specification for Non-Floating Biodegradable Products in the Aquatic Environment – Replacement for **D7081**

ASTM INTERNATIONAL

ASTM International Collaboration Area

Current Collaboration Area | 75797 - WK75797 - Non-Floating Biodegrad...

Aquatic

75797 - WK75797 - Non-Floating Biodegradable Products in the Marine Environment

Collaboration Area | Drafts | Polls | Discussions | Files

Overview | Members | History

Aquatic

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ASTM INTERNATIONAL

Standard Specification for
Non-Floating Biodegradable Products Designed for use in an Aquatic Environment[1]

This standard is issued under the fixed designation DXXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers non-floating products that are designed for use in an aquatic environment and are biodegradable in a stated aquatic environment.

1.2 This specification is intended to establish the requirements for labeling products as "Biodegradable in *a stated aquatic* environment as a non-floating object at *20°C* in *X*, per ASTM DXXXX." The label must use qualifying language that states the type of aquatic environment.

NOTE 1- The stated aquatic environment will be based on the testing standard and the inoculum. It is not the intent of this standard to specify the type of aquatic environment.

NOTE 2 - 20°C may be replaced with 68°F if the claim is being made in a country that uses the imperial system.

NOTE 3 - Where "X" is the time and can be denoted in either total days or a combination of years and days.

1.3 The properties in this specification are those required to determine if products designed for use in the aquatic environment will biodegrade with specific rate/rate constant in aquatic environments at designated temperature(s).

1.4 This standard does not promote or encourage the disposal or loss or leakage of biodegradable materials or products into the aquatic environment. Nor does it address microplastics, nanoplastics, microparticles or nanoparticles. However, a fully biodegradable material or product will not, by this standard, permanently generate microplastics, nanoplastics, microparticles or nanoparticles. Microplastics, nanoplastics, microparticles or nanoparticles may be generated in the process of the material or product going through full biodegradation, though they will not exist after complete biodegradation.

- Requires biodegradation rates at three different temperatures
- Uses Kinetic Rate Law and Arrhenius Equation
- Used to obtain lifetime predictions of products to achieve 90% biodegradation at a given temperature as a basis for comparative analyses

ASTM INTERNATIONAL

Revision: D6691

ASTM International Collaboration Area

Current Collaboration Area: 79317 - WK82370 - Revision of D6691-17 S...

79317 - WK82370 - Revision of D6691-17 Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum

Collaboration Area | Drafts | Polls | Discussions | Files

Overview | Members | History

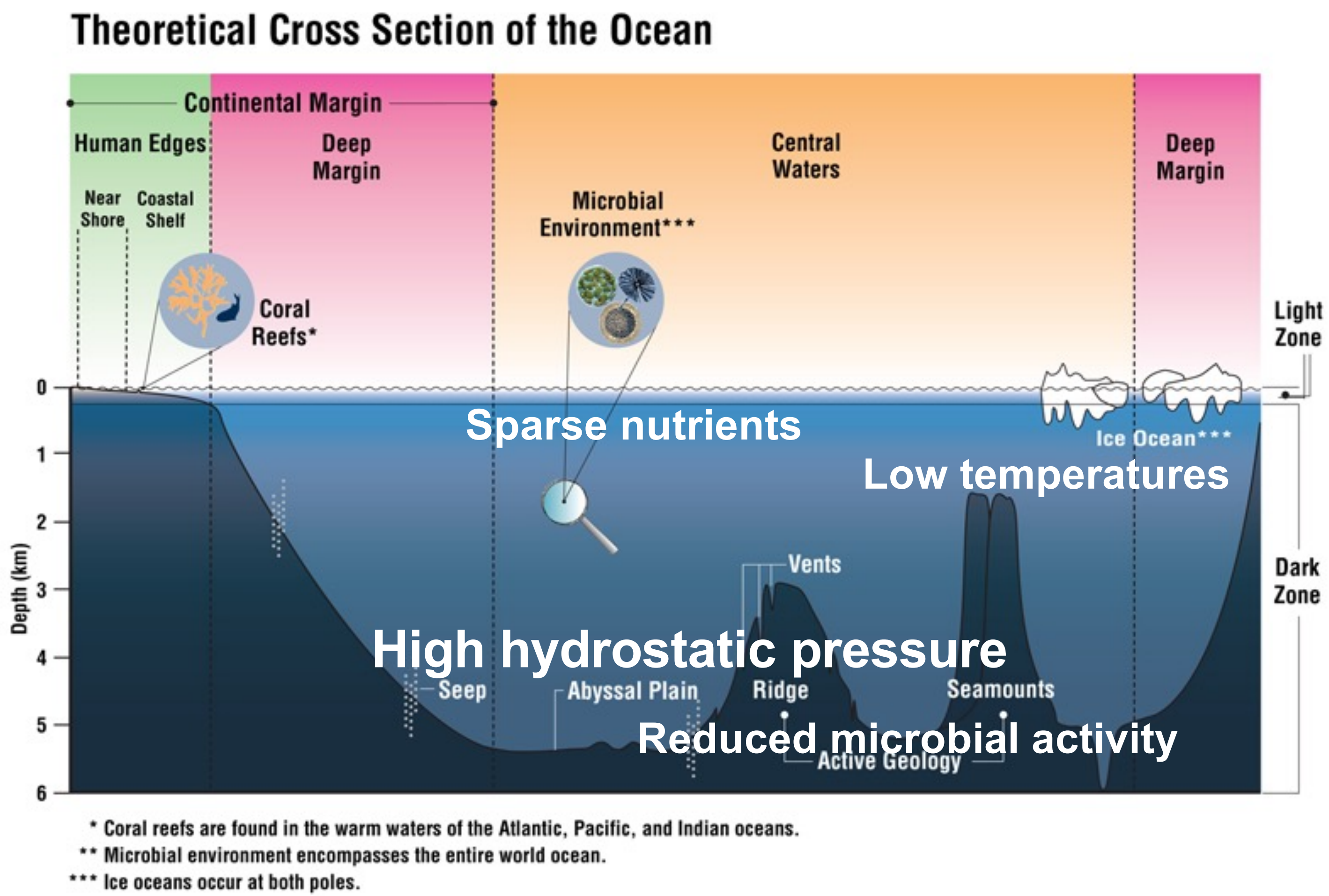
WK82370 - Revision of D6691-17 Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum

WorkItem Creation Date: 06/22/2022
Ballot Target Date: 12/2023
Work Item Status: Draft Under Development
Status: Draft Under Development

Work Item Description

ASTM D6691 is scheduled for review, and committee members have advised that more data is available which might be considered.

The Marine Environment is Not Homogeneous



CoML defines its realms & zones in 2003 Baseline Report, *The Unknown Ocean*

Open Bio: (opening the market for biobased products) Recommendations

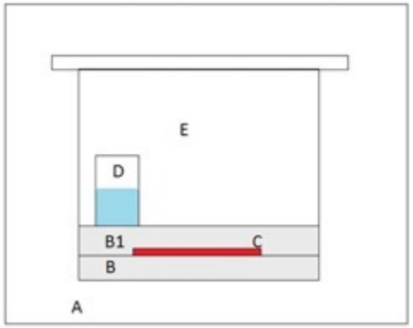
EU 7th Framework
Nov 2013-Oct 2016

- Tests under **anaerobic** conditions should be developed
- Tests under **high-pressure** and **low temperature** should be developed
- Tests with fine sediments under **low oxygen** conditions are needed
- Effects of **different levels of nutrients** and **organic contents** should be considered to develop all the standard tests
- Testing in **mesocosms**
- Extract **representative habitats** from nature and translate their conditions to a set of standard laboratory and mesocosm tests to be developed and implemented, representing the **most important regions** of our oceans.

ASTM D7991-22

"Standard Test Method for Determining Aerobic Biodegradation of Plastics Buried in Sandy Marine Sediment under Controlled Laboratory Conditions"

Francesco Degli Innocenti



ISO
Beat plastic pollution
with ISO standards
ISO 22526
Carbon and
environmental footprint
ISO 15270
Recovery and recycling
of plastic waste
ISO/CD 22766
Disintegration
of plastic materials
in marine habitats
ISO 18830
Biodegradation test

ISO (International Standards Organization):
Subcommittee 14: Plastics and the Environment
Working Group 2: Biodegradability

ISO/CD 22403, Plastics - Assessment of the inherent aerobic biodegradability and environmental safety of non-floating materials exposed to marine inocula under laboratory and mesophilic conditions - Test methods and requirements

ISO 19679:2016(E) Plastics - Determination of aerobic biodegradation of non-floating plastic materials in a seawater/sediment interface - Method by analysis of evolved carbon dioxide

ISO/DIS 23977-1/2 Plastics - Determination of aerobic biodegradation of plastic materials exposed to seawater-
1 - Method by analysis of evolved carbon dioxide
2 - Method by measuring the oxygen demand in closed respirometer

ISO-TAG Meeting
September 23-28, 2019
Chengdu, China

Marine Standards

	Respirometry / BOD		Weight Loss – Aging / Weathering / Disintegration				
	Laboratory		**Aquarium**			**Field**	
Pelagic (Seawater)	**ASTM D6691** CO_2	ISO 23977/1- CO_2 ISO 23977/2 -O_2	ISO 15314	ISO/CD 16636	**ASTM D7473**	ISO 15314	ISO/CD 16636
Pelagic (Seawater/ Seawater + Sediment)	ISO 23977/1- CO_2 ISO 23977/2 -O_2						
Benthic (Seafloor)	ISO 18830 O_2	ISO 19679 CO_2	ISO 23832		**ASTM D7473**		
Eulittoral (Beach)	**ASTM D7991** CO_2	ISO 22404 CO_2	ISO 23832			ISO 22766	

Science

Temperature is the main driver of microbial community composition

OCEAN PLANKTON

Structure and function of the global ocean microbiome

Shinichi Sunagawa,[1*†] Luis Pedro Coelho,[1*] Samuel Chaffron,[2,3,4*] Jens Roat Kultima,[1] Karine Labadie,[5] Guillem Salazar,[6] Bardya Djahanschiri,[1] Georg Zeller,[1] Daniel R. Mende,[1] Adriana Alberti,[5] Francisco M. Cornejo-Castillo,[6] Paul I. Costea,[1] Corinne Cruaud,[5] Francesco d'Ovidio,[7] Stefan Engelen,[5] Isabel Ferrera,[6] Josep M. Gasol,[6] Lionel Guidi,[8,9] Falk Hildebrand,[1] Florian Kokoszka,[10,11] Cyrille Lepoivre,[12] Gipsi Lima-Mendez,[2,3,4] Julie Poulain,[5] Bonnie T. Poulos,[13] Marta Royo-Llonch,[6] Hugo Sarmento,[6,14] Sara Vieira-Silva,[2,3,4] Céline Dimier,[10,15,16] Marc Picheral,[8,9] Sarah Searson,[8,9] Stefanie Kandels-Lewis,[1,17] *Tara* Oceans coordinators‡ Chris Bowler,[10] Colomban de Vargas,[15,16] Gabriel Gorsky,[8,9] Nigel Grimsley,[18,19] Pascal Hingamp,[12] Daniele Iudicone,[20] Olivier Jaillon,[5,21,22] Fabrice Not,[15,16] Hiroyuki Ogata,[23] Stephane Pesant,[24,25] Sabrina Speich,[26,27] Lars Stemmann,[8,9] Matthew B. Sullivan,[13§] Jean Weissenbach,[5,21,22] Patrick Wincker,[5,21,22] Eric Karsenti,[10,17†] Jeroen Raes,[2,3,4†] Silvia G. Acinas,[6†] Peer Bork[1,28†]

Microbes are dominant drivers of biogeochemical processes, yet drawing a global picture of functional diversity, microbial community structure, and their ecological determinants remains a grand challenge. We analyzed 7.2 terabases of metagenomic data from 243 *Tara* Oceans samples from 68 locations in epipelagic and mesopelagic waters across the globe to generate an ocean microbial reference gene catalog with >40 million nonredundant, mostly novel sequences from viruses, prokaryotes, and picoeukaryotes. Using 139 prokaryote-enriched samples, containing >35,000 species, we show vertical stratification with epipelagic community composition mostly driven by temperature rather than other environmental factors or geography. We identify ocean microbial core functionality and reveal that >73% of its abundance is shared with the human gut microbiome despite the physicochemical differences between these two ecosystems.

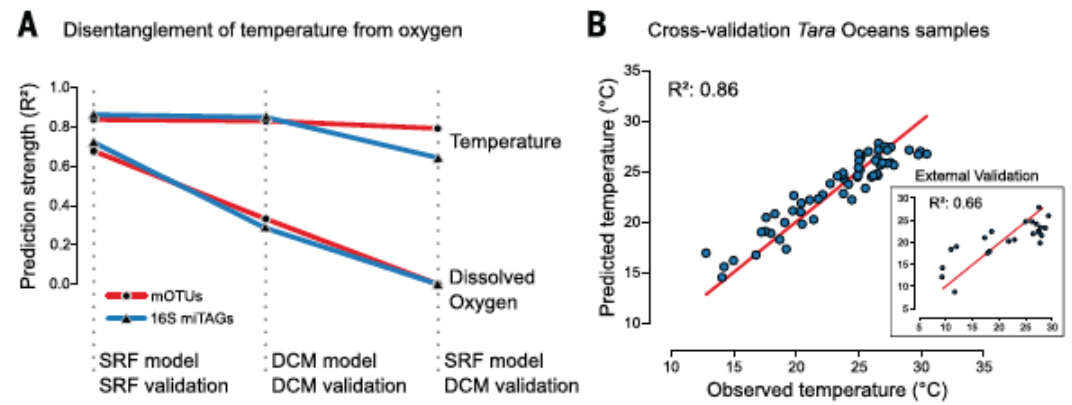


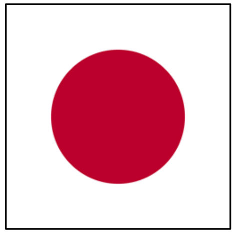
Fig. 6. Temperature as main environmental driver for microbial community composition in the epipelagic layer. (**A**) The strength of association between (meta)genomic and environmental data was tested by statistical models that were first generated with a subset of data for training and then validated

22 May 2015 Vol 348, Issue 6237 DOI: 10.1126/science.1261359

ISO Round Robin Participants

ISO/DIS 23977-1/2 Plastics

Determination of aerobic biodegradation of plastic materials exposed to seawater



BASF Germany – lead (Chong Becker)

Novamont, Italy

Yahata-Bussan Co., Ltd. Japan

Chemicals Evaluation and Research Institute, Japan

NTSQP, Beijing Technology and Business University

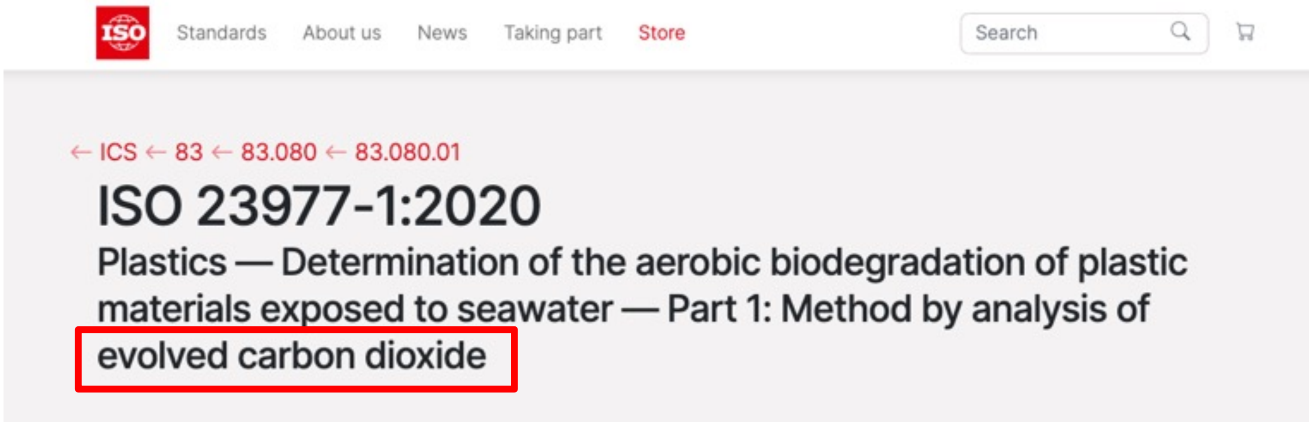
NIOZ Royal Netherlands Institute for Sea Research

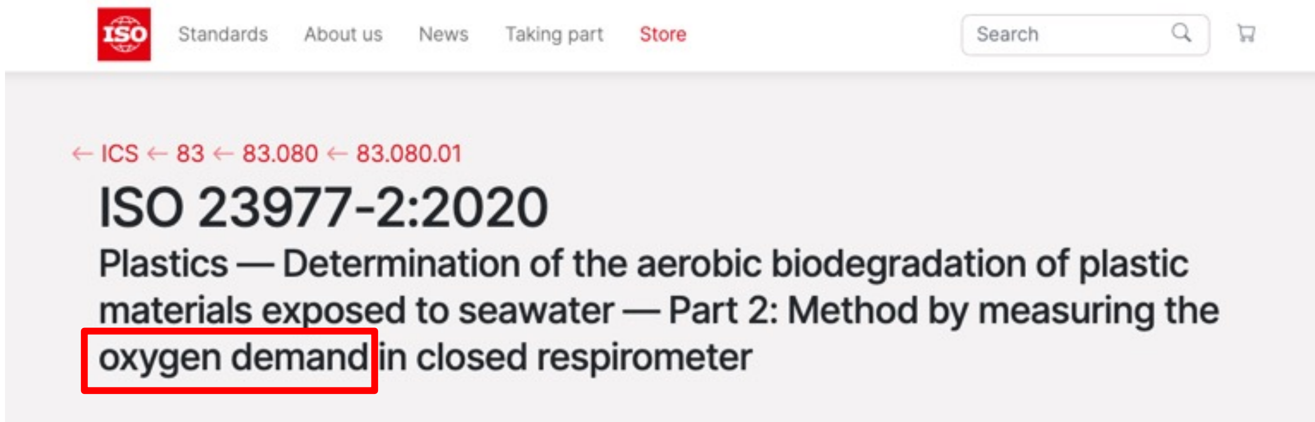
Eastman, USA

OWS, Belgium

ISO 22403 Specification Requirements:

- 90 % absolute biodegradation or relative to reference material
- Test duration: Max. 24 months
- Temperature: 15 – 25 ° C (not exceeding 28 ° C)






ISO/DIS 23977-1/2
Round Robin Test
Open System
Biodegradation
(CO_2 & O_2 infrared)
A
B
Same
Inoculum
C
Closed
System
Biodegradation
(BOD & evolved CO_2
Via DIC measurement)
Parallel
System
No Biodegradation
monitoring
(Weekly sampling for
Microbial DNA Profiling
& Microscopy)

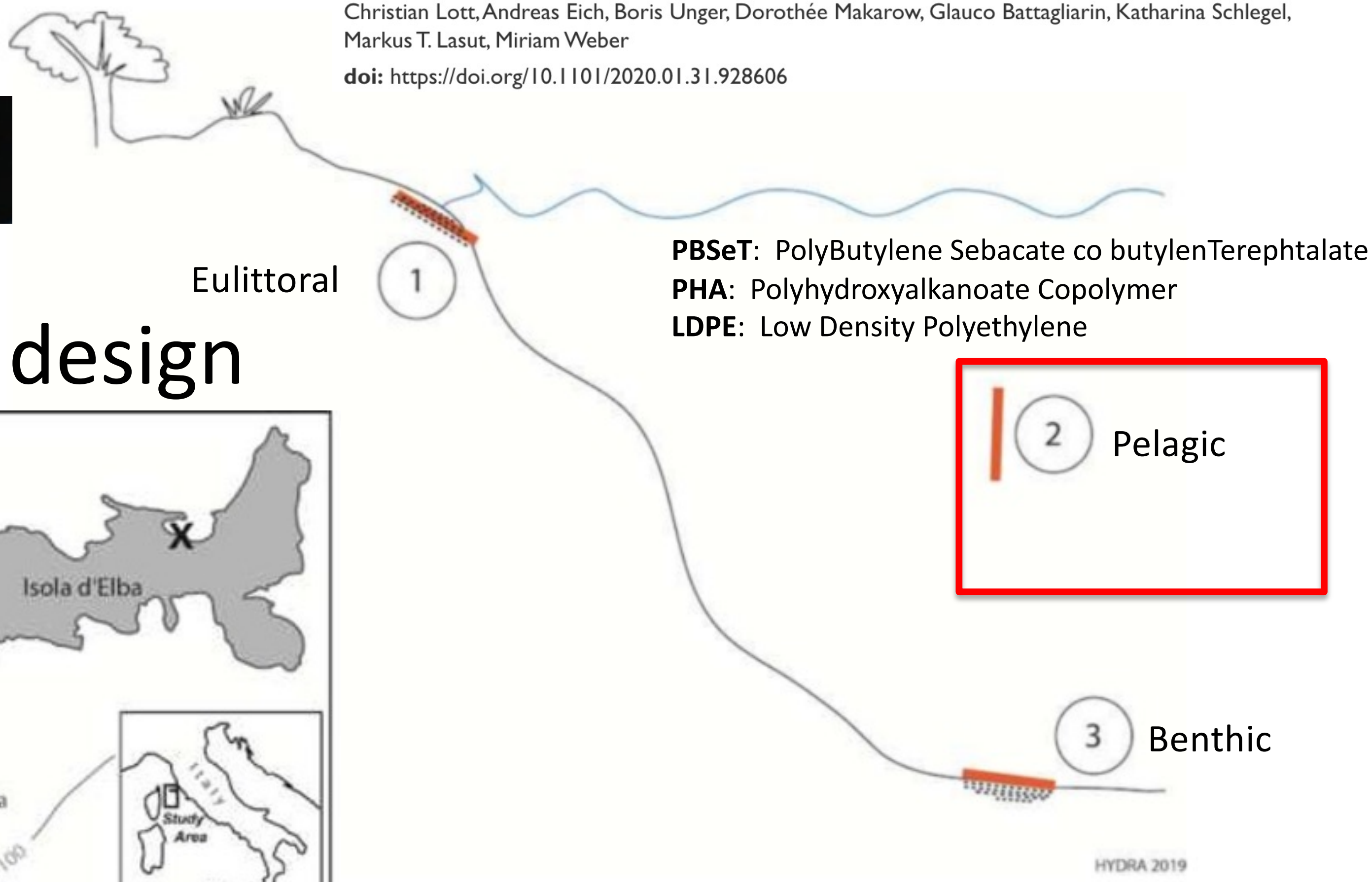
New Results

Comment on this paper

Field and mesocosm test methods to assess the performance of biodegradable plastic under marine conditions

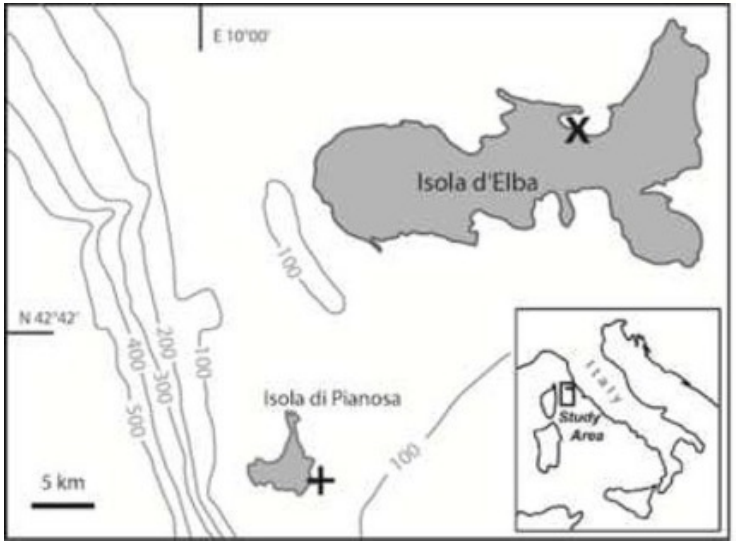
Christian Lott, Andreas Eich, Boris Unger, Dorothée Makarow, Glauco Battagliarin, Katharina Schlegel, Markus T. Lasut, Miriam Weber

doi: https://doi.org/10.1101/2020.01.31.928606



PBSeT: PolyButylene Sebacate co butylenTerephtalate
PHA: Polyhydroxyalkanoate Copolymer
LDPE: Low Density Polyethylene

Open-Bio design



Lott et al. 2020. Field and mesocosm test methods...

Elba Sediment and Water

Date of collection: July 6, 2020
Depth of collection (m): Mid water line at the Fetovaia Beach on Elba, Italy
Appearance of Seawater sample – (turbid, clear etc.): Clear
Temperature (°C): 25 °C
Salinity (PSU): 38.5
TOC: 1.9 mg/L
Total-N: 12.6 mg/L (after nutrient addition)
pH: 8.15
No pre-conditioning process applied

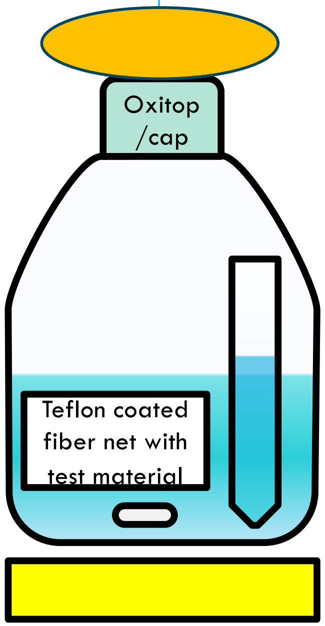
OxiTop – Closed System – 12 bottles

Test material	Nr. of replicates
PHBH	3
PE-LD (- control RRT)	3
Cellulose filter (+ control RRT)	3
Blank	3
Total	12

PHBH: copolymer of 3-hydroxybutryate and 3-hydroxyhexanoate) - 25-30 µm
LDPE: low density polyethylene - 25-30 µm
Cellulose Filter Paper: Blauband NEU filter paper - 170 µm

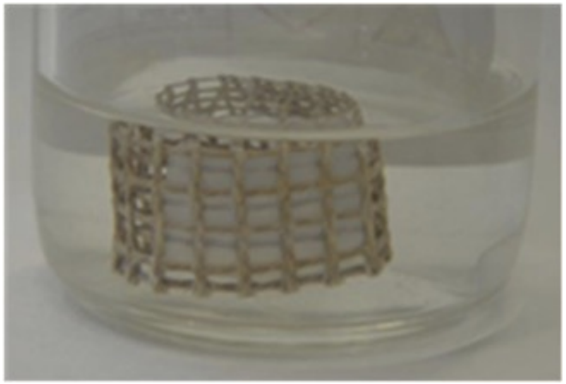
OxiTop – Closed System

Determine Biological Oxygen Demand
via
Oxygen Consumption

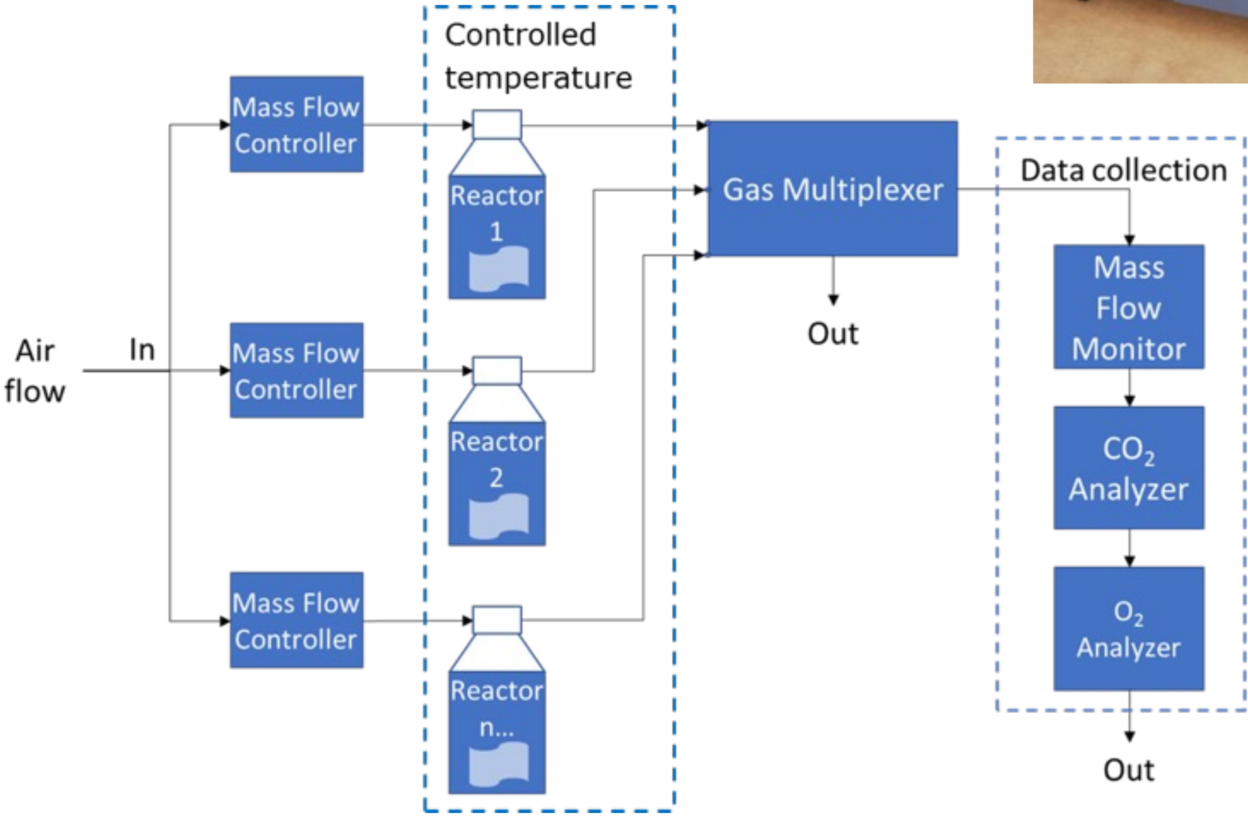


$CO_2 + 2\ NaOH \rightarrow Na_2CO_3 + H_2O$

Measure total Dissolved
Inorganic Carbon as a proxy for CO_2
Evolution



Respirometry – Open System – 20 bottles

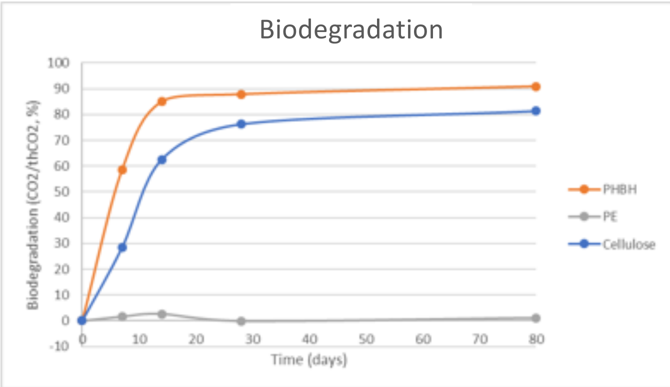


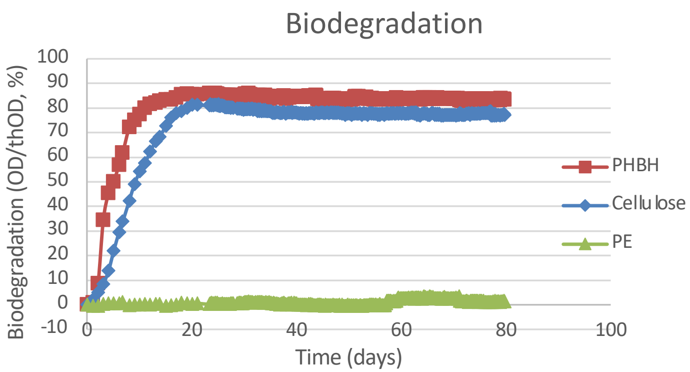
Parallel Plastisphere Sampling Bottles – 48 bottles

Test material	Nr. of replicates
PHBH	39
PE-LD (- control RRT)	3
Cellulose filter (+ control RRT)	3
Blank	3
Total	48

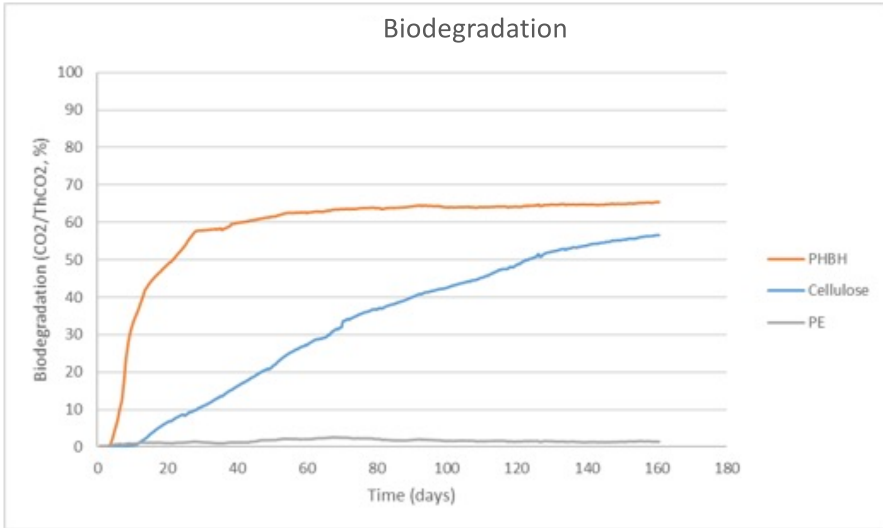
ISO Round Robin Test Results

Closed System



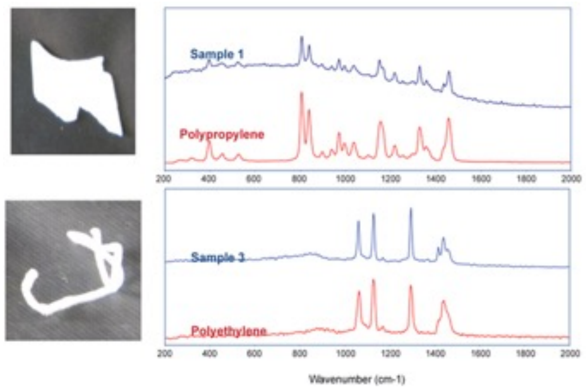


Open System



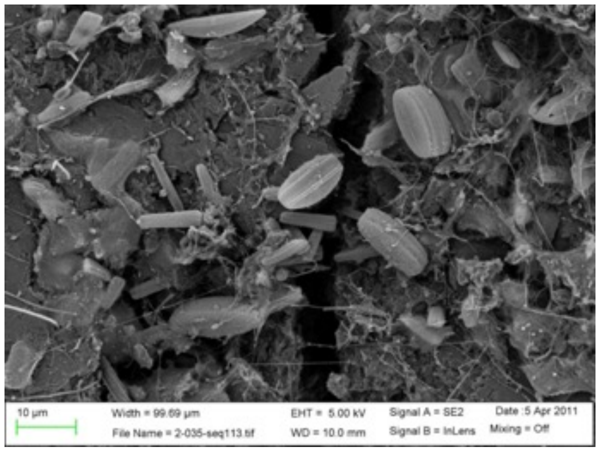
Amaral-Zettler, unpublished

Plastic identification, microscopy, molecular tools, and culturing



Raman / FT-IR Spectroscopy

Illumina Next-Gen Sequencing



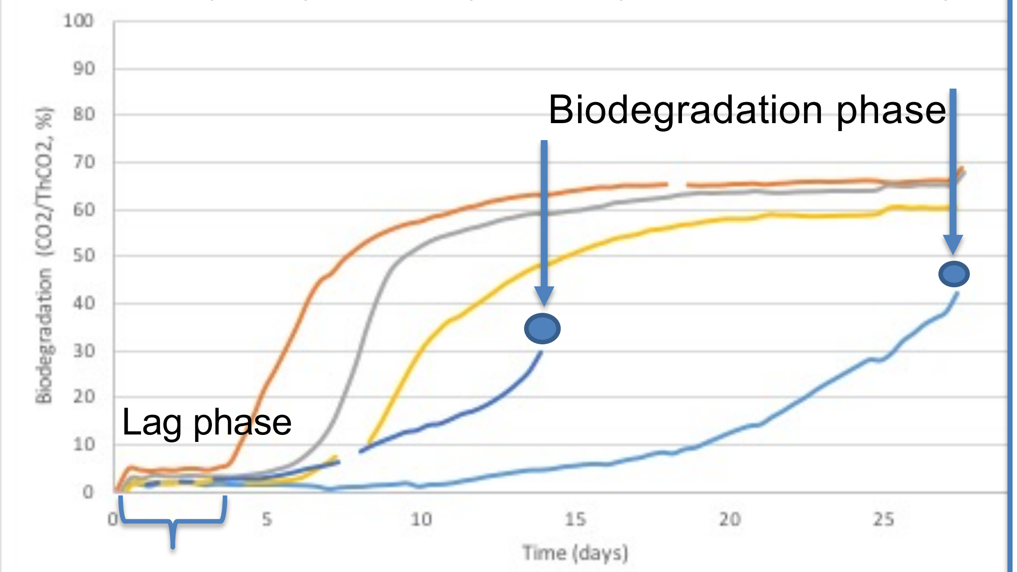
Scanning Electron Microscopy

Culture Isolation

Sampling For Microbial Community Profiling

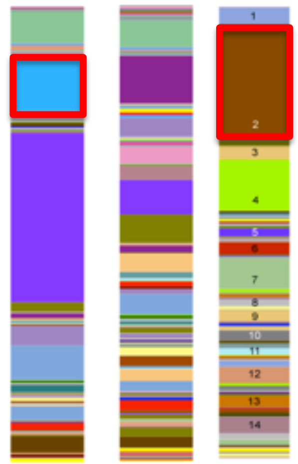
Closed System OxiTop: 0, 80 days

Open System Respirometry: 0, 14, 28, 160 days



Plastisphere:
7, 14, 21, 28 & 93 days

BIOLOGY



SEM
FISH **Who?**

Amplicon Sequencing **Where?**

Metagenomics/ Metatranscriptomics **What?**

New Results

Comment on this paper

Field and mesocosm test methods to assess the performance of biodegradable plastic under marine conditions

Christian Lott, Andreas Eich, Boris Unger, Dorothée Makarow, Glauco Battagliarin, Katharina Schlegel, Markus T. Lasut, Miriam Weber

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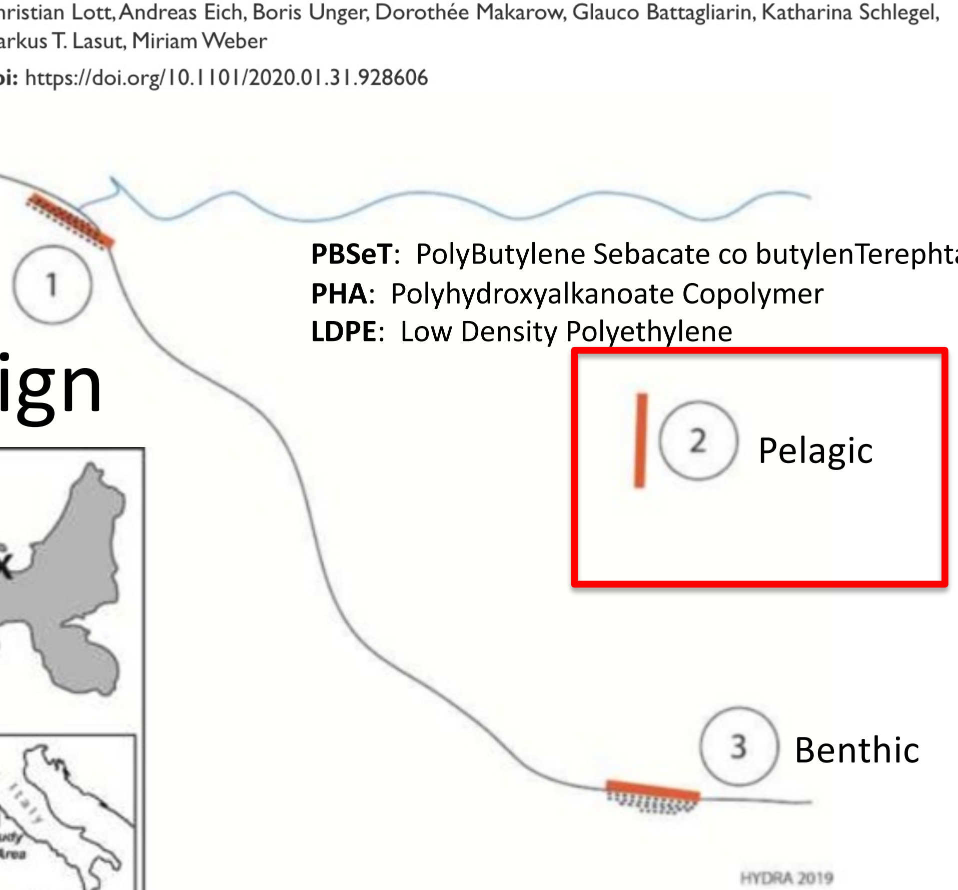
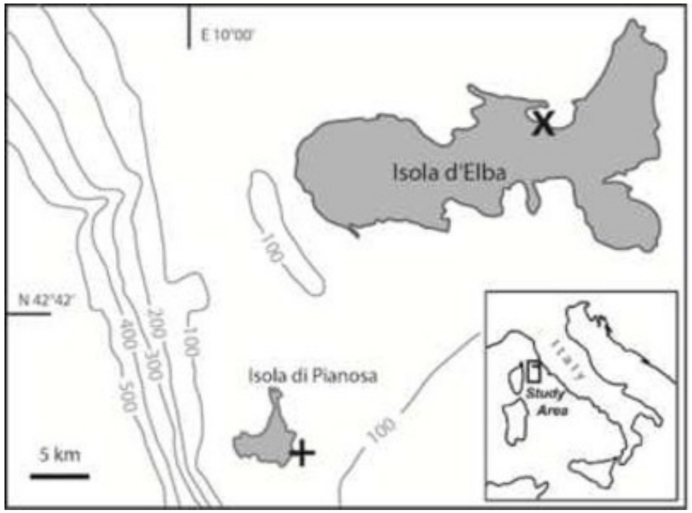
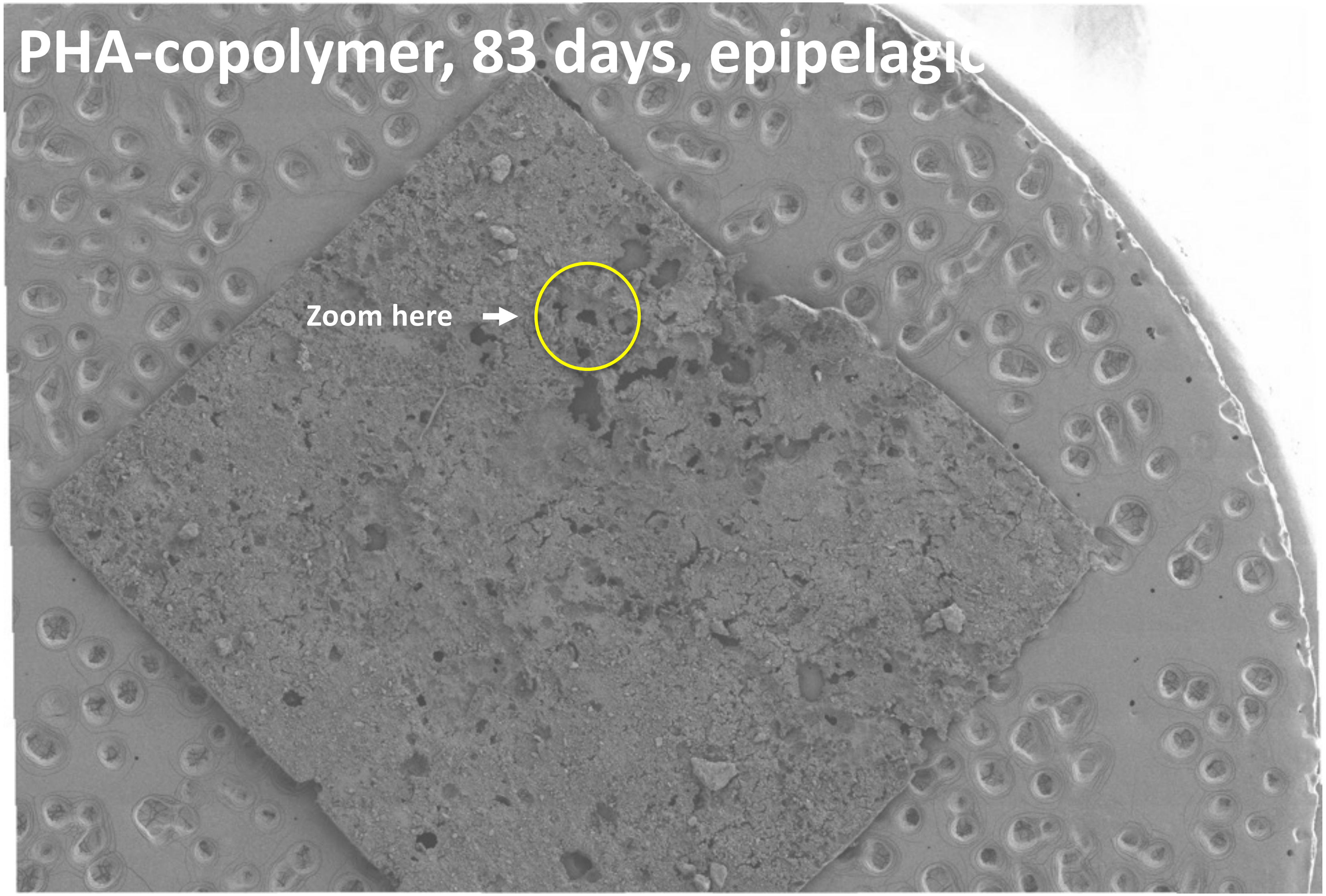


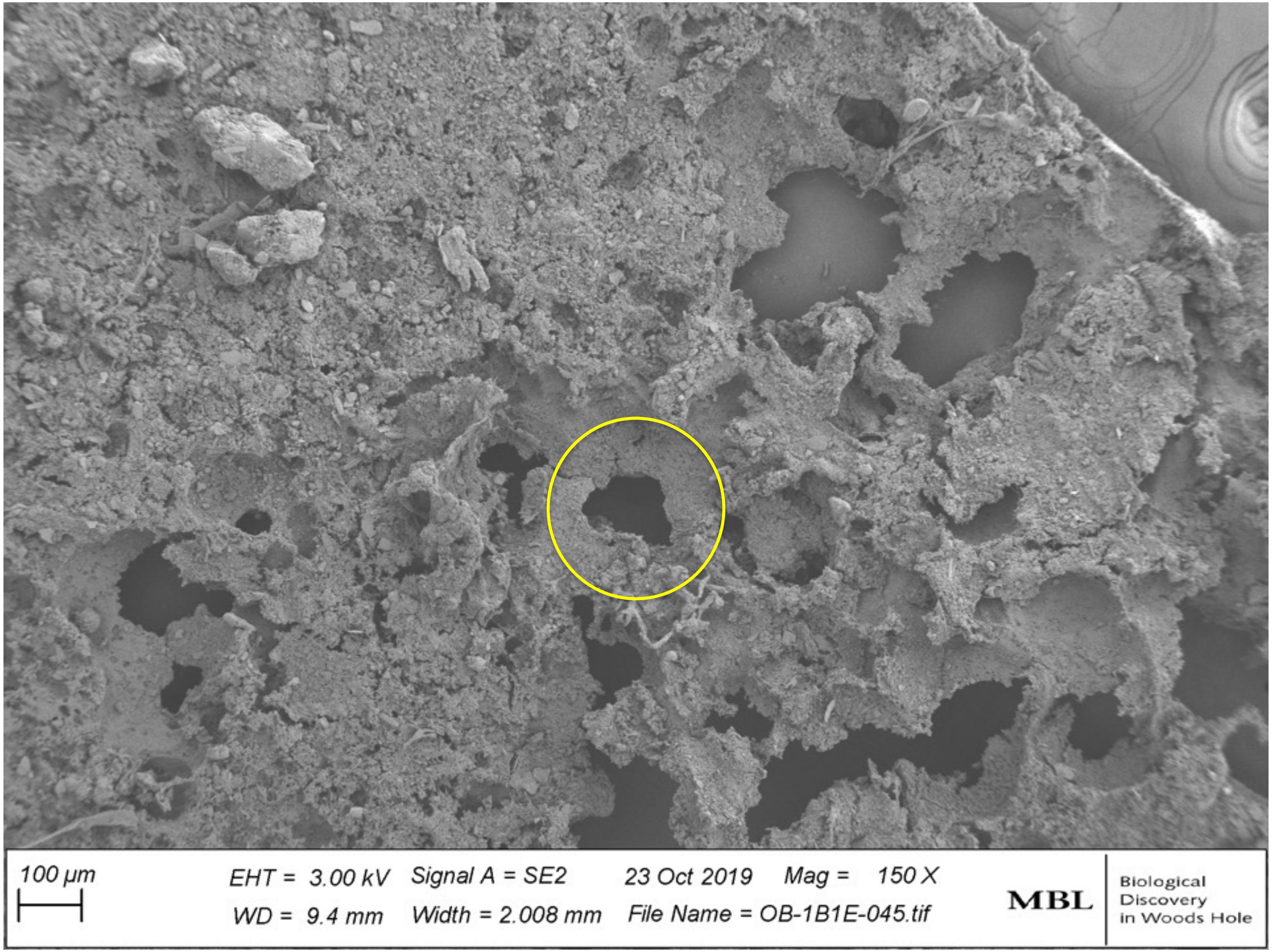
PBSeT: PolyButylene Sebacate co butylenTerephtalate
PHA: Polyhydroxyalkanoate Copolymer
LDPE: Low Density Polyethylene

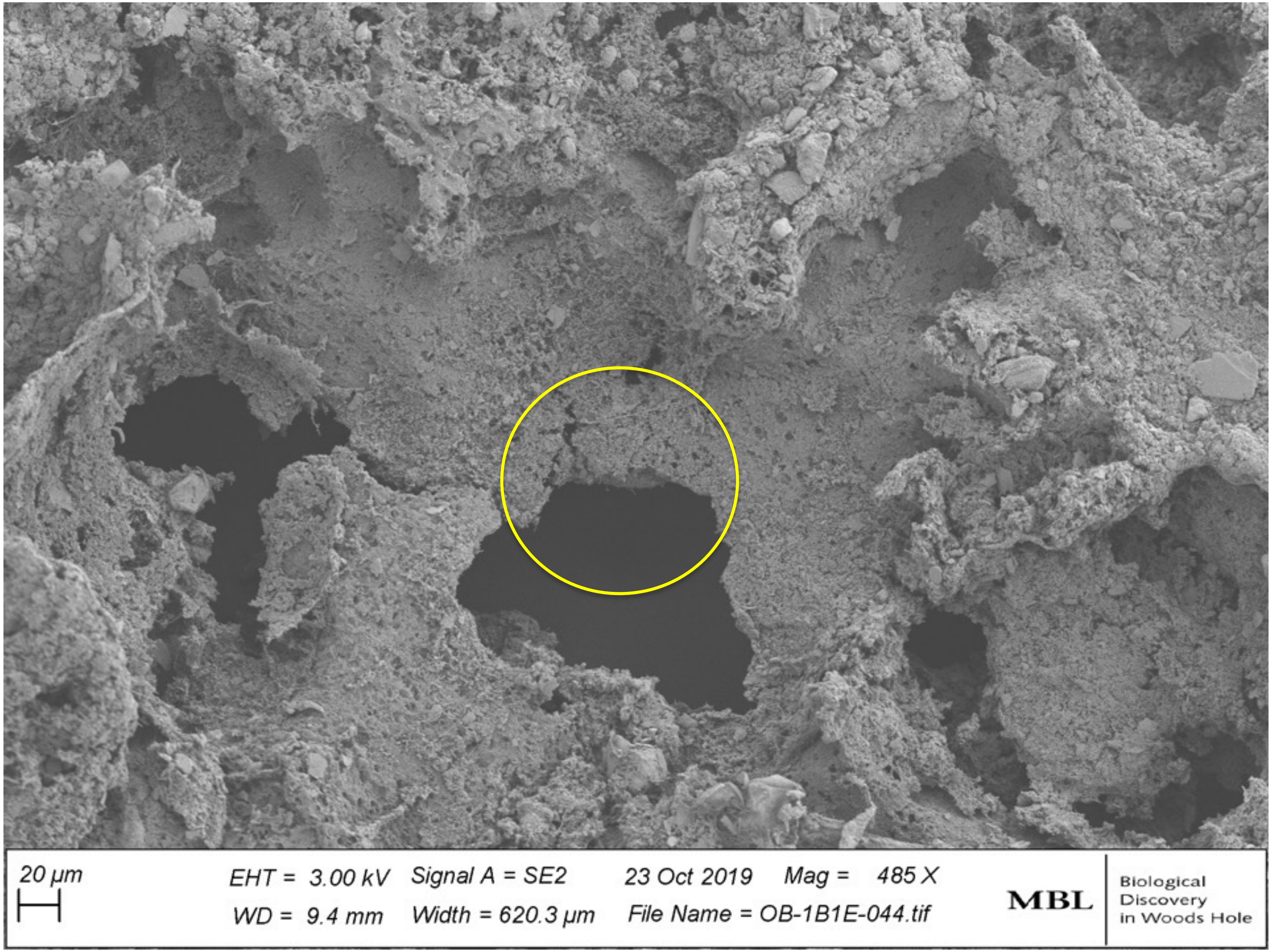
Open-Bio design

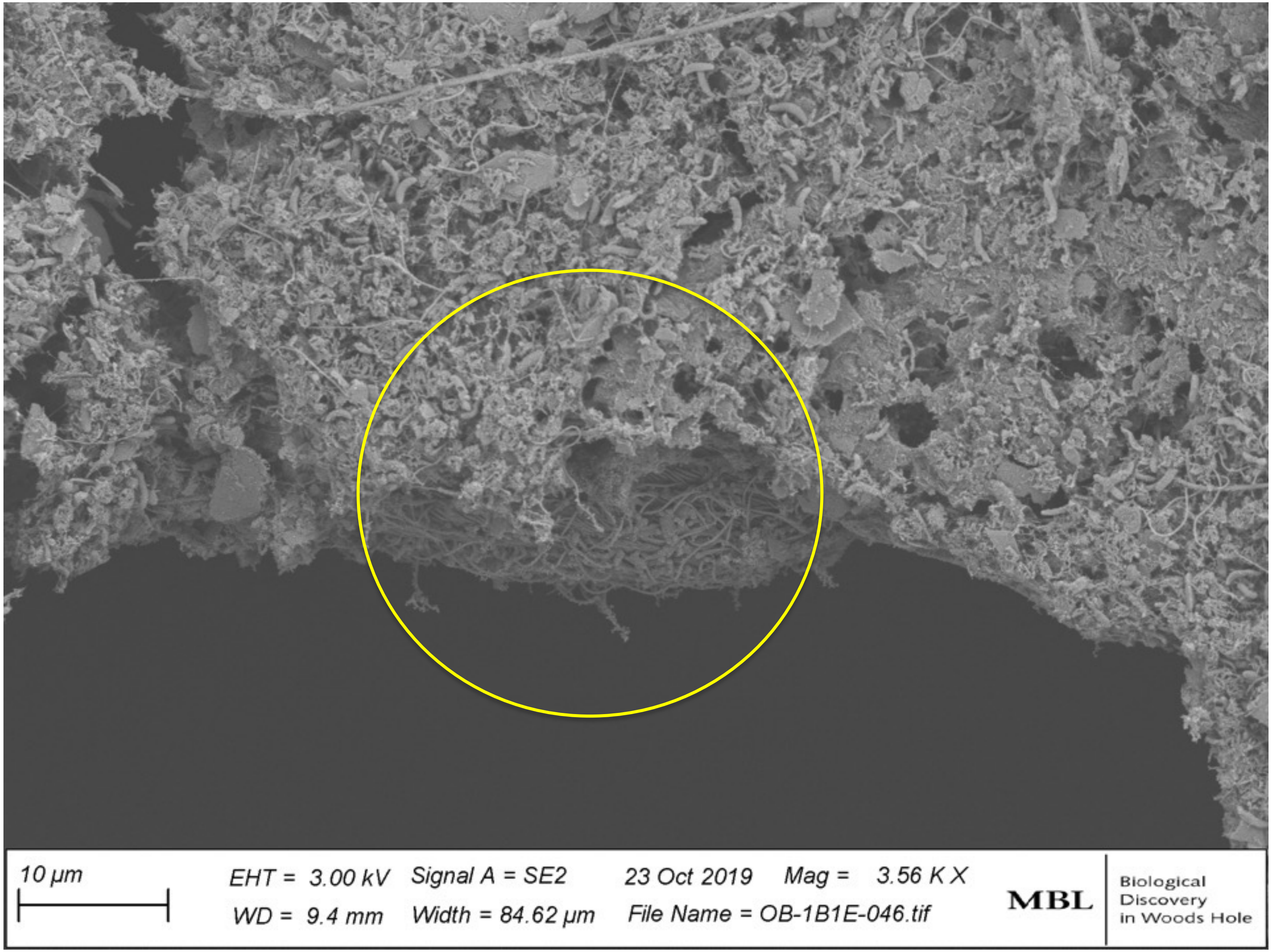


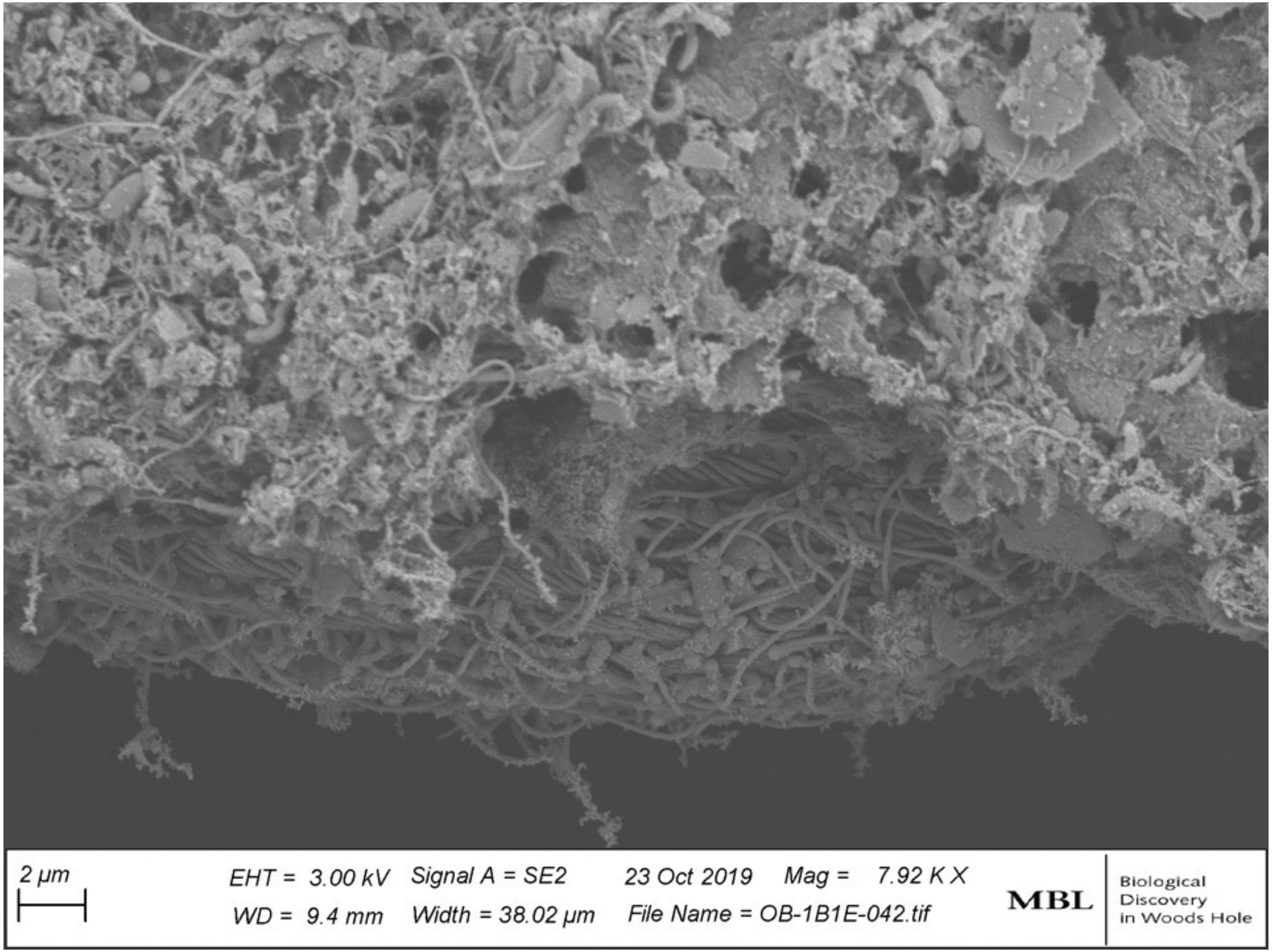
Lott et al. 2020. Field and mesocosm test methods...

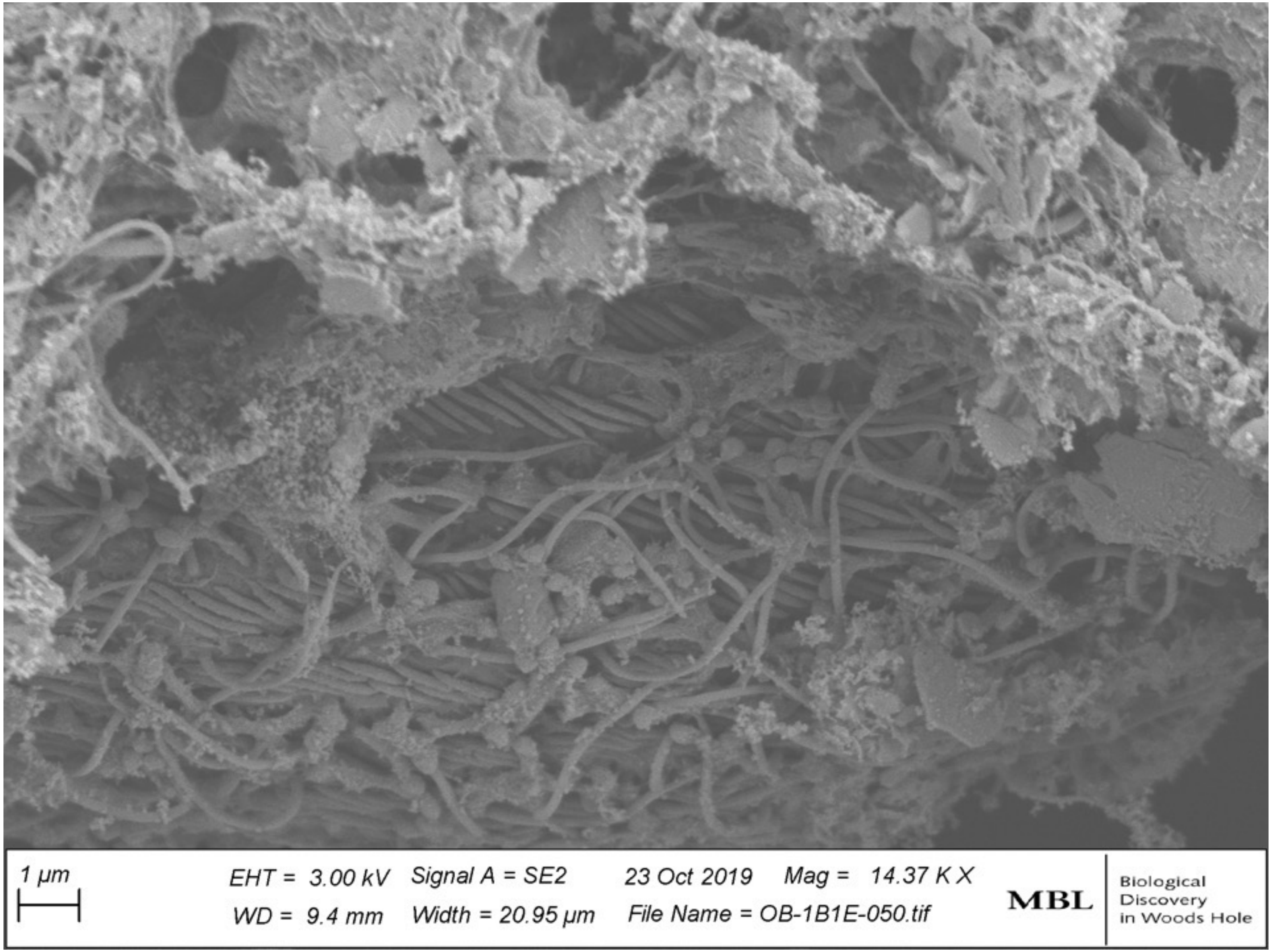

PHA-copolymer, 83 days, epipelagic
Zoom here

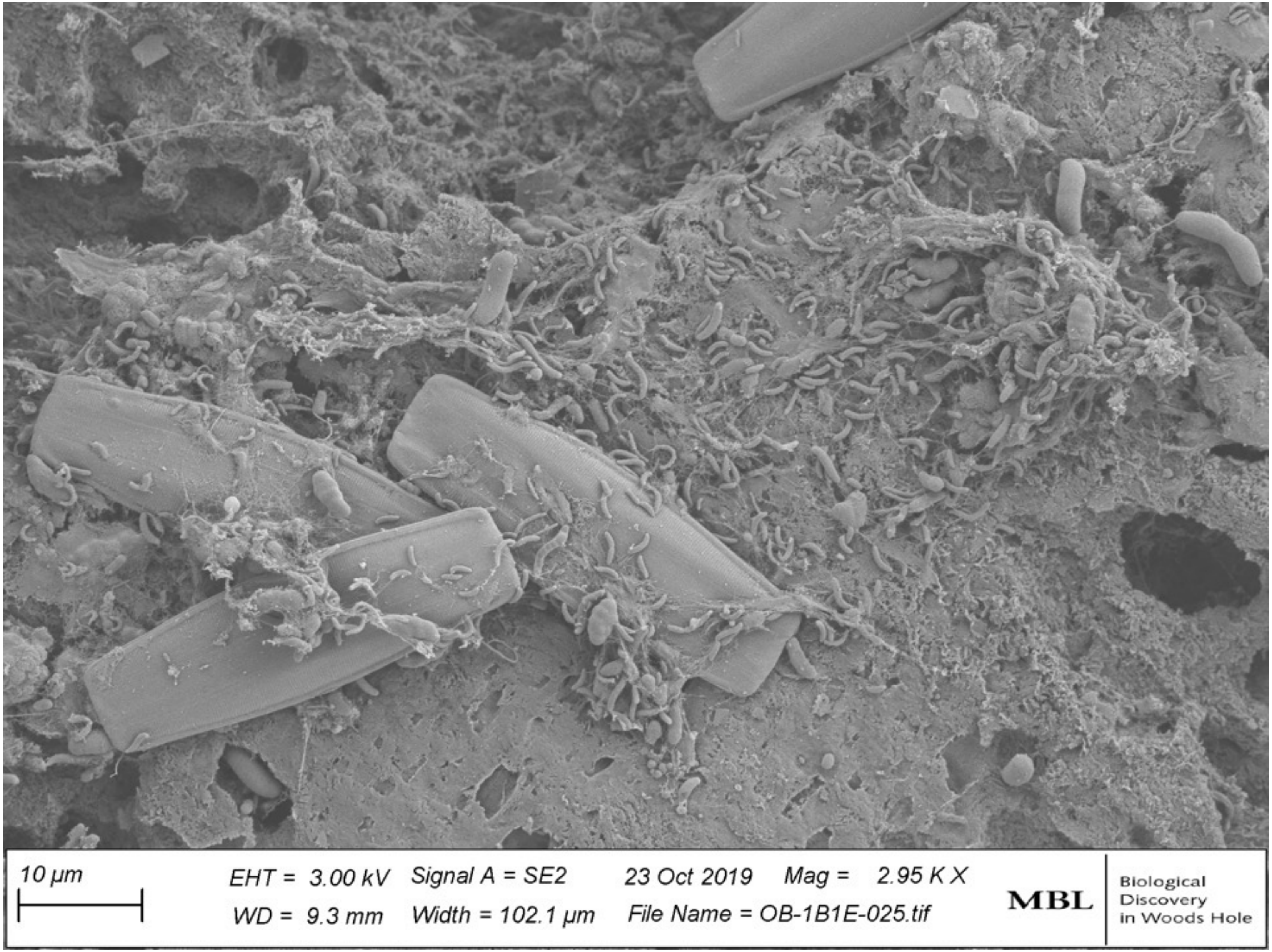

100 µm
EHT = 3.00 kV
Signal A = SE2
23 Oct 2019
Mag = 150 X
WD = 9.4 mm
Width = 2.008 mm
File Name = OB-1B1E-045.tif
MBL
Biological Discovery in Woods Hole


20 µm
EHT = 3.00 kV
WD = 9.4 mm
Signal A = SE2
Width = 620.3 µm
23 Oct 2019
File Name = OB-1B1E-044.tif
Mag = 485 X
MBL
Biological
Discovery
in Woods Hole


10 µm
EHT = 3.00 kV
WD = 9.4 mm
Signal A = SE2
Width = 84.62 µm
23 Oct 2019
File Name = OB-1B1E-046.tif
Mag = 3.56 K X
MBL
Biological Discovery in Woods Hole


2 µm
EHT = 3.00 kV
WD = 9.4 mm
Signal A = SE2
Width = 38.02 µm
23 Oct 2019
Mag = 7.92 K X
File Name = OB-1B1E-042.tif
MBL
Biological Discovery in Woods Hole


1 µm
EHT = 3.00 kV
WD = 9.4 mm
Signal A = SE2
Width = 20.95 µm
23 Oct 2019
File Name = OB-1B1E-050.tif
Mag = 14.37 K X
MBL
Biological Discovery in Woods Hole


10 µm
EHT = 3.00 kV
WD = 9.3 mm
Signal A = SE2
Width = 102.1 µm
23 Oct 2019
Mag = 2.95 K X
File Name = OB-1B1E-025.tif
MBL
Biological
Discovery
in Woods Hole


Outlook

Ongoing Marine Biodegradation Studies with D6691 original defined consortium:

ASTM INTERNATIONAL

CULTURING

Columbus Instruments Micro-Oxymax

Direct CO_2, O_2 and CH_4 Measurements!

microorganisms

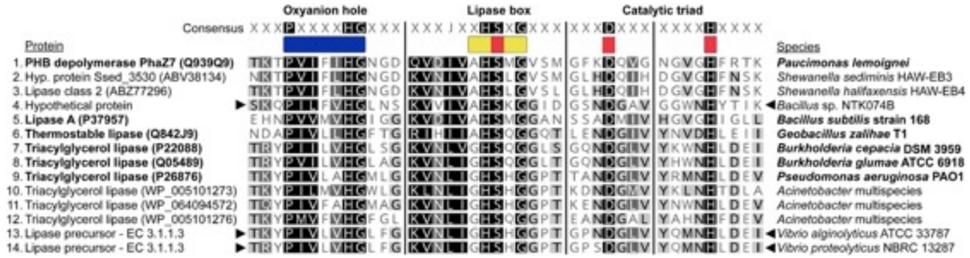
MDPI

Article

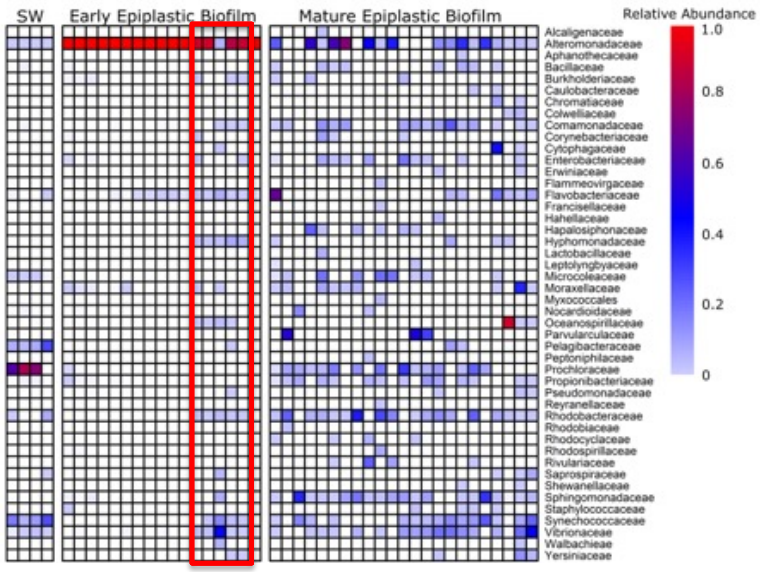
Comparative Genomics of Marine Bacteria from a Historically Defined Plastic Biodegradation Consortium with the Capacity to Biodegrade Polyhydroxyalkanoates

Fons A. de Vogel [1,2], Cathleen Schlundt [3,†], Robert E. Stote [4], Jo Ann Ratto [4] and Linda A. Amaral-Zettler [1,3,5,*]

Isolate	Depolymerase Activity	Growth on PHA
Bacillus sp. NTK034	–	–
Bacillus sp. NTK071	–	–
Bacillus sp. NTK074B	✓	✓
Rhodobacter sp. NTK016B	–	-
Vibrio proteolyticus ATCC 15338	✓	N.D.
Vibrio alginolyticus ATCC 33787	–	N.D.

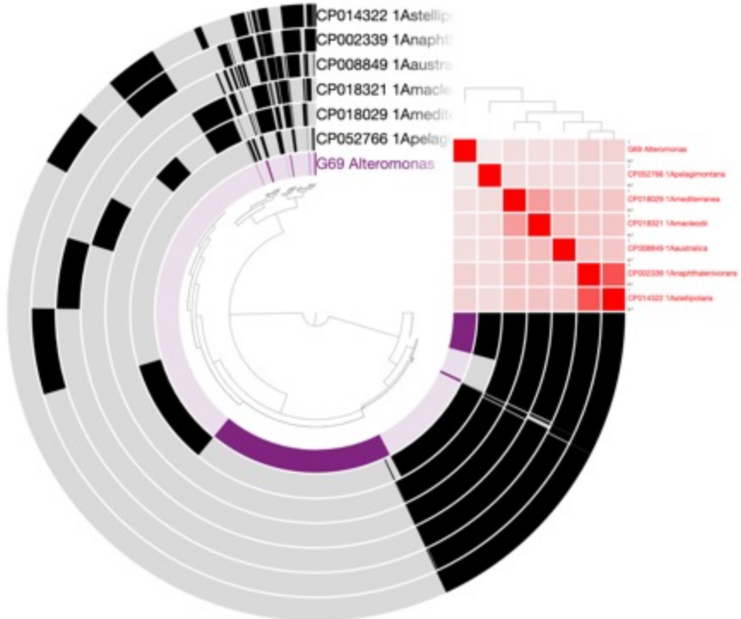


Are Early Colonizers also Biodegraders?



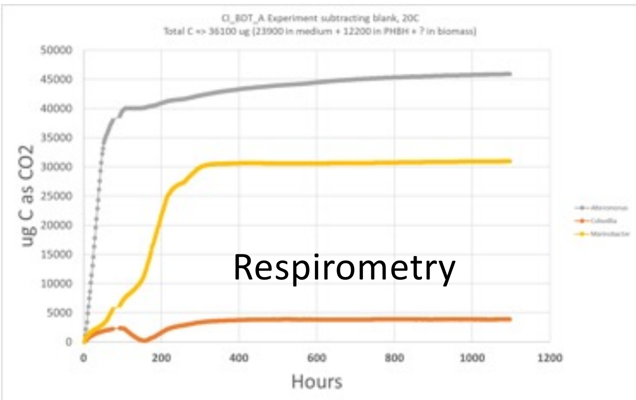
PHA

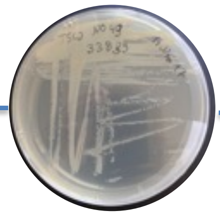
Bos et al., 2023



Comparative Genomics

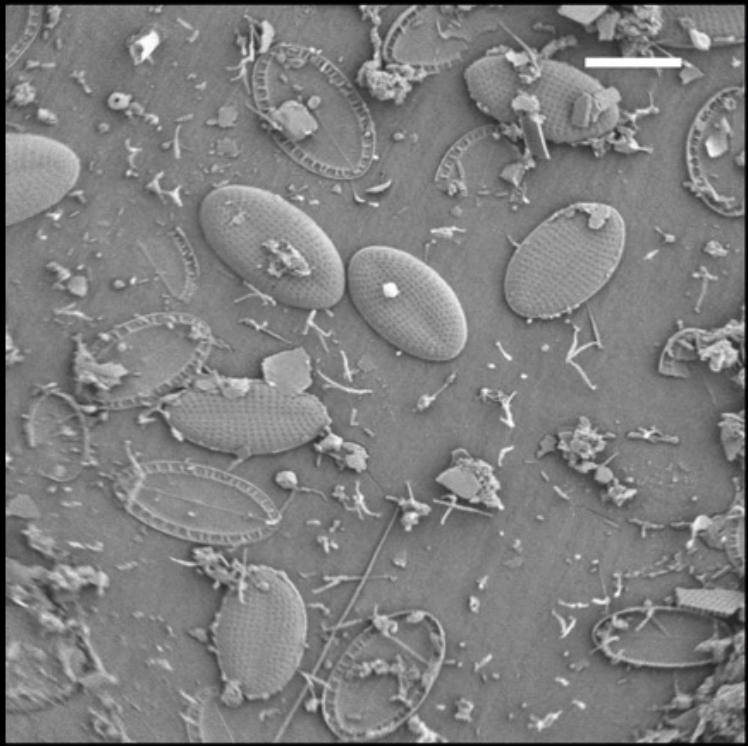
Micro-Oxymax Data



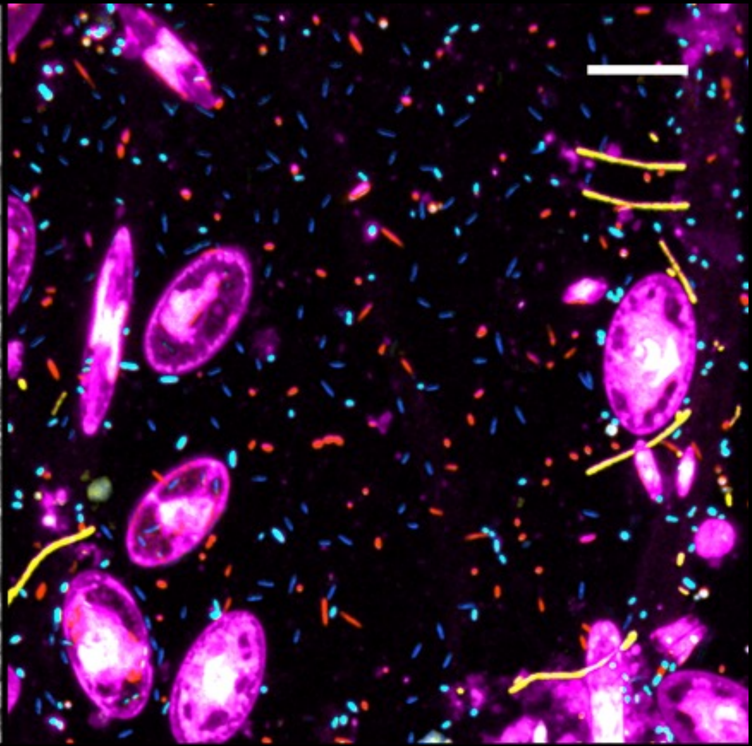


Long read sequencing

Can we open the Biodegradation Black box?



Scanning Electron Microscopy

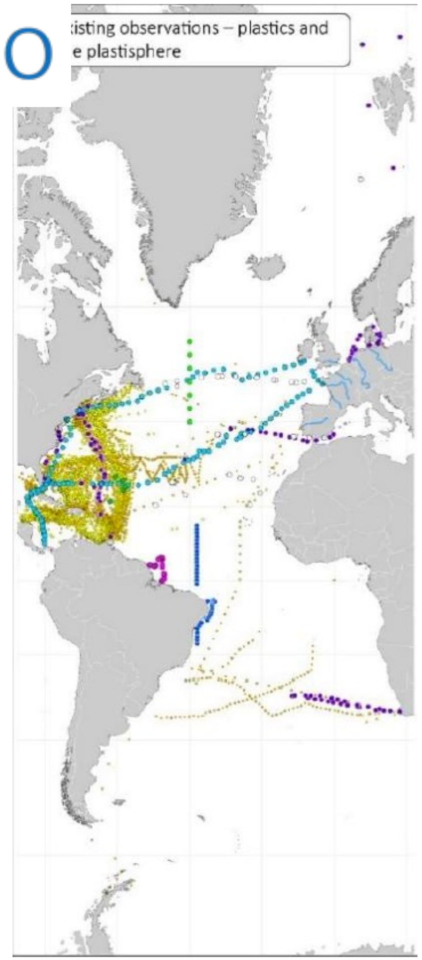


CLASI-FISH
(Combinatorial Labeling and Spectral Imaging Fluorescence In Situ Hybridization)

Schlundt et al. 2020

Atlantic Ecosystems Assessment, Forecasting and Sustainability

AtlantECO



WP2: Plastic and Plastisphere data observations

WP5: Network Analysis

Amplicon
Bacteria/Archaea (V4-V5)
Eukaryotes (V4)
Fungi (ITS)

Metagenomes

Plastics in surface waters
- Van Sebille Review *[1980-2010] (0-1 m)*
- Van Sebille Review *[2010-2019] (0-1 m)*

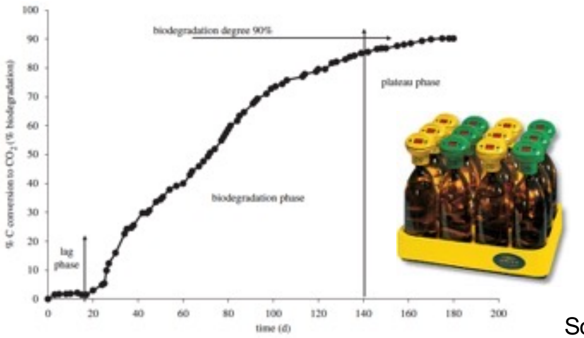
Plastics & plastisphere in surface waters
- Camadas Finas V *[2014] (0-10 m)*
- Expedition 7th Continent *[2015] (0-1 m)*
- PIRATA-BR *[2018] (0-1 m)*
- Amaral-Zettler *[2012-2018] (0-1 m)*

Plastics & microbiomes in rivers
- Tara microplastics *[2019] (0-1 m)*

Plastics & microbiomes in aerosols
- Tara Pacific *[2016-2018] (15 m)*
- NAAMES *[2015-2018] (15 m)*

Plastics & microbiomes in sediments
- eDNAbyss *[2016-2018] (0-50 cm)*

TransAtlantECO Biodegradation Test*



Song et al., 2009
doi:10.1098/rstb.2008.0289

Test material	No. of replicates
PHBH	3
PLA	3
LDPE	3
OXO-PE	3
Cellulose filter (+ control RRT)	3
Blank	3
Total	18

*Proposed project requires funding

Take-home Messages on Plastic Debris and Biodegradation

1. There is one Ocean shared by all: litter doesn't respect EEZ's
2. Marine environments are not homogeneous
3. Out of sight shouldn't be out of mind when it comes to biodegradation
4. **Reduce**, Reuse, Recycle
5. Biodegradable plastic is a **part** of the solution to the plastic problem
6. Proper waste infrastructure and composting facilities are required
7. **Global problems require global cooperation – collaborative efforts across International standardization bodies**

It’s time to start caring about what’s on the bottom of the ocean

The New Yorker

Barnes et al., 2009.

Saxon, (c) 1983 The New Yorker

“I don’t know why I don’t care about the bottom of the ocean, but I don’t.”

Thanks for your attention!

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@plastisphere

MBL Central Microscopy Facility (Woods Hole, USA)
Gulbenkian Sequencing Facility (Oeiras, Portugal)
University Medical Center (Amsterdam, NL)
MMB department (NIOZ)
Leslie Murphy, Fons de Vogel, Lia Corbett, Ryan Bos, Chris Dupont, Tracy Mincer, Erik Zettler

An Artist’s Interpretation of the “Plastisphere” - Pinar Yoldas