

Mikroplastik in Klärwerken

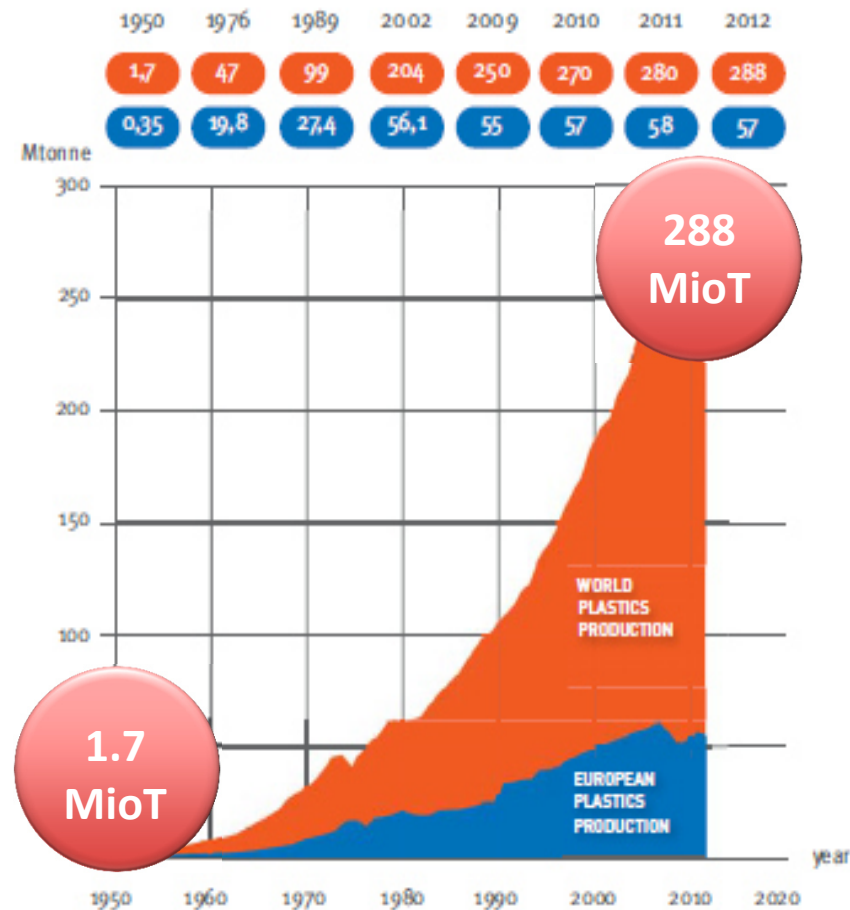
Fallstudie: Mikroplastik in ausgewählten Kläranlagen des Oldenburgisch-Ostfriesischen Wasserverbandes (OOWV) in Niedersachsen

Gunnar Gerdts^{a)}, Svenja Mintenig^{a)}, Ivo Int-Veen^{a)} & Martin Löder^{b)}
^{a)}Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research

^{b)}Universität Bayreuth, D-95440 Bayreuth

Plastik...

- Plásticos (gr.) „Bildhauer-Kunst“
- Perfekte Eigenschaften für unzählige Anwendungen



PlasticsEurope, 2013

Plastik...

- Plasticos (gr.)
„Bildhauer-Kunst“
- Perfekte Eigenschaften für unzählige Anwendungen
 - Mehr-Weg
 - Dauerhafter Gebrauch



WDR; Planet Wissen: Leben ohne Plastik? Eine Familie probiert's aus

Plastik...

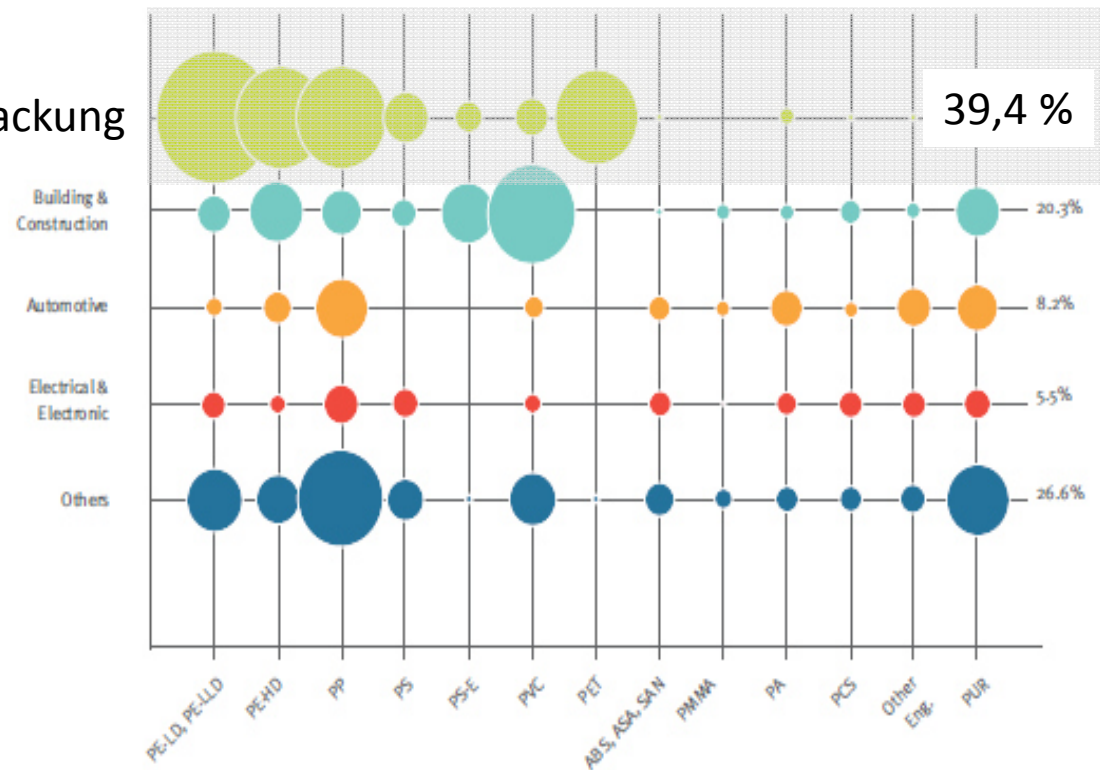
- Plasticos (gr.)
„Bildhauer-Kunst“
- Perfekte Eigenschaften für unzählige Anwendungen
 - Einweg



Plastik...

- Plastics (gr.) „Bildhauer-Kunst“
- Perfekte Eigenschaften für unzählige Anwendungen
 - Einweg

Verpackung



PlasticsEurope, 2013

Plastik...

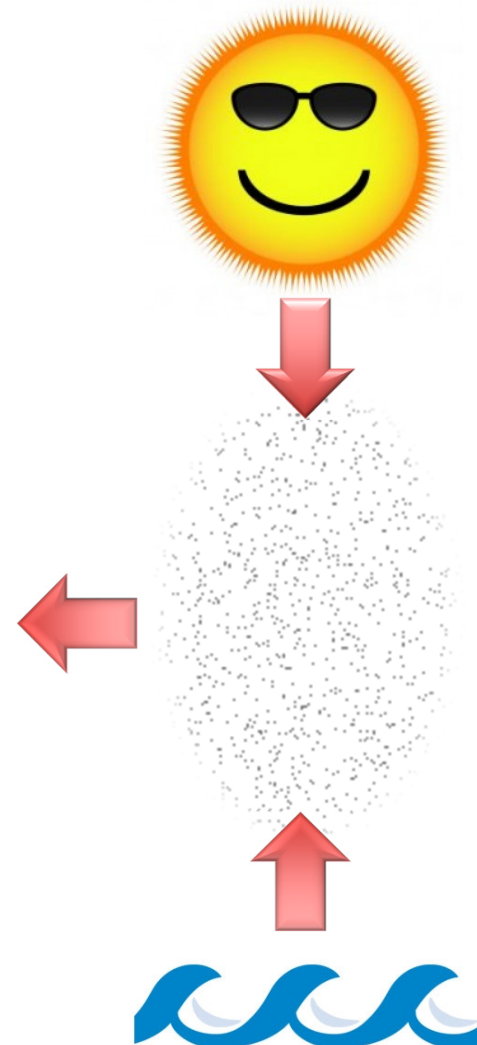
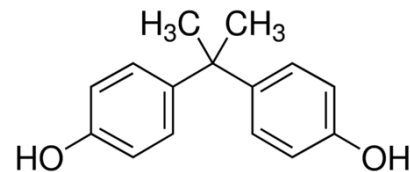
- Plásticos (gr.)
„Bildhauer-Kunst“
- Perfekte Eigenschaften für unzählige Anwendungen
- Recyclingraten, Entsorgungs- und **Umweltprobleme**
- **Persistenz: ~ 10 - 1000 Jahre** (Galgani, Hanke et al. 2013; Hopewell, Dvorak et al. 2009)



Photo by Chris Jordan

Mikroplastik...

- **Persistenz: ~ 10 - 1000 Jahre????**
(Galgani, Hanke et al. 2013;
Hopewell, Dvorak et al. 2009)



Mikroplastik...

Primäres Mikroplastik



Sekundäres Mikroplastik



- Sekundäres Mikroplastik: Fragmentiertes „Makro-Plastik“
- Primäres Mikroplastik: Pellets, Kosmetika etc.
- MP Größe: Keine verbindliche Standardisierung; < 5 mm (Betts 2008; Barnes, Galgani et al. 2009)
- Ubiquitär: v.a. marine Habitate untersucht, Süßwasserökosysteme (→ M. Löder)

Mikroplastik in der Umwelt...

Vielzahl negativer Effekte in aquatischen Ökosystemen

- Aufnahme als „Nahrung“ (Cole, Lindeque et al. 2013)
- „leaching “ von Additiven (Debenest, Gagne et al. 2010)
- Adsorption von Schadstoffen (POPs) (Koelmans et al. 2013)
- Bioakkumulation in der Nahrungskette (Setäläet al. 2014)
- Verbreitung fremder und invasiver Arten (Browne, Galloway et al. 2010)
- Gewebeveränderungen (Browne et al 2008; Moos et al. 2012)
- Veränderung von Ökosystemfunktionen (Gregory 2009)

Quantifizierung von Mikroplastik



Notwendigkeit

- der Anreicherung
- von physikalischen und chemischen Behandlungen
- der eindeutigen Identifizierung

Quantifizierung von Mikroplastik

Notwendigkeit

- der Anreicherung
 - „Netzfänge“; (Fraktionierte) Filtration (Anreicherung 10 µm; Fraktionierung > 500 µm & < 500 µm)
- von physikalischen und chemischen Behandlungen
 - Abtrennung von Sand: Dichteseperation; z.B. $ZnCl_2$
 - Entfernung von „Organik“: Säuren, Laugen, Enzyme...
- der eindeutigen Identifizierung
 - FT-IR, Raman, Py-GCMS....

Entfernung von „Organik“: Säuren, Laugen, Enzyme...

...20 mL of HNO_3 (22.5 M) at room temperature, followed by 2 h of boiling (100 °C)...

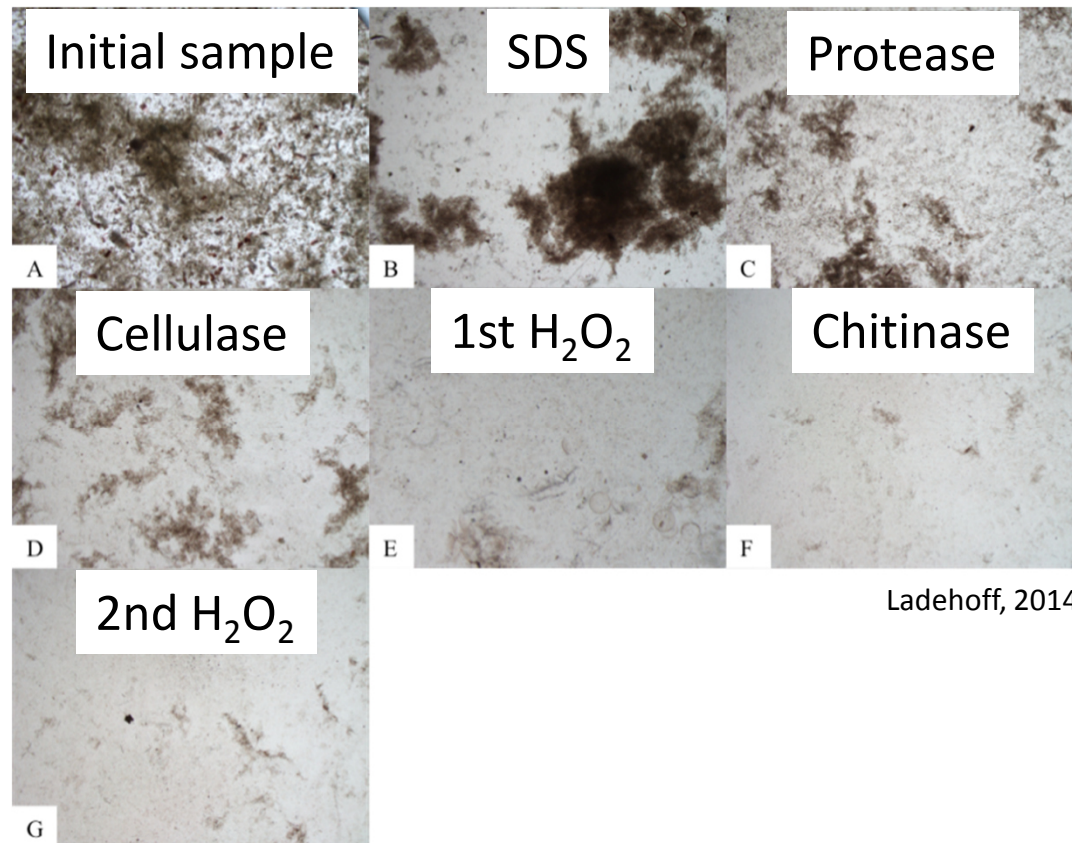
Claessens et al., Mar Poll Bull (2013)

Alphabetical Listing of Materials	Concentration + Weight %	ABS	Acrylic	CAB	CPVC	ECTFE (Halar®)	Fluorosint®	HDPE	PEEK	Polycarbonate	Polypropylene	Polysulfone	PPS	PVC, Type I	PVC, Type II	PVDF	PTFE	Tecator™/Torlon®	UHMW
Nitric Acid Aq.	10	*	*	*	A	A	A	*	A	*	*	A	A	A	A	B	A	*	B

http://www.plasticsintl.com/plastics_chemical_resistance_chart.html

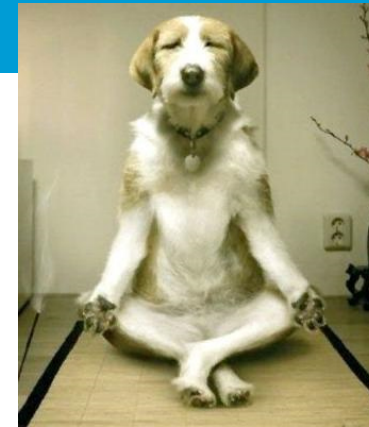
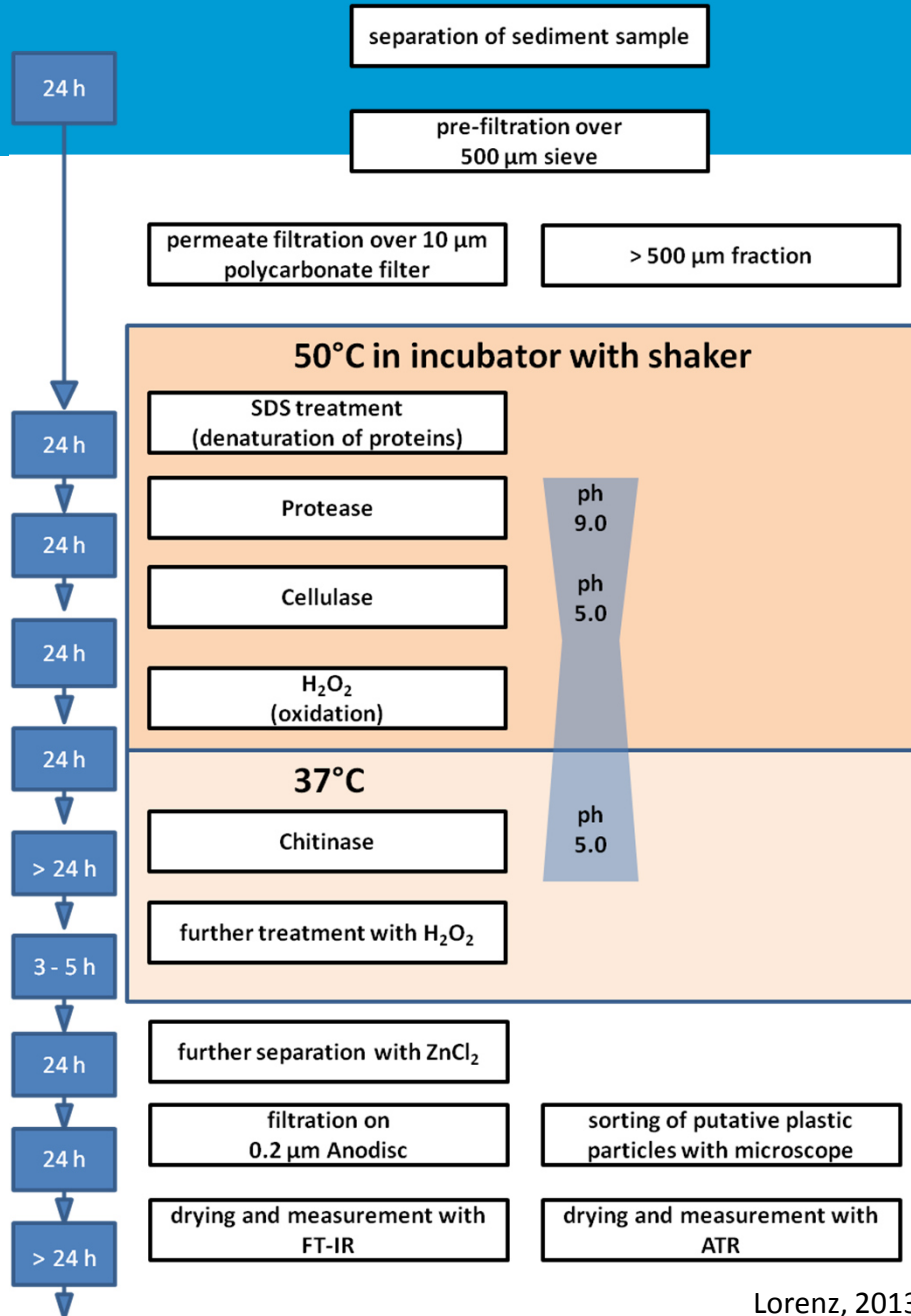
- A: No attack
- B: Slight attack
- C: Moderate attack
- D: Material will decompose

Entfernung von „Organik“: Säuren, Laugen, Enzyme...



Unsere Lösung: Enzyme und relativ Polymer-schonende Chemikalien

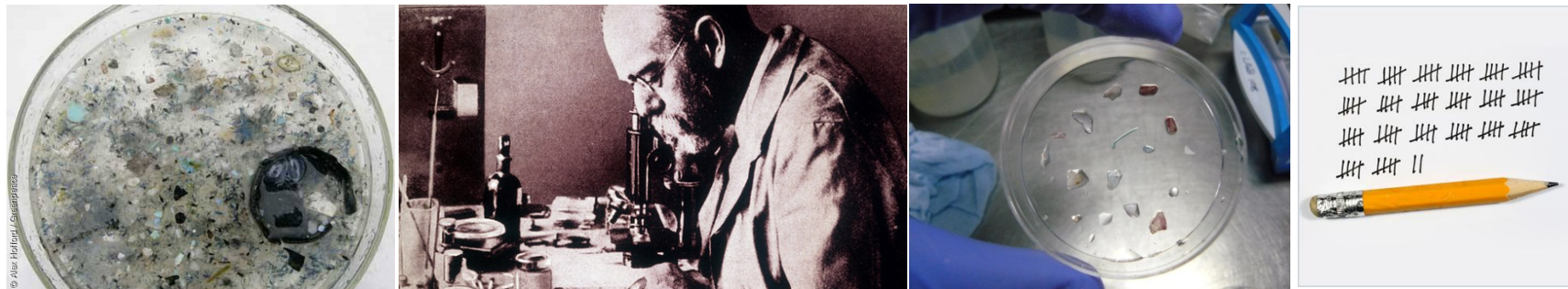
- Preiswerte technische Enzyme (Proteinase, Cellulase and Chitinase)
- Abbau von Organik
- Kein Abbau von „Plastik“



Unsere Lösung: Enzyme und relativ Polymer-schonende Chemikalien

- Preiswerte technische Enzyme (Proteinase, Cellulase and Chitinase)
- Abbau von Organik
- Kein Abbau von „Plastik“
- **Zeitaufwendig!**

Quantifizierung von Mikroplastik



Generelle Regeln für die Identifizierung und Quantifizierung von Mikroplastik

Das Objekt ist offensichtlich..

- ..Plastik
- ..kein Sand
- ..kein Organismus oder ein Teil davon
- ..sichtbar

BASE Project - Implementation of the Baltic Sea Action Plan in Russia



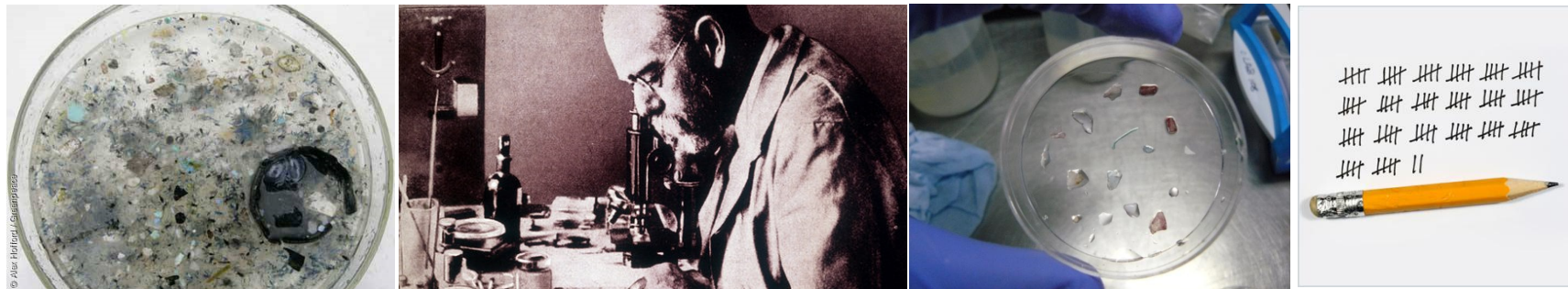
Baltic Marine Environment Protection Commission

Preliminary study on
Synthetic microfibers and particles at a municipal waste water treatment plant





Quantifizierung von Mikroplastik



*„...up to 70% of particles that visually resemble microplastics are not confirmed as plastics by **FT-IR spectroscopy**...“*

Hidalgo-Ruz et al. 2012

..und sehr kleine Partikel?



Quantifizierung und Identifizierung von Mikroplastik

BREVIA

Lost at Sea: Where Is All the Plastic?

Richard C. Thompson,^{1*} Ylva Olsen,¹ Richard P. Mitchell,¹ Anthony Davis,¹ Steven J. Rowland,¹ Anthony W. G. John,² Daniel McGonigle,³ Andrea E. Russell²

Millions of metric tons of plastic are produced annually. Countless large items of plastic debris are accumulating in marine habitats worldwide and may persist for centuries (1-4). Here we show that microscopic plastic fragments and fibers (Fig. 1A) are also widespread in the oceans and have accumulated in the pelagic zone and sedimentary habitats. The fragments appear to have resulted from degradation of larger items. Plastics of this size are ingested by marine organisms, but the environmental consequences of this contamination are still unknown.

Over the past 40 years, large items of plastic debris have frequently been recorded in habitats from the poles to the equator (1-4). Smaller fragments, probably also plastic, have been reported (5) but have received far less attention. Most plastics are resistant to biodegradation, but will break down gradually through mechanical action (6). Many "biodegradable" plastics are composites with materials such as starch that biodegrade, leaving behind numerous, nondegradable, plastic fragments (6). Some cleaning agents also contain abrasive plastic fragments (2). Hence, there is considerable potential for large-scale accumulation of microscopic plastic debris.

To quantify the abundance of microplastics, we collected sediment from beaches and from estuarine and subtidal sediments around Plymouth, UK (Fig. 1B). Less dense particles were separated by flotation. Those that differed in appearance to natural particulate material (Fig. 1A) were removed and identified with Fourier Transform infrared (FT-IR) spectroscopy (7). Some were of natural origin and others could not be identified, but about one third were synthetic polymers (Fig. 1C). These polymers were present in most samples (23 out of 30), but were significantly more abundant in subtidal sediment (Fig. 1D). Nine polymers were conclusively identified: acrylic, alkylid, poly (ethylene:propylene), polyamide (nylon), polyester, polyethylene, polymethylacrylate, polypropylene, and polyvinylalcohol. These have a wide range of uses, including clothing, packag-

ing, and rope, suggesting that the fragments resulted from the breakdown of larger items. To assess the extent of contamination, a further 17 beaches were examined (Fig. 1B). Similar fibers were found, demonstrating that microscopic plastics are common in sedimentary habitats. To assess long-term trends in abundance, we examined plankton samples collected regularly since the 1960s along routes between Aberdeen and the Shetlands (315 km) and from Sule Skerry to Is-

land (850 km) (7) (Fig. 1B). We found plastic archived among the plankton in samples back to the 1960s, but with a significant increase in abundance over time (Fig. 1E). We found similar types of polymer in the water column as in sediments, suggesting that polymer density was not a major factor influencing distribution.

It was only possible to quantify fragments that differed in appearance from sediment grains or plankton. Some fragments were granular, but most were fibrous, ~20 µm in diameter, and brightly colored. We believe that these probably represent only a small proportion of the microscopic plastic in the environment, and methods are now needed to quantify the full spectrum of material present. The consequences of this contamination are yet to be established. Large plastic items can cause suffocation and entanglement and disrupt digestion in birds, fish, and mammals (3). To determine the potential for microscopic plastics to be ingested, we kept amphipods (detritivores), lugworms (deposit feeders), and barnacles (filter feeders) in aquaria with small quantities of microscopic plastics. All three species ingested plastics within a few days (7) (Fig. S1).

Our findings demonstrate the broad spatial extent and accumulation of this type of contamination. Given the rapid increase in plastic production (Fig. 1E), the longevity of plastics, and the disposable nature of plastic items (2, 3), this contamination is likely to increase. There is the potential for plastics to adsorb, release, and transport chemicals (3, 4). However, it remains to be shown whether toxic substances can pass from plastics to the food chain. More work is needed to establish whether there are any environmental consequences of this debris.

References and Notes

1. P. G. Ryan, C. L. Moloney, *Nature* **361**, 23 (1993).
2. M. R. Gregory, P. G. Ryan, in *Marine Debris*, J. M. Coe, D. B. Rogers, Eds. (Springer, Berlin, 2006), pp. 48-70.
3. J. C. B. Derrak, *Mar. Pollut. Bull.* **44**, 842 (2002).
4. E. J. Carpenter, S. J. Anderson, G. R. Harvey, H. P. Miklas, R. F. Bradford, *Science* **178**, 749 (1972).
5. J. B. Colton, F. D. Knapp, B. R. Burns, *Science* **185**, 491 (1974).
6. P. P. Klemchuk, *Polym. Degrad. Stab.* **27**, 183 (1990).
7. Materials and methods are available as supporting material online on Science Online.
8. We thank C. Hoare, R. Ticehurst, G. Mandair, and F. Bismantov for help with sample collection and analysis. Supported by the Leverhulme Trust, UK.

Supporting Online Material
www.sciencemag.org/cgi/content/full/304/5672/839/DC1

Materials and Methods
Fig. S1

References and Notes

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¹University of Plymouth, PL4 8AA, UK. ²Sir Alister Hardy Foundation for Ocean Science, Plymouth, PL1 2PB, UK. ³University of Southampton, SO17 1BJ, UK.

*To whom correspondence should be addressed. E-mail: rcthompson@plymouth.ac.uk

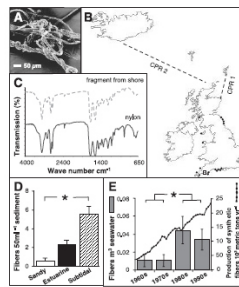
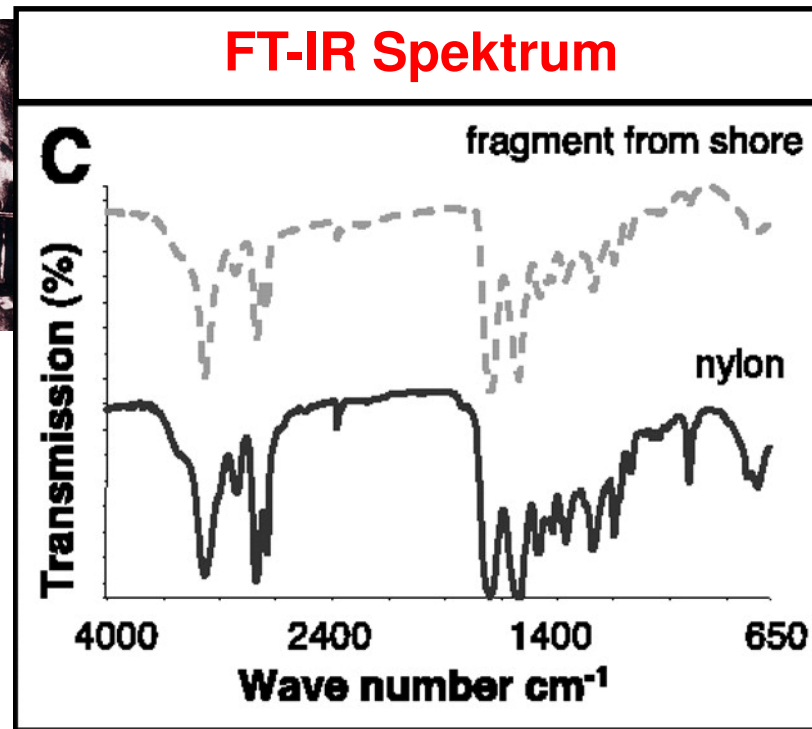


Fig. 1. (A) One of numerous fragments found among marine sediments and identified as plastic by FT-IR spectroscopy. (B) Sampling locations in the northeast Atlantic. Six sites near Plymouth (3) were used to compare the abundance of microplastic among habitats. Similar fragments (4) were found on other shores. Routes sampled by Continuous Plankton Recorder (CPR 1 and 2) were used to assess changes in microplastic abundance since 1960. (C) FT-IR spectra of a microscopic fragment matched that of nylon. (D) Microplastics were more abundant in subtidal habitats than on sandy beaches (*, $F_{2,3} = 13.26$, $P < 0.05$), but abundance was consistent among sites within habitat types. (E) Microscopic plastic in CPR samples revealed a significant increase in abundance when samples from the 1960s and 1970s were compared to those from the 1980s and 1990s (*, $F_{3,9} = 14.42$, $P < 0.05$). Approximate global production of synthetic fibers is overlain for comparison. Microplastics were also less abundant along oceanic route CPR 1 than along CPR 2 ($F_{1,38} = 3.18$, $P < 0.05$).





Quantifizierung und Identifizierung von Mikroplastik

FT-IR Analyse-System auf Helgoland (BMBF Projekt MICROPLAST)

- Sortierbare Partikel (Fraktion > 500 µm): ATR-FT-IR
- „Bulk samples“ (Fraktion < 500 µm > 10 µm): „Chemical imaging“ (µFT-IR) von Proben auf 0.2 µm Filtern (Anodisc)

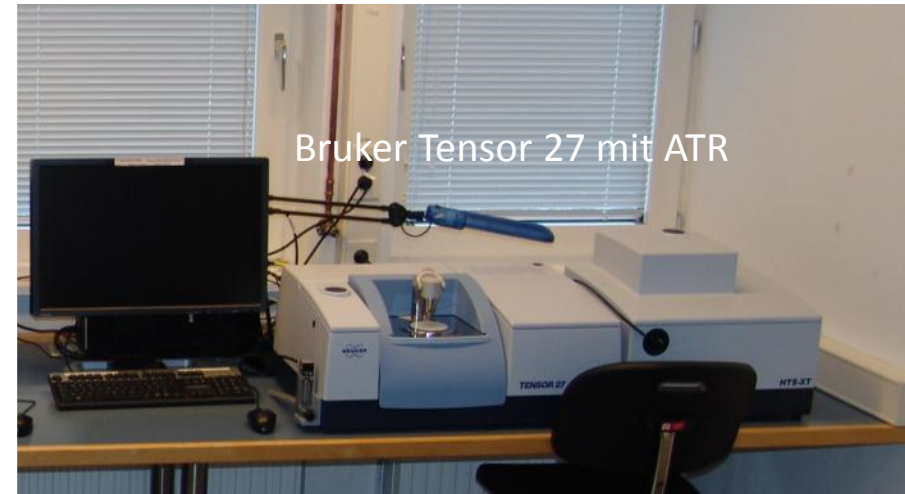
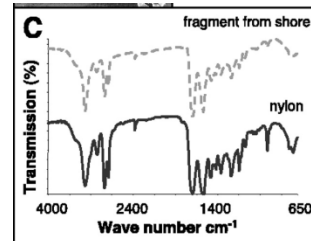
BREVIA

Lost at Sea: Where Is All the Plastic?

Richard C. Thompson,¹ Yim Yan Yeo,² Richard E. Mikaloff,³ Anthony Devlin,⁴ Thomas J. Lambert,⁵ Anthony W. G. Johnston,⁶ Daniel Fortinong,⁷ Katrina L. Barnes⁸

Millions of metric tons of plastic are produced annually. Considerable input of plastic debris are accumulating in remote marine ecosystems and may impact the species that inhabit them. The environmental consequences of this debris are still poorly understood. The authors report on the results of a study that investigated the distribution of plastic debris in the North Atlantic Ocean. The authors found that plastic debris is widely distributed in the North Atlantic Ocean, and that the distribution of plastic debris is related to the distribution of marine mammals. The authors also found that plastic debris is found in the stomachs of marine mammals, suggesting that plastic debris may be a source of food for these animals. The authors conclude that plastic debris is a significant component of the marine environment and that it may have adverse effects on marine mammals.

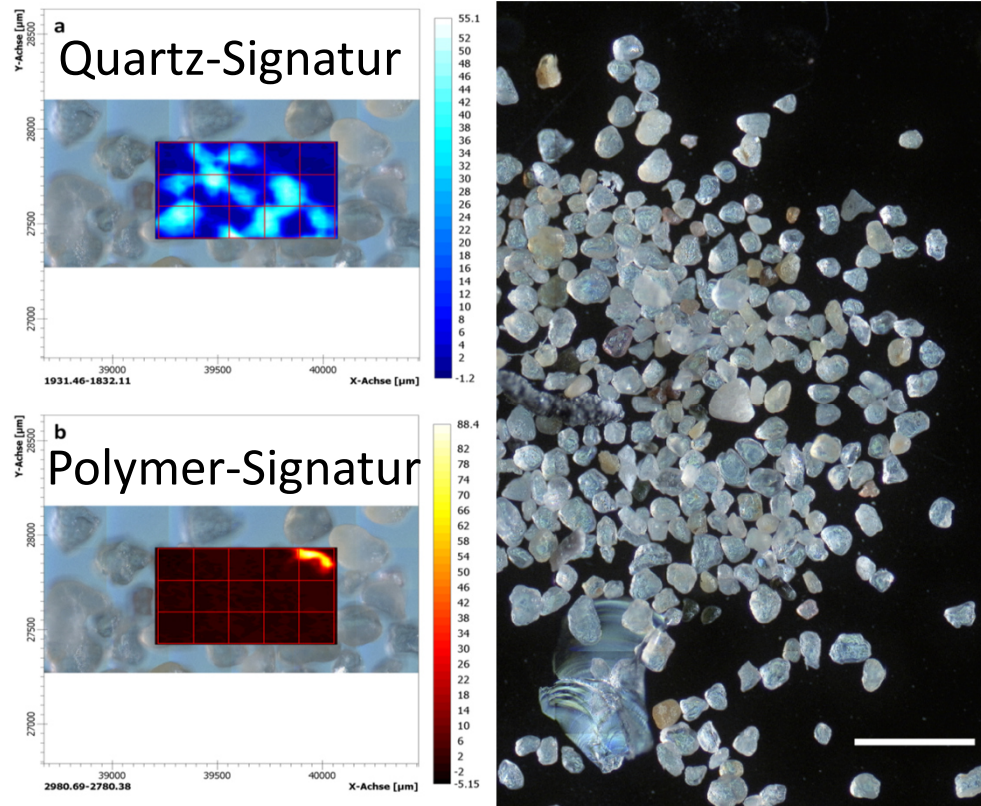
The authors suggest that the fragments of plastic debris that are found in the stomachs of marine mammals may be a source of food for these animals. The authors also found that plastic debris is found in the stomachs of marine mammals, suggesting that plastic debris may be a source of food for these animals. The authors conclude that plastic debris is a significant component of the marine environment and that it may have adverse effects on marine mammals.



...und sehr kleine Partikel?

Quantifizierung und Identifizierung von Mikroplastik

Re-Analyse einer vorherigen Studie

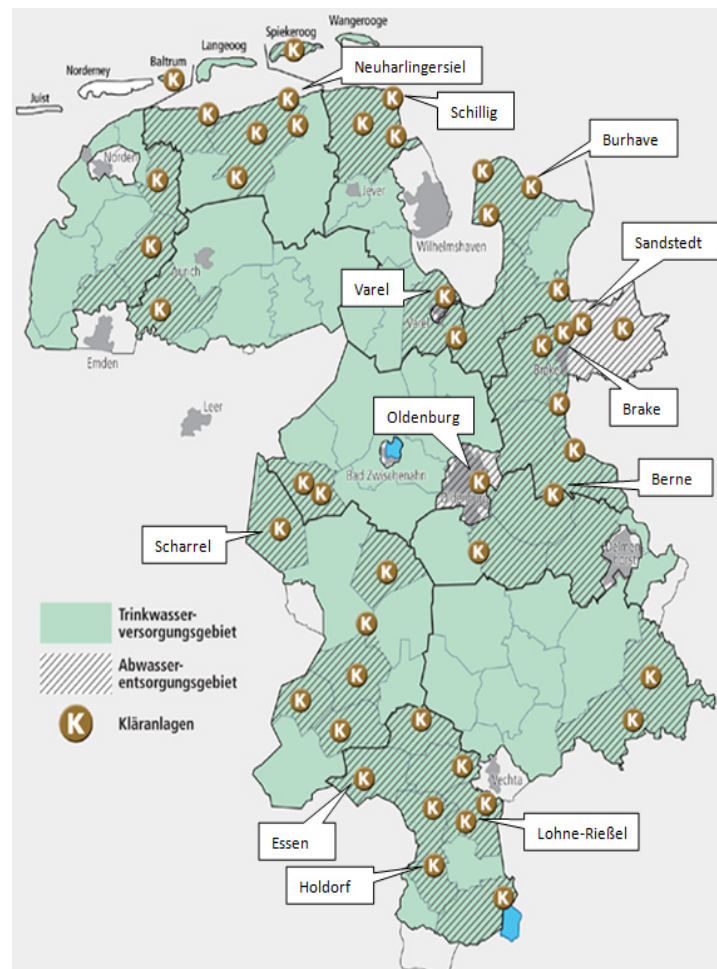


- 100% Mikroplastik
- Re-Analyse mittels μ FT-IR
 - **1.4 %: „Plastik“-
Polymere“**
 - **Quartz (Sand)
dominiert**

Fallstudie: Mikroplastik in ausgewählten Kläranlagen des Oldenburgisch-Ostfriesischen Wasserverbandes (OOWV) in Niedersachsen (Beauftragung: OOWV, NLWKN)

- Deutschlandweit erste Untersuchung zu Mikroplastik in Klärwerken
- Probenahme in 12 Klärwerken in Friesland
- Geklärtes Abwasser, Klärschlamm und Klärfett
- Aufbereitung der Proben mittels enzymatisch-oxidativer Mazeration und Dichteseperation
- Identifizierung und Quantifizierung von Mikroplastik mittels μ FT-IR- und FT-IR-ATR-Spektroskopie

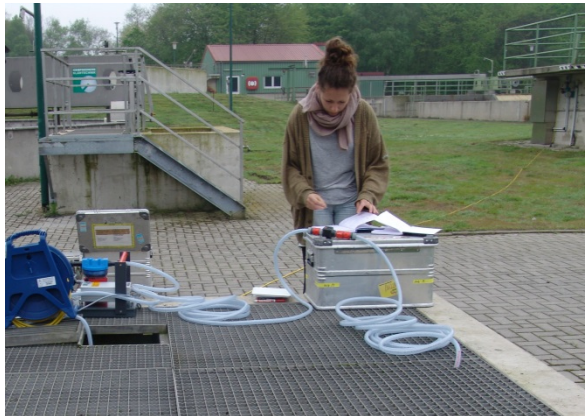
Kläranlagen



- Ausbaugröße
- Einwohnergleichwert
- gewerblicher Einfluss
- Oldenburg mit Schlussfiltration

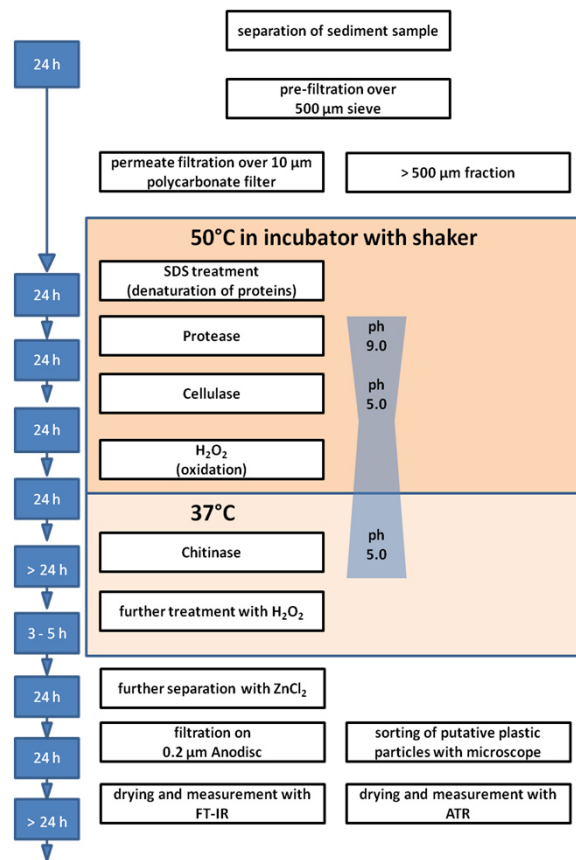
Bewirtschaftungsgebiet des OOWVs
www.oowv.de

Proben



- Probenahme (geklärtes Abwasser) mittels Pumpe
 - Anreicherung auf 10 µm Edelstahl-Kerzenfiltern
 - Bis zu 1 m³ Probenvolumen (0.39 - 1 m³)
- Schlamm- und Fettproben als Schöpfproben direkt vor Ort

Aufbereitung geklärtes Abwassers



- Alle Schritte sofern möglich innerhalb Kerzenfiltergehäuse (kein Transfer)
- Blindproben mit vorfiltriertem (3 µm) Trinkwasser
- Enzymatische Mazeration
- Fraktionierung über 500 µm und 10 µm Edelstahlfilter
- Rückstand auf 0.2 µm Al₂O₃-Filter

Aufbereitung Klärschlamm



- Klärschlamm: Matrix aus schwerlöslichen organischen und anorganischen Verbindungen
- Alkalische Aufbereitung anhand von Cole et al. (2014)
 - 10 M NaOH-Lösung, 24 h, 60°C, ständiges Rühren; Neutralisierung mit HCl
- Fraktionierung über 500 µm und 10 µm Edelstahlfilter
- Rückstand auf 0.2 µm Al₂O₃-Filter (5 ml Aliquot)

Aufbereitung Klärfett



- Fettige und ölige und Bestandteile des Abwassers
- Keine Vergleichsstudien
- Behandlung mit Waschbenzin
- Dichteseperation
- Aufbereitung wie Klärschlamm
- **Nicht erfolgreich**

FT-IR Analysen

Optisch vorsortierte Partikel > 500 μm

- Einzelne Partikel mittels ATR-FT-IR gemessen
- IR Spektren an der Oberfläche der Partikel
- Abgleich mit Referenzdatenbank

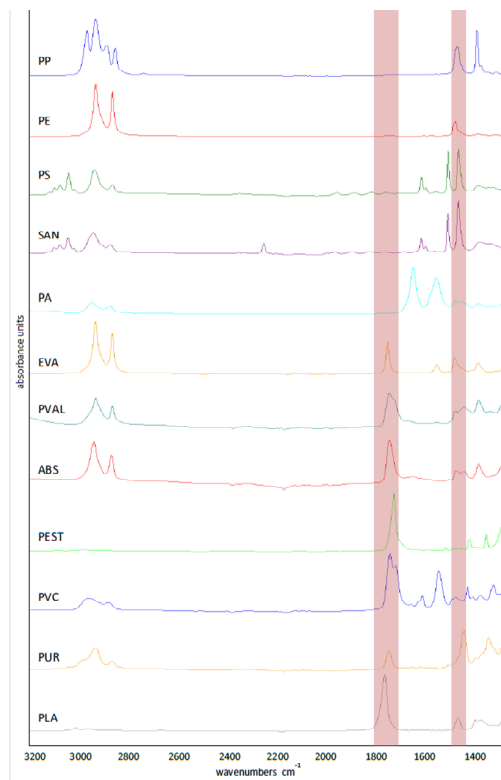
FT-IR Analysen

Partikel < 500 μm

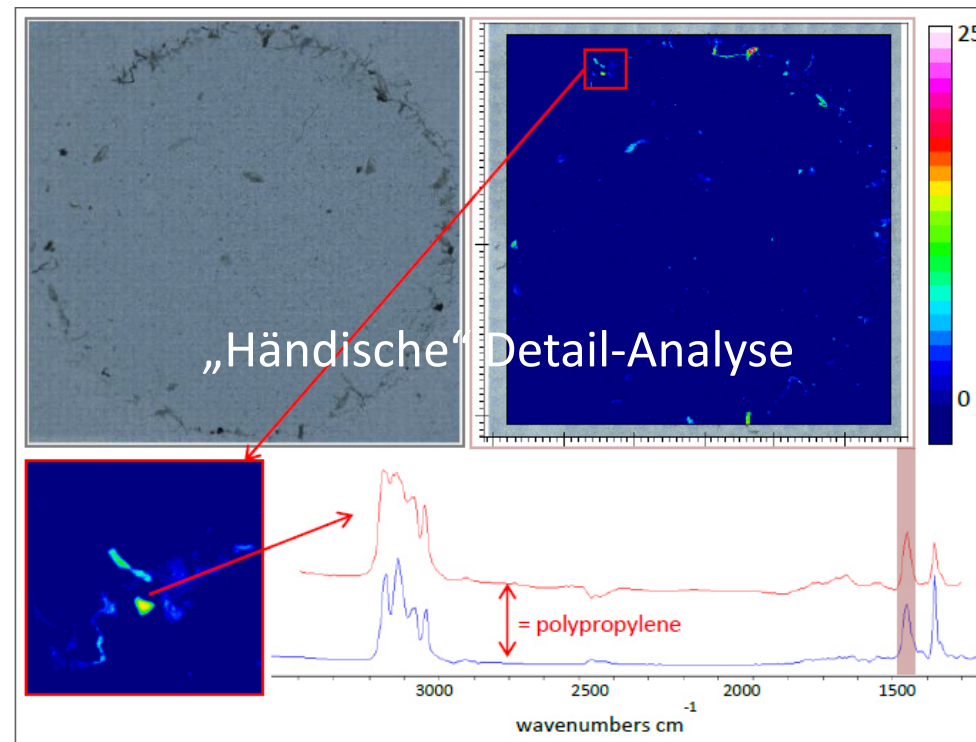
- $\mu\text{FT-IR}$
- Untersuchung ganzer Filterflächen in einer Messung
- „chemical images“
 - 2 Integrationsintervalle: 1430 bis 1480 cm^{-1} und 1700 bis 1790 cm^{-1}
- Händische Bestimmung der Plastikpolymere

FT-IR Analysen

Polymer-Signaturen



„Chemical Images“ für jeweils eine Signatur



FT-IR Analysen

Fasern

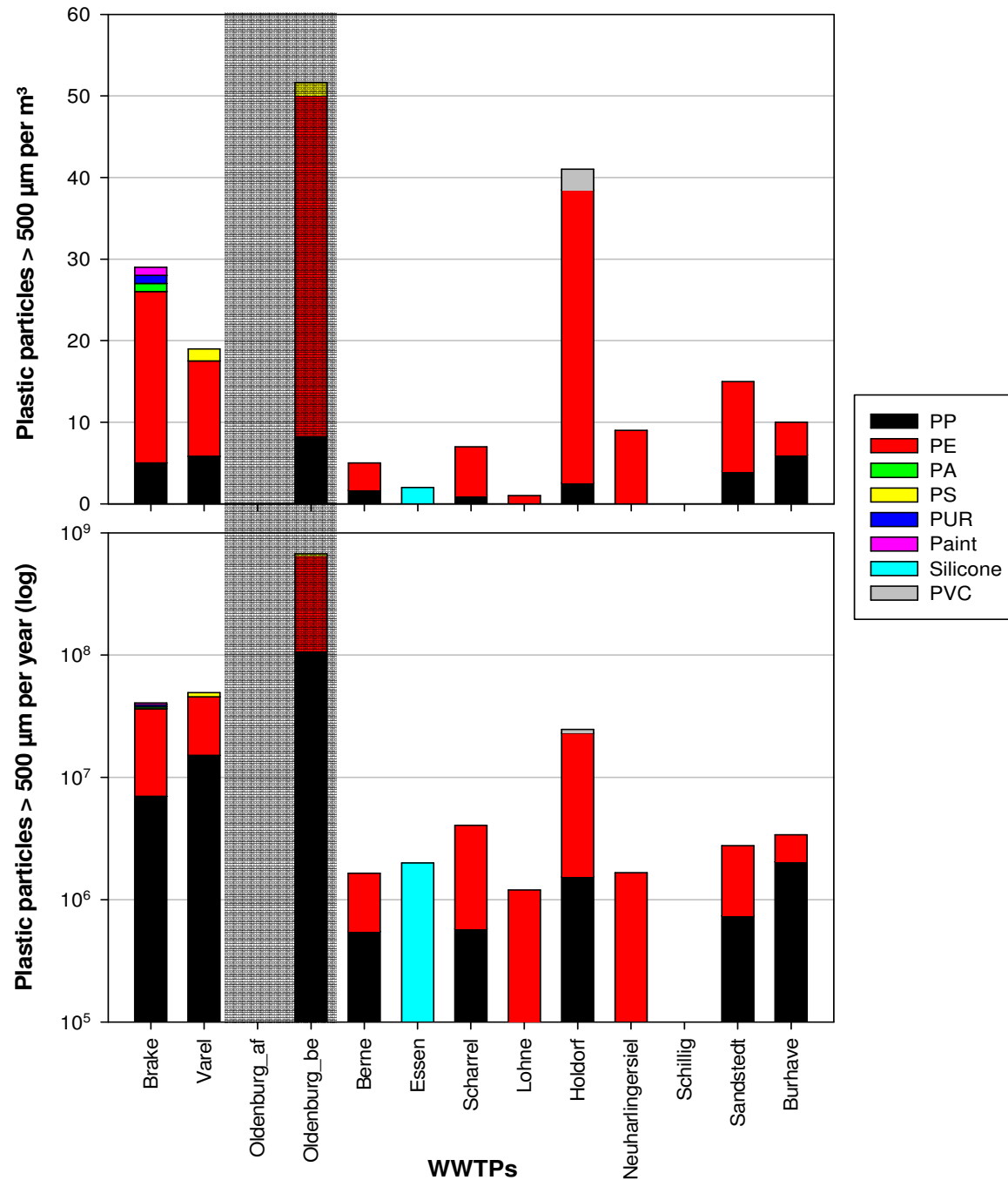
- Aufgrund der runden und dünnen Form während der „normalen μ FT-IR Analyse“ nicht identifizierbar
- Fasern mittels Stereomikroskop gezählt und anschließend mit höchstmöglicher Auflösung und verlängerter Messzeit gemessen (μ FT-IR)
- 60 Fasern pro Probe und Hochrechnung auf Gesamtzahl der Fasern

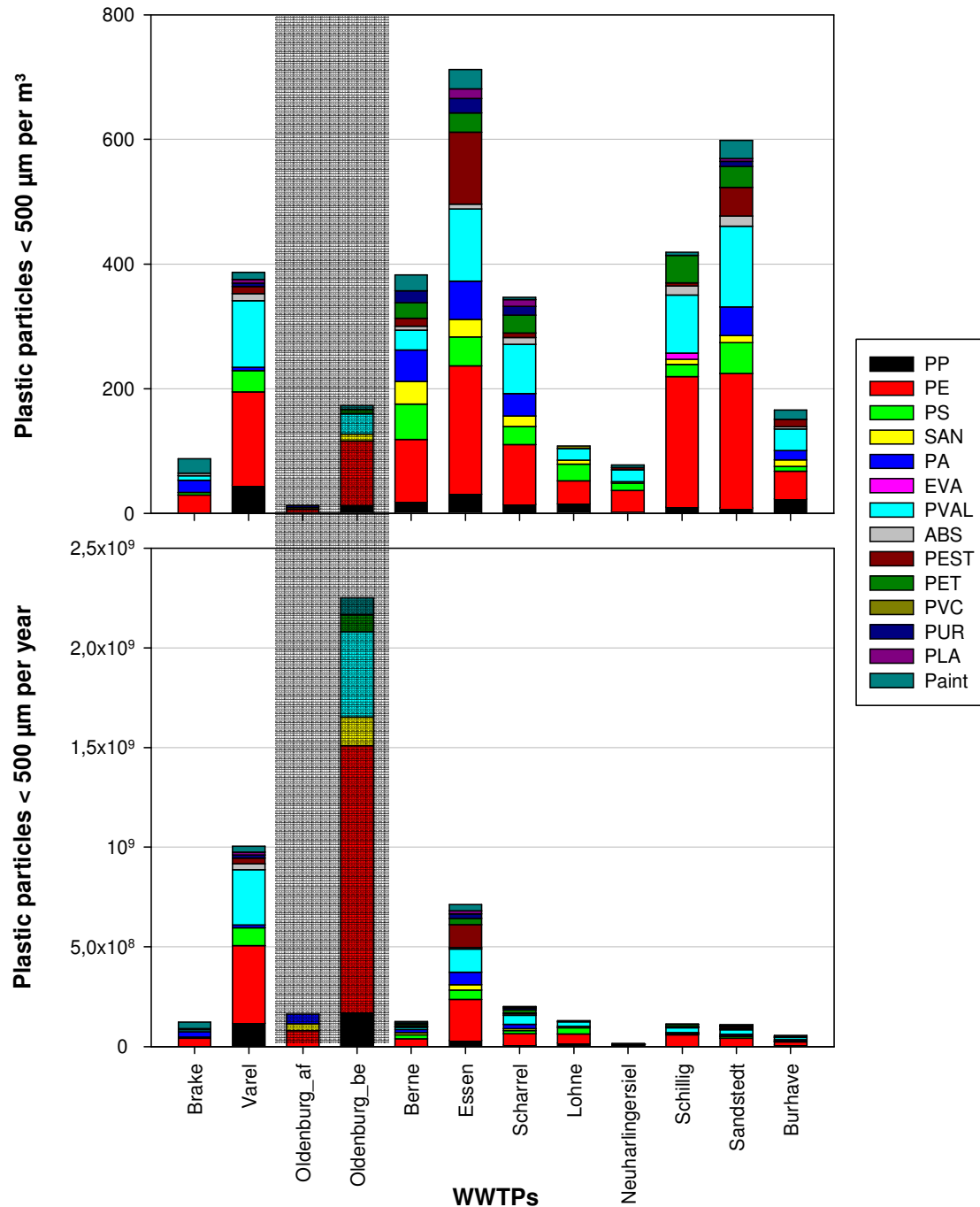
Ergebnisse der Studie



Gekl. Abwasser Partikel > 500 µm

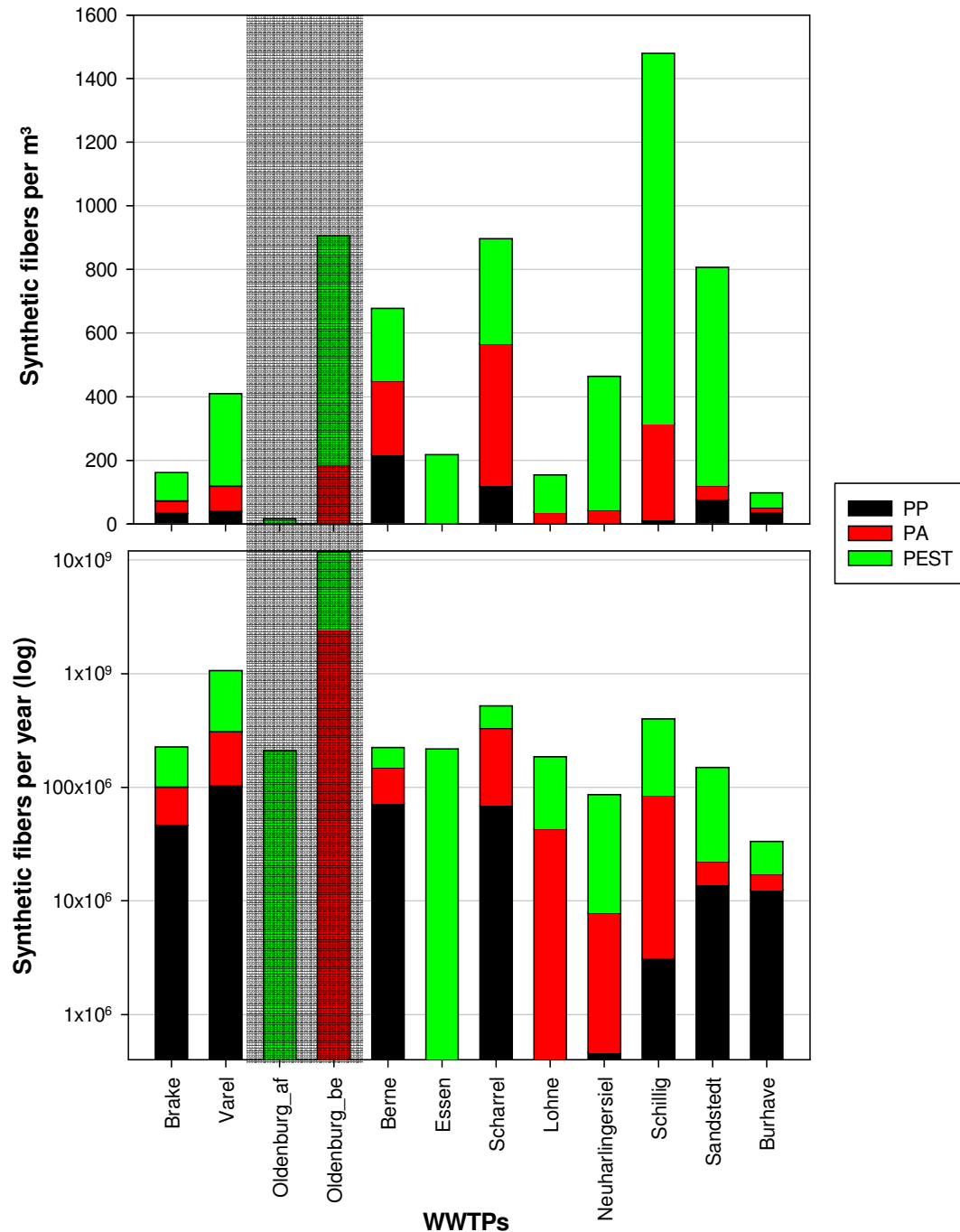
- 8 Polymer-Typen
- 0 bis 52 Partikel pro m³
- 0 bis 650 Mio. Partikel pro Jahr





Gekl. Abwasser Partikel < 500 µm

- 14 Polymer-Typen
- 12 bis 712 Partikel pro m³
- 14 Mio. bis 2.3 Mrd. Partikel pro Jahr
- Holdorf (nicht dargestellt): 5.3 Mrd. Partikel pro Jahr!!!!

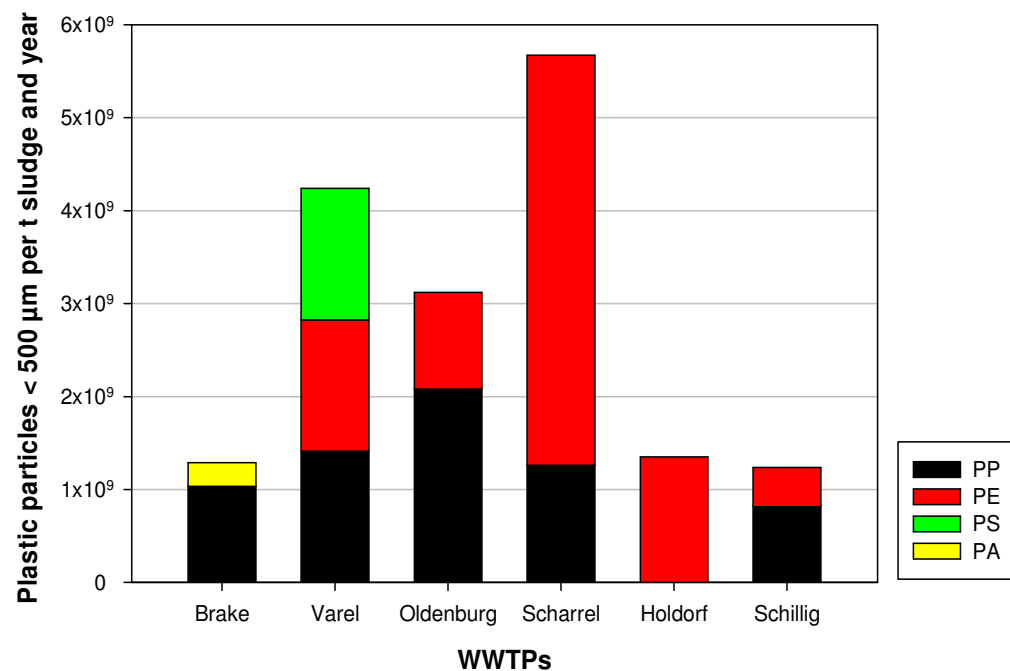
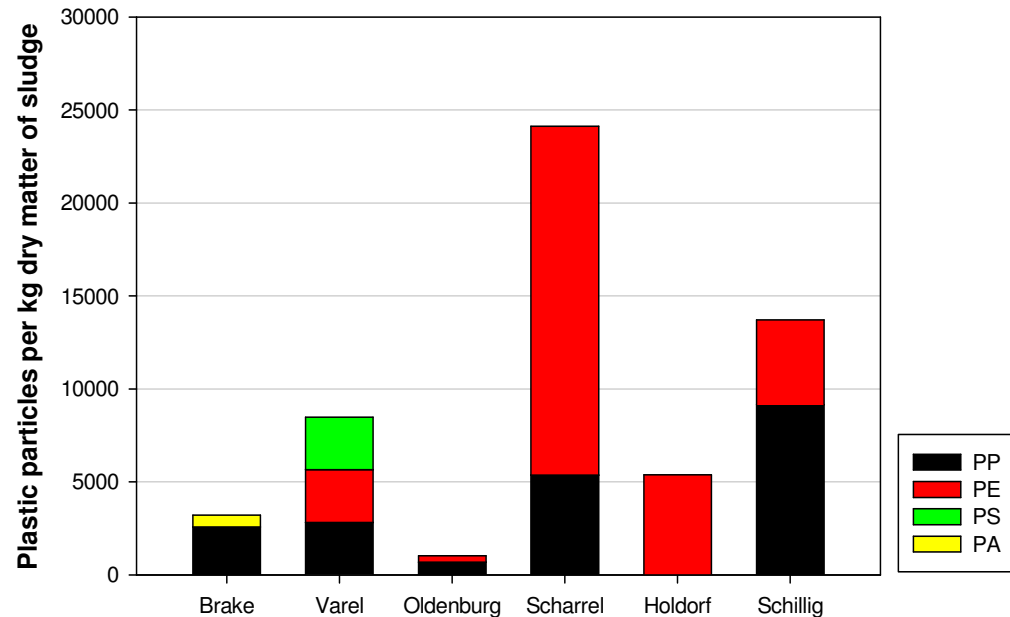


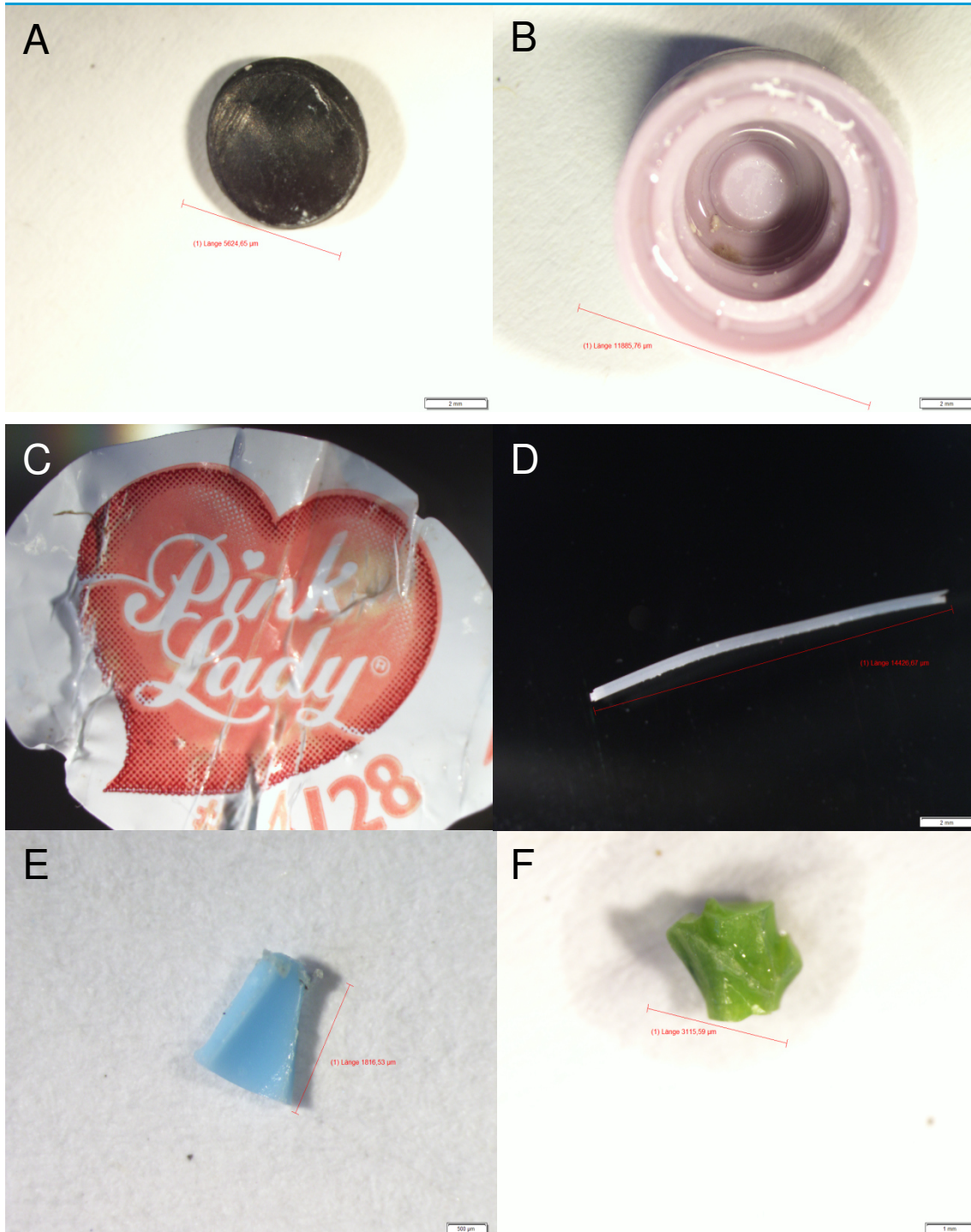
Gekl. Abwasser Fasern

- 3 Polymer-Typen
- 98 bis 1479 Fasern pro m³
- 33 Mio. bis 12 Mrd. Fasern pro Jahr

Klärschlamm Partikel < 500 µm

- 4 Polymer-Typen
- 1041 bis 24129 Partikel pro kg Trockengewicht
- 1.2 Mrd. bis 5.7 Mrd. Partikel pro kg Trockengewicht und Jahr





Klär fett

- A: Schwarze PE Kugel (Oldenburg)
- B: PE Deckel (Schillig)
- C: PE Fruchtsticker (Brake)
- D: Transparentes PP (Oldenburg)
- E: Blaues PP Fragment (Varel)
- F: Grünes PE Fragment (Scharrel)

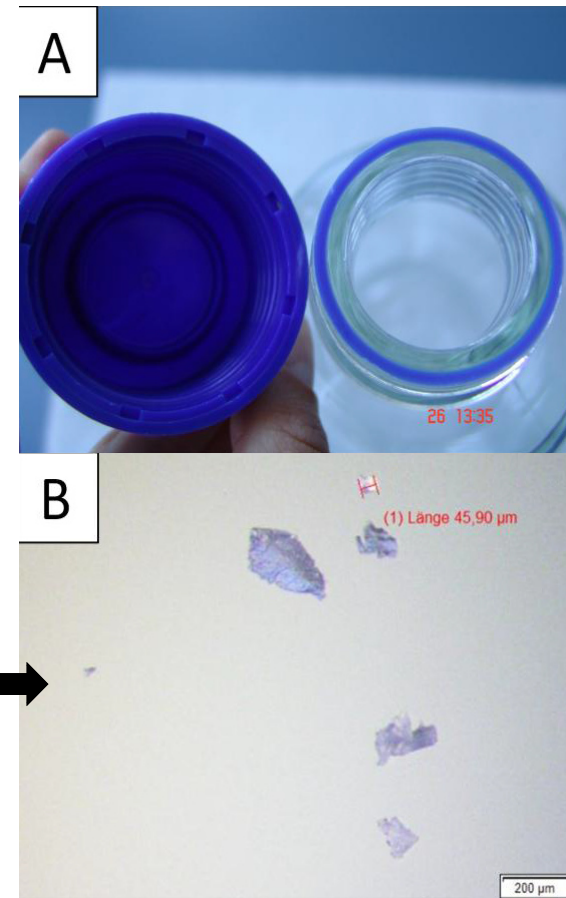
Blindwerte

- Laborinventar und -umgebung plastikdominiert

	PP*	Partikel				Fasern			
		PE	PA	SAN	PEST	schwarz blau	farblos	rot	anders
BP 1	42	8	0	4	4	30	133	3	2
BP 2	69	4	0	4	4	37	95	6	0
BP 3	85	4	4	8	4	32	43	5	4
Mittelwert	65,3	5,3	1,3	5,3	4	33	90,3	4,7	2
Standardabw.	21,7	2,3	2,3	2,3	0	3,6	45,2	1,5	2

Blindwerte

- Laborinventar und -umgebung plastikdominiert
- „Labor-Forensik“
- Fabrik-neue MilliQ gespülte Laborflaschen mit Deckel
- 10 x geöffnet/geschlossen



Blindwerte

- Laborinventar und -umgebung plastikdominiert
- Kontamination trotz vorgenommener Maßnahmen zur Vermeidung **unterstreicht Wichtigkeit von Blindwerten bei Mikroplastikuntersuchungen**

Zusammenfassung

Geklärtetes Abwasser - Partikel > 500 μm

- $\sim 0 - 10^2 \text{ m}^{-3}$ ($0 - 10^6 \text{ a}^{-1}$)
- PE > PP >.. (Σ 8 Polymer-Typen)

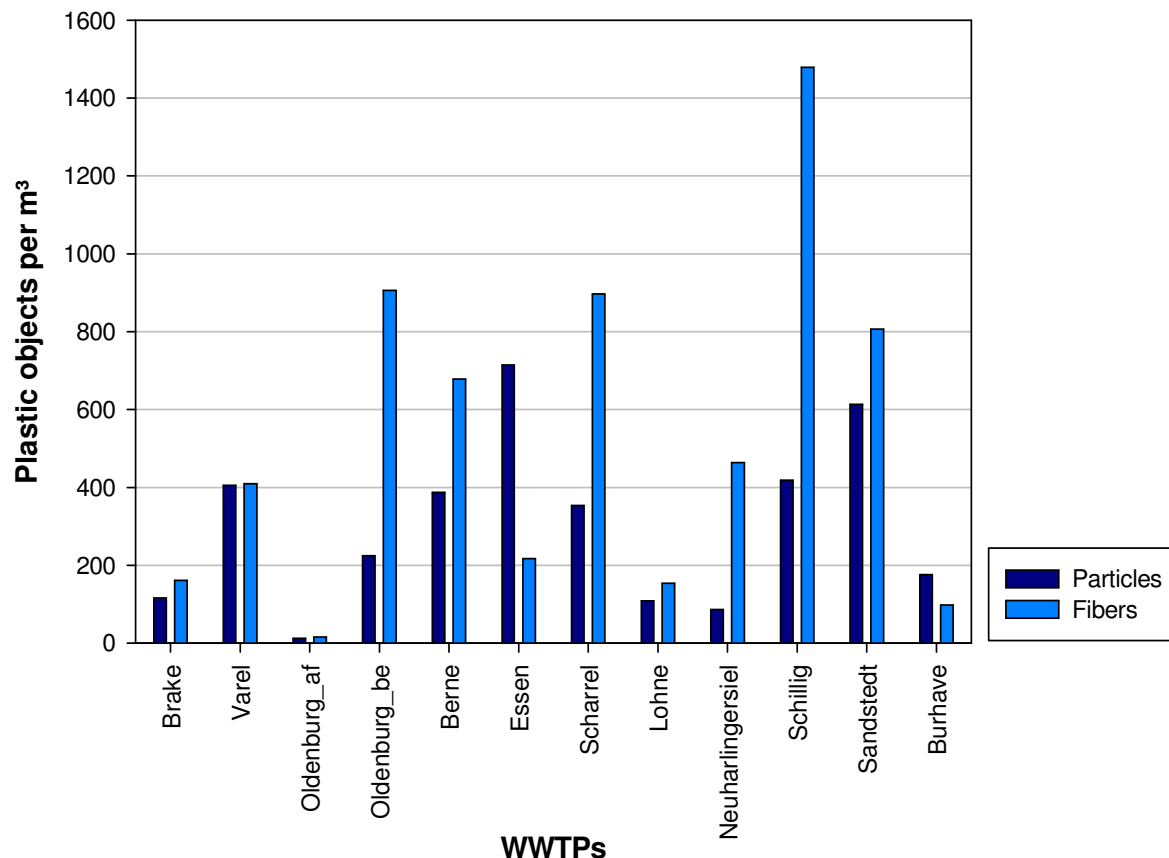
Geklärtetes Abwasser - Partikel < 500 μm

- $\sim 10^0 - 10^3 \text{ m}^{-3}$ ($10^6 - 10^7 \text{ a}^{-1}$)
- Keine eindeutige Dominanz eines Polymer-Typs (Σ 14 PolymerTypen)

Geklärtetes Abwasser - Fasern

- $\sim 10^2 - 10^3 \text{ m}^{-3}$ ($10^6 - 10^7 \text{ a}^{-1}$)
- PEST > PA & PP (Σ 3 PolymerTypen)

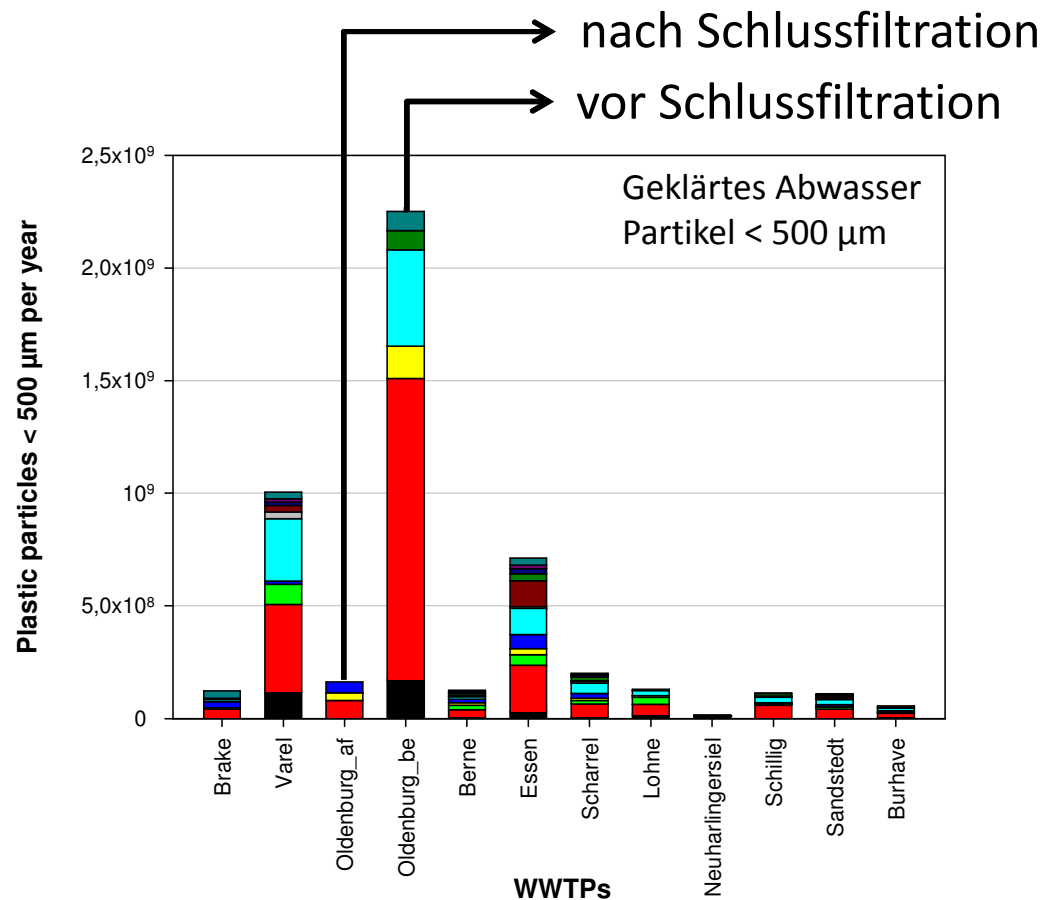
Zusammenfassung



Partikel versus Fasern

- Fasern dominieren meist
- Hauptquelle: häusliche Abwässer aus Waschmaschinen
 - Bis zu 1900 Fasern pro Kleidungsstück pro Waschgang (Browne, Crump et al. 2011)

Zusammenfassung



Effekt Schlussfiltration

- Schlussfiltration in Oldenburg reduziert Mikroplastikfracht stark
- Partikel > 500 µm 100 %
- Partikel < 500 µm 92,8 %
- Fasern 98,2 %

Zusammenfassung

Klärschlamm

- $\sim 10^3 - 10^4 \text{ kg}^{-1} (10^7 \text{ a}^{-1})$
- PE > PP >.. (Σ 4 Polymer-Typen)
- ! Kleines Probenvolumen: 125 g Nassgewicht (zwischen 2,5 und 30 g Trockensubstanz)
- ! Aggressive (alkalische) Extraktion

Klärfett

- Kein Analyse möglich
- Vorhandensein von großen Plastikteilen macht Fettabscheider als (Mikroplastik)-Senke wahrscheinlich

Fazit

Vergleich mit anderen Studien

- Bislang nur sehr wenige Studien
- In Russland (HELCOM 2014) und den Niederlanden (Leslie, Van Velzen et al. 2014) deutlich höhere Werte in geklärtem Abwasser festgestellt
 - Niederlande: 9-91 Partikel pro Liter
 - Russland: 16 Fasern, 7 Partikel und 302 schwarze Partikel pro Liter
 - Zum Vergleich: Holdorf: 8.9 Partikel < 500 μm pro Liter, 0.4 Partikel > 500 μm und 4.8 Fasern pro Liter
- **Keine Verifizierung durch spektroskopische Analysen birgt hohes Risiko der Überschätzung**

Fazit

Vergleich mit anderen Studien

- Tagg et al., 2015
- Dotierte Proben
- Wesentlich geringes Volumen
- FTIR-“Reflektion“!

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analytical
chemistry

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Identification and Quantification of Microplastics in Wastewater Using Focal Plane Array-Based Reflectance Micro-FT-IR Imaging

Alexander S. Tagg,[†] Melanie Sapp,[‡] Jesse P. Harrison,[§] and Jesús J. Ojeda^{*†}

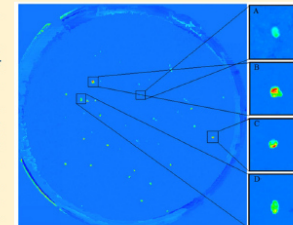
[†]Brunel University London, Experimental Techniques Centre, Institute of Materials and Manufacturing, Bragg Building, Kingston Lane, Uxbridge, Middlesex, United Kingdom, UB8 3PH

[‡]Fera Science Ltd, Sand Hutton, York, United Kingdom, YO41 1LZ

[§]The University of Edinburgh, School of Physics and Astronomy, James Clerk Maxwell Building, Peter Guthrie Tait Road, Edinburgh, United Kingdom, EH9 3FD

Supporting Information

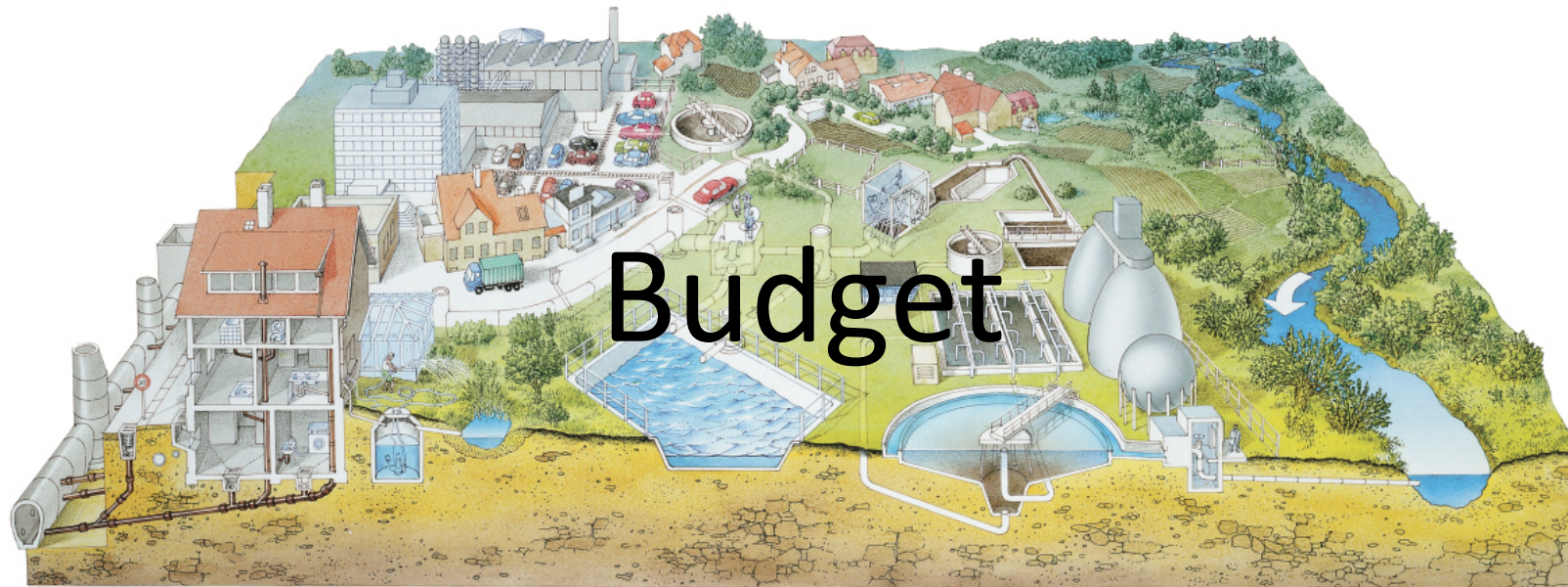
ABSTRACT: Microplastics (<5 mm) have been documented in environmental samples on a global scale. While these pollutants may enter aquatic environments via wastewater treatment facilities, the abundance of microplastics in these matrices has not been investigated. Although efficient methods for the analysis of microplastics in sediment samples and marine organisms have been published, no methods have been developed for detecting these pollutants within organic-rich wastewater samples. In addition, there is no standardized method for analyzing microplastics isolated from environmental samples. In many cases, part of the identification protocol relies on visual selection before analysis, which is open to bias. In order to address this, a new method for the analysis of microplastics in wastewater was developed. A pretreatment step using 30% hydrogen peroxide (H₂O₂) was employed to remove biogenic material, and focal plane array (FPA)-based reflectance micro-Fourier-transform (FT-IR) imaging was shown to successfully image and identify different microplastic types (polyethylene, polypropylene, nylon-6, polyvinyl chloride, polystyrene). Microplastic-spiked wastewater samples were used to validate the methodology, resulting in a robust protocol which was nonselective and reproducible (the overall success identification rate was 98.33%). The use of FPA-based micro-FT-IR spectroscopy also provides a considerable reduction in analysis time compared with previous methods, since samples that could take several days to be mapped using a single-element detector can now be imaged in less than 9 h (circular filter with a diameter of 47 mm). This method for identifying and quantifying microplastics in wastewater is likely to provide an essential tool for further research into the pathways by which microplastics enter the environment.



Fazit

- Klärwerke sind eine potentielle Quellen für Mikroplastik
- In fast 100 % der Abwasser- und Klärschlammproben wurde Mikroplastik gefunden
- Differenzierung primäres Mikroplastik – sekundäres Mikroplastik problematisch
- Synthetische Fasern sehr häufig
- **Momentaufnahme: Mehr Studien nötig** um weitere Quellen und deren Anteile an Belastung zu erforschen → Voraussetzung für Gegenmaßnahmen
 - Technische Verbesserungen, Bildung/Aufklärung, umweltbewusstes Handeln, Verändern von Konsummustern

Fazit



www.wasserforscher.de

<http://www.oowv.de/downloads-formulare/downloads/downloads/>



I. Int-Veen, S. Mintening, M. Löder & Gerds, G (in prep) Identification and quantification of microplastics in waste water treatment plants

PLASTIC PLANET

Danke für Ihre Aufmerksamkeit

